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TITLE:

Double-pass technique and compensation-comparison method in eyes with cataracts: a clinical comparative study

Running head:

Comparison of double-pass and compensation-comparison methods in eyes with cataracts

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ABSTRACT

Purpose

To clinically assess the objective scatter index (OSI) obtained from double-pass images and the log(s) parameter measured with the direct compensation-comparison psychophysical technique in eyes with cataracts, performing a comparative study.

Setting

Ophthalmology service, Terrassa Hospital.

Design

Prospective, observational, cross-sectional, non-consecutive case series study.

Methods

The analysis comprised 78 eyes diagnosed with nuclear, cortical and posterior subcapsular cataracts and 10 healthy eyes - control group -. Patient examination included assessment of the manifest subjective refraction, best-corrected visual acuity, contrast sensitivity, and cataract grade using the LOCS III score. The protocol also included the straylight measured by the C-Quant – log(s) –, the measurement of the objective optical quality – Strehl ratio and MTFcutoff – and the OSI.

Results

Significant correlations with LOCSIII classification were found in terms of log(s) and OSI, although they were slightly stronger with OSI for all cataract types, which could be probably attributable to higher order aberrations. OSI and log(s) were found to share about 44% of the scattering estimation and to coincide on the visual function decline with scattering for the three types of cataracts studied. Limits to discriminate between healthy and cataractous eyes and sensitivity (Sn) and specificity (Sp) values were 1.15 (Sn:91%, Sp:100%) for log(s) and 1.18 (Sn:89%, Sp:100%) for OSI ($p<0.05$).

Conclusions

Both instruments provide complementary information to diagnose cataracts and follow patients up. Although backscattered light from deeper retinal layers can have an impact on OSI, the double-pass image provides information to grade different types of cataract when dealing with cataractous eyes.

INTRODUCTION

Intraocular scattering is an important cause of visual function impairment in eyes with cataracts. Patients with cataracts often complain of glare and contrast loss before a decrease in visual acuity is manifested. Several approaches have been considered for measuring disability glare[1]. One of the first methods proposed was the measurement of the contrast sensitivity function with and without a glare source[2]. In contrast, the brightness acuity test (BAT) considered the evaluation of visual acuity[3]. Other psychophysical testing tools have also been developed recently to evaluate straylight. Examples include systems for the assessment of the visual discrimination capacity in which the subject's task consists of detecting luminous peripheral stimuli around a central high-luminance stimulus over a dark background, from which a disturbance index is computed[4], or using a brightness comparison method based on a haploscopic arrangement that allows determining the brightness reduction of a test when there is a steady glare source in the visual field[5]. Besides the former experimental systems, in recent years a new commercial instrument (C-Quant, Oculus GmbH, Wetzlar-Dutenhofen, Germany) has gained acceptance for controllable assessment of straylight in the clinical setting [6–9]. It is based on the so-called compensation-comparison method which uses a central test field subdivided into two half fields: one with and one without counterphase compensation light. The subject's task is a forced-choice comparison between the two half fields, to decide which one flickers more intensely. From these measurements, a psychometric function is fitted to the subject's responses and it is used to determine the straylight compensation level log(s) on the basis of a few stimuli responses. This method is an improved version of the direct comparison method[10], in which a ring-shaped glare source produces straylight on a dark background test field lightening it, due to the fact that some of the light is scattered by the lens and other parts of the eye and is thus projected on the part of the retina onto which the test field projects. This straylight is sequentially compared with the luminance of a stimulus in the same test region. Authors have used this instrument to evaluate straylight in eyes with different optical conditions such as cataracts of different morphologies[11] and eyes undergoing laser peripheral iridotomy[12].

Besides the preceding psychophysical techniques, which capture the impact of forward scattering in vision, attempts to objectively assess the retinal scattered light allowing cataract classification have also been made. In this context, the most widespread technique is the Lens Opacities Classification System III (LOCS III), which involves the observation of the lens through a slit lamp from which a gradation of the state of every cataract is assessed[13]. LOCS III provides information related to the back-scattered light but not forward scattering, which is responsible for the degradation of vision. Moreover, the results may show variability among physicians[14]. To overcome this, other approaches concerning the use of Scheimpflug images[15] and optical coherence tomography[16] have also been proposed, and studies conclude that they can help in characterizing grades of cataracts from a density or anatomical point of view although not from a functional one.

On the other hand, the double-pass (DP) technique is an objective procedure used in clinics to assess the ocular optical quality that was intended to capture the complete optical information of the eye, including the effect of higher-order aberrations and intraocular scattering restricted to a small visual angle[17]. A combined analysis of double-pass images and subjective measurements was already proposed some years ago by Westheimer and Liang to evaluate diffusion of light in the eye, although the contribution of aberrations was not considered and the procedure was not applied in eyes where scatter was the main cause of degraded vision[18]. A commercial instrument based on the double-pass technique is currently available (HD Analyzer - HDA, Visiometrics S.L.- A Halma Company, Terrassa, Spain) and its clinical use is also becoming more generalized[19–22]. It computes an objective scatter index (OSI)[23], which is a dimensionless parameter based on the relative intensity divided by 10 between the central area within 1 minute of arc and a peripheral ring between 12 and 20 minutes of arc of the DP image of the eye. The OSI is limited to the measurement of the central part of the point spread function (PSF), and therefore susceptible to the effect of aberrations both lower and higher order ones[24,25]. However, a study[23] available in the literature suggests that the correction of both defocus and astigmatism with a precision better than 1.00 D might probably be enough to grade scattering in eyes with cataracts. In any other situation in which sphere and cylinder are imprecisely corrected or higher order aberrations play an important role, OSI might be misleading.

The 12-20 minutes ring is affected by the artefact of infrared light diffusion in the choroid, which can be considered a relatively constant background[24,25]. As infrared light penetrates easily into the choroid, where diffusion and back reflection takes place, this artefact is added to the recorded image but the use of near infrared light - 780 nm - in the HDA instrument represents an advantage for the patient’s comfort during image acquisition. Alternatives[26] have been proposed recently to overcome the limitation of registering back reflection from the choroid by using a modified DP system that includes an extended green light source – 530±30 nm. This system provides wide-angle PSF of the human eye up to 8 degrees by means of the reconstruction of the PSF from double-pass images obtained with disks of uniform radiance. This might allow new methods evaluating the scatter at PSF angles wider than 1 degree, where it is unlikely to be influenced by reflection from the deep choroid. A different part of the pupil is also used for projection (first pass) and recording (second pass) so that backscattering from the cornea and the lens is removed from the recorded retinal images. It has to be taken into account though, that a minimum 6 mm iris opening is required and thus pupil's dilation might be needed. However, a clinical instrument including this technology is not available yet.

In this study clinical measurements are performed by using the two available commercial instruments formerly mentioned: the C-Quant and the HDA systems. The analysis is conducted over a large number of eyes presenting three different morphologies of cataracts: nuclear (NUC), cortical (COR) and posterior subcapsular (PSC); as well as in a control group (CG). A quantitative comparison between the log(s) provided by the C-Quant system and the OSI given by the HDA is established, studying their relationship. In addition, we compare these results with those obtained using more conventional subjective procedures such as the LOCS III gradation and contrast sensitivity (CS) measurements, and with objective optical quality parameters given by the HDA instrument related to the Modulation Transfer Function (MTF) of the eye.

PATIENTS AND METHODS

A total of 112 patients with different morphologies and grades of cataracts enrolled this prospective, observational, cross-sectional, non-consecutive case series study. From them, 14 patients were excluded due to the absence of reliable C-Quant values, 10 due to the presence of mixed cataracts, 6 because they did not meet the inclusion criterion for spherical equivalent, and 4 due to lack of correct images with the HDA. For individuals who had bilateral cataract, only one eye was randomly selected (R/L), respecting the best proportionality of the different grades of cataracts (especially for extreme values). 10 eyes of 10 healthy subjects were also considered as a control group.

The study was conducted at the Hospital de Terrassa from September 2013 to May 2014 under supervision of two ophthalmologists (M. A. A. and L. A. C.). After providing a written and verbal explanation on the nature of the study, written informed consent was obtained. The study was approved by an ethical committee and conforms to the Declaration of Helsinki tenets of 1975 - as revised in Tokyo in 2004.

Patients with a history of ocular pathology - except cataracts - and surgery were excluded. All patients underwent a clinical evaluation for determining the manifest refractive error, best-corrected visual acuity (BCVA) with a Bailey-Lovie chart and contrast sensitivity function with the CSV-1000E test (VectorVision, Greenville OH, USA) at frequencies of 3, 6, 12 and 18 cycles per degree (cpd) measured in mesopic conditions. Cataracts were graded with the slit lamp after dilating the pupil by instilling 0.2ml of tropicamide (1%) according to the LOCS III based on nuclear opalescence (NO1, NO2, NO3, NO4), cortical cataract (C1, C2, C3), and posterior subcapsular cataract (P1, P2, P3, P4). Mixed cataracts with more than one morphological type were excluded. Mixed cataracts were considered when they had two gradations (NO, C or P) greater than 1, or alternatively when they had two or more gradations of 1 (NO, C or P). No cortical cataract whose grade was C4 with NO or P less than 2 was found. An independent classification was performed by both an ophthalmologist and an optometrist. The results matched in most cases and, in case of disagreement, the grading was reviewed by the same ophthalmologist.

The protocol included the assessment of straylight measured by the C-Quant. Higher values of log(s) indicate more straylight and more sensitivity to glare. This test also gives an assessment of the reliability of the test outcome, specified as the expected standard deviation (SD) of the individual measurement value in case of repeated measurements (Esd) and Q, which is a further quality criterion. According to the manual of the instrument, if Esd < 0.08 and Q > 1, the reliability of the result is considered to be good and if Esd < 0.08 and Q > 0.5, the reliability is considered to be acceptable. However, a warning is given if Esd > 0.08 or Q < 0.5. Eyes with outcomes fulfilling this last condition were excluded from analysis in this study. Participants carried out the test without pupillary dilation.

For a quantitative measurement of the optical quality, the Strehl ratio (SR) was considered. A parameter commonly used for estimating the overall optical quality that defined in the HDA instrument as the ratio between the 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 SR ranges from 0 to 1. A lower value of this parameter indicates that there is a greater contribution of aberrations and therefore poorer optical quality. On the other hand, we analysed the MTF cutoff frequency (MTF_{cutoff}), which corresponds to the largest spatial frequency - in cycles per degree (cpd) - that can be resolved on the retina at maximum contrast. In the HDA instrument, it is defined as that corresponding to a 0.01 MTF value, since there is background noise in the profile computed from the real recorded double-pass image and the “0” value cannot be reached.

Furthermore was also measured OSI by means of the double-pass instrument HDA. In this case, measurements were carried out without dilation too and using a pupil diameter of 4mm. Since optical quality may be dependent of tear film quality, measurements were taken just after a blink [27]. Spherical refractive error was automatically corrected by the double-pass system – from -8.00 D to +6.00 D with an accuracy of 0.06 D – while astigmatism was corrected with an external cylindrical lens – with an accuracy of 0.25 D – to obtain the best possible retinal image.

Statistical analysis

Statistical analysis was performed using the software SPSS for Windows (version 20, SPSS Inc., Chicago, IL, USA). $p<0.05$ was considered to be statistically significant. The Kolmogorov-Smirnov test was used to evaluate the normal distribution of variables. The Mann-Whitley U-test for nonparametric variables and independent sample t-test for parametric ones were used to compare the mean between different types of cataracts and between them and the control group.

An analysis of variance (ANOVA) test was used to test whether the differences in terms of BCVA, CS, log(s), SR, MTF_{cutoff} and OSI among grades of cataracts scored with

LOCS III were statistically significant. An ANOVA test was also used for log(s) and OSI to establish significant differences among types of cataracts, i. e. NUC, COR and PSC. In addition, the validity of log(s) and OSI with respect to optical quality – SR and MTF_{cutoff} - and psychophysical vision quality tests – BCVA and CS - was studied to avoid any bias of age in the results by using the Pearson`s partial correlation coefficient (r) controlling for age.

Agreement between log(s) and OSI was also analysed using a linear regression and a Pearson's partial correlation coefficient controlling for age for the different types of cataracts was calculated.

Finally, the area under the Receiver-Operating Characteristic (ROC)[28] plot was used to quantify the diagnostic accuracy of log(s) and OSI between the cataract group and the control group. The maximum Youden index (J)[29] was considered as the cutoff point to classify healthy and diseased eyes and the corresponding specificity and the sensitivity [30] were calculated. The Youden index (J = Sensitivity + Specificity – 1) is seen to be equal to the sum, diminished by unity, of the two fractions showing the proportions correctly diagnosed for the diseased and control groups.

RESULTS

A total of 78 cataractous eyes of 78 patients and 10 healthy eyes of 10 patients were finally included in the study. Table 1 presents the patient demographics and the number of eyes included in each group.

Eye and gender distribution occurs with equal probability for the whole sample and for the different cataract groups. There were no significant differences in spherical equivalent between the three types of cataracts or between them and the control group although the range of values was clearly greater in the cataract group.

Table 2 shows the mean age distribution of the sample. The Student's t-test did not reveal any statistically significant difference between the three types of cataracts in terms of age but it did so between the control group and the whole cataract group ($t=7.765$, $p<0.001$). Particularly, the mean age ± SD (range) in the control group was 58 ± 4 (52 to 65) years while in the cataract group the mean age was 70 ± 8 (47 to 86) years.

When comparing the means between the control group and the whole cataract group, difference was significant for BCVA ($t=-6.676$, $p<0.001$), CS at 3 cpd ($t=2.210$, $p=0.030$), at 6 cpd ($t=2.748$, $p=0.007$) and at 12 cpd ($t=2.574$, $p=0.012$), log(s) ($t=-9.545$, $p<0.001$), SR ($t=4.888$, $p<0.001$), MTF_{cutoff} ($t=8.493$, $p<0.001$) and OSI ($t=-10.418$, $p<0.001$), but it was not for CS at 18 cpd ($t=1.116$, $p=0.268$).

When comparing the three types of cataracts - Table 3 - no statistically significant difference ($p>0.05$) was found in any of the parameters studied - BCVA, CS, log(s), SR, MTF_{cutoff}, or OSI. Although the maximum LOCS III-scored degree of COR cataracts was lower (i. e. C3), they showed the worst mean BCVA, SR and MTF_{cutoff}.

Table 4 shows the mean values (±SD) for the variables grouped following the LOCSIII classification scale. As it was expected, the log(s) and OSI values increase with cataract severity grade and all the other parameters related to optical quality and vision quality decrease. The analysis of variance (ANOVA) between the LOCSIII score classification groups shows statistically significant differences for BCVA ($F=18.3$, $p<0.001$), CS at 3cpd ($F=2.7$, $p=0.035$), CS at 6cpd ($F=7.4$, $p<0.001$), CS at 12cpd ($F=6.5$, $p<0.001$), CS at 18 cpd, (F=3.9, p=0.005), log(s) (F=21.4, $p<0.001$), SR (F=17.1, $p<0.001$), MTF_{cutoff} (F=20.4, $p<0.001$) and OSI (F=37.3, $p<0.001$), .

In the three types of cataracts the analysis of variance (ANOVA) for parameters log(s) and OSI between the LOCSIII classification groups showed statistically significant difference ($p<0.05$), being the highest for OSI in nuclear cataracts (F=40.367), followed by cortical (F=36.719) and subcapsular ones (F=12.682). Although for log(s) the highest difference was also for nuclear cataracts (F=21.013), it was followed by the subcapsular group (F=13.059), and the lowest one being for the cortical group (F=9.055). Box plots in Figure 1 show log(s) and OSI for the three types of cataracts.

To investigate about comparison between log(s) and OSI, Figure 2 represents the scatterplot for log(s) and OSI, where it can be seen that these two parameters share about 44% of the scattering estimation when taking into account all subjects. Pearson's correlations between these two parameters are moderate and statistically significant for the three types of cataracts ($p<0.001$), being slightly higher in the nuclear cataract group (r= 0.694, n=35), followed by the cortical cataract one (r=0.693, n=18), and the posterior subcapsular one (r=0.673, n=25).

Table 5 shows the partial correlations (r) controlling for age of log(s) and OSI with the psychophysical parameters and optical quality also analysed in the study – BCVA, CS and MTF_{cutoff} and SR , respectively. Both log(s) and OSI behaved in a similar way although OSI correlation values were stronger in all cases; this was expected since the latter is computed taking into account the peak of the PSF and thus, the presence of ocular aberrations, especially the higher order ones which have not been corrected, might have an influence on it.

There were differences in this relation depending on the type of cataract. For NUC cataracts, strong correlations were observed with the BCVA, CS at intermediate frequencies, SR and MTF_{cutoff}. Specifically, OSI presented a stronger correlation with CS at 6cpd than with BVCA. For COR cataracts, both log(s) and OSI showed a much stronger correlation with objective parameters related with optical quality than with psychophysical ones but correlation with log(s) was stronger at lower frequencies – CS at 3cpd -, whereas with OSI it was stronger at medium frequencies - CS at 12 cpd. Moderate correlations were observed in both cases with BCVA. As for PSC cataracts, strong correlations were observed between both log(s) and OSI and MTF_{cutoff}, but not so much with SR. There was also a generalised close association between log(s) and OSI and CS at all frequencies. Particularly, OSI showed a stronger correlation with CS at medium and high frequencies - 6, 12 or 18cpd – than with BCVA.

Finally, ROC curves were used to quantify the diagnostic accuracy between the cataract and control groups. Taking into account all subjects, the area under the ROC curve for log(s) and 95% confidence interval (CI) was 0.909 (CI: 0.847 to 0.970) and for OSI it was 0.980 (CI: 0.953 to 1.000) while in terms of SR and MTF_{cutoff} they were 0.830 (CI: 0.790 to 0.894) and 0.897 (CI: 0.820 to 0.920) respectively. This represents the probability for a randomly selected eye from the cataract group to have a higher OSI value than a randomly selected eye from the control group. Since the OSI provided a larger area under the ROC curve than the SR and MTF_{cutoff} parameters, the same analysis was repeated to investigate separately the three types of cataracts only in terms of OSI and log(s). For NUC cataracts, the area under the ROC curve was 0.911 (CI: 0.824 to 0.999) and 0.970 (CI: 0.920 to 1.000) for log(s) and OSI, respectively; for

COR ones it was 0.833 (CI: 0.677 to 0.990) and 0.994 (CI: 0.977 to 1.000); and for PSC cataracts it was 0.984 (CI: 0.950 to 1.000) and 0.960 (CI: 0.883 to 1.000).

Using the maximized Youden index (J_{max}) as the limit value to discriminate between healthy and cataractous eyes in terms of both log(s) and OSI, we found the following values - the sensitivity (Sn) and specificity (Sp) values are also given: 1.15 (Sn:91%, Sp:100%) for log(s) and 1.18 (Sn:89%, Sp:100%) for OSI. The results for each of the cataract types were slightly different. In NUC cataracts they were 1.15 (Sn:89%, Sp:100%) for log(s) and 1.19 (Sn: 89%, Sp:100%) for OSI. In COR cataracts they were 1.25 (Sn:94%, Sp:100%) and 1.18 (Sn:79%, Sp:100%) while in PSC cataracts they were 1.15 (Sn:92%,Sp:100%) and 1.18 (Sn:96%, Sp:100%), respectively.

Accordingly, both of the parameters studied showed a high ability to discriminate between cataractous and healthy eyes for every type of cataract. Sensitivity values were similar except for cortical cataracts, where OSI showed a higher sensitivity than log(s). As it can be expected in a cataractous population, both parameters showed a very high specificity (100%). The most important difference between OSI and straylight, i. e. the log(s), is that the first one is calculated from the PSF, specifically taking into account the intensity recorded between 12 to 20 minutes of arc and that of the peak. Therefore, it is obvious that depending on the particular pattern of higher order aberrations present on an eye, the OSI might change.

DISCUSSION

The following classification was established for the OSI parameter based on the results obtained for 38 eyes with diagnosed nuclear cataracts[23]: values below 1 correspond to normal eyes with low amounts of scatter, between 1 and 3 to older eyes with associated scatter of an early cataract, between 3 and 7 to developed cataracts that should undergo surgery, and higher than 7 to eyes with severe cataracts. This classification was later used in 188 eyes with nuclear, cortical and posterior subcapsular cataracts obtaining consistent results [31]. The OSI values obtained in this study according to LOCSIII classification are consistent with those previously published.

Cutoff values proposed by European drivers studies[11] of 1.4 log(s) as safe margins for driving would correspond in our study to cataracts with a LOCSIII score lower than 2. In this sense, a parallel could be drawn here and it could be suggested that the OSI safe margin for driving is approximately 3.

Although both log(s) and OSI are related to scattering, there are significant differences between the two instruments as they are based on different principles. The most important one is that the OSI is calculated from the PSF, specifically taking into account the intensity of the central part of the PSF, and therefore is susceptible to artefacts related to the effect of aberrations and backscattered light. It is also important to highlight the impact that backscattered light from deeper retinal layers can have on the DP image, and thus on the OSI. The results in this study are in accordance with those already reported by authors[23,31], who found good correlations between the OSI and the LOCS III classification system in eyes with cataracts.

It must be noted that the OSI parameter was measured using a constant 4mm exit pupil for the whole procedure whereas log(s) was measured using the individuals' natural pupil. Another aspect to consider, especially when it comes to older individuals, is that log(s) requires a more active participation of the individual.

Part of the disagreement between the two parameters, regardless of the individual's participation, may be also due to the fact that the scattering provided by HDA, unlike C-Quant, is for a specific 780 nm wavelength

Another interesting aspect to consider is the results in Figure 2, in which it can be seen that the greatest differences between both parameters are present in subjects with high scattering levels.

However, there is correlation between visual function deterioration caused by the different types of cataracts and both the log(s) and OSI parameters allow discriminating between healthy and cataractous eyes in a similar way with cutoff values of 1.18 for OSI and 1.15 for log(s). It is noteworthy that the age in the control group is slightly lower than that in the group of patients with cataracts. They both also provide a similar clinical classification of cataractous patients regardless of the cataract type.

It has been found that visual function in terms of BCVA and CS is affected differently by intraocular scattering if we take into account the cataract type. Similarly to what other studies have reported, for the same intraocular scattering value, CS deteriorates the most in PSC cataracts[32]. On the other hand, NUC cataracts show a more linear CS deterioration than COR ones. It has also been found that, although there is moderate correlation between scattering and BCVA in PSC and NUC cataracts, such correlation is much weaker in COR ones. It is worth mentioning there is weak correlation between intraocular scattering and SR for PSC cataracts – especially for log(s) – whereas this correlation is much stronger for NUC and especially for COR cataracts. The morphology of cortical cataracts, which advances from the periphery of the lens toward the center, is likely to affect optical quality more rapidly and strongly than CS, contrarily to what happens with posterior subcapsular cataracts, where CS experiences a generalized decrease due to intraocular scattering.

In conclusion, both log(s) and OSI are useful parameters to study the effect of intraocular scattering on visual impairment and provide important complementary information to diagnose cataracts and follow those patients up. Correlations with LOCSIII classification are found in both cases, although they are slightly stronger with OSI for all cataract types.

In addition, CS is affected the most in PSC cataracts, while in COR cataracts optical quality is. The latter could suggest a higher presence of higher-order aberrations but such a point cannot be confirmed with this study.

The cortical cataract is the one that has a lower impact on visual function deterioration as scattering increases. Nevertheless, it would be interesting to investigate the optical quality deterioration caused by scattering in COR cataracts with a bigger number of individuals, and how it affects other aspects such as night vision, double vision or halos.

WHAT WAS KNOWN

- Several papers that relate cataract severity and morphology to OSI and log(s) are available. However, they have not been compared so far in the same cataract clinical study.
- There is no established scale to assess the visual impact of cataracts, plus the subjectivity of some tests adds a high variability between individuals.

WHAT THIS PAPER ADDS

- Both instruments add noteworthy information to the traditional methods regarding patients' follow-up and cataract surgery management. We provide clinical values obtained with both instruments.
- We found that the optical quality – SR and MTF_{cutoff} – provided by the HDA is affected the most in COR cataracts, while in PSC cataract visual function is.

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Figure legends

Figure 1. Box plots showing log(s) and OSI values for the control group and eyes with nuclear cataracts graded as NO1, NO2, NO3 and NO4 (top), cortical cataracts graded as C1, C2, and C3 (middle), and posterior subcapsular cataracts graded as P1, P2, P3 and P4 (bottom). Five statistical descriptors are shown in these plots: maximum, 3rd quartile, median, 1st quartile, and minimum as well as the outliers.

Figure 2. Scatterplot for log(s) and OSI. Dotted line: linear regression.

Tables

Table 1. Patient demographics – gender, right and left eyes, number of eyes – of the control group and cataract group, and subjective refraction – spherical equivalent.

	Control group	**Cataract group**
Gender (Male / Female)	4/6	43 / 35
Right / Left eyes	4/6	37 / 41
Number of eyes	10	78
Spherical equivalent (D)*	-0.47 ± 1.24 (-2.20 to 1.25)	0.44 ± 2.36 (-5.50 to 5.75)

* For this variable the Mean ± Standard Deviation [range] is given

Table 2. Age distribution in the sample by type and grade of cataract. LOCSIII scores are NO for nuclear cataract (NUC), C for cortical cataract (COR) and P for posterior subcapsular cataract (PSC). Mean of age, standard deviation (SD), minimum (min), and maximum (max) are shown. The number of eyes (n) belonging to each group considered regardless of the LOCSIII score is also shown.

Age distribution		***LOCSIII score***	***Mean ± SD (years)***	***Range***
Control group		<1 (n=10)	58 ± 4	52 to 65
Cataract group	**NUC**	Total (n=35)	70 ± 9	47 to 86
		NO1 (n=8)	74 ± 6	67 to 85
		NO2 (n=13)	67 ± 10	47 to 83
		NO3 (n=9)	68 ± 9	55 to 86
		NO4 (n=5)	74 ± 5	68 to 81
	COR	Total (n=18)	69 ± 6	57 to 79
		C1 (n=3)	67 ± 6	62 to 74
		C2 (n=8)	68 ± 7	57 to 79
		C3 (n=7)	71 ± 4	66 to 77
	PSC	Total (n=25)	69 ± 9	47 to 85
		P1 (n=4)	64 ± 5	57 to 69
		P2 (n=10)	73 ± 11	57 to 85
		P3 (n=8)	69 ± 10	47 to 79
		P4 (n=3)	68 ± 4	64 to 71

Table 3. Mean and standard deviation (SD) for the parameters studied. – Psychophysical: visual acuity (BCVA), contrast sensitivity (CS) at 3, 6, 12, 18 cpd and log(s); and Double-pass ones: Strehl ratio (SR), MTF_{cutoff} and OSI; – for the control group and for each of the cataract groups (nuclear: NUC, cortical: COR and posterior subcapsular: PSC).

Parameters studied (Mean ± SD)	***Control group***	***Cataract group***		
		NUC	**COR**	**PSC**
Psychophysical				
BCVA(logMAR)	-0.10 ± 0.12	0.21 ± 0.29	0.25 ± 0.16	0.24 ± 0.33
CS 3cpd	1.69 ± 0.12	1.47 ± 0.31	1.48 ± 0.33	1.49 ± 0.26
CS 6cpd	1.92 ± 0.19	1.61 ± 0.33	1.68 ± 0.30	1.65 ± 0.31
CS 12cpd	1.51 ± 0.20	1.19 ± 0.33	1.26 ± 0.36	1.23 ± 0.37
CS 18cpd	0.93 ± 0.27	0.83 ± 0.31	0.85 ± 0.33	0.74 ± 0.42
log(s)	1.09 ± 0.08	1.49 ± 0.26	1.43 ± 0.29	1.45 ± 0.26
Double-pass				
SR	0.20 ± 0.04	0.11 ± 0.05	0.09 ± 0.03	0.11 ± 0.09
MTF_{cutoff} (cpd)	39.6 ± 6.3	16.2 ± 10.2	11.92 ± 8.0	12.7 ± 8.1
OSI	0.67 ± 0.18	4.19 ± 3.12	4.28 ± 2.12	5.20 ± 3.99

Table 4. Mean values and standard deviation (SD) for the parameters studied. – Psychophysical: visual acuity (BCVA), contrast sensitivity (CS) at 3, 6, 12, 18 cpd and log(s); and Double-pass ones: Strehl ratio (SR), MTF_{cutoff} and OSI – for all the subjects with cataract grouped following the LOCSIII classification score. NO for nuclear, C for cortical, and P for posterior subcapsular cataracts.

Parameters studied (Mean ± SD)	**LOCS III score (NO, C or P)**			
	1 (n=15)	**2** (n=31)	**3** (n=24)	**4** (n=8)
Psychophysical				
BCVA(logMAR)	0.03 ± 0.16	0.18 ± 0.20	0.31 ± 0.30	0.59 ± 0.25
CS 3cpd	1.56 ± 0.28	1.52 ± 0.27	1.43 ± 0.34	1.31 ± 0.23
CS 6cpd	1.81 ± 0.25	1.70 ± 0.31	1.57 ± 0.30	1.30 ± 0.19
CS 12cpd	1.41 ± 0.28	1.29 ± 0.28	1.12 ± 0.41	0.90 ± 0.21
CS 18cpd	0.99 ± 0.24	0.81 ± 0.36	0.80 ± 0.34	0.46 ± 0.31
log(s)	1.22 ± 0.22	1.43 ± 0.22	1.55 ± 0.20	1.83 ± 0.15
Double-pass				
SR	0.16 ± 0.10	0.10 ± 0.04	0.07 ± 0.02	0.06 ± 0.02
MTF_{cutoff} (cpd)	23.9 ± 8.4	15.5 ± 8.4	8.9 ± 5.1	5.7 ± 4.5
OSI	1.56 ± 0.99	3.47 ± 1.63	5.88 ± 2.52	10.23 ± 3.69

Table 5. Partial correlations coefficient (r) controlling for age of parameters log(s) and OSI with psychophysical vision quality and objective optical quality parameters.

	Partial correlation coefficient (r) controlling for age					
	log(s)			**OSI**		
Types of cataracts	**NUC** (n=35)	**COR** (n=18)	**PSC** (n=25)	**NUC** (n=35)	**COR** (n=18)	**PSC** (n=25)
Psychophysical						
BCVA(logMAR)	0.581*	0.331	0.528*	0.518*	0.453*	0.513*
CS 3cpd	-0.273	-0.325	-0.441*	-0.404*	-0.375	-0.477*
CS 6cpd	-0.460*	-0.275	-0.514*	-0.560*	-0.219	-0.652*
CS 12cpd	-0.497*	-0.151	-0.503*	-0.453*	-0.455*	-0.682*
CS 18cpd	-0.233	-0.249	-0.482*	-0.393	-0.153	-0.635*
Optical quality						
SR	-0.614*	-0.568*	-0.328	-0.759**	-0.757**	-0.549*
MTF_{cutoff} (cpd)	-0.635*	-0.544*	-0.656*	-0.762**	-0.780**	-0.726**

* r from 0.4 to 0.69; ** r from 0.7 to 0.9

Figure

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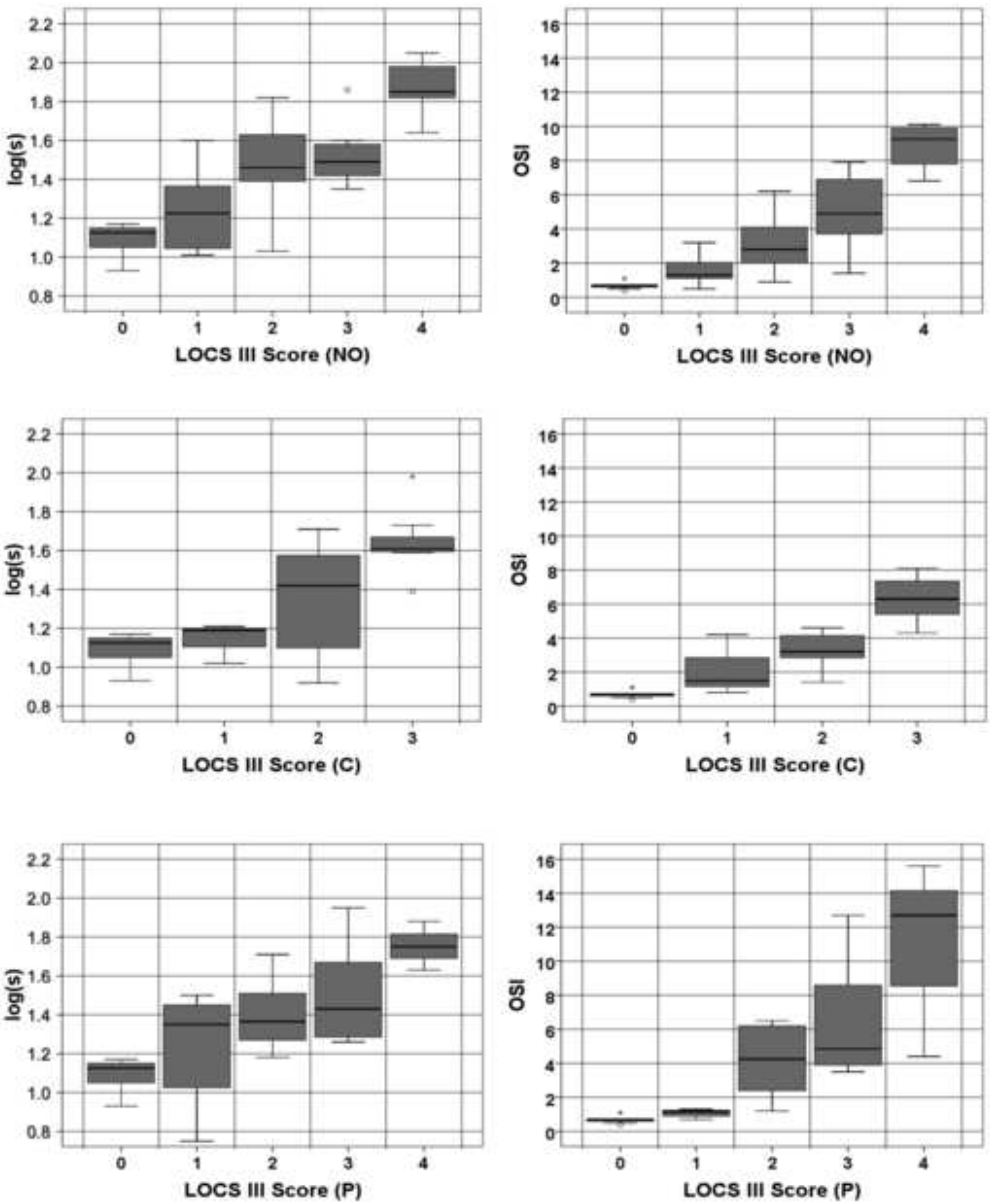

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