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EFFECTS OF AGING ON OPTICAL QUALITY AND VISUAL FUNCTION

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Keywords:	optical quality, intraocular scattering, visual function, visual acuity, contrast sensitivity, modulation transfer function, age

Title: **EFFECTS OF AGING ON OPTICAL QUALITY AND VISUAL FUNCTION**

Running title: Optical quality, visual function and aging.

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Background: We assessed the effects of aging on visual function and optical quality in a healthy adult population and provide reference values for different age ranges.

Methods: We conducted a prospective study with 198 healthy volunteers from 31 to 70 years of age. The best-corrected visual acuity (BCVA) and contrast sensitivity (CS) at 3, 6, 12 and 18 cycles per degree (cpd) frequencies were assessed, together with values of optical quality and intraocular scattering obtained with a double-pass system, specifically the modulation transfer function cutoff frequency (MTF_{cutoff}), the Strehl ratio, the OQAS Values (OV) at contrasts 100%, 20% and 9% and the objective scatter index (OSI). We studied the progression of these variables with age and obtained standard values for optical quality and intraocular scattering parameters for four age groups: 31-40 years, 41-50, 51-60, and 61-70.

Results: We found significant correlations between age and all variables analyzed and significant differences among the age groups considered except for CS (3 cpd) (p=0.067). Age decline particularly affected low-contrast parameters such as the OV 9% and the OSI, which decreased to 37% and 50% of their original value, respectively. The OSI was found to provide high sensitivity and specificity values when healthy and caratactous eyes were considered. The results suggest that optical deficits are compensated until 50 years of age with sensory and perceptual factors, since smaller changes were found for visual function than for objective measurements of optical quality and intraocular scattering.

Conclusions: Psychophysical and objective variables evolved differently with age. Reference values can be used to determine normal limits of optical quality and intraocular scattering for diagnosis of ocular conditions.

Keywords: optical quality; intraocular scattering; visual function; visual acuity; contrast sensitivity; modulation transfer function; age.

The aging population in societies with high life expectancy is associated with an increase in the prevalence of eye diseases. There are three main categories of age-related vision loss: firstly, changes in the optics of the aging eye; secondly, sensory changes (from retina to early visual cortex); and finally, perceptual changes (mid and high level visual cortex)[1]. Understanding the mechanisms of vision impairment caused by age is crucial to prevent vision loss[2].

Vision and aging have been extensively investigated; researchers have traditionally analysed visual function with psychophysical tests. For instance, Elliot et al.[3] studied visual acuity (VA) changes in a population of 223 subjects from 18 to 80 years of age with normal, healthy eyes. They reported optimal values in the 25 to 29-year-old group and a gradual linear decline thereafter. Several studies have established that older adults have impaired contrast sensitivity (CS) at intermediate and high spatial frequencies which starts at the age of 30 and progress into old age[4]. The deficit has been found to increase with increasing spatial frequency, whereas CS is preserved at low spatial frequencies[1,2]. Researchers have often attributed this decline to a decrease of retinal illuminance in older eyes. In contrast, other authors have associated poorer visual performance with factors beyond structural changes in the eye that affect sensory and perceptual performance, such as density of photoreceptors, efficacy of phototransduction and photopigment regeneration, and quality of synaptic transmission and signal processing in the retina and beyond[1,5].

More recently, new objective systems to analyse optical quality have been used to better elucidate the effects of aging. Methods such as wavefront sensors and double-pass systems[6] only consider optical changes and do not take into account posterior neural and perceptual factors. Guirao and colleagues[7] used a double-pass system to determine the modulation transfer function (MTF) as a function of age in 20 participants aged 20 to 30 years, 20 aged 40 to 50 years, and 20 aged 60 to 70 years. They found

that optical performance declined with age since a reduced MTF was obtained, and suggested that an important part of CS decline could be explained by the increasing amount of aberrations[8]. Indeed, the same authors found[9] that aberrations associated with the anterior surface of the cornea changed with age, in particular the spherical aberration, coma and other higher-order aberrations. However, they concluded that this increase alone did not explain the reduction found in retinal image quality, and suggested that changes in the aberrations of the lens with age and the possible loss of part of the balance between corneal and lenticular aberrations during youth might be the main factors responsible for the progressive reduction of retinal image quality.

Elliott et al.[10] used adaptive optics (AO) to correct monochromatic higher-order aberrations measured using a Shack-Hartmann wavefront sensor when assessing CS in older adults. On average, CS improved with AO, but did not reach the sensitivity level of younger adults when they had no AO compensation. These results suggest that neural factors intervene in loss of vision in older adults. In addition, they could underline the significance of optical variables other than monochromatic aberrations.

On the other hand, it has been shown that vision loss might be related to retinal straylight, which causes disability glare[11]. Van den Berg et al.[12] found that straylight measured with a psychophysical compensation comparison method increases with age, doubling at 65 years of age and trebling by the age of 77.

The study of the optical quality of the eye has been more widespread since the commercialization of a new clinical instrument based on the double-pass technique (OQAS 2, Visiometrics S. L., Terrassa, Spain)[13,14]. This system has already been used for the evaluation of patients undergoing refractive and cataract surgery[15–20]. In a previous study[21], we reported optical quality and intraocular scattering values in healthy young subjects measured with this system. We obtained new reference values useful for discriminating healthy eyes from abnormal ones in which the optical quality or sensory function is impaired. Participants were 18 to 30 years of age and 181 eyes were included in the study. Kamiya et al.[22] conducted a similar study to analyse the

effect of aging on optical quality and intraocular scattering. They prospectively examined 100 healthy eyes of volunteers aged 20 to 69 years and found significant negative correlations between parameters related to the optical quality of the eye and age, and a significant positive correlation between intraocular scattering and age. Similarly, Miao et al.[23] reported optical quality and intraocular scattering values in 274 eyes of adults with myopia aged 18 to 40 and found that high myopia has more influence on retinal image quality and scattering than moderate and low myopia.

None of the former studies provide reference values for optical quality and intraocular scattering parameters for different age ranges. Furthermore, they do not analyse the relationship between the decline in objective parameters and psychophysical deficits in relation to visual function characteristics such as CS at different spatial frequencies, which might also be affected by sensory and perceptual processing. We analyse the decline of the optical quality of the eye and the increase of intraocular scattering as a consequence of normal aging and provide normal values beyond 30 years of age. We compare these values with the decline of visual performance through age to establish reference values for the optical quality of the eye and intraocular scattering.

METHODS

This prospective study was conducted on volunteers aged 31 to 70 years from the University Vision Centre (CUV) of the Technical University of Catalonia (Terrassa, Barcelona, Spain) between September 2009 and June 2014. All subjects signed the written consent form before any examination and ethical committee approval was obtained. The study followed the tenets of the Declaration of Helsinki (2004 Tokyo revision).

Participants underwent a comprehensive ophthalmologic and optometric examination including anterior segment observation with slit-lamp, retinography, assessment of intraocular pressure with a noncontact air-puff tonometer, retinoscopy, manifest subjective refraction, best-corrected VA (BCVA) measured with a Bailey-Lovie chart,

and CS with the CSV-1000E test (VectorVision, Greenville OH, USA) under photopic conditions at frequencies of 3, 6, 12 and 18 cycles per degree (cpd). Exclusion criteria were corneal opacities, anterior segment diseases, cataracts with nuclear opalescense (NO), nuclear colour (NC), cortical (C) or posterior subcapsular (P) scores higher than 1 according to the LOCS III chart, abnormal posterior pole evaluation, intraocular pressure values over 21 mmHg, abnormal tear film and previous ocular surgery. Inclusion criteria were eyes with BCVA of at least 20/25 and with spherical equivalent (SE) and cylinder (C) under 3.00 Diopters (D) to avoid non-desired correlations between refraction and optical quality as well as refraction and age as reported by some authors.[23,24]

A total of 198 subjects (396 eyes) participated in the study. From them, 101 eyes were excluded due to refractive error, 98 to the presence of a cataract and 16 to other reasons which were mainly presence of exudates in fundus photography, corneal injury and surgery.

Optical quality and intraocular scattering measurements

The optical quality and intraocular scattering of the eyes included in the study were measured using the OQAS 2 system. We obtained the following parameters related to the modulation transfer function[21]: the MTF_{cutoff}, the Strehl ratio and the OQAS values (OV) at 100, 20 and 9 per cent contrasts. The Objective Scatter Index (OSI) was also measured[16,19]. A 4-mm artificial pupil was used to compute these parameters.

The MTF_{cutoff} is calculated as that corresponding to a 0.01 MTF value, since there is a background noise in the profile computed from the real recorded double-pass image. The system computes the Strehl ratio in two dimensions as the ratio between the areas under the MTF curve of the measured eye and that of the aberration-free eye[7]. The three OVs are normalised values of three spatial frequencies that correspond to the MTF values of optical quality for three contrast conditions used in ophthalmological practice: 100 per cent (OV100%), 20 per cent (OV20%) and 9 per cent (OV9%). These

values can be used to obtain more specific information on the performance of the eye's optics at different contrasts. This information is less obvious when more general parameters that integrate the information of all available spatial frequencies are considered. OV 100% is directly related to the MTF_{cutoff} (MTF_{cutoff} divided by 30 cpd) and therefore to the patient's visual acuity, although it is not affected by retinal and neural factors. OV 20% and OV 9% are computed from smaller frequencies linked to 0.05 and 0.1 MTF values, respectively, which maintain the proportion of contrasts at 20% and 9%. The OSI parameter is computed as the ratio of the amount of light within an annular area of 12 and 20 minutes of arc (inner and outer radii) and that recorded within one minute of arc of the central peak in the acquired double-pass image.

Statistical analysis

To study the changes of the analysed variables - i. e. the psychophysical variables as well as the optical quality and intraocular scattering parameters - with age, we divided the subjects into four age groups: 31-40, 41-50, 51-60, and 61-70 years. The Kolmogorov-Smirnov test was used to evaluate the normal distribution of all variables. Next, the correlations of variables with age were assessed using Pearson's correlation coefficients. Balanced analysis of variance was used to analyse the influence of gender, right and left eyes, SE, and C among age groups. An analysis of variance and a Bonferroni post-hoc analysis were performed to establish significant differences among age groups. The results are shown as mean ± standard deviation (SD). Additionally, the corresponding range (minimum and maximum) are also given for variables related to optical quality and intraocular scattering. The lower limits of normal values for optical quality parameters are defined at the 95% level of agreement by mean - 1.96 × SD. For the intraocular scattering the upper limits of normal values are calculated as the mean + 1.96 × SD. Since the excluded population showed a strong asymmetry related to age, belonging most of them to the group of from 61 to 70 years of age, the sensitivity (Sn) and specifity (Sp) of normal values were also calculated for

the group of patients between 61 and 70 years old who met the refraction criteria but were excluded only because an incipient cataract, i.e., with LOCSIII indexes lower than 4, had been detected. Sn was calculated from eyes with pathology that were found to have pathology and Sp from healthy eyes that were found to have no pathology. Data were analysed using the SPSS software for Windows (V.20.0). A value of $p<0.05$ was considered significant.

RESULTS

A total of 181 (93 right and 88 left) healthy eyes of 102 participants (54.1% female and 45.9% male) were included in the study. Mean age (± SD) and range (minimum to maximum) were 48.2 ± 10.9 years (31 to 70 years). Manifest refraction for SE was of -0.07 ± 1.12 D (-2.88 to +2.75 D) and of 0.47 ± 0.54 D (0.00 to 3.00 D) for C. All variables showed a normal distribution ($p>0.05$).

Additionally, 47 (23 right and 24 left) eyes of 36 participants (63.8% female and 36.2% male) excluded because of the presence of a cataract were considered for the sensitivity (Sn) and specifity (Sp) calculations. Mean age (± SD) and range (minimum to maximum) were 66 ± 4 years (61 to 70 years). Manifest refraction for SE was of +0.63 ± 1.18 D (-1.25 to +2.75 D) and of 0.43 ± 0.55 D (0.00 to 2.00 D) for C.

We found significant correlations between age and all variables analysed (Table 1). The visual function parameters (BCVA and CS) worsened in the aging eye, although correlations were stronger for parameters related to optical quality and intraocular scattering. Specifically, the OSI parameter had the strongest correlation ($r=0.584$, $p<0.001$), i.e., the most relevant change with age was the increase of intraocular scattered light. OV 100% had the weakest negative correlation ($r=-0.407$, $p<0.001$, whereas the strongest correlation was for OV 9% ($r=-0.524$, $p<0.001$). Consequently, the decrease in optical quality with age is greater for lower contrasts. With regard to CS, higher frequencies presented stronger negative correlations; the most significant corresponded to 18 cpd ($r=-369$, $p<0.001$).

No statistically significant differences were found among age groups in relation to gender, right and left eyes, SE and C (Table 2). The mean (± SD) for each analysed variable for eyes of each age group are shown in Table 3, Table 4, Figure 1, and Figure 2. The analysis of variance reported significant differences among age groups for the psychophysical variables and those related with optical quality and intraocular scattering ($p<0.05$). The only exception was for CS at 3 cpd ($p=0.067$). The Bonferroni post-hoc analysis revealed that statistically significant differences ($p<0.05$) could always be established when considering psychophysical variables and the 61-70 age group, except for the CS at 3 cpd as already stated. The comparisons among younger groups of age did not provide statistically significant differences in terms of BCVA and CS.

The post-hoc analysis of variables related with optical quality and intraocular scattering revealed a different pattern. For the OV 100% there were not significant differences among the first three decades of age, i.e., from 31 to 60 years. On the contrary, OV 20% and OV 9% reported differences between the 31-40 and 41-50 age groups, and the 51-60 and 61-70 age groups, but not between the 41-50 and 51-60 age groups. Finally, when considering the OSI statistically significant differences could be established between groups of age older than 50 years, but not between the 31-40 and 41-50 age groups.

Additionally, Table 4 provides normal values beyond 30 years of age of the variables related to optical quality and intraocular scattering. The limits of normal for each variable are given as well as the Sn and Sp when the healthy and cataratous eyes of patients aged 61 to 70 years are taken into consideration. As it can be seen, the proposed limits of normal provided Sn values close to 100% for all the optical quality variables. The OSI showed also a high Sp (82.9%), whereas the rest of variables did not provide acceptable Sp values. This was already expected as the OSI is prominent in eyes with cataracts.

Figure 3 shows the CS function for each age group; CS remains practically unaltered until the age of 50. A significant and progressive decrease with age more noticeable at higher spatial frequencies is observed thereafter.

Figure 4 compares the ratios between each variable analysed for each age group with the 31-40 age group, to highlight differences of variables with age. The Strehl ratio shows a negative linear correlation with age; it declines about 10% for each decade between 30 and 70 years of age. This optical worsening does not translate into visual function, which on average remains practically unaffected until 50 years of age for BCVA and CS. The maximum loss at the ages of 61-70 was found for 18 cpd, for which a decrease of about 30% was registered. At the other frequencies the decline was smaller, only 5% for 3 cpd. Similarly, BCVA showed a marked decline only in the last decade, with a total loss of 15% of its original value.

With regard to the other parameters that describe ocular optical quality (MTF_{cutoff}, and OVs at different contrasts), those related to low contrasts are more affected by age. In particular, MTF_{cutoff} and OV 100%, both closely related to the VA (and thus with high contrasts), suffer only a decline of about 25% over 50 years of age in relation to their value in the 31-40 decade. However, the decline is more progressive for parameters related to lower contrasts, i.e., OV 20% and OV 9%. As with to the Strehl ratio, the loss is about 35%. The OSI has a relevant role in the aging eye, since it is the most affected with an increase of about 50% in the oldest subjects. The increase of intraocular scattering is particularly relevant beyond the age of 60.

DISCUSSION

Martinez-Roda et al.[21] reported normal values of ocular optical quality and visual performance for a healthy population aged 18 to 30 years. Specifically, the authors used the OQAS 2 system based on the double-pass technique and psychophysical parameters such as VA and CS tests. The comparison of these values with those obtained in the current study reveal that visual function remains practically unaltered

after the age of 30, and that a significant decline does not start until the age of 50 and particularly in the 61-70 year decade. After 60 years of age, CS loss increases with increasing spatial frequency, whereas low frequency sensitivity is only minimally impacted by aging[2].

With regard to optical quality parameters, an independent analysis needs to be carried out for each contrast considered; on the one hand, high-contrast parameters such as MTF_{cutoff} and OV 100% are not much affected by age and a marked decline was only obtained after 50 years of age. In contrast, variables related with overall optical quality, such as the Strehl ratio, and the OV of lower contrasts (20% and 9%), are linked to a more progressive decline. However, the first age group considered in the current study (31-40 years) obtained very similar values to those reported for individuals 18 to 30 years of age; only beyond the age of 40 a noticeable decrease is found. The difficulty of seeing low contrast stimuli has already been reported by researchers who noted that VA underestimates the degree of vision function loss suffered by many older individuals, and that spatial vision measured under conditions of reduced contrast or luminance reveal significant impairment in a large portion of the elderly[25]. Some authors have attributed these changes to the reduction of retinal illuminance due to pupillary miosis, the change of transparency of ocular tissues, especially of the lens, and the increased optical aberrations in the aging eye that can reduce image contrast[2,9].

Finally, the OSI assessment highlighted a decline that increased exponentially with age, with doubled values for the last decade considered (61-70 years of age), in agreement with other studies that have used different methods to evaluate scattered light in the eye and have reported a rapid increase in forward scatter after the age of 45[12,26].

It is worth noting the usefulness of the limits of normal for variables related to optical quality and intraocular scattering reported in this study for individuals beyond 30 years of age. The Sn and Sp values obtained for each variable support the fact that they can

be used to improve the early diagnosis of certain ocular diseases. In this case OSI is a good parameter to detect cataracts.

Kamiya et al.[22] also measured the MTF_{cutoff}, Strehl ratio and OSI in a population of 100 eyes of volunteers aged 20 to 69 years with the OQAS instrument. Their results correlate well with ours for the Strehl ratio, which in both cases declines progressively with age. However, they found a linear decline with age for the MTF_{cutoff} ($r = -0.606$), whereas our results show a marked decline after 50 years of age. With regard to the OSI, they reported a positive correlation between intraocular scattering and age ($r = 0.691$) and suggested that the Strehl ratio and the OSI evolved differently, i.e., some extra scatter occurs in the eyes of the older population as a result of the decrease in the transparency of the crystalline lens and the cornea. These results agree with our findings, since OSI also increases with age, and in particular after the age of 50.

In agreement with previous studies, our study shows that vision loss in older adults is largely optical in origin as objective measures are linked to a decline with age[7,8]. Indeed, we found a decrease of the optical quality beyond 30 years of age, especially when the Strehl ratio and parameters related to low contrasts were considered. However, our results also suggest that these optical deficits are compensated during the first decades of adult life by means of sensory and perceptual factors which through neural adaptation preserve visual function until the age of 50. The preserved parameters of visual processing and visual behavior and the neurological mechanisms involved are yet poorly understood[2]. However, recent research suggests that perceptual learning and plasticity of the visual system could be used to improve visual function in older individuals[27,28]. The results obtained in this study also highlight that beyond the age of 50 this compensation is no longer effective, and a decline in visual performance is then revealed. This is also corroborated when the mean ratios between values of psychophysical parameters and objective parameters (optical quality and intraocular scattering) among different groups of age are considered (Figure 4); those obtained by means of objective outputs are generally higher, meaning that the optical

changes are larger than the psychophysical ones. In consequence, age-related declines in sensory and perceptual performance are of crucial importance beyond the age of 50.

In conclusion, our study demonstrates that visual function, optical quality and intraocular scattering change with age, in particular parameters related to low contrast stimuli and scattered light. Additionally, the results suggest that these optical deficits are compensated throughout the first decades of adult life by means of sensory or perceptual factors since the visual function showed smaller changes than objective outputs, in particular until the age of 50. Our study also contributes optical quality and intraocular scattering reference values for individuals up to 70 years of age. These reference values can be used as complementary information for the diagnosis of ocular conditions such as the presence of a cataract.

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TABLES:

Table 1. Pearson's correlation coefficients (r) and corresponding significance (p-value) between each analysed variable and age (cpd: cycles per degree).

	r	p-value
BCVA	0.268	<0.001*
CS (3 cpd)	-0.162	0.029*
CS (6 cpd)	-0.242	0.001*
CS (12 cpd)	-0.249	0.001*
CS (18 cpd)	-0.369	<0.001*
MTF_{cutoff} (cpd)	-0.407	<0.001*
Strehl ratio	-0.522	<0.001*
OV 100%	-0.407	<0.001*
OV 20%	-0.482	<0.001*
OV 9%	-0.524	<0.001*
OSI	0.584	<0.001*

*Statistically significant correlations

Table 2. Characteristics of age groups (n: number of eyes, D: Diopters, SE: Spherical equivalent, C: Cylinder)

Age group	n	Age (years)		Eyes (n)		Gender (n)		SE (D)		C (D)	
		Mean	SD	Right	Left	Female	Male	Mean	SD	Mean	SD
31-40	43	34	2	21	22	19	24	-0.04	0.92	0.43	0.64
41-50	55	45	3	29	26	30	25	-0.11	1.11	0.41	0.45
51-60	51	54	3	25	26	32	19	-0.21	1.06	0.64	0.53
61-70	32	64	4	18	14	17	15	0.16	1.48	0.37	0.54

Table 3. BCVA, CS (log) at 3, 6, 12 and 18 cpd spatial frequencies, for the age groups considered. The mean and standard deviation (SD) are shown (cpd: cycles per degree).

Age group	BCVA		CS (3 cpd)		CS (6 cpd)		CS (12 cpd)		CS (18 cpd)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
31-40	1.47	0.32	1.71	0.18	1.91	0.23	1.56	0.27	1.05	0.26
41-50	1.47	0.21	1.70	0.25	1.87	0.24	1.53	0.25	1.05	0.26
51-60	1.42	0.28	1.62	0.17	1.84	0.20	1.47	0.28	0.94	0.24
61-70	1.23	0.28	1.63	0.21	1.73	0.23	1.35	0.35	0.72	0.34

Table 4. MTF_{cutoff} (cpd), Strehl ratio, OV at 100%, 20% and 9% contrasts and OSI for the age groups considered. The mean and standard deviation (SD), range (minimum-maximum), lower limits of normal at the 95% level of agreement (upper for the OSI) are shown. Additionally, the sensitivity (Sn) and specificity (Sp) for the 61-70 group are given when healthy eyes and those with cataracts are considered (cpd: cycles per degree).

Age group	Mean	SD	Range (min-max)	Normal límit (low)	Sn. %	Sp. %	Mean	SD	Range (min-max)	Normal límit (low)	Sn. %	Sp. %
			MTF_{cutoff}						**Strehl ratio**			
31-40	44.4	7.6	27.2 - 56.1	**29.4**			0.263	0.056	0.165 - 0.425	**0.154**		
41-50	43.2	7.4	22.0 - 55.9	**28.7**			0.233	0.054	0.148 - 0.420	**0.126**		
51-60	41.7	7.5	27.5 - 54.3	**26.9**			0.209	0.047	0.116 - 0.342	**0.116**		
61-70	33.3	8.8	18.9 - 53.3	**16.1**	100	59.6	0.177	0.044	0.102 - 0.264	**0.091**	100	53.2
			OV 100 %						**OV 20%**			
31-40	1.48	0.25	0.91 - 1.87	**0.99**			1.56	0.30	1.04 - 2.28	**0.97**		
41-50	1.44	0.25	0.73 - 1.86	**0.95**			1.47	0.33	0.74 - 2.20	**0.82**		
51-60	1.39	0.25	0.92 - 1.81	**0.90**			1.37	0.32	0.82 - 2.06	**0.74**		
61-70	1.11	0.29	0.63 - 1.78	**0.54**	100	59.6	1.02	0.32	0.57 - 1.91	**0.40**	100	51.1
			OV 9 %						**OSI**			
31-40	1.59	0.35	1.01 - 2.66	**1.01**			0.49	0.16	0.20 - 0.90	**0.81**		
41-50	1.42	0.38	0.82 - 2.59	**0.82**			0.54	0.20	0.14 - 1.11	**0.94**		
51-60	1.26	0.33	0.66 - 2.23	**0.66**			0.68	0.18	0.31 - 1.20	**1.04**		
61-70	1.00	0.30	0.52 - 1.62	**0.52**	96.9	66.0	0.97	0.35	0.38 - 1.61	**1.65**	98.2	82.9

FIGURE CAPTIONS

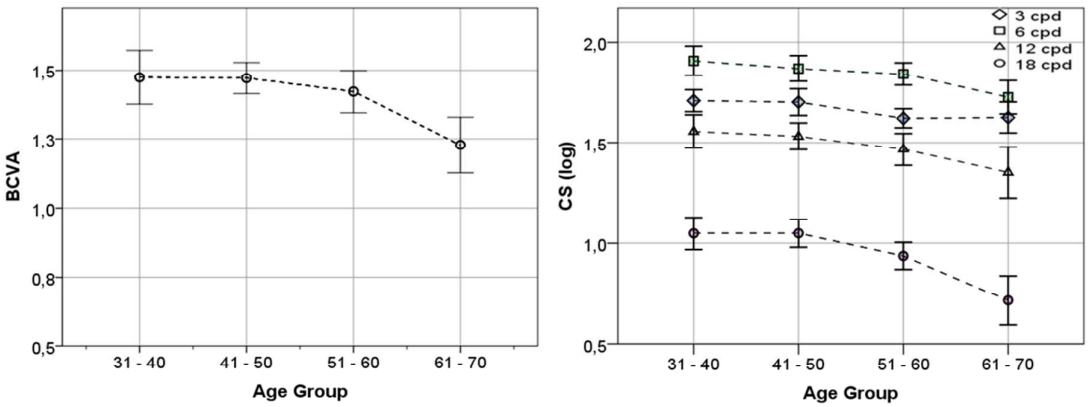

Figure 1. Decline of BCVA and CS (log) at spatial frequencies of 3, 6, 12 and 18 cpd in relation to age. The mean and 95% confidence interval are shown (cpd: cycles per degree).

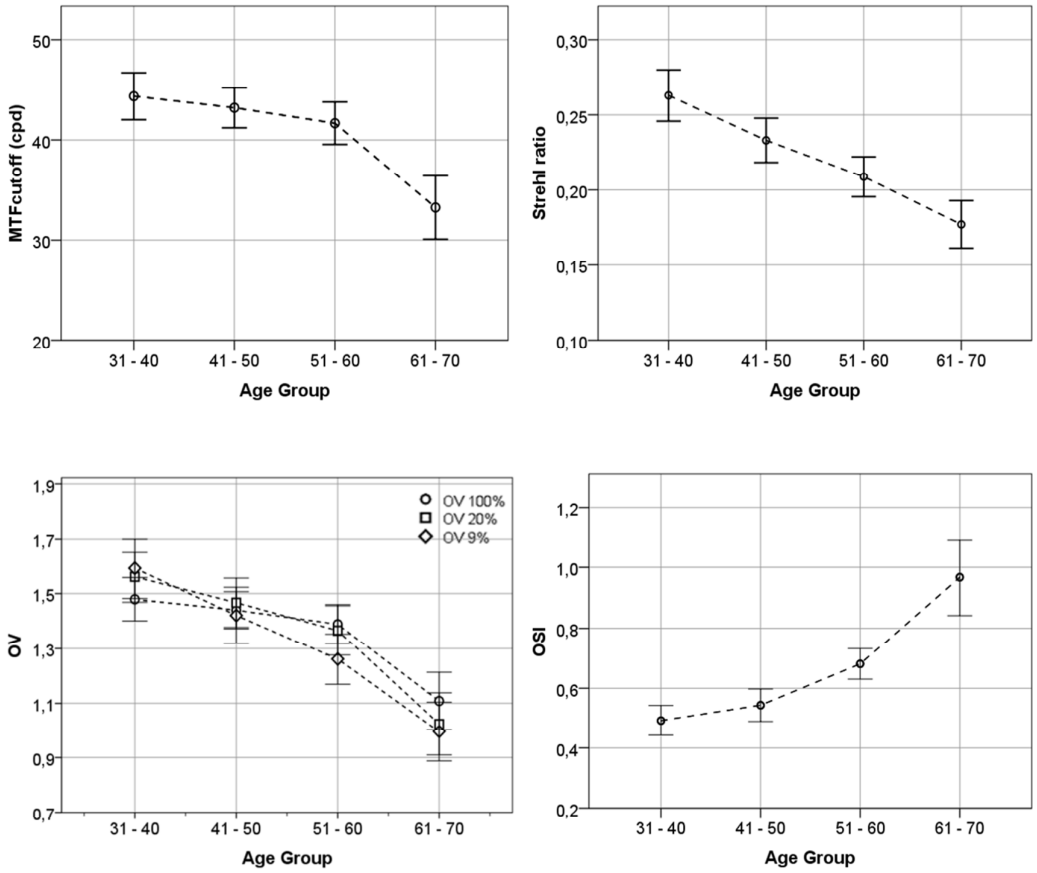

Figure 2. Change of MTF_{cutoff} (cpd), Strehl ratio, OV at 100%, 20% and 9% contrasts, and OSI in relation to age group. The mean and the 95% confidence interval are shown (cpd: cycles per degree)

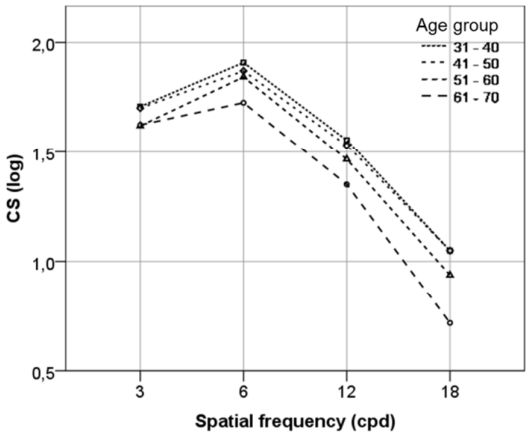

Figure 3. Mean CS for the age groups considered for spatial frequencies of 3, 6, 12 and 18 cpd (cpd: cycles per degree).

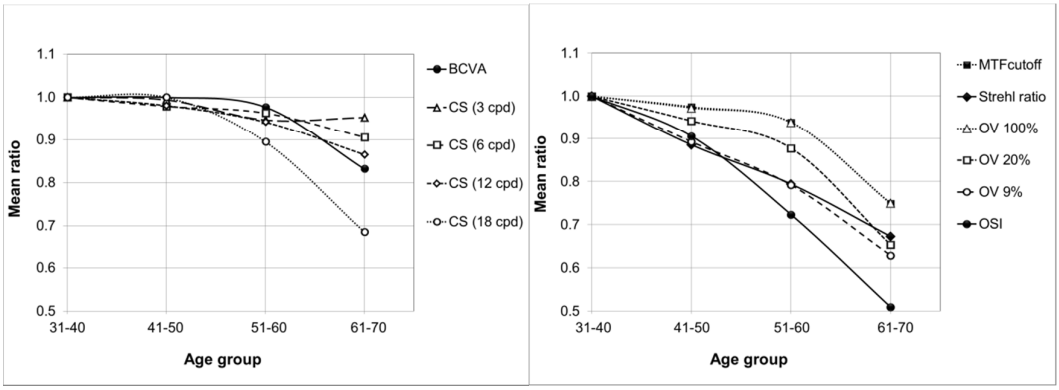

Figure 4. Mean ratio of all psychophysical variables (left) and optical quality and intraocular scattering parameters (right) corresponding to each age group in relation to the 31-40 age group. Mean values for the BCVA, CS (log) at spatial frequencies of 3, 6, 12 and 18 cpd, MTF_{cutoff} (cpd), Strehl ratio, OV at 100%, 20% and 9% contrasts, and OSI are shown (cpd: cycles per degree).