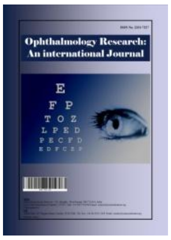

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The Effect of Monochromatic Aberrations of the Cornea on Contrast Sensitivity under Photopic and Mesopic Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. Author EP wrote the first draft of the manuscript and managed the literature searches. Author KL took the measurements and performed the statistical analysis. Author PD designed the study. All authors read and approved the final manuscript.

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ABSTRACT

Purpose: Vision is one of the most important senses. The first stage of vision is the creation of the observed object's image on the retina. The quality of the retinal image is affected by several factors, such as diffraction, sampling on the retina, chromatic aberration, scattering and higher order aberrations. The measurement of the quality is achieved both with subjective (visual acuity, contrast sensitivity) and objective methods (PSF, MTF, Strehl ratio, RMS). The purpose of this project is the measurement of higher order aberrations of the anterior corneal surface (with a Placido corneal topographer) and of the contrast sensitivity (with a Pelli Robson optotype). Then, we will try to find if there is a correlation between them.

Methods and Materials: 20 persons participated in this survey, divided in two groups of 10 persons each. The first group (group 1) included subjects up to 39 years old and the second group (group 2) from 40 years and up. The participants didn't have any pathological problems, except lower order refractive errors. Both eyes of each individual were included in the procedure. First, the higher order aberrations of the anterior corneal surface were measured, with the implementation of a Placido corneal topographer. This was followed by a measurement of the contrast sensitivity. The whole procedure took place under two lighting conditions, both photopic and mesopic. The examination presentation of the higher order aberrations is performed with the use of Zernike polynomials.

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Results: The results of the measuring procedure showed that for the first group, under photopic conditions (luminance 32.70 cd/m^2) the mean value (± standard deviation) for the higher order aberrations RMS and decimal logarithm contrast sensitivity was 0.073 ± 0.018μm and 1.54 ± 0,16 (contrast 2.88 ± 1.24%) respectively. For the second group the corresponding values were 0.080 ± 0.036μm and 1.59 ± 0.16 (contrast 2.57 ± 1.24%). Accordingly, under mesopic conditions (luminance 1.14 cd/m^2) the values for the first group were 0.252 ± 0.064 μm and 1.27 ± 0.15 (contrast 5.37 ± 2.06%), while for the second were 0.253 ± 0.069μm and 1.32 ± 0.12 (contrast 4.79 ± 1.35%). Spherical aberration and coma (horizontal and vertical) were also measured for both groups under photopic and mesopic conditions. The results showed that for the first group, under photopic conditions, RMS for coma and spherical aberration is 0.033 ± 0.014 μm and 0.022 ± 0.011 μm respectively, while for the second group 0.041 ± 0.027 μm and 0.024 ± 0.008 μm. Under mesopic conditions, the relevant results are 0.139 ± 0.065 μm and 0.124 ± 0.035μm for the first group and 0.149 ± 0.066 μm and 0.107 ± 0.038 μm for the second group.
Finally, we should mention here that the equivalent defocus error corresponding to the higher order aberration RMS was estimated. The results for all the participants (without age separation), are 0.23 ± 0.09D (photopic conditions) and 0.28 ± 0.07D (mesopic conditions).
Conclusions: From the statistical analysis of the results we conclude that there exists a symmetry between left and right eyes regarding higher order aberrations. Furthermore, it seems that age is not a significant factor for differences on the magnitude of higher order aberrations both under photopic and mesopic conditions as well. Similar conclusions are also reached for the contrast sensitivity measurements. In addition, we have observed that a correlation exists between the higher order aberrations of the anterior corneal surface and the contrast sensitivity, for both photopic and mesopic conditions. Correlation also exists between coma and contrast only under photopic conditions. But there is no significant correlation between spherical aberration and contrast. The age difference of these two groups has not an effect on the results. Finally, the equivalent defocus is too small, both for photopic and mesopic conditions and between each other, in order to be clinically significant.

Keywords: Coma; contrast sensitivity; higher order aberrations; spherical aberration; RMS.

1. INTRODUCTION

The image formation entering the pupil of the eye plays a very important role on retinal imaging. It is influenced by many factors, since the human eye is a not so perfect structure. The ocular low and high order aberrations, the wave nature of light (diffraction), scattering and the anatomical restrictions on the retina can cause problems in quality of formed image [1-4]. This can result in recognition problems of objects. The aberrations of low (defocus and astigmatism) and high order (coma, spherical aberration, high order astigmatism) play a very important roll on the quality of vision [5]. The high order aberrations are due to structural defects of the refractive structures of the eye (mainly corneal and crystalline lens), as well as in their eccentric placement in relation to the visual axis of the eye. Usually, corneal and lens aberrations are minimized in younger people. In older people these aberrations increase, mainly due of changes of the crystalline lens [6-9]. The measurement of aberrations is performed with the assist of special devices, called aberrometers (deflectometers), while the aberrations of the anterior surface of the cornea can be imaged with corneal topography [10,11].

The quality of the image formed can be evaluated with various ways. The most common is through the visual acuity tests. This is a routine procedure in ophthalmology and optometry and is the simplest method of determining the resolution of the visual system but also of the overall vision in general. The measurement of visual acuity is a subjective method of determining the quality of the retina, since in the formation of the final result the examined patient participates.

Another subjective method is the measurement of contrast sensitivity in order to estimate the retinal quality. It is a method of determining the minimum contrast that an optotype symbol must have of a certain size, in relation to the background, in order to be perceived. Many times, the contrast sensitivity test can reveal problems, which at an early stage do not affect visual acuity. There are many ways to measure sensitivity contrast, always with the participation of the examinee, but also the determination of contrast sensitivity is a subjective method as too [12].

There are, however, objective methods of determining the retinal quality. With the methods the final result, therefore the results are more objective. The tests that are performed relate only to visual formation of the retina and not recognition of the object observed. The Point Spread Function (PSF), the Modulation Transfer Function MTF and the ratio of Strehl, were calculated by these methods [13-15]. Many times the combination of both methods (subjective and objective) gives us useful information about the quality of the image, where us they help to we take out conclusions for the evaluation of vision of subject.

2. METHODS

As it was mentioned before the high order aberration are a major factor degrading the quality of the retinal image. In the present work contrast sensitivity is presented to be effected by aberrations of the anterior surface of the cornea. The research took place in the ophthalmology clinic of the UNIWA Athens. 20 people were examined, all of them agreed in writing to participate voluntarily to undergo the methods used for the purpose of this research. Our research was conducted on over 20 people. These individuals were divided into two equal groups of 10 people. The first group (group 1) consisted by people up to 39 years old. The average age of this group was 25.60 ± 3.95 years. In the second group (group 2) were placed elderly people over 40 years. The mean age of the second group was 46.00 ± 6.09 years. The separation was made on the basis that over the age of 40 are observed changes in vision, such as the appearance of presbyopia. All participants did not have any pathological conditions related to vision, such as diabetes, glaucoma, cataracts, etc. In case there was a refractive error the measurements were made using of corrective spectacle lenses in order not to affect the measured contrast sensitivity from low-order aberrations (myopia, hyperopia, astigmatism).

The lighting conditions of the room were completely controlled and the room was completely isolated from the effect of external lighting (light pollution). The necessary lighting was provided by a LED lamp with the ability to control its light flow (dimmable). Initially, with the help of a spectrophotometer the emission spectrum of the lamp was measured in extreme brightness. The results of the measurements are presented in the following Fig. 1.

Depending on the brightness of a room we can distinguish the following conditions vision:

- Photopic conditions, which are activated when the brightness is greater than 3cd/m^2 (eg a sunny day). In such conditions these retinal response is dominated by the cone and the vision is colored and detailed.
- Scotopic conditions, which are activated when the brightness is less than 0.001cd/m^2 (eg a very dark room). The response of the retina is dominated by rods and vision is monochromatic (shades of gray) and with low resolution.
- Mesopic conditions, are observed for luminosities from 0.001cd/m^2 up to 3cd/m^2 (eg artificial lighting). In these conditions the retinal response is dominated partially by the operation of the rods and partially by cones.

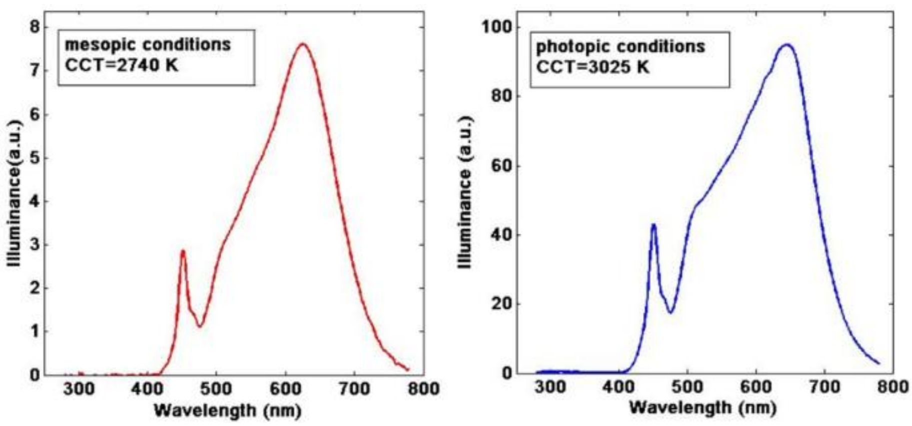

Fig. 1. Lamp emission spectrum in mesopic (left diagram) and photopic (right diagram) conditions

From the diagrams in Fig. 1 it appears that at the maximum of the light flux (photopic conditions) the lamp has a color temperature of 3025K and is dominant wavelength of 520 nm. At a minimum (intermediate conditions) the temperature color is 2740K and the dominant wavelength is 580nm. Therefore, the change in brightness of the lamp does not significantly affect the conditions of the experiment, since the spectral distribution of the light produced is approximately the same in both conditions and the experiments can be considered colorless.

The lighting conditions selected, was 1.14cd/m^2 for mesopic conditions and 32.70 cd/m^2 for photopic conditions. The RMS of high order aberrations of the anterior surface of the cornea for pupil diameter 5mm (mesopic conditions) and 3mm (photopic conditions) were measured by a topographer (Oculus modi 2, CSO Firenze Italy, Phoenix software v 2.6).

A calibrated luxometer, mounted at the the Pelli-Robson optotype, and a brightness recorder (photometer) of a professional DSLR camera were used to calculate the relationship between the illumination at the optotype (E) and brightness that reaches the pupil level (L). The results are presented in Fig. 2. Using the calibration curve, the excitation brightness (stimulus luminance) of each subject examined was obtained simply by measuring the illumination at the level of the optotype.

All subjects underwent visual acuity testing with ETDRS on Vistavision screen-optotype, based on the specifications of the screen. Both eyes were measured. Their visual acuity, with the best correction, was *0 logMAR* or better. Proper history was taken and slit lamp examination was used to rule out existence systemic or ocular diseases that may affect measurements.

The high-order aberrations of the anterior surface of the cornea were then determined, with the help of a topographer (Oculus modi 2, CSO Firenze Italy, Phoenix software v 2.6). The topographer software enables to objectively determine the quality of the retinal image in various pupil diameters. The 3mm, for photopic conditions, and 5mm, for mesopic. The topographer besides the RMS of low and high order aberrations (Fig. 3), produced the PSF, the MTF and Strehl's fraction ratio for each eye measured (Fig. 4).

Afterwards, the examinees remained in a specially designed space with eyes covered wearing special opaque masks, for about 20 minutes. This was done in order for the photo receivers to be completely reconstructed in order to have the maximum sensitivity in the retina levels.

Contrast sensitivity measurements were performed under fully controlled lighting contrast (photopic and mesopic). The brightness of 1.14cd/m^2 was selected for mesopic conditions and 32.70cd/m^2 for photopic conditions. The above values represent the brightness at the level of the examinee's pupil. The measurements were taken for each eye separately in each patient examined. Recording of contrast sensitivity of each examinee was taken by wearing his corrective glasses in order to exclude the possibility that the aberrations of low order will affect the measurements. The contrast sensitivity was measured with the help of a Pelli-Robson type optotype [16,17]. The examinee was placed at a distance of 3m away of the optotype, and requested to read the letters until arrives in a series were the letter were not seen any longer. The examination started in the mesopic conditions and then switched in photopic ones. Here we should mention that to

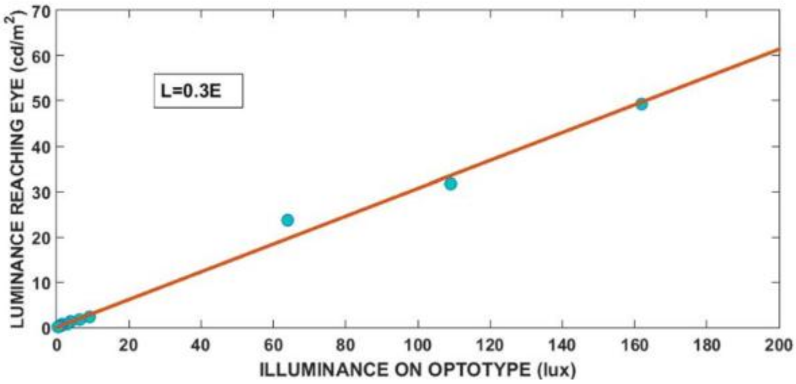

Fig. 2. Relationship between brightness at pupil level and lighting at the optotype level

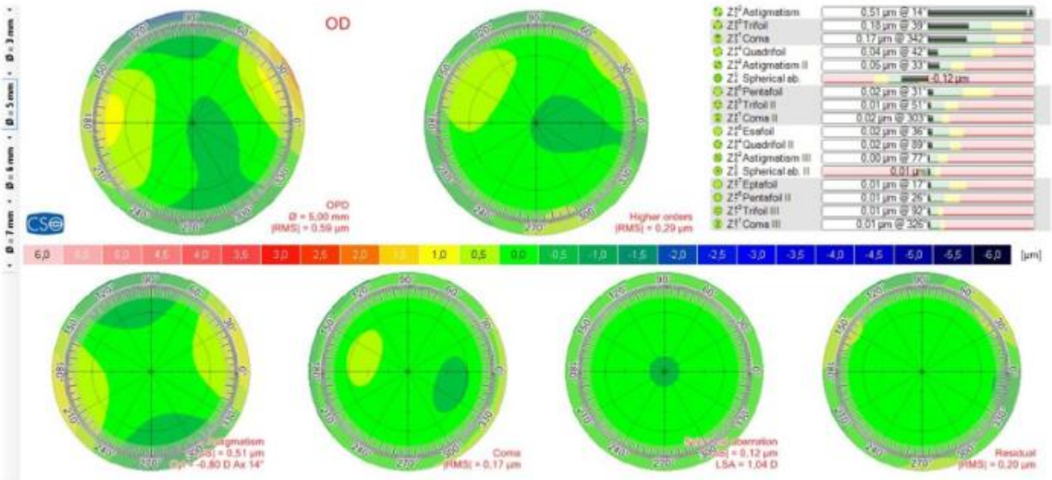

Fig. 3. The RMS of the ocular aberrations for the right eye of one examinee (pupil diameter 5 mm) who participated in the research

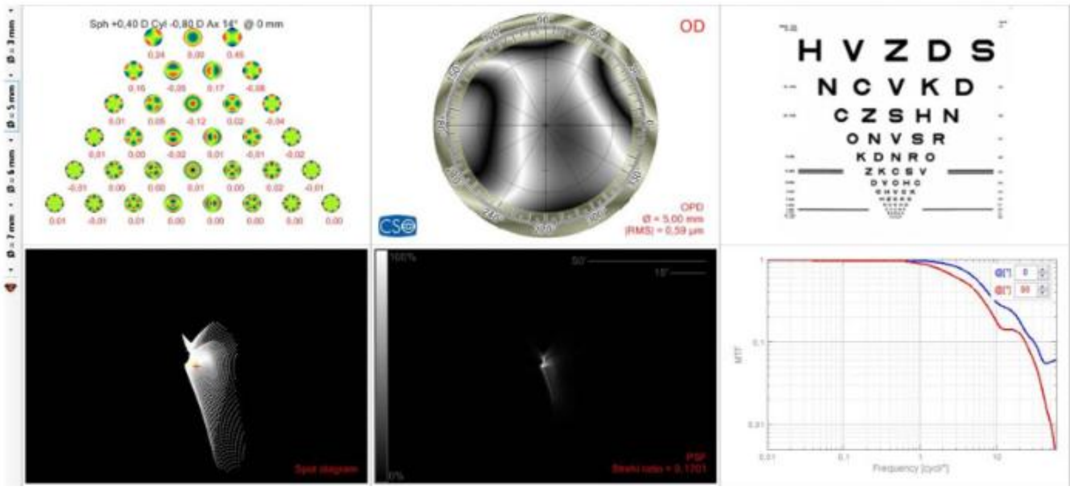

Fig. 4. Measurements that objectively determine the quality of the retinal image, such as PSF, MTF, Strehl's ratio. The illustration concerns the same examinee of the previous image and same pupil diameter

determine the contrast sensitivity CS we used the classification suggested by Elliot et al, (suggested each of the letters of the optotype to be rated at 0.05 logCS [18]. In this way the result becomes more specific and more realistic. The statistical analysis was performed at significance level α = 0.05, which considered particularly satisfactory for such measurements, carried out with statistical software IBM, SPSS v.24.

3. RESULTS AND DISCUSSION

The measurements were taken in both eyes, in each eye separately. The mean value of RMS under photopic conditions for group 1 was 0.073 ± 0.018 μm, while for group 2 was 0.080 ± 0.036 μm. In mesopic conditions the values were 0.252 ± 0.064 μm and 0.253 ± 0.069 μm respectively. Then, the decimal logarithm of contrast sensitivity (logCS) of the participants was measured using Pelli-Robson's. The calculation was carried out for each examinee, wearing his corrective glasses if they were necessary so that the result is not affected by the low-order aberrations (myopia, hyperopia, astigmatism), and in photopic and in mesopic conditions. The mean value of photopic conditions for group 1 was 1.54 ± 0.16 (contrast 2.88 ± 1.24%), while for group 2 was 1.59 ± 0.16 (contrast 2.57 ± 1.24%). For the mesopic conditions the value of logCS was 1.27 ± 0.15 (contrast 5.37 ± 2.06%) and 1.32 ± 0.12 (contrast 4.79 ± 1.35%) respectively. The results are shown in summary at Tables 1 and 2.

Table 1. Age with log contrast sensitivity (RMS Mesopic conditions)

	Age	*RMS Mesopic conditions (μm)*	*Log Contrast Sensitivity*	*Contrast %*
Group 1	25.60 ± 0.064	0.252 ± 0.064	1.27 ± 0.15	5.37 ± 2.06
Group 2	46.00 ± 6.09	0.253 ± 0.69	1.32 ± 0.12	4.79 ± 1.35

Table 2. Age with log contrast sensitivity (RMS Photopic conditions)

	Age	*RMS Photopic conditions (μm)*	*Log Contrast Sensitivity*	*Contrast %*
Group 1	25.60 ± 0.064	0.073 ± 0.018	1.54 ± 0.16	2.88 ± 1.24
Group 2	46.00 ± 6.09	0.080 ± 0.036	1,59±0,16	2.57 ± 1.24

The RMS of the most basic high order aberrations were also recorded coma (third order) and spherical aberration (fourth order). The results of the RMS concerning both groups are shown in summary at Tables 3 and 4.

Finally, it should be noted that the equivalent defocus was also calculated for the RMS of aberrations of high order. The calculation was done without age separation, as this was judged not to affect the results. Thus, the equivalent defocus was found to be 0.23 ± 0.09D in photopic conditions and 0.28 ± 0.07D in the mesopic.

In the histogram we observe that the maximum of the graph reaches at low RMS values. Also, after the maximum (0.08 μm) the frequency occurrence of aberrations is small. This is something to be expected, after all in photopic conditions the pupil size is small and the aberrations of high order are not is such obvious.

Table 3. The results of the RMS concerning both groups (Photopic conditions)

	RMS Coma Photopic conditions (μm)	*RMS Spherical aberration Photopic conditions (μm)*
Group 1	0.033 ± 0.014	0.022 ± 0.011
Group 2	0.041 ± 0.027	0.024 ± 0.008

Table 4. The results of the RMS concerning both groups(Mesopic conditions)

	RMS Coma Mesopic conditions (μm)	*RMS Spherical aberration Mesopic conditions (μm)*
Group 1	0.139 ± 0.065	0.124 ± 0.035
Group 2	0.149 ± 0.066	0.107 ± 0.038

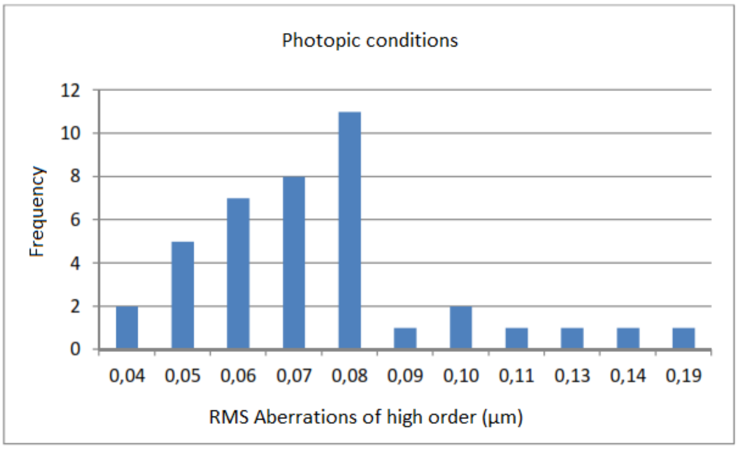

Fig. 5. Histogram of RMS Aberrations of high order in photopic conditions

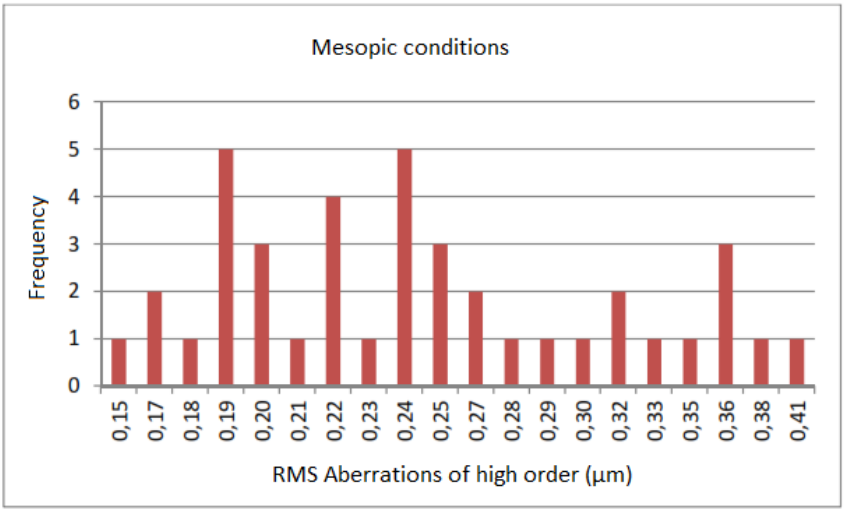

Fig. 6. Histogram of RMS Aberrations of high order in mesopic conditions

Here we observe that the spread of RMS is clearly greater. The RMS values are higher, while there is a significant frequency appearance and at the highest prices. This finding is not surprising, because in mesopic conditions the high-order aberrations begin to manifest.

The display of results are scattering for coma (horizontal and vertical) in our sample, under photopic conditions. Here we see a more normal distribution, while RMS values are low due to lighting conditions. It is noteworthy that an eye has almost zero coma. Things are more complicated, when the histogram shows three maxima and the dispersion value is higher. The latter is something to be expected, because like we also mentioned above in the mesopic conditions the aberrations of high order is more obvious. Similar conclusions are drawn from the histograms of the spherical aberration.

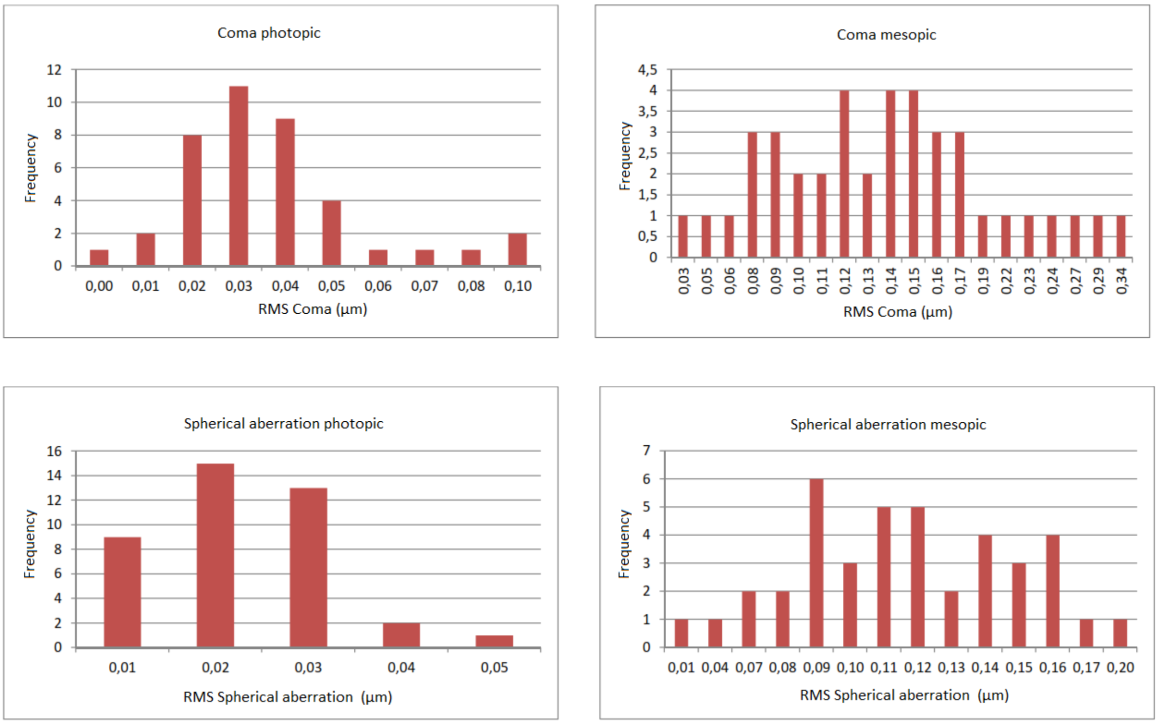

Fig. 7. Histogram of RMS coma and spherical aberrations in photopic and mesopic conditions

Also, from the results it seems that there is symmetry of aberrations between right and left eye examined. So, for group 1 the high-order RMS aberrations in photopic conditions is exactly the same for the left and the right eye (0.07 ± 0.02μm). For the same group in intermediate conditions the differences are negligible (R: 0.26 ± 0.07μm, L: 0.25 ± 0.06μm). For group 2 the values in photopic conditions are approximately the same (R: 0.08 ± 0.04μm, L: 0.08 ± 0.03μm), while for the mesopic conditions again the differences are not significant (R: 0.24 ± 0.06μm, L: 0.26 0 0.08μm). Similar things apply and for the sub-deviations of coma and spherical aberration, as we can see in Tables 3 and 4. All of these agree with the findings of other researchers (Liang & Williams 1997; Porter et al. 2001).

In Fig. 8 we have the RMS diagram of the high order aberrations and contrast in photopic conditions. We notice that it exists correlation between the two quantities (contrast = 1.080 + 24.298 RMS, R = 0.304, Pearson r = 0.551). That is, there is a linear relationship between the two sizes and contrast is 55% affected by RMS.

In mesopic conditions, however, what fits best is a polynomial model. Indeed, there is a correlation between high order aberrations and contrast. That is, the relationship between contrast and RMS of high order aberrations is polynomial (contrast = 13.040-68.309 RMS + 140.413 RMS^2, $R^2 = 0.212$, r = 0.461).

From the results we tried to see if it exists correlation and between coma and contrast. The processing of the results shown that there is correlation between coma and sensitivity contrast (or contrast). In photopic conditions, then, their correlation is linear (contrast = 2.031 + 24.378 RMS_{coma}, $R^2 = 0.177$, r = 0.421) (Fig. 9). In the mesopic conditions, however, coma does not seem to affect contrast sensitivity and consequently contrast.

The results of our research show that there is no correlation between spherical aberration of the anterior surface of corneas and contrast. This applies both in photopic conditions, as well as in mesopic. The above comes in partial agreement with the results of van Gaalen et al., who [19] found that spherical aberration did not affect contrast sensitivity in both photopic and mesopic conditions. Here we should mention that the above research concerned the total aberrations of the eye [19,20]. The fact is that this correlation is not the same in all conditions due to other factors. The internal aberrations of high order (aberrations mainly of the crystalline lens and less of the posterior surface of the cornea) also play their role in the final formation of retinal image. So they affect the way the examinee perceives the image [6].

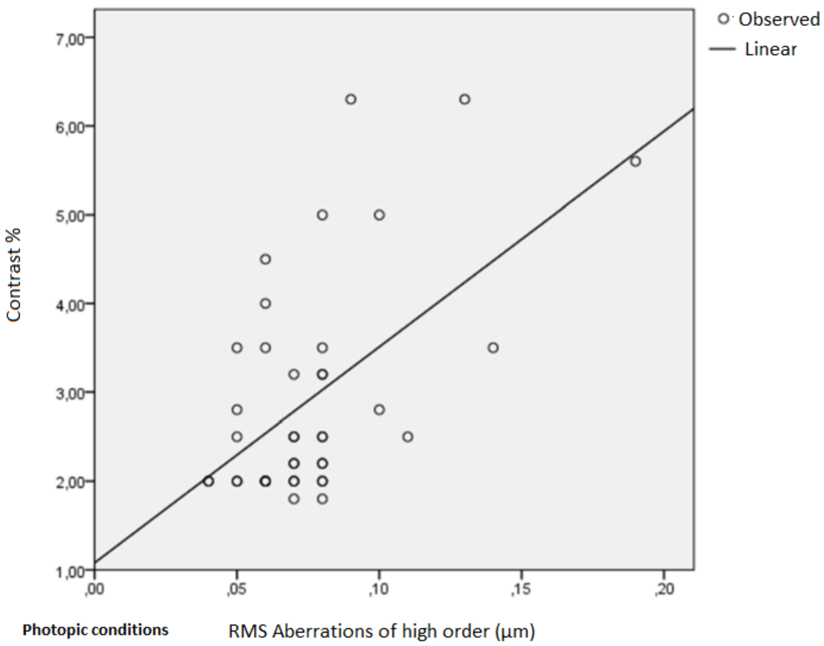

Fig. 8. RMS diagram of high-order aberrations and contrast (photopic conditions)

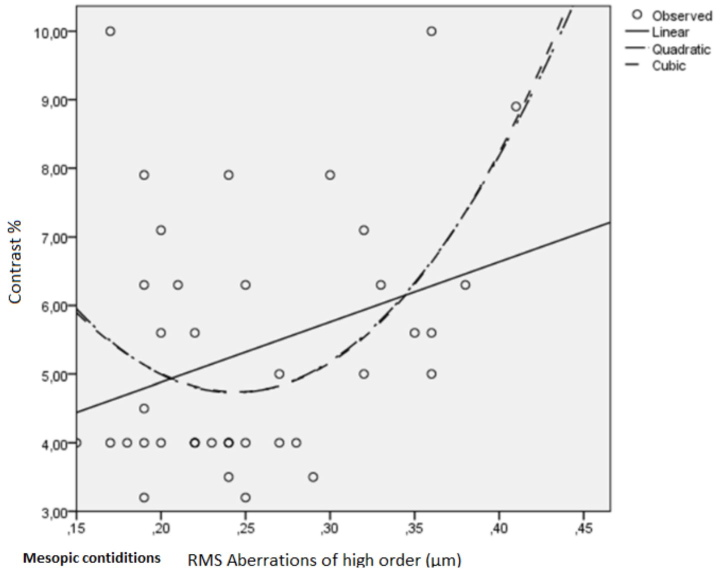

Fig. 9. RMS diagram of high-order aberrations and contrast (Mesopic conditions)

4. CONCLUSIONS

Summing up, then, we come to the following conclusions. There is a symmetry between the high-order aberrations of the anterior surface of the cornea between left and right eye of the examinee. The differences between high-order aberrations between the two age groups groups are small, both in photopic and mesopic conditions. The same is true for contrast sensitivity and therefore for contrast in photopic and mesopic conditions. There is a correlation between high-order aberrations of the anterior surface of corneas and contrast and in photopic, but and in mesopic conditions. There is a correlation between coma and contrast in photopic conditions. This however, is not the case in mesopic conditions. There isn't a correlation between spherical aberration and contrast in both photopic as well as in mesopic conditions. This is due to that the total spherical aberration of the eye (corneal and crystalline lens) is much smaller than when it is measured only on the anterior surface of the cornea. We must mention that there are no differences in high order aberrations of the anterior surface of the cornea between the two age groups. This proves that under normal conditions over age the cornea is not changing. Equivalent defocus is so small that it does not affect the clinical results of the research.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

CONSENT

As per international standard or university standard, patients' written consent has been collected and preserved by the author(s).

ETHICAL APPROVAL

As per international standard or university standard written ethical approval has been collected and preserved by the author(s).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Marcos S. Image quality of the human eye, International Ophthalmology Clinics. 2003;43(2):43-62.
2. Marcos S. Aberrometry: Basic Science and Clinical Applications. Bulletin of the Belgian Society of Ophthalmology. 2006;(302):197-213.

3. Martinez-Conte S, Macknick SL., Hubel DH. The role of fixational eye movements in visual perception Nature Reviews/ Neuroscience. 2004;(5):229-240.
4. Megbelayin EO. Aberropia: Concept and Misconception. South Africa Ophthalmology Journal. 2012;7(2):1-11.
5. Agarwal A, Prakash G, Jacob S, Ashokkumar D, Agarwal A. Can uncompensated higher order aberration profile or aberropia be responsible for subnormal best corrected vision and pseudo-amblyopia. Medical Hypotheses. 2009;(72):574-577.
6. Artal P, Guirao A, Berrio E, Williams DR. Compensation of corneal aberrations by the internal optics of the human eye. Journal of Vision. 2001;(1):1-8.
7. Artal, P., Navarro, R. Monochromatic modulation transfer function of the human eye for different pupil diameters: An analytical expression. Journal of Optical Society of America. 1994;11(1):246-249.
8. Artal P, Benito A, Tabernero J. The human eye is an example of robust optical design. Journal of Vision 2006;(6):1-7.
9. Berrio, E, Tabernero, J, Artal, P. Optical aberrations and alignment of the eye with age. Journal of Vision. 2010;10(34):1-17.
10. Atchison DA. Recent advances in representation of monochromatic aberrations of human eyes Clinical and Experimental Optometry. 2004;87(3):138-148.
11. Atchison D, Smith G. Optics of the Human Eye, Elsevier; 2002. ISBN 0-7506-3775-7.
12. Sukha AY, Rubin A. Psychophysical aspects of contrast sensitivity. The South African Optometrist. 2013;72(2):76-85.
13. Smolek MK. Method for Expressing Clinical and statistical significance of Ocular and Corneal Wave Front Error Aberrations. Cornea. 2012;31(2):212-221.
14. Unterhorst HA, Rubin A. Ocular aberrations and wavefront aberrometry: a review. African Vision Eye Health. 2015;74(1):1-6.
15. Nam J, Thibos LN, Iskander RD. Describing ocular aberrations with wavefront vergence maps. Clinical and Experimental Optometry. 2009;9(3):194-205.
16. Pelli DG, Bex P. Measuring contrast sensitivity. Vision Research. 2013;90:10-14.
17. Pelli DG, Robson JG, Wilkins AJ. The design of a new letter chart for measuring contrast sensitivity. Clinical Vision and Science. 1988;2(3):187-199.
18. Elliot DB, Bullimore MA, Bailey IL. Improving the reliability of Pelli-Robson contrast sensitivity chart. Clinical Vision and Science. 1991;6(6):471-475.
19. van Gaalen KW, Jansonius NM, Koopmans SA, Terwee T, Kooijman AC. Relationship between contrast sensitivity and spherical aberration: Comparison of 7 contrast sensitivity tests with natural and artificial pupils in healthy eyes. Journal of Cataract and Refractive Surgery. 2009; 35:47-56.
20. Porter J, Guirao A, Cox IG, Williams DA. The human eye's monochromatic aberrations in a large population. Journal of Optical Society of America. 2001; 12:2348-2357.

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