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Similarity of Aberrations between Right and Left Eyes

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Abstract

The purpose of this study was to measure wavefront aberration between the right and left eyes and to examine the relevance of aberration between them. All coefficients excluding Z4-2 between second and fourth orders of the Zernike showed significant correlation between the right and left eyes. However, coefficients for fifth and sixth orders of the Zernike showed no or extremely low correlation. Defocus (Z20) aberration had extremely high correlation between the right and left eyes with correlation coefficient of 0.908. Spherical (Z40) aberration also showed high correlation with coefficient of 0.820. Astigmatism aberration Z2-2 and Z22 were respectively –0.429 and 0.820. Second astigmatism Z42 had correlation coefficient of 0.484, but Z4-2 did not have significant relevance. Coma aberrations Z3-1 (r = 0.795) and Z31 (r = –0.715) showed high correlation between the right and left eyes. Trefoil aberrations, Z3-3 (r = 0.637) and Z33 (r = –0.510), and tetrafoil aberrations, Z4-4 (r = –0.334) and Z44 (r = 0.386), had significant relationship between the right and left eyes.

Keywords: Astigmatism, Coma, Defocus, Spherical Aberration, Zernike Polynomials

1. Introduction

Though high order aberration in the eyes exists in smaller amount compared to low order aberration, it has been receiving attention in relation to quality of image formed on the retina. Diverse aberrometers measuring high order aberration in the eyes have been developed for use, and development of aberrometer allowed for various researches about aberration occurring in the eyes.

Aberrometer using objective methods which do not require feed-backs between the tester and testee include Laser Ray Tracing, Tscherning, and Hartmann-Shack aberrometer. Recently, aberrometer based on the Hartmann-Shack method has been most widely used. The Taylor, Seidel, Zernike, and Legendre polynomials are used to express aberration. The Zernike polynomials are widely used as standard forms of computatively quantifying wavefront aberration[1–3].

Studies on the relevance between the right and left eyes are reporting relevance of aberration between the right and left eyes, as well as existence of mirror symmetry between the two eyes[4,5]. If wavefront aberration function is expressed as a Zernike polynomials, then bilateral symmetry would cause the Zernike coefficients for the two eyes to be of opposite sign for all those modes with odd symmetry about the y-axis. The slopes for odd coefficients Z2-2, Z31, Z33, Z4-4, and Z4-2 are all negative, whereas the other slopes are all positive[6].

This study intends to examine the relevance of aberration between the two eyes by measuring wavefront aberration between the right and left eyes and to provide basic data about whether it is possible to test aberration by only measuring one of the two eyes.

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2. Methods

188 eyes of 94 university students (68 males and 26 females) who have never received eye surgery and do not wear contact lenses were selected as subjects of this study. Age was distributed between 19 and 31 years, and the mean age was 22 years old. S.E was 0D ~ –8.23D with the mean of –3.15D.

All measurements of higher order aberrations were made using a TOPCON KR-9000PW which is the wavefront aberrometer using Hartmann-Shack method.

Rear projection type of Hartmann-Shack aberrometer uses Lenslet Array made up of multiple small lenses with the same focal distance. Once the wavefront with aberration passes the grid-shaped Lenslet Array, it dedinates from the focal location of ideal wavefront with no aberration. The calculated wavefront is expressed using Zernike Polynomials[7,8]. Aberration in the entire eye was measured within 6mm of pupil diameter. Coefficients between second and sixth orders of the Zernike polynomials were analyzed. The Zernike polynomials are defined as[1,6].

$$Z_n^m(\rho,\theta)=\begin{Bmatrix} N_n^m R_n^{|m|}(\rho)\cos m\theta;\ \text{for } m\geq 0 \\ -N_n^m R_n^{|m|}(\rho)\sin m\theta;\ \text{for } m<0 \end{Bmatrix} \quad (1)$$

Where n is called the order of the polynomial with a positive integer or zero and the meridional frequency m = –n, –n + 2, –n + 4, …n. N_n^m is the normalization factor and radial part $R_n^{|m|}$ is given by

$$R_n^{|m|}(\rho)=\sum_{s=0}^{\frac{n-|m|}{2}}\frac{(-1)^s(n-s)!}{s!\left[\frac{n+|m|}{2}-s\right]!\left[\frac{n-|m|}{2}-s\right]!}\rho^{n-2s} \quad (2)$$

Usually a normalization factor is multiplied with the polynomials. The normalization factor is given by

$$N_n^m=\sqrt{\frac{2(n+1)}{1+\delta_{m0}}} \quad (3)$$

Where δ_{m0} is the Kronecker delta function, with a value 1 if m = 0 and a value 0 otherwise.

3. Results

As a result of Pearson correlation analysis, all coefficients between second and fourth orders of the Zernike except for Z4-2 showed significant correlation between the right and left eyes. On the contrary, coefficients for fifth and sixth orders of the Zernike showed no or extremely low correlation (Table 1).

Since correlation coefficient between the right and left eyes about all Zernike coefficients of fifth and sixth orders was extremely low at r = 0.156 with relatively smaller amount compared to coefficients between second and fourth, analysis was only carried out on coefficients for second through fourth orders. Coefficients between second and fourth orders of the Zernike polynomials were classified into individual aberrations such as astigmatism (Z2-2, Z22), defocus (Z20), trefoil (Z3-3, Z33), coma (Z3-1, Z31), tetrafoil (Z4-4, Z44), second astigmatism (Z4-2, Z42), and spherical (Z40). Correlation between the right and left eyes is shown in (Figures 1–8).

Table 1. Correlation between the right and left eyes about coefficients between second and sixth orders of the Zernike polynomials

Zernike Term		Right eye (Mean)	Left eye (Mean)	Correlation coefficient	p-value
Z2-2(4)	Astigmatism	–0.096	0.129	–0.429	0.000
Z20(5)	Defocus	3.754	3.527	0.908	0.000
Z22(6)	Astigmatism	–0.5967	–0.698	0.854	0.000
Z3-3(7)	Trefoil	–0.071	–0.104	0.637	0.000
Z3-1(8)	Coma	0.066	0.082	0.795	0.000
Z31(9)	Coma	0.009	0.035	–0.715	0.000
Z33(10)	Trefoil	0.022	–0.037	–0.510	0.000
Z4-4(11)	Tetrafoil	0.014	–0.021	–0.334	0.001
Z4-2(12)	2nd Astigmatism	–0.015	0.022	–0.003	0.976
Z40(13)	Spherical	0.088	0.080	0.820	0.000
Z42(14)	2nd Astigmatism	–0.011	–0.015	0.484	0.000
Z44(15)	Tetrafoil	0.017	0.022	0.386	0.000
Z5-5(16)	Pentafoil	–0.007	0.004	–0.020	0.847
Z5-3(17)	Trefoil	–0.003	–0.004	0.193	0.062
Z5-1(18)	Coma	0.004	–0.009	0.268	0.000
Z51(19)	Coma	–0.006	0.003	–0.284	0.000
Z53(20)	Trefoil	–0.007	0.006	–0.018	0.865
Z55(21)	Pentafoil	–0.001	–0.007	–0.098	0.000
Z6-6(22)	Hexafoil	0.001	0.001	0.015	0.889
Z6-4(23)	Tetrafoil	–0.001	0.004	0.180	0.083
Z6-2(24)	Astigmatism	–0.004	0.005	–0.026	0.801
Z60(25)	Spherical	–0.009	–0.010	0.583	0.000
Z62(26)	Astigmatism	0.007	0.008	0.429	0.000
Z64(27)	Tetrafoil	–0.006	–0.001	0.129	0.217
Z66(28)	Hexafoil	0.008	0.004	0.271	0.000

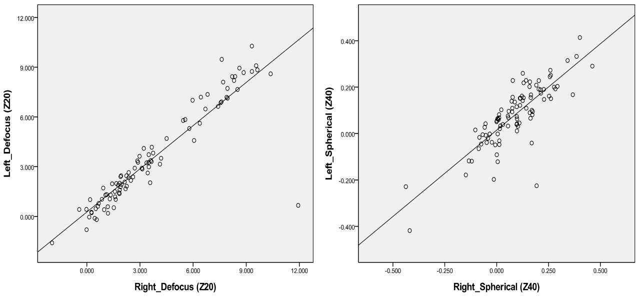

Figure 1. Correlation between right and left eye's aberration for defocus (Z20) and spherical (Z40).

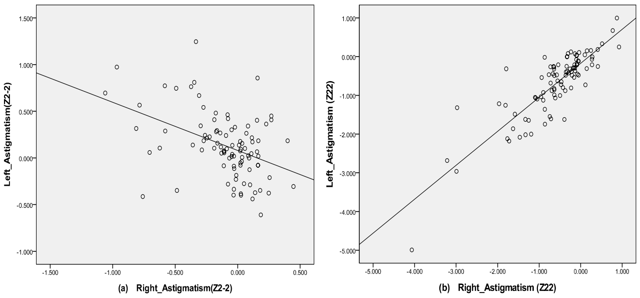

Figure 2. Correlation between right and left eye's astigmatism aberration for Z2-2 with negative slope (a) and Z22 with positive slope (b).

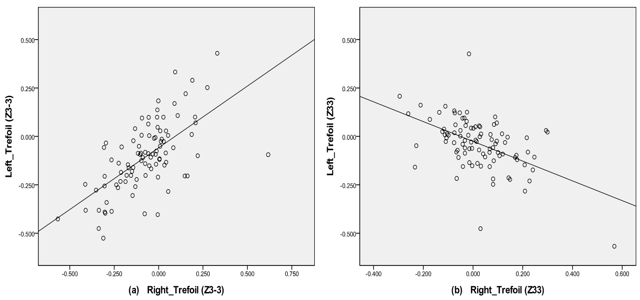

Figure 3. Correlation between right and left eye's trefoil aberration for Z3-3 with positive slope (a) and Z33 with negative slope (b).

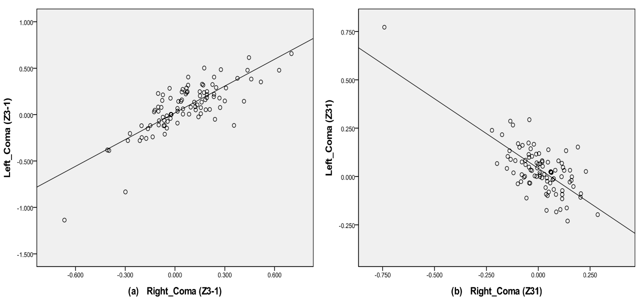

Figure 4. Correlation between right and left eye's coma aberration for Z3-1 with positive slope (a) and Z31 with negative slope (b).

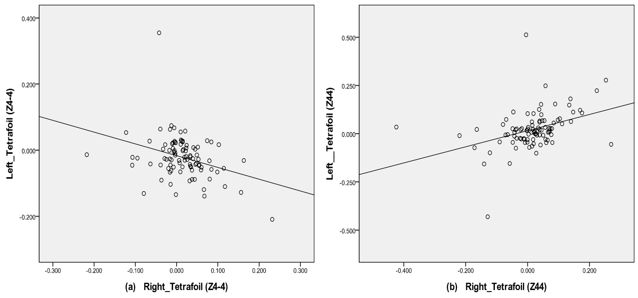

Figure 5. Correlation between right and left eye's tetrafoil aberration for Z4-4 with negative slope (a) and Z44 with positive slope (b).

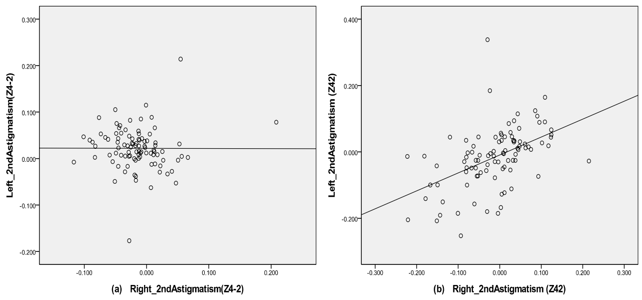

Figure 6. Correlation between right and left eye's 2nd astigmatism aberration for Z42 with negative slope (a) and Z4-2 with positive slope (b).

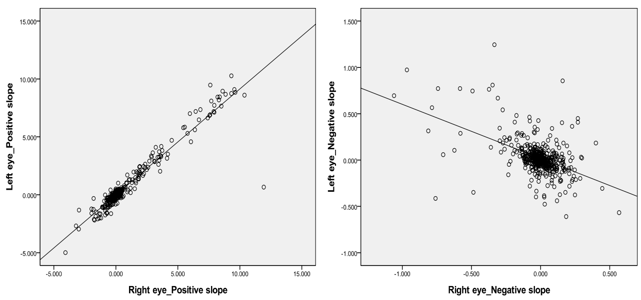

Figure 7. Correlation between right and left eye's Zernike coefficients with total positive slope (Z20, Z22, Z3-3, Z3-1, Z40, Z42, Z44) and total negative slope (Z2-2, Z31, Z33, Z4-4, Z4-2).

Defocus (Z20) aberration showed extremely high correlation between the right and left eyes with correlation coefficient of 0.908, and spherical (Z40) aberration also showed high correlation of 0.820. Astigmatism (Z2-2, Z22) as a low order aberration had significant correlation between the two eyes, both for Z2-2 ($r = -0.429$) with negative slope and Z22 ($r = 0.854$) with positive slope. On the other hand, second astigmatism (Z4-2, Z42) as a high order aberration only showed significant correlation in Z42 ($r = 0.484$) with positive slope. For coma aberration, both Z3-1 (r = 0.795) with positive slope and Z31 (r = –0.715) with negative slop showed high correlation. In addition, trefoil aberrations, Z3-3 (r = 0.637) and Z33 (r = –0.510), and tetrafoil aberrations, Z4-4 (r = –0.334) and Z44 (r = 0.386), had significant relevance between the right and left eyes, both for positive and negative coefficients.

After classifying all coefficients between second and fourth orders of the Zernike polynomials into coefficients with positive slope and coefficients with negative slope, correlation between the two eyes about total aberration was found as shown in Figure 7. Correlation coefficients of Zernike coefficients with positive slope and negative slope were found to be 0.956 and –0.504, respectively.

In relation to total aberration between the right and left eyes about all coefficients between second and fourth orders of the Zernike, coefficients with positive slope (r = 0.956) were higher than coefficients with negative slope (r = –0.504). This is not just because defocus (Z20) and spherical (Z40) aberrations with high correlation only had positive slope but also because correlation of positive slope coefficients was higher for most of other aberrations that had both positive and negative slopes.

4. Conclusion

From the above results, most of the Zernike coefficients were found to have relevance between the right and left eyes. However, since there are differences in the degree of correlation among the Zernike coefficients, decision on whether to measure both eyes or only one of the two eyes should be determined based on the type of aberration being studied.

5. Acknowledgement

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