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A pilot study on the differences in wavefront aberrations between two ethnic groups of young generally myopic subjects

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Abstract

A comparative population-based cross-sectional study design was used to examine the prevalence of wavefront patterns in two different ethnic groups, and the relationship of these patterns with ocular biometrics and gender. The Shin–Nippon SRW5000 open field autorefractor, the Wavefront Analysis Supported Customized Ablation (WASCA) wavefront analyser and the IOLMaster were used to determine wavefront aberrations, mean spherical equivalent (SE) refractive error and axial length (AL). Seventy-four eyes from 74 young healthy subjects (44 British Asians, 30 Caucasians; 36 men, 38 women; mean age 22.51 ± 3.89 years) with mean SE averaging −1.90 ± 2.76 D (range −10.88 to +2.19 D) were examined. Relationships between ethnicity, gender, AL and SE, against the wavefront high-order root mean square, and aberration components up to the fifth order, were assessed by using multiple regression and correlation analysis. AL on its own accounted for 4.7% of the variance in trefoil component Z_3^{-3} ($F_{1,72}$ = 4.602; p = 0.035), 13.7% of coma component Z_3^1 ($F_{1,72}$ = 12.536; p = 0.001), 6.1% of trefoil component Z_3^3 ($F_{1,72}$ = 5.705; p = 0.020) and 9.8% of coefficient Z_4^{-2} ($F_{1,72}$ = 8.908; p = 0.004). A significant model emerged ($F_{2,71}$ = 6.164; p = 0.003) for ethnicity and axial length, accounting for 12.4% of variance in primary spherical aberration with ethnicity accounting for 8.4% of that variance. For Caucasian subjects, a significant correlation was found between axial length and Z_3^1 (Pearson's correlation coefficient −0.500; p = 0.005) and Z_4^0 (Pearson's correlation coefficient −0.423; p = 0.020). For British Asian subjects, AL was only correlated with coefficient Z_4^{-2} (Pearson's correlation coefficient −0.358; p = 0.017). Ethnicity is a factor to be considered in the variability of wavefront aberration, particularly spherical aberration. Relationship between AL and wavefront aberrations seems to vary between ethnicities. If higher order aberrations play a role in the emmetropization process, this may be different for different populations.

Keywords: axial length, ethnicity, spherical aberration, wavefront aberrations

Introduction

The human eye is an optical imaging system that is far from perfect, suffering from chromatic and monochromatic wavefront aberrations, light scattering and diffraction. It is widely accepted that spherical refractive error is due primarily to an axial length (AL) that is either too long or too short (Strang *et al.*, 1998; Gwiazda *et al.* 2002), although there is some evidence that the optical components may also vary with refractive error (Carney *et al.*, 1997; Mainstone *et al.*, 1998;

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Strang *et al*., 1998; Horner *et al*., 2000). It has been suggested that high levels of higher order aberrations (HOA) could play a role in myopia development (He *et al*., 2002). Increased coma and spherical aberration have been found in myopic eyes (Collins *et al*., 1995; He *et al*., 2002). The role of HOA is not clear, but all studies agree on the great variability of wavefront aberrations with little, if any, relationship with refractive error.

Hyman *et al*. (2005) found in a 3-year follow-up of children involved in the Correction of Myopia Evaluation Trial (COMET) that progression in myopia varied among different ethnic groups, showing Afro-American children as those having the slowest myopia progression. Logan *et al*. (2005) did not find significant differences in refractive error and ocular components between Caucasian and British Asian university students suggesting that onset and progression of juvenile myopia is not dependent on ethnicity. In a recent report comparing children of two age groups and two ethnicities (Caucasian and East Asian), Ip *et al*. (2007) found a different contribution of AL to refractive error in each ethnic group.

Given the lack of differences in ocular biometric components and refractive error between Caucasian and British Asian students under the same educational system reported previously by Logan *et al*. (2005), the present study aims to determine if any difference exists in the distribution of aberrometric patterns between these ethnicities for a given range of ocular biometrics and refractive errors.

Materials and methods

Seventy-four young adult volunteers were examined in this study (36 men, 38 women; mean age 22.51 ± 3.89 years). All the subjects were British university students with similar educational backgrounds. Exclusion criteria included history of ocular pathology or abnormal findings on slit lamp and ophthalmoscopic examination. Only data obtained from the right eyes were used for analysis. Care was taken to have a roughly even distribution between ethnic groups in terms of refractive error and gender.

Informed consent was obtained from each participant after explanation of procedures. The protocol followed the tenets of the Declaration of Helsinki and was approved by the Human Ethics Committee of Aston University.

Measurements of refractive error, AL and wavefront aberrations were taken using different instruments. Objective refractive error was assessed using the Shin–Nippon SRW5000®, also marketed as the Grand Seiko WV500®, (Shin–Nippon Ltd, Tokyo, Japan), which is an infrared, open-view, objective autorefractor. The fixation target was a Maltese cross located at 6 m, and both eyes were open during acquisition. Its open-view arrangement minimises instrument myopia. This instrument has been shown to compare favourably with subjective refraction being reliable in both adults (mean difference for the spherical equivalent (SE), 0.16 ± 0.44 D) (Mallen *et al*., 2001) and children (mean difference for the SE 0.24 ± 0.34 D, cyclopleged) (Chat and Edwards, 2001), and can be converted to continuously measure the accommodative response with high precision (Wolffsohn *et al*., 2001, 2004). It has been used previously to assess the presence of instrument myopia when measuring wavefront aberrations with clinical aberrometers (Cervino *et al*., 2006).

The IOLMaster (Carl Zeiss Meditec, Jena, Germany) was used to assess AL: the system uses partial coherence laser interferometry to provide measurements of AL with high precision and accuracy (Connors *et al*., 2002; Santodomingo-Rubido *et al*., 2002; Carkeet *et al*., 2004). Partial coherence interferometry is based on the Michelson interferometer. In brief, the laser beam is split into two coaxial beams which enter the eye where reflection on the corneal surface and the retina take place and the phase difference of the coaxial beams when leaving the eye is measured and related to AL (Santodomingo-Rubido *et al*., 2002).

Wavefront aberration was measured for natural pupils using the Wavefront Analysis-Supported Customized Ablation system (WASCA®; Carl Zeiss Meditec), which is a Hartmann–Shack wavefront analyser. In brief, a Hartmann–Shack wavefront sensor divides the wavefront spatially so that each subdivision can be approximated to a tilted flat wave focusing on the image plane, which is displaced from a reference depending on its tilt. Reconstruction of all the tilted flat waves from each subdivision produces the original wavefront (Cervino *et al*., 2007b).

The sensor used by the WASCA gives highly accurate and reproducible measures of both low and higher order aberrations up to the fourth order in human and model eyes (Cheng *et al*., 2003a; Cervino *et al*., 2007a, 2008) with low variability (Cheng *et al*., 2004). Care was taken to ensure a fair agreement (±0.50 D) between mean SE obtained with the WASCA and the autorefractor: as subjects were not cyclopleged prior to examination, it was necessary to avoid significant instrument myopia with the wavefront analyser that would affect the wavefront values obtained (Cervino *et al*., 2006).

Values for Zernike coefficients Z_3^{-1}, Z_4^{-4}, Z_4^{-2}, Z_4^{4}, Z_3^{-3}, Z_3^{1}, Z_3^{3}, Z_4^{0} and Z_4^{2}, as well as for high-order root mean square (HO RMS), were obtained for the central 5-mm diameter of the entrance pupil.

Multiple regression analysis was applied to look for significant models to account for the variability of the Zernike coefficients. Correlations between gender, mean spherical equivalent (MSE) and biometric parameters

Table 1 . Descriptive statistics of the sample used in the study in the different ethnic groups

	p-value	British Asians (n = 44) (22 men, 22 women) Mean ± S.D. (min–max)	Caucasians (n = 30) (14 men, 16 women) Mean ± S.D. (min–max)
Age	<0.001*	20.73 ± 2.37 (18–27)	24.80 ± 4.40 (18–34)
AL	0.486	24.23 ± 1.32 (21.84–27.89)	24.01 ± 1.34 (21.30–27.12)
SE	0.100	−2.37 ± 3.08 (−10.88–2.19)	−1.28 ± 2.24 (−8.31–0.75)
Z_3^{-3}	0.437	−0.058 ± 0.069 (−0.196–0.137)	−0.045 ± 0.066 (−0.200–0.053)
Z_3^{-1}	0.844	0.010 ± 0.113 (−0.187–0.363)	0.016 ± 0.114 (−0.247–0.301)
Z_3^{1}	0.341	0.009 ± 0.050 (−0.096–0.106)	0.022 ± 0.065 (−0.101–0.157)
Z_3^{3}	0.031*	0.012 ± 0.054 (−0.081–0.206)	−0.017 ± 0.061 (−0.165–0.107)
Z_4^{-4}	0.964	0.004 ± 0.021 (−0.092–0.039)	0.004 ± 0.017 (−0.041–0.034)
Z_4^{-2}	0.075	0.002 ± 0.015 (−0.022–0.046)	−0.005 ± 0.017 (−0.034–0.045)
Z_4^{0}	0.007 *	0.020 ± 0.042 (−0.052–0.135)	0.053 ± 0.061 (−0.045–0.228)
Z_4^{2}	0.546	−0.001 ± 0.031 (−0.087–0.053)	−0.005 ± 0.031 (−0.081–0.056)
Z_4^{4}	0.154	0.009 ± 0.026 (−0.053–0.089)	0.001 ± 0.020 (−0.046–0.043)
RMS	0.567	0.163 ± 0.063 (0.048–0.430)	0.173 ± 0.079 (0.093–0.455)

RMS, root mean square; SE, spherical equivalent; AL, axial length.
*Statistically significant difference between the groups (p < 0.05).

were then obtained for each ethnic group. Analysis of covariance (ANCOVA) was applied to look for the effect of ethnicity on the variability of wavefront aberration with biometric parameters.

Results

The MSE was −1.90 ± 2.76 D (range −10.88 to +2.19 D) with astigmatism up to 1.75 D (mean 0.49 ± 0.49 D). As the aim of the study was to determine if there were significant differences in the distribution of wavefront error among different racial groups, the sample was divided by ethnicity. Descriptive statistics by ethnicity are shown in *Table 1*.

A strong correlation was found between AL and SE for both racial groups combined (Pearson's correlation coefficient = −0.841; p < 0.001) (*Figure 1*). Multiple regression analysis using the stepwise method has shown significant models. Axial length on its own accounted for 4.7% of the variance in trefoil component Z_3^{-3} ($F_{1,72}$ = 4.602; p = 0.035), 13.7% of coma component Z_3^1 ($F_{1,72}$ = 12.536; p = 0.001), 6.1% of trefoil component Z_3^3 ($F_{1,72}$ = 5.705; p = 0.020) and 9.8% of coefficient Z_4^{-2} ($F_{1,72}$ = 8.908; p = 0.004).

A significant model emerged ($F_{2,71}$ = 6.164; p = 0.003), accounting for 12.4% of variance in primary spherical aberration (Z_4^0). Ethnicity accounted for 8.4% of the variance, whereas AL added the remaining 4.0%. Gender and MSE were not found to be good predictors for the variability of spherical aberration in the sample analysed.

Equality of error variances was tested applying Levene's test. ANCOVA has shown a significant effect of ethnicity (F = 7.06; p = 0.010) in the variance of spherical aberration. Adjusted mean spherical aberration scores suggest that young Caucasian adults have higher values of spherical aberration than British Asian eyes (0.052 ± 0.009 and 0.020 ± 0.007 μm, respectively, adjusted for an eye of AL 24.14 mm). As can be observed in *Figure 2*, however, both racial groups show considerable variability.

When different ethnicities are analysed separately, some differences in the distribution of wavefront error can be observed (*Figure 3*). For Caucasian subjects, a significant correlation was found between AL and Z_3^1 (Pearson's correlation coefficient −0.500; p = 0.005) and Z_4^0 (Pearson's correlation coefficient −0.423; p = 0.020). For British Asian subjects, AL was only

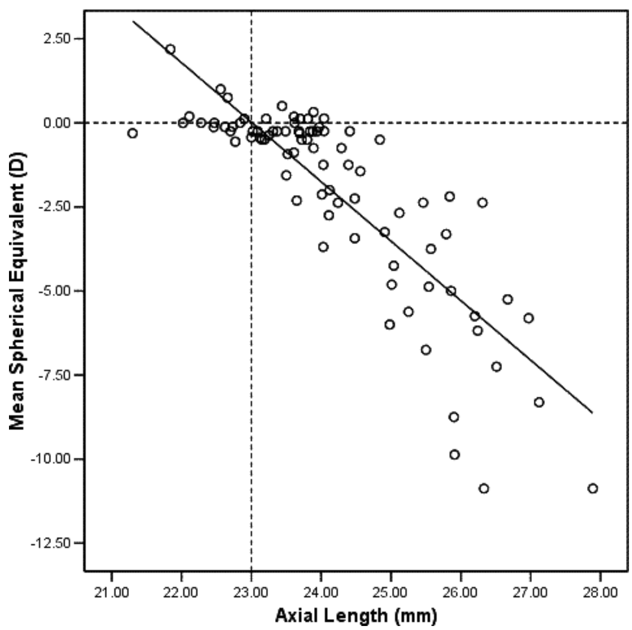

Figure 1. Scatterplot showing the variation in spherical equivalent (SE) with axial length for both ethnic groups combined.

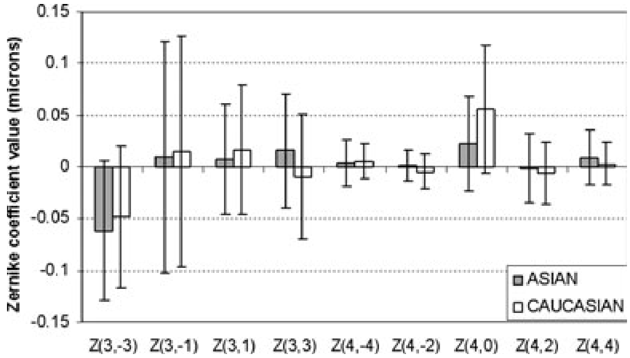

Figure 2. Distribution of Zernike coefficients through the populations studied, by ethnicity. Error bars represent ± 1 S.D.

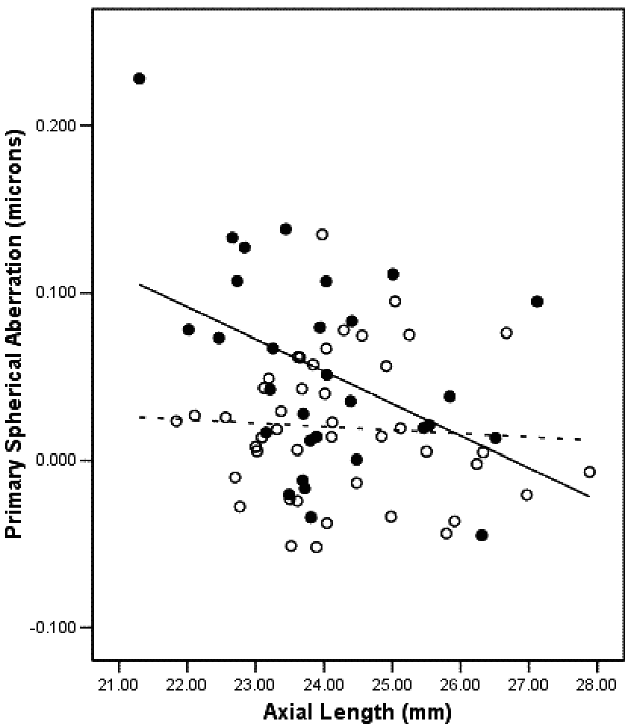

Figure 3. Scatterplot showing the variation in spherical aberration with axial length for the two ethnic groups studied: British Asian (open circles, dashed line; r^2 = 0.004) and Caucasian (filled circles, solid line; r^2 = 0.179).

correlated with coefficient Z_4^{-2} (Pearson's correlation coefficient −0.358; $p = 0.017$).

Discussion

Charman (2005) suggested that based on the observations regarding the optical quality of the retinal image and the onset of myopia, it could be hypothesized that high levels of aberration could produce an excessively blurred point spread function which could lead to the development of myopia. The hypothesis of higher levels of image degradation inducing greater final levels of myopia is supported by animal experiments (Bartmann and Schaeffel, 1994) and the finding of greater values of aberration RMS in myopes than emmetropes (He *et al.*, 2002). Collins *et al.* (1995) found, however, lower average spherical aberrations in myopes than in emmetropes. Carkeet *et al.* (2002) also found decreased values of spherical aberration in low myopes compared with high myopes, emmetropes and hyperopes in Singaporean children. Cheng *et al.* (2003b) examined the relationship between ametropia and optical aberrations, but did not find significant differences in spherical aberration as a result of variation in AL, even though both theoretical and experimental models had predicted this association (Marcos *et al.* 2002). The results reported here agree with the great variability in aberration values observed previously, and with the lack of significant difference between the two ethnic groups in ocular components for a given refractive state reported by Logan *et al.* (2005).

The results found in the present study do not clarify the role of overall aberrations in ametropia, as HO RMS was not found to be correlated with the level of myopia or the AL of the eye. In this study, AL has been found to correlate to a greater or lesser extent with most aberration components studied, including spherical aberration.

Brunette *et al.* (2003) analysed monochromatic aberrations as a function of age, and they were found to fit a quadratic model. RMS, third, fourth and fifth to seventh orders decreased progressively until early adulthood, and increased progressively with age after the fourth decade of life. Their results suggest a possible role of HOA in the emmetropization process. Their results also suggest that the period of optimal optical quality of the human eye is between the third and fourth decade of life. According to this, subjects examined in the present study were in the period of 'wavefront error improvement'.

Although there were no significant differences in HO RMS between the two ethnic groups, ethnicity has been found in this study to be strongly linked to Z_4^0, with British Asian subjects having less primary spherical aberration than Caucasians.

In a recent study, Ciuffreda *et al.* (2007) state that the axial elongation observed in myopic eyes results from the interaction between the myopic and relatively hyperopic retinal defocus in the fovea and peripheral retina, agreeing with results provided previously by Smith *et al.* (2005). Charman *et al.* (2006) concluded that orthokeratology seems to be the ideal method for controlling peripheral refraction while correcting central refractive error. The difference between peripheral and central refractions has been hypothesised as the most likely explanation for the lower myopic progression in eyes submitted to corneal refractive therapy, first observed in isolated cases (Cheung *et al.*, 2004) and then in the controlled LORIC study (Cho *et al.*, 2005).

Joslin *et al*. (2003) reported a considerable increase in spherical aberration (about five times) for the central 6 mm after 1 month of overnight orthokeratology treatment, agreeing with values obtained by other authors using other reverse geometry lens designs (Berntsen *et al*., 2005). The control of induced aberrations through reverse geometry contact lenses, to manipulate the visual experience of peripheral regions of the visual field in order to influence development of refractive error, is being investigated in a search for a cure for myopia. The differences in spherical aberration observed in the present study may imply the existence of differences in peripheral refraction and myopia progression for different ethnic groups and that should be the subject of further research.

When doing a correlation analysis by ethnicity, AL is correlated significantly with spherical aberration only for Caucasian eyes. Hyman *et al*. (2005) found, on a 3-year evaluation, evidence of differences in the progression of myopia with ethnicity. Refractive error is a multifactorial condition that involves the interplay of all the ocular components (Eysteinsson *et al*., 2005; Olsen *et al*., 2007). In a very recent report, Ramamirtham *et al*. (2007) concluded that high-order aberrations are influenced by visual experience and that the higher amounts of wave aberrations observed in ametropic humans are likely to be a consequence of abnormal refractive development. The role of HOA in the onset and progression of refractive defects may not be the same for different populations. This finding may contribute to a better understanding of the mechanisms underlying the progression of refractive defects for different ethnic groups.

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