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Prevalence of Astigmatism in 6 to 72 Months Old African American and Hispanic Children: The Multi-Ethnic Pediatric Eye Disease Study

The Multi-Ethnic Pediatric Eye Disease Study Writing Committee* for the MEPEDS Group

Abstract

Purpose—To determine the age-, gender- and ethnicity-specific prevalence of astigmatism in African American and Hispanic children aged 6 to 72 months.

Design—Population-based cross-sectional study.

Participants—The Multi-Ethnic Pediatric Eye Disease Study is a population-based evaluation of the prevalence of vision disorders in children ages 6–72 months in Los Angeles County, California. Seventy-seven percent of eligible children completed a comprehensive eye exam. This report provides the results from 2994 African American and 3030 Hispanic children.

Methods—Eligible children in 44 census tracts were identified during an in-home interview and scheduled for a comprehensive eye examination and in-clinic interview. Cycloplegic auto-refraction was used to determine refractive error.

Main outcome measures—The proportion of children with astigmatism defined as cylindrical refractive error ≥ 1.50 diopters (D) in the worse eye. The astigmatism type was defined as with-the-rule (WTR) (+ cylinder axis $90^\circ \pm 15^\circ$) and against-the-rule (ATR) (+ cylinder axis $180^\circ \pm 15^\circ$); all other orientations were considered oblique (OBL). The prevalence of astigmatism and its types were also determined for worse eye cylindrical refractive error ≥ 3.00 D.

Results—Prevalence of astigmatism (≥ 1.50 D) was higher in Hispanic children compared to African American children (16.8% vs. 12.7%, respectively; $P < 0.0001$). Hispanic children also showed a higher prevalence of astigmatism (≥ 3.00 D) than African American children (2.9% vs. 1.0% respectively; $P < 0.0001$). The prevalence of astigmatism ≥ 1.50 D showed a significant decreasing trend with age ($P < 0.0001$). The prevalence of WTR, ATR and OBL astigmatism ≥ 1.50 D was 13.9%, 0.6% and 2.2%, respectively, in Hispanic children, and 7.8%, 2.2% and 2.7%, respectively, in African American children.

This article contains additional online-only material. The following should appear online-only: Table 5, Table 6, Table 7, Table 8 Figure 5, and MEPEDS study group.

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Corresponding author: Rohit Varma, MD, MPH, Doheny Eye Institute, Department of Ophthalmology, 1450 San Pablo St., Room 4900, Los Angeles, CA 90033. Phone: (323) 442-6411, FAX: (323) 442-6412, rvarma@usc.edu.

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Writing Committee: Arezoo Fozailoff, MD.; Kristina Tarczy-Hornoch, MD, DPhil.; Susan Cotter, OD, MS; Ge Wen, MS; Jesse Lin, MS; Mark Borchert, MD; Stanley Azen, PhD; Rohit Varma, MD, MPH.

Conclusion—We observed ethnicity-related differences in astigmatism prevalence in preschool children. The age-related decrease in astigmatism prevalence in preschool children likely reflects emmetropization.

Introduction

Our knowledge regarding the prevalence of astigmatism in preschool children is limited. A number of studies have investigated different features of astigmatism in preschool children,^{1–15} but because of their non-population based design and variability in definitions and methods of measurement, the results may not be representative of the true characteristics of astigmatism in preschool children. Furthermore, until recently, no population-based study has ever investigated the prevalence of astigmatism in African American and Hispanic preschool children. Existing reports regarding the axis orientation of astigmatism in the preschool age range have yielded disparate findings.¹⁶ Moreover no population-based studies have applied power vector analysis to the study of astigmatism over this age range.

The ongoing population-based Multi-Ethnic Pediatric Eye Disease Study (MEPEDS) was designed to investigate the prevalence of vision disorders in 6 to 72 month old children from four racial/ethnic groups (African American, Asian, Hispanic, and Non-Hispanic White) in Los Angeles County, California. To address the issues related to refractive error, cycloplegic refractions were performed. To date, examination of the African American and Hispanic cohorts has been completed.

This report presents the age- and gender-specific prevalence of astigmatism in African American and Hispanic preschool children 6–72 months of age. We also present the distribution of subtypes of astigmatism and apply a power vector analysis to describe variations in astigmatism by age and ethnicity.

Methods

This study was supported through a cooperative agreement with the National Eye Institute of the National Institutes of Health and was conducted in Los Angeles County, CA. The protocol and informed consent forms were reviewed and approved by the Institutional Review Board (IRB)/Ethics Committee of the Los Angeles County University of Southern California Medical Center and a parent or guardian (referred to subsequently as “parent”) of each study participant gave written informed consent. An independent data monitoring and oversight committee provided study oversight.

Study Cohort

The study population consisted of 6 to 72 month old children, who were participants in the Multi-Ethnic Pediatric Eye Disease Study (MEPEDS) and living within 44 census tracts in and around the city of Inglewood and adjacent communities in Los Angeles County, California. The particular census tracts were chosen because they encompassed primarily residential neighborhoods with a high proportion of African American and Hispanic children, with a sufficient census to ascertain precise prevalence estimates. Details of the study design and sampling plan have been described previously.¹⁷

In brief, after conducting a door-to-door census of all dwelling units within the targeted census tracts, eligible children (aged 5–70 months on the day of the household screening) whose parents consented to participate were identified. Following an interview consisting of questions regarding the child’s eyesight and current or past use of spectacles or contact lenses, an appointment was scheduled for an eye examination at the local MEPEDS examination center. African American race and Hispanic ethnicity were determined through

parental report of the child's race/ethnicity, according to National Institutes of Health guidelines available at (<http://grants.nih.gov/grants/guide/notice-files/NOT-OD-01-053.html>), accessed on March 15, 2010.

In-Clinic Ocular Examination and Interview

The clinic visit included a structured interview and a comprehensive eye examination performed by MEPEDS optometrists or ophthalmologists who specialized in pediatric eye care and who were trained and certified using standardized protocols. Details of the interview and eye examination can be found elsewhere.¹⁷

Refractive error was determined by cycloplegic refraction performed with the Retinomax Auto-refractor (Right Manufacturing, Virginia Beach, VA) at least 30 minutes after instillation of the last of two drops of 1% cyclopentolate (0.5% if child ≤ 2 months) separated by 5 minutes. Cycloplegic retinoscopy was performed if Retinomax readings with confidence ratings of ≥ 8 were not obtained in both eyes after 3 attempts. Non-cycloplegic retinoscopy was performed if parents did not allow any cycloplegic eye drops. In the rare instances where the child received the first drop of cyclopentolate, and parents refused the second drop, the child was considered to have received cycloplegia.

Definitions of Astigmatism

Cylindrical refractive error was expressed as positive correcting cylinder form. Astigmatism was defined using two different threshold levels of cylindrical (cyl) refractive error in the worse eye: ≥ 1.50 diopter (D) and ≥ 3.00 D. Astigmatism type was defined as with-the-rule (WTR) (+ cylinder axis $90^\circ \pm 15^\circ$) and against-the-rule (ATR) (+ cylinder axis $180^\circ \pm 15^\circ$); all other orientations were considered oblique (OBL). The eye with the greater absolute amount of cylindrical refractive error was considered to be the worse eye. When both eyes had equal absolute amounts of cylinder, an eye with OBL astigmatism was considered worse than a fellow eye having WTR or ATR astigmatism. For children with equal absolute amounts of cylinder in the two eyes having WTR in one eye and ATR in the other, the child was counted among both children with worse-eye WTR astigmatism and children with worse-eye ATR astigmatism. If only one eye had refractive error data, that eye was considered to be the worse eye. Cylindrical refractive error in the worse eye was categorized by 0.50 D increments for histograms of cylindrical refractive error distribution. The tables presenting the prevalence data for astigmatism in the right eye and in the better eye are available as on-line only at <http://aaojournal.org/>.

We used the vector analysis method modified by Thibos¹⁸ to decompose the refractive cylinder into J0 (Cartesian) and J45 (Oblique) vector components as follows:

$$J0 = (-C/2) * \cos 2\alpha$$

$$J45 = (-C/2) * \sin 2\alpha$$

Where C is cylindrical power and α is the axis in degrees.

The J0 vector describes a Jackson cross-cylinder (JCC) with its axes at 90° and 180° . A positive J0 represents with-the-rule astigmatism while a negative J0 represents against-the-rule astigmatism. The J45 vector describes a JCC with its axes at 45° and 135° , representing oblique astigmatism; a J45 value < 0 corresponds to a plus cylinder axis $< 90^\circ$.

Statistical Analysis

Prevalence was calculated as the ratio of participants with astigmatism to the total number of children for whom refraction was successfully completed for at least one eye. Results are presented for 6 age ranges, referred to herein as age groups.

Logistic regression was used to compare the prevalence of astigmatism between ethnic, gender and age groups. Trends over age were analyzed using logistic regression, Cochran-Armitage trend tests and linear regression. All analyses employed SAS 9.1 software (SAS institute, Inc., Cary, NC) and a 0.05 significance level. A locally weighted regression line of estimated prevalence of astigmatism, mean cylindrical power, mean J0 and mean J45 by months of age was fitted using MATLAB 7.7 software (The Mathworks, Inc., Natick, MA).

Results

Study Cohort

The participation rate, previously reported,¹⁹ was 77% for in-home interview and clinical exam completion. Fewer non-participants than participants had been previously told by their doctor as needing eyeglasses (1.2% vs. 1.9%, $P=0.049$) and non-participants were less likely to use eyeglasses compared to participants (0.7% vs. 1.4% $P=0.02$). Further comparisons between participants and non-participants has been reported elsewhere.¹⁹

Of children completing both the in-home interview and clinical examination, 6043 were African American or Hispanic. Twelve African American and 6 Hispanic children could not be refracted in either eye. One bilaterally aphakic child was excluded, leaving 6024 (99.7%) children with successful refraction in at least one phakic eye. All but 8 of these were successfully refracted in both eyes.

Table 1 shows the demographic characteristics of participants. There were equal proportions of Hispanic ($n= 3030$) and African American ($n= 2994$) children; 49.0% of participants were female.

In 161 participants (2.7%), non-cycloplegic retinoscopy was performed because parents refused cycloplegic eye drops, more often in African American than Hispanic children (4.2% vs. 1.1%, $P<0.001$). Auto-refraction was unsuccessful in one or both eyes of 618 (10.5%) cycloplegic children; in these cases, cycloplegic retinoscopy was performed and analyzed for both eyes. Unsuccessful auto-refraction occurred mostly in younger children, showing a decreasing trend with age in both ethnic groups ($P<0.001$, Cochran-Armitage trend test),²⁰ and was slightly more common in African American than Hispanic children (11.2% vs. 9.4%, $P=0.02$).

Astigmatism as a Function of Age and Ethnicity

The mean absolute cylindrical refractive error was 0.58 D (± 0.61) for right eyes and 0.58 D (± 0.60) for left eyes of African American children. For Hispanic children, it was 0.66 D (± 0.76) and 0.64 D (± 0.75) for right and left eyes, respectively. Table 2 provides mean cylindrical refractive error, J0 and J45 for each eye stratified by age and ethnicity, with p-values for comparison of means between ethnicities.

Mean right eye cylindrical power decreased significantly with age group in both ethnicities ($P<0.0001$, logistic regression), as did mean right eye J0 ($P<0.0001$ and $P=0.0014$ for African American and Hispanic children, respectively). Mean J45 varied little with age group, showing no significant trend with age in either ethnicity.

Figure 1 shows LOWESS (locally weighted scatterplot smoothing) graphs of mean absolute cylinder amount and mean J0 and J45 vector components of astigmatism for right eyes, by month of age. Based on the non-monotonic trend observed for J0 (Figure 1-B), we performed stratified linear regression of mean J0 by age in months, for children under and over 24 months of age. J0 decreased with age in children <24 months for both African American ($P=0.0018$) and Hispanic children ($P<0.0001$), but increased with age for both African American ($P<0.0001$) and Hispanic ($P=0.0002$) children 24 months and older. Stratified linear regression of J45 by age was performed for children <24 months, 24 to <48 months, and ≥ 48 months of age (Figure 1-C). Positive right eye J45 values indicate an angle of plus cylinder astigmatism >90 degrees, so an increase in right eye J45 corresponds to an increase in the angle of plus cylinder astigmatism. J45 showed no significant trend with age in any age stratum in African American children. Hispanic children showed a decreasing trend with age in children <24 months ($P=0.01$), no trend from 24 to <48 months, and an increasing trend for children ≥ 48 months ($P=0.01$).

Scatter plots of J0 and J45 power vector components of astigmatism are shown in Figure 2. The origin of each graph (0, 0) represents an eye free of astigmatism, and each data point shows the endpoint of the 2-dimensional vector (J0, J45) extending from the origin, for one eye. Data are presented for right and left eyes and youngest and oldest age groups of children in each ethnic group, showing similar patterns in both ethnicities. Data points are clustered around the origin, and collapse further around the origin in older children. By 72 months of age, the J0 distribution is skewed toward positive values, and the J45 distribution is skewed toward positive values in the right eye and negative values in the left eye, with a correlation between larger values of J0 and larger absolute values of J45.

Prevalence of Astigmatism

Tables 3 and 4 show astigmatism prevalence in the worse eye stratified by age and ethnic group, with p-values for comparisons between ethnicities, using two different threshold definitions of astigmatism, Table 3 also presents the prevalence of different subtypes of astigmatism ≥ 1.50 D. Data for subtypes of astigmatism ≥ 3.00 D (table 5) is available online at <http://aaojournal.org/>.

The overall prevalence of astigmatism (≥ 1.50 D) was 12.7% in African Americans and 16.8% in Hispanic children; this difference was significant after adjustment for age group and gender ($P<0.0001$, logistic regression).

Excluding cycloplegic and non-cycloplegic retinoscopy refractions, the prevalence of astigmatism among children undergoing cycloplegic auto-refraction was similar to the overall prevalence for each ethnicity: 12.5% in African American and 15.9% in Hispanic children (significantly higher in Hispanic children; $P=0.0004$).

Astigmatism (≥ 1.50 D) was more prevalent in Hispanic boys (18.5%) than girls (14.9%) ($P=0.02$ adjusting for age); however, the difference was no longer significant after excluding children refracted with techniques other than cycloplegic autorefraction ($P=0.06$). There was no significant difference between African American boys (12.3%) and girls (13.0%) ($P=0.41$).

Astigmatism prevalence (≥ 1.50 D) decreased with age group in both ethnicities ($P<0.0001$, logistic regression adjusting for gender). Excluding non-cycloplegic and cycloplegic retinoscopy refractions yielded a similar trend with age ($P<0.001$).

The overall prevalence of astigmatism ≥ 3.00 D was 3.0% for Hispanic and 1.2% for African American children; this difference was significant ($P<0.0001$, logistic regression adjusting

for age and gender). There was no significant gender difference in either ethnic group (1.1% in boys vs. 1.4% in girls in African Americans; 3.2% in boys vs. 2.9% in girls in Hispanics). Astigmatism ≥ 3.00 D showed no significant trend with age in either ethnicity overall, or after exclusion of retinoscopy refractions ($P \geq 0.50$).

Figure 3 panels A and B show LOWESS plots of the decreasing prevalence of astigmatism ≥ 1.50 D and ≥ 3.00 D by month of age in African American and Hispanic children. The drop in the prevalence of astigmatism ≥ 1.50 D is most pronounced in children < 24 months of age, especially in Hispanic children. In Hispanic children, the prevalence of astigmatism ≥ 3.00 D decreases to its lowest point by around 24 months of age, but rises again thereafter. African American children follow a similar but a more subtle course.

Figure 4 shows frequency distribution histograms of absolute cylinder amount in 0.50 D increments for all age groups for both African American and Hispanic children. These show a gradual, progressive shift toward less astigmatic values in both ethnicities. High cylinder amounts are much less common in the oldest than in the youngest age groups.

Prevalence of Subtypes of Astigmatism

Figure 5 (available at <http://aaojournal.org/>) shows the distribution of proportions of different astigmatism subtypes ≥ 1.50 D, stratified by age group, in both ethnicities. Table 3 and table 5 (available at <http://aaojournal.org/>) present the prevalence of different astigmatism subtypes by age group for both ethnicities. For astigmatism ≥ 1.50 D, subtype prevalence was 7.8%, 2.2%, and 2.7% for WTR, ATR, and OBL, respectively, in African American children, and 13.9%, 0.6%, and 2.2% in Hispanic children. WTR astigmatism was the most prevalent type at all ages, in both ethnic groups.

Astigmatism Prevalence and Subtypes in the Right Eye and Better Eye

Tables 6 and 7 (available at <http://aaojournal.org/>) show the prevalence of astigmatism and its subtypes for the right eye and better eye, stratified by age group, for both African American and Hispanic children.

Discussion

We have presented estimates of astigmatism prevalence in African American and Hispanic children aged 6–72 months from a large, population-based study conducted in Los Angeles County, California showing that astigmatism is more prevalent in Hispanic than African American children, and that it decreases significantly as a function of age in this cross-sectional sample.

Analysis of mean values of astigmatism components shows that mean cylindrical power differs significantly between African American and Hispanic children aged 6–72 months, both overall, and particularly in the youngest age group. Mean absolute cylindrical power decreases with age in both ethnic groups. There seems to be a more prominent drop in the mean cylindrical refractive error of Hispanic children before as compared to after 24 months of age, while the decline in mean cylinder of African American children appears to proceed at a more constant rate through around 48 months of age. The more prominent early drop in the mean cylindrical power of Hispanic children may be a manifestation of higher rates of emmetropization associated with higher baseline refractive errors, a pattern that has been previously observed in other studies.^{6, 21}

The differences in mean cylinder power between ethnicities are primarily a reflection of differences in the mean J0 vector component of astigmatism, which is clinically and statistically significantly larger in Hispanic children in all age groups, and especially in the

first year of life. The differences between ethnicities for the J45 component, by contrast, are small and clinically insignificant, although African American children show greater mirror-image differences in average oblique astigmatism axis between eyes than Hispanic children (mean J45 <0 in the right eye and >0 in the left eye).

Mean J0 and J45 components vary by age as well as ethnicity. Overall, mean J0 declines as a function of age in months, although further analysis reveals an initial decrease until approximately 24 months of age, followed by a gradual increase in both ethnicities. The initial decrease in mean J0 signifies a shift of the mean toward less positive values (away from WTR astigmatism, toward ATR astigmatism), while the subsequent increase in mean J0 signifies a shift in the opposite direction. The J45 component shows much less variation as a function of age, and no overall trend with age, although Hispanic children do again demonstrate subtle opposing trends with age in the youngest and oldest children studied. Scatter plots showing the power vector components of astigmatism in individual eyes reveal how both amount and axis of astigmatism differ by age group. In these scatter plots, the x-coordinate is the amplitude of J0, the y-coordinate is the amplitude of J45, and the distance of a point from the origin (0,0) is proportional to (is half of) the absolute amount of cylinder. Meanwhile, the angle formed by the x-axis on one hand, and a line passing through the data-point and the origin on the other, reflects the axis of astigmatism; specifically, a point directly above or below the origin represents plus-cylinder axis 135 degrees or 45 degrees, respectively, while a point directly to the right or left of the origin represents plus-cylinder axis 90 degrees or 180 degrees, respectively. In the youngest age group, there is broad scatter around the origin in both ethnicities studied, although Hispanic children show a J0 distribution shifted toward more WTR astigmatism relative to African American children. In the oldest age group, by contrast, the data points are more clustered around the origin. Furthermore, with age there emerges a clear pattern in both ethnicities, in which large amounts of astigmatism tend to be WTR, with oblique components showing mirror-image symmetry between eyes (angles <90 degrees in the left eye and >90 degrees in the right). Although this is not a longitudinal study, this analysis suggests a process of emmetropization occurring over the first few years of life. Only longitudinal evaluation can determine whether there exists a subset of children with large amounts of early WTR astigmatism that is relatively resistant to emmetropization.

No previous population-based studies have ever studied the changes in the value of astigmatism vector components with age in these ethnic groups over this age range. Cowen et al present one scatter graph from preschool children with non-cycloplegic auto-refraction data from a screening study in Canada.³ The scatter graph shows a distribution weighted toward positive values of J0 and J45 in the right eye for 48-month-old children, similar to our oldest age group.

Histograms illustrating age-related variations in the distribution of the absolute amount of cylinder are again suggestive of emmetropization with age, showing a progressive leftward shift of the peak (toward lesser amounts of cylinder) with each age group in both ethnicities. The distribution of astigmatic refractive error in a population-based study of six year old children in Australia is comparable to that seen in our oldest age groups.

Using threshold definitions of astigmatism, Hispanic children showed a higher prevalence of astigmatism than African American children, regardless of whether a threshold of ≥ 1.50 D or ≥ 3.00 D is used to define astigmatism. The non-population based Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE) study on older school-aged children, similarly reports a higher prevalence of astigmatism in Hispanics compared to African Americans.²³

The Baltimore Pediatric Eye Disease Study (BPEDS), a population-based study paralleling the MEPEDS and examining African American and non-Hispanic white children,²⁴ found astigmatism prevalence in African American children very similar to that reported here: 13.0% of BPEDS African American children had astigmatism ≥ 1.50 D, compared to 12.7% in MEPEDS ($P=0.88$), and 1.5% had astigmatism ≥ 3.00 D, compared to 1.2% in MEPEDS ($P=0.56$). Table 8 (available at <http://aaojournal.org/>) provides a detailed comparison of the two studies; only a single age group (36–47 months) showed any significant difference in prevalence of astigmatism ≥ 1.50 D between studies.

The BPEDS found a lower prevalence of astigmatism in non-Hispanic white than African American children.²⁴ Similarly, in a population-based study of 6 year-old children in Australia,²² the prevalence of astigmatism ≥ 1.50 D was 4.8%; thus, both the African American and Hispanic 5-year-old children studied here show more than double the prevalence of astigmatism seen in Australian children of non-Hispanic white and Asian descent.

A majority of Hispanic individuals residing in California are classified as Mexican Hispanics. The majority of estimates have indicated an Amerindian component in Mexican Americans ranging between 30% to 40%.²⁵ There are multiple reports showing a high prevalence of astigmatism in Amerindians,^{5, 26–31} and this genetic background may contribute to the relatively high prevalence of astigmatism seen in our Hispanic children.

Considering variations in astigmatism prevalence as a function of age, there is an overall decrease in prevalence of astigmatism ≥ 1.50 D with increasing age. In our Hispanic population, which has the higher prevalence of infantile astigmatism, the most rapid change occurs between 6 to 24 months. Similar decreases in astigmatism prevalence with increasing age have been reported in other, non-population-based studies, including both cross-sectional^{8, 13} and longitudinal studies.^{1, 4, 9–12, 14, 32–33} BPEDS similarly reported a decreasing trend with age in non-Hispanic white children.²⁴ While the prevalence of astigmatism in African American children in their study was reported to be stable across age groups overall, the highest prevalence was observed in the youngest age group, consistent with the present findings.

The prevalence of astigmatism ≥ 3.00 D shows considerably less absolute variation with age, but shows a similar decreasing trend over the first 24 months. Thereafter, it increases again, but does not ever exceed the initial prevalence levels seen in infants. It cannot be determined without longitudinal study whether this cross-sectional pattern results from separate subsets of highly astigmatic children, some with infantile astigmatism reducing through emmetropization, and others with increasing astigmatism, or whether individual children may show decreases and subsequent increases in the amount of astigmatism. Increases in astigmatism have been observed in a minority of astigmatic infants in previous longitudinal studies.³⁴

In both African American and Hispanic children, and in all age groups, WTR astigmatism was by far the most common form, followed by OBL astigmatism and then ATR. Similar findings were seen in the BPEDS (table 8, available at <http://aaojournal.org/>). Although absolute ATR prevalence was higher in African American children than Hispanic children, in older age groups even African American children showed an ever greater relative predominance of WTR astigmatism. The higher proportion of WTR astigmatism compared to ATR and OBL has been shown in previous non-population based studies in other ethnic groups,^{6–7} while other studies have shown a higher prevalence of ATR astigmatism.^{1, 11} Some studies have reported a shift in the predominance of ATR astigmatism in younger children to predominance of WTR in older children.^{4, 10} The population-based study on 6-

year-old children in Sydney, using cycloplegic refraction, reported a predominance of OBL astigmatism followed by WTR in its children.²² This latter study suggests that there may be true ethnic differences in astigmatism subtype prevalence, but some of the variability of findings across studies may be related to variations in study design (non-population-based samples) and/or study methodology (particularly the use of a non-cycloplegic refraction).

Although a minority of children in this study could not be measured using autorefraction, and were evaluated using retinoscopy instead, our secondary analysis excluding these children found very similar results to our primary analysis, for both overall prevalence and age-related trends of astigmatism.

There was a statistically significant difference between study participants and non-participants with regard to spectacle wear. However, this potential selection bias is unlikely to have affected our prevalence estimates, because the overall frequency of previous diagnosis and spectacle correction of refractive error in this population was very low compared to the prevalence of refractive error.

One of the limitations of our findings is that while cross-sectional astigmatism distributions in different age groups suggest age-related trends such as emmetropization, only longitudinal data can provide definitive evidence that refractive error distributions change over time in a given group of children. Cross-sectional data are not predictive of the longitudinal behavior of individuals. Population-based longitudinal studies are required to further clarify age-related trends in astigmatism in individual children.

Strengths of the MEPEDS include population-based data that was collected with meticulous interview and detailed examination protocols with excellent quality control, high participation rates, and a large sample size. We believe our findings are likely generalizable to most African American and Hispanic children in the United States.

In conclusion, in this population-based of children younger than 6 years of age, we identified ethnicity-related differences in the prevalence of astigmatism and its subtypes in African American and Hispanic preschool children. However, children of both racial/ethnic groups showed similar patterns with regard to age-related distributions of astigmatism by age. The observed lower prevalence of astigmatism in older children is suggestive of early emmetropization in preschool children.

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1A **1B**

1C

Figure 1.

Locally weighted regression lines derived for mean right eye cylindrical power, J0 and J45 as a function of age in months in African American and Hispanic children in the Multi-Ethnic Pediatric Eye Disease Study. Panel 1A: mean right eye cylindrical power. Panel 1B: mean right eye J0 (Cartesian) vector component of astigmatism. J0 is defined as $(-C/2) \cdot \cos 2\alpha$, where α and C are axis and magnitude of cylindrical refractive error. Panel 1C: mean right eye J45 (oblique) vector component of astigmatism. J45 is defined as $(-C/2) \cdot \sin 2\alpha$, where α and C are axis and magnitude of cylindrical refractive error. Gray shading represents 95% confidence interval of the estimated mean values.

Figure 2.

Scatter plots of the power vector components of astigmatism in the youngest and oldest age groups of African American and Hispanic children in the Multi-Ethnic Pediatric Eye Disease Study. Each data point on a scatter plot represents the power vector expression of astigmatism for one eye using the 2-dimensional vector (J_0 , J_{45}). The origin of the graph (0, 0) represents an eye free of astigmatism. Panel 2A: Right and left eyes of 6–11 month-old and 60–72 month-old African American children. Panel 2B: Right and left eyes of 6–11 month-old and 60–72 month-old Hispanic children. X axis: J_0 vector components of right eye and left eye astigmatism. J_0 is defined as $(-C/2) \cdot \cos 2\alpha$, where α and C are axis and magnitude of cylindrical refractive error. Y axes: J_{45} vector components of right and left eye astigmatism. J_{45} is defined as $(-C/2) \cdot \sin 2\alpha$, where α and C are axis and magnitude of cylindrical refractive error.

Figure 3.

Locally weighted regression lines derived for prevalence of astigmatism as a function of age in months for African American and Hispanic children in the Multi-Ethnic Pediatric Eye Disease Study. Panel 3A: Vertical axis shows the estimated prevalence of astigmatism ≥ 1.50 D in the worse eye (CYL ≥ 1.50 D). Panel 3B: Vertical axis shows the estimated prevalence of astigmatism ≥ 3.00 D in the worse eye (CYL ≥ 3.00 D). Gray shading represent 95% confidence interval of the estimated prevalence. CYL: cylindrical refractive error; D: diopters

Figure 4.

Distribution of cylindrical power of the eye with greater absolute amount of cylinder, binned by 0.50 diopter (D) increments of cylinder power, stratified by age and ethnic group in the Multi-Ethnic Pediatric Eye Disease Study. Vertical axis shows the prevalence (%) of a given level of cylindrical refractive error. Horizontal axis shows cylindrical refractive error in 0.50 D intervals.

5A

5B

Figure 5.

Bar graph of proportions of subtypes of astigmatism relative to overall cases of worse-eye astigmatism ≥ 1.50 diopters (D), by age group, in African American (**5A**) and Hispanic (**5B**) children in the Multi-Ethnic Pediatric Eye Disease Study. WTR: With-the-rule astigmatism, defined as astigmatism with the axis of greatest power within ± 15 degrees of 90, i.e., in the range $[75-105^\circ]$; ATR: Against-the-rule astigmatism, defined as astigmatism with the axis of greatest power within ± 15 degrees of 180, i.e., in the range $[1-15^\circ]$ or $[165-180^\circ]$; OBL: Oblique axis astigmatism, which includes all other orientations (axis of greatest power in the range $[106-164^\circ]$ or $[16-74^\circ]$); AA=African American; H=Hispanic. X axis shows age groups in months. Y axis shows percentage of overall number of cases of worse-eye

astigmatism ≥ 1.50 D. The worse eye is defined as the eye with the largest absolute amount of cylindrical refractive error. In ties for magnitude, oblique astigmatism is considered worse than WTR or ATR astigmatism. There were no ties for magnitude between ATR and WTR astigmatism ≥ 1.50 D.

Table 1

Age and gender distributions of African American and Hispanic children in the Multi-Ethnic Pediatric Eye Disease Study.

Age group in months	Hispanic Total n=3030 n (%)	African American Total n=2994 n (%)	All Total n=6024 n (%)
6 to 11	296 (10%)	277 (9%)	573 (10%)
12 to 23	543 (18%)	549 (18%)	1092 (18%)
24 to 35	572 (19%)	545 (18%)	1117 (19%)
36 to 47	532 (17%)	532 (18%)	1064 (18%)
48 to 59	543 (18%)	548 (18%)	1091 (18%)
60 to 72	544 (18%)	543 (18%)	1087 (18%)
Gender			
Male	1557 (51%)	1514 (51%)	3071 (51%)
Female	1473 (49%)	1480 (49%)	2953 (49%)

Table 2

Mean absolute cylindrical power, mean J0 vector component of astigmatism, and mean J45 vector component of astigmatism in right and left eyes of African-American and Hispanic children, stratified by age, in the Multi-Ethnic Pediatric Eye Disease Study.

Age group In months	N*		Mean (SD) cylindrical power, in diopters					
			Right eye			Left eye		
	AA	Hisp	AA	Hisp	p value**	AA	Hisp	p value**
6 to 11	277	296	0.86 (0.69)	1.13 (0.87)	<0.001	0.85 (0.67)	1.08 (0.87)	<0.001
12 to 23	549	543	0.65 (0.62)	0.71 (0.69)	0.13	0.66 (0.59)	0.70 (0.67)	0.30
24 to 35	545	572	0.60 (0.56)	0.60 (0.63)	0.97	0.62 (0.57)	0.61 (0.67)	0.80
36 to 47	532	532	0.48 (0.50)	0.60 (0.75)	0.004	0.48 (0.52)	0.58 (0.78)	0.01
48 to 59	548	543	0.52 (0.59)	0.55 (0.71)	0.37	0.51 (0.60)	0.54 (0.72)	0.49
60 to 72	543	544	0.50 (0.69)	0.59 (0.83)	0.0498	0.49 (0.64)	0.52 (0.74)	0.48
Total	2994	3030	0.58 (0.61)	0.66 (0.76)	<0.001	0.58 (0.60)	0.64 (0.75)	<0.001
Age group in months	N *		Mean (SD) J0 ⁻¹ in diopters					
			Right eye			Left eye		
	AA	Hisp	AA	Hisp	p value**	AA	Hisp	p value**
6 to 11	277	296	0.09 (0.47)	0.45 (0.47)	<0.001	0.08 (0.49)	0.43 (0.48)	<0.001
12 to 23	549	543	0.01 (0.40)	0.19 (0.42)	<0.001	0.01 (0.39)	0.17 (0.42)	<0.001
24 to 35	545	572	0.05 (0.37)	0.14 (0.37)	<0.001	0.04 (0.38)	0.13 (0.40)	<0.001
36 to 47	532	532	0.05 (0.30)	0.20 (0.40)	<0.001	0.05 (0.32)	0.18 (0.43)	<0.001
48 to 59	548	543	0.12 (0.34)	0.21 (0.37)	<0.001	0.10 (0.34)	0.18 (0.38)	<0.001
60 to 72	543	544	0.13 (0.37)	0.24 (0.42)	<0.001	0.12 (0.35)	0.19 (0.39)	0.004

Age group In months	N*		Mean (SD) cylindrical power, in diopters					
			Right eye			Left eye		
			AA	Hisp	** p value	AA	Hisp	** p value
Total	2994	3030	0.08 (0.37)	0.22 (0.41)	<0.001	0.07 (0.37)	0.20 (0.42)	<0.001
Age group in months	N*		Mean (SD) J45 [‡] in diopters					
			Right eye			Left eye		
			AA	Hisp	** p value	AA	Hisp	** p value
6 to 11	277	296	-0.01 (0.28)	0.06 (0.28)	0.02	0.01 (0.23)	0.00 (0.25)	0.32
12 to 23	549	543	-0.01	0.01	0.07	0.01	0.02	0.51
24 to 35	545	572	-0.03 (0.17)	-0.00 (0.18)	0.02	0.04 (0.18)	0.03 (0.15)	0.28
36 to 47	532	532	-0.04 (0.16)	0.00 (0.14)	<0.001	0.03 (0.15)	0.02 (0.14)	0.30
48 to 59	548	543	-0.02 (0.15)	0.00 (0.14)	0.002	0.02 (0.17)	0.02 (0.14)	0.84
60 to 72	543	544	-0.00 (0.17)	0.03 (0.16)	<0.001	0.01 (0.15)	0.01 (0.14)	0.73
Total	2994	3030	-0.02 (0.18)	0.01 (0.18)	<0.001	0.02 (0.18)	0.02 (0.16)	0.25

* N: number of children with data for one or both eyes. One African American and 3 Hispanic children had data for right eye only; one African American and 3 Hispanic children had data for left eye only.

** p value: p value for comparison of mean values between ethnicities using Student's t-test.

[‡] J0 vector component of cylindrical refractive error, defined as $(-C/2)*\cos 2\alpha$, where α and C are axis and magnitude of cylindrical refractive error.

[‡] J45 vector components of cylindrical refractive error, defined as $(-C/2)*\sin 2\alpha$, where α and C are axis and magnitude of cylindrical refractive error.

AA: African American; Hisp: Hispanic, SD: Standard deviation.

Table 3

Prevalence of astigmatism (worse eye cylinder power ≥ 1.50 diopters), overall and by subtypes of astigmatism, stratified by age, in African American and Hispanic children in the Multi-Ethnic Pediatric Eye Disease Study.

Age group group in months	N	Prevalence of astigmatism ≥ 1.50 D n (%) *					Prevalence of subtypes of astigmatism ≥ 1.50 D n (%) *							
		WTR			ATR			OBL						
AA	Hisp	AA	Hisp	** p	AA	Hisp	** p	AA	Hisp	** p				
6 to 11	277	296	70 (25.3)	119 (40.2)	<0.001	36 (13.0)	99 (33.5)	<0.001	15 (5.42)	0 (0.0)	<0.001	19 (6.9)	20 (6.8)	0.96
12 to 23	549	543	75 (13.7)	90 (16.6)	0.18	33 (6.0)	70 (12.9)	<0.001	20 (3.6)	6 (1.1)	0.006	22 (4.0)	14 (2.6)	0.19
24 to 35	545	572	75 (13.8)	86 (15.0)	0.54	42 (7.7)	63 (11.0)	0.06	19 (3.5)	10 (1.8)	0.07	14 (2.6)	13 (2.3)	0.75
36 to 47	532	532	36 (6.8)	74 (13.9)	<0.001	25 (4.7)	64 (12.0)	<0.001	5 (0.9)	1 (0.2)	0.10	6 (1.1)	9 (1.7)	0.44
48 to 59	548	543	64 (11.7)	77 (14.2)	0.22	46 (8.4)	70 (12.9)	0.02	6 (1.1)	0 (0.0)	0.01	12 (2.2)	7 (1.3)	0.26
60 to 72	543	544	59 (10.9)	62 (11.4)	0.78	50 (9.2)	56 (10.3)	0.55	2 (0.4)	1 (0.2)	0.56	7 (1.3)	5 (0.9)	0.56
Total	2994	3030	379 (12.7)	508 (16.8)	<0.001	232 (7.8)	422 (13.9)	<0.001	67 (2.2)	18 (0.6)	<0.001	80 (2.7)	68 (2.2)	0.28

AA: African American; Hisp: Hispanic; D: diopters.

^{*} Percentage of total in corresponding age and ethnic group

^{**} p: p value for comparison of proportions between ethnicities using Chi-square test

WTR: With-the-rule astigmatism, defined as astigmatism with the axis of greatest power within ± 15 degrees of 90, i.e., in the range [75–105°]; ATR: Against-the-rule astigmatism, defined as astigmatism with the axis of greatest power within ± 15 degrees of 180, i.e., in the range [165–180°]; OBL: Oblique axis astigmatism, which includes all other orientations (axis of greatest power in the range [106–164°] or [16–74°]).

The worse eye is defined as the eye with the largest absolute amount of cylindrical refractive error. In ties for magnitude, oblique astigmatism is considered worse than WTR or ATR astigmatism. There were no ties for magnitude between ATR and WTR astigmatism ≥ 1.50 D.

Table 4

Prevalence of high astigmatism (worse eye cylinder power ≥ 3.00 diopters) in African-American and Hispanic children, stratified by age, in the Multi-Ethnic Pediatric Eye Disease Study.

Age group in months	N		Prevalence of astigmatism ≥ 3.00 D n (%) [*]		p value ^{**}
	AA	Hisp	AA	Hisp	
6 to 11	277	296	6 (2.2)	16 (5.4)	0.04
12 to 23	549	543	6 (1.1)	10 (1.8)	0.30
24 to 35	545	572	3 (0.6)	10 (1.8)	0.06
36 to 47	532	532	4 (0.8)	18 (3.4)	0.003
48 to 59	548	543	7 (1.3)	16 (3.0)	0.06
60 to 72	543	544	11 (2.0)	22 (4.0)	0.05
Total	2994	3030	37 (1.2)	92 (3.0)	<0.001

AA: African American; Hisp: Hispanic; D: diopters.

^{*} Percentage of total in corresponding age and ethnic group

^{**} p value: p value for comparison of proportions between ethnicities using Chi-square test The worse eye is defined as the eye with the largest absolute amount of cylindrical refractive error.

Table 5

Prevalence of subtypes of high astigmatism (worse eye cylinder power ≥ 3.00 diopters) in African-American and Hispanic children, stratified by age, in the Multi-Ethnic Pediatric Eye Disease Study.

Age group (months)	N	Types of Astigmatism n (%) [*]									
		WTR		ATR				OBL		p [*]	
		AA	Hisp	AA	Hisp	p ^{**}		AA	Hisp		
6 to 11	277	296	3 (1.1)	15 (5.1)	0.006	1 (0.4)	0 (0.0)	0.30	2 (0.7)	1 (0.3)	0.52
12 to 23	549	543	5 (0.9)	8 (1.5)	0.39	0 (0.0)	1 (0.2)	0.31	1 (0.2)	1 (0.2)	0.99
24 to 35	545	572	3 (0.6)	10 (1.8)	0.06	0 (0.0)	0 (0.0)	-	0 (0.0)	0 (0.0)	-
36 to 47	532	532	4 (0.8)	18 (3.4)	0.003	0 (0.0)	0 (0.0)	-	0 (0.0)	0 (0.0)	-
48 to 59	548	543	6 (1.1)	15 (2.8)	0.045	0 (0.0)	0 (0.0)	-	1 (0.2)	1 (0.2)	0.99
60 to 72	543	544	10 (1.8)	21 (3.8)	0.046	0 (0.0)	0 (0.0)	-	1 (0.2)	1 (0.2)	0.999
Total	2994	3030	31 (1.0)	87 (2.9)	<0.001	1 (0.03)	1 (0.03)	0.99	5 (0.2)	4 (0.1)	0.99

AA: African American; Hisp: Hispanic

^{*} Percentage of total in corresponding age and ethnic group

^{**} p: p value for comparison of proportions between ethnicities using Chi-square test

WTR: With-the-rule astigmatism, defined as astigmatism with the axis of greatest power within ± 15 degrees of 90, i.e., in the range [75–105°]; ATR: Against-the-rule astigmatism, defined as astigmatism with the axis of greatest power within ± 15 degrees of 180, i.e., in the range [165–180°]; OBL: Oblique axis astigmatism, which includes all other orientations (axis of greatest power in the range [106–164°] or [16–74°]).

The worse eye is defined as the eye with the largest absolute amount of cylindrical refractive error. In ties for magnitude, oblique astigmatism is considered worse than WTR or ATR astigmatism. There were no ties for magnitude between ATR and WTR astigmatism ≥ 3.00 D.

Table 6

Prevalence of astigmatism (right eye cylinder power ≥ 1.50 diopters), overall and by subtypes of astigmatism, stratified by age, in African American and Hispanic children in the Multi-Ethnic Pediatric Eye Disease Study.

Age group in months	N		Prevalence of astigmatism ≥ 1.50 D n (%) *		Prevalence of subtypes of astigmatism ≥ 1.50 D n (%) *					
					WTR		ATR		OBL	
	AA	Hisp	AA	Hisp	AA	Hisp	AA	Hisp	AA	Hisp
6 to 11	277	295	50 (18.1)	98 (33.2)	28 (10.1)	81 (27.5)	9 (3.3)	0 (0.0)	13 (4.7)	17 (5.8)
12 to 23	549	543	53 (9.7)	73 (13.4)	23 (4.2)	60 (11.1)	16 (2.9)	4 (0.7)	14 (2.7)	9 (1.7)
24 to 35	544	571	49 (9.0)	61 (10.7)	35 (6.4)	46 (8.1)	10 (1.8)	3 (0.5)	4 (0.7)	12 (2.1)
36 to 47	532	531	27 (5.1)	57 (10.7)	19 (3.6)	50 (9.4)	5 (0.9)	0 (0.0)	3 (0.6)	7 (1.3)
48 to 59	548	543	44 (8.0)	63 (11.6)	33 (6.0)	59 (10.9)	3 (0.6)	0 (0.0)	8 (1.5)	4 (0.7)
60 to 72	543	544	47 (8.7)	56 (10.3)	40 (7.4)	50 (9.2)	1 (0.2)	1 (0.2)	6 (1.1)	5 (0.9)
Total	2993	3027	270 (9.0)	408 (13.5)	178 (6.0)	346 (11.4)	44 (1.5)	8 (0.3)	48 (1.6)	54 (1.8)

AA: African American; Hisp: Hispanic; D: diopters

* Percentage of total in corresponding age and ethnic group

WTR: With-the-rule astigmatism, defined as astigmatism with the axis of greatest power within ± 15 degrees of 90, i.e., in the range [75–105°]; ATR: Against-the-rule astigmatism, defined as astigmatism with the axis of greatest power within ± 15 degrees of 180, i.e., in the range [1–15°] or [165–180°]; OBL: Oblique axis astigmatism, which includes all other orientations (axis of greatest power in the range [106–164°] or [16–74°]).

Table 7

Prevalence of astigmatism (better eye cylinder power ≥ 1.50 diopters), overall and by subtypes of astigmatism, stratified by age, in African American and Hispanic children in the Multi-Ethnic Pediatric Eye Disease Study.

Age group in months	N		Prevalence of astigmatism ≥ 1.50 D n (%) [*]		Prevalence of subtypes of astigmatism ≥ 1.50 D n (%) [*]							
					WTR		ATR				OBL	
							AA	Hisp	AA	Hisp		
6 to 11	277	296	34 (12.3)	70 (23.7)	26 (9.4)	63 (21.4)	4 (1.4)	0 (0.0)	4 (1.4)	7 (2.4)		
12 to 23	549	543	31 (5.7)	49 (9.0)	14 (2.6)	44 (8.1)	9 (1.6)	1 (0.2)	8 (1.5)	4 (0.7)		
24 to 35	545	572	34 (6.3)	41 (7.2)	27 (5.0)	34 (6.0)	7 (1.3)	2 (0.4)	0 (0.0)	5 (0.9)		
36 to 47	532	532	19 (3.6)	38 (7.2)	14 (2.6)	37 (0.7)	4 (0.8)	0 (0.0)	1 (0.2)	1 (0.2)		
48 to 59	548	543	25 (4.6)	41 (7.2)	20 (3.7)	039 (7.2)	0 (0.0)	0 (0.0)	5 (0.9)	2 (0.4)		
60 to 72	543	544	28 (5.2)	44 (8.1)	23 (4.2)	42 (7.7)	1 (0.2)	0 (0.0)	4 (0.7)	2 (0.4)		
Total	2994	3030	171 (5.7)	283 (9.4)	124 (4.1)	259 (8.6)	25 (0.8)	3 (0.1)	22 (0.7)	21 (0.7)		

AA: African American; Hisp: Hispanic; D: diopters

^{*} Percentage of total in corresponding age and ethnic group

WTR: With-the-rule astigmatism, defined as astigmatism with the axis of greatest power within ± 15 degrees of 90, i.e., in the range [75–105°]; ATR: Against-the-rule astigmatism, defined as astigmatism with the axis of greatest power within ± 15 degrees of 180, i.e., in the range [165–180°]; OBL: Oblique axis astigmatism, which includes all other orientations (axis of greatest power in the range [106–164°] or [16–74°]).

The better eye is defined as the eye with the least absolute amount of cylindrical refractive error.

In ties for magnitude, WTR astigmatism is considered better than ATR astigmatism. WTR and ATR are considered better than oblique. There were no ties for magnitude between ATR and WTR astigmatism ≥ 1.50 D.

Table 8

Prevalence of astigmatism in the worse eye for African-American Children in the Baltimore Pediatric Eye Disease Study and the Multi-Ethnic Pediatric Eye Disease Study.

Age group in months	Prevalence of astigmatism $\geq 1.50D$ n (%) [*]		Prevalence of astigmatism $\geq 3.00D$ n (%) [*]		Prevalence of subtypes of astigmatism $\geq 50 D$ n (%) [*]					
	M	B	M	B	WTR		ATR		OBL	
6 to 11 months (M, n=277 B, n=83)	70 (25.3)	13 (16.0)	6 (2.2)	0 (0.0)	36 (13.0)	6 (7.4)	15 (5.4)	3 (3.7)	19 (6.9)	4 (4.9)
12 to 23 months (M, n=549 B, n=181)	75 (13.7)	20 (10.8)	6 (1.1)	0 (0.0)	33 (6.0)	12 (6.5)	20 (3.6)	3 (1.6)	22 (4.0)	5 (2.7)
24 to 35 months (M, n=545 B, n=248)	75 (13.8)	34 (13.8)	3 (0.6)	3 (1.2)	42 (7.7)	18 (7.3)	19 (3.5)	2 (0.8)	14 (2.6)	14 (5.7)
36 to 47 months (M, n=532 B, n=240)	36 (6.8)	33 (13.9)	4 (0.8)	2 (0.8)	25 (4.7)	27 (11.4)	5 (0.9)	1 (0.4)	6 (1.1)	5 (2.1)
48 to 59 months (M, n=548 B, n=261)	64 (11.7)	31 (12.0)	7 (1.3)	5 (1.9)	46 (8.4)	26 (10.1)	6 (1.1)	0 (0.0)	12 (2.2)	5 (1.9)
60 to 72 months (M, n=543 B, n=245)	59 (10.9)	32 (13.2)	11 (2.0)	9 (3.7)	50 (9.2)	23 (9.5)	2 (0.4)	3 (1.2)	7 (1.3)	6 (2.5)
Total (M, n=2994 B, n=1268)	379 (12.7)	163 (13.0)	37 (1.2)	19 (1.5)	232 (7.7)	112 (9.0)	67 (2.2)	12 (1.0)	80 (2.7)	39 (3.1)

AA: African American; Hisp: Hispanic; D: diopters

^{*} Percentage of total in corresponding age and study group

WTR: With-the-rule astigmatism, defined as astigmatism with the axis of greatest power within ± 15 degrees of 90, i.e., in the range [75–105°]; ATR: Against-the-rule astigmatism, defined as astigmatism with the axis of greatest power within ± 15 degrees of 180, i.e., in the range [1–15°] or [165–180°]; OBL: Oblique axis astigmatism, which includes all other orientations (axis of greatest power in the range [106–164°] or [16–74°]).

The worse eye is defined as the eye with the largest absolute amount of cylindrical refractive error.

M: MEPEDS (Multi-Ethnic Pediatric Eye Disease Study); B: BPEDS (Baltimore Pediatric Eye Disease Study).