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Anisometropia Prevalence in a Highly Astigmatic School-Aged Population

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Abstract

Purpose—To describe prevalence of anisometropia, defined in terms of both sphere and cylinder, examined cross-sectionally, in school-aged members of a Native American tribe with a high prevalence of astigmatism.

Methods—Cycloplegic autorefraction measurements, confirmed by retinoscopy and, when possible, by subjective refraction were obtained from 1,041 Tohono O'odham children, 4 to 13 years of age.

Results—Astigmatism ≥ 1.00 diopter (D) was present in one or both eyes of 462 children (44.4%). Anisometropia ≥ 1.00 diopter (D) spherical equivalent (SE) was found in 70 children (6.7%), and anisometropia ≥ 1.00 D cylinder was found in 156 children (15.0%). Prevalence of anisometropia did not vary significantly with age or gender. Overall prevalence of significant anisometropia was 18.1% for a difference between eyes ≥ 1.00 D SE or cylinder. Vector analysis of between-eye differences showed a prevalence of significant anisometropia of 25.3% for one type of vector notation (difference between eyes ≥ 1.00 D for M and/or ≥ 0.50 D for J0 or J45), and 16.2% for a second type of vector notation (between-eye vector dioptric difference ≥ 1.41).

Conclusions—Prevalence of SE anisometropia is similar to that reported for other school-aged populations. However, prevalence of astigmatic anisometropia is higher than that reported for other school-aged populations.

Keywords

anisometropia; astigmatism; prevalence; children; Native American

Anisometropia is a difference in refractive error in the two eyes of an individual. It is often associated with amblyopia, both in the presence of and in the absence of strabismus.[1,2] The prevalence (i.e., the proportion of individuals who have a condition at a point in time) of anisometropia reported in school-based and population-based studies of school-aged children is typically less than 5%, but varies depending on the manner in which anisometropia is defined, as shown in Table 1.[3-20] For the most frequently-used definition of anisometropia (≥ 1 diopter (D) difference in spherical equivalent (SE) between eyes), prevalence values range from 1.6% in a sample of young (5- to 8-year-old) Australian children[19] to 9.3% in a large sample of Taiwanese children 7 to 18 years of age.[16]

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Several population-based studies of school-aged children have examined the relation between age and prevalence of anisometropia. Three studies reported an increase in prevalence of anisometropia with age, [9,14,16] while others have shown a non-linear relation between age and anisometropia[13,21] or no relation between age and prevalence of anisometropia.[10,17,19] Gender differences in prevalence of anisometropia in school-aged children have generally not been found.[9,10,13,16,19] However, it has been reported that prevalence of anisometropia[14] and astigmatic anisometropia[15] may be higher in girls than in boys.

The majority of studies reporting prevalence of anisometropia have focused on differences in SE between eyes. It is possible that prevalence of anisometropia and risk for anisometropic amblyopia are underestimated in these studies, due to the absence of information on differences in astigmatism between eyes. We are aware of only four studies that report prevalence of astigmatic differences between eyes in children.[6,10,15,19] These studies reported prevalence of ≥ 1 D astigmatic anisometropia ranging from 1.0% in a sample of young Australian children[19] to 3.3% in a sample of 6- to 11-year-old Japanese children.[10]

As shown in Table 1, prevalence of astigmatic anisometropia among school-aged children has been examined only for Caucasian and Asian populations. It would be of interest to know whether prevalence of astigmatic anisometropia is higher in populations with a high prevalence of astigmatism, e.g., certain Native American populations,[22] than among Caucasian and Asian populations. Although overall prevalence data are not available, Garber[23] reported that nearly half (146, 49%) of 296 Navajo school children and teenagers with 1.50 D or more of astigmatism in one or both eyes had at least 0.75 D of astigmatic anisometropia. Bezan,[24] in a study of 1,000 Native American (primarily Cherokee) optometry patients 4 to 89 years of age, reported that anisometropia >1.00 D sphere or cylinder was present in 92/697 (13.2%) of individuals with at least 0.25 D of astigmatism, but in only 6/303 (2.0%) of individuals with no astigmatism.

Finally, calculation of the prevalence of astigmatic anisometropia is complicated by the two-dimensionality of this measurement, i.e. the presence of both magnitude (dioptric power) and orientation (axis). Although methods have been established that allow calculation of astigmatic differences in terms of vector space that depends on both dioptric power and axis,[25,26] studies published to date that have reported prevalence of astigmatic anisometropia have been based on differences in cylinder power between eyes, without regard for axis. This may provide an oversimplified description of anisometropia, since amblyopia has been shown to be more prevalent among anisometropes with oblique-axis astigmatism than among those with main-axis astigmatism.[27,28] Furthermore, consideration of differences in cylinder power alone ignores the possibly-amblyogenic effects of cylinder axis differences between fellow eyes with similar cylinder powers. For example, if astigmatic anisometropia were calculated in terms of differences in cylinder power only, a child with equivalent power of astigmatism of, for example, 3.00 D in each eye, but with axis at 45° in one eye and 135° in the other eye (where blur orientation in each eye is a mirror image of that in the other eye), would not be classified as anisometropic, despite the fact that the axis difference introduces a different set of distortions between the eyes, even in the presence of equivalent blur.[29] Especially at near, meridional blur results in changes in space sense and stereopsis, and there is evidence that a large between-eye differences in cylinder axis result in a significant risk for dissatisfaction with glasses[29] and, especially in the case of an oblique axis difference forming either a V or an A pattern, a significant risk for amblyopia.[28] We provide a more detailed discussion of issues related to vector analysis of between-eye differences in the Appendix (available online at www.optivissci.com).

The purpose of the present report is to examine the prevalence of anisometropia in a population of school-aged children who are members of a Native American tribe with a high prevalence of astigmatism.[30,31] To allow comparison with previous studies, prevalence of anisometropia is provided for interocular differences in SE and for interocular differences in astigmatism, and analyses by age and gender are presented. In addition, prevalence data are provided for anisometropia analyzed in terms of vector differences (J0 and J45,[26] vector dioptric differences (VDD)[25,32]) between eyes.

METHODS

Subjects

Subjects were 1,047 children four to thirteen years of age who attended elementary schools on the Tohono O'odham Reservation, and who underwent a comprehensive eye examination as part of a prospective study of optical treatment of astigmatism-related amblyopia in two age cohorts (grades K-2 and grades 4-6).[33,34] Participation was offered to all children in both age cohorts at one school during the 2000/01 and 2001/02 academic years (116 participants), to all children in the older cohort at the four remaining schools on the reservation during the 2001/02 and 2002/03 academic years (368 participants), and to all children in the younger age cohort during the 2003/04 and 2004/05 academic years (557 participants). Overall, participation rate was approximately 85% or greater at all schools. Results are cross-sectional, as data are reported for only the first examination conducted on each child.

Procedures

During the eye examination, eye alignment was assessed using the cover-uncover test at distance and near. Refractive error was measured at least 40 minutes after instillation of one drop of proparacaine (0.5%) and two drops of cyclopentolate (1%) in each eye, using the Retinomax K+ autorefractor (Nikon, Inc., Melville, NY). The autorefractor reading was then placed in a phoropter and a single experienced retinoscopist (JMM) determined by retinoscopy whether the autorefractor reading did or did not show residual with or against motion. If residual motion occurred, the retinoscopist adjusted the phoropter to eliminate the motion and recorded the result as the final estimate of refractive error. This step was taken as a safety measure, because the measurement from the autorefractor was used for the prescription of spectacles. In children older than seven years, the retinoscopist also conducted subjective refraction, in which he adjusted sphere in the phoropter by ± 0.50 D, under cycloplegia, to determine if the child preferred a change in the autorefractor reading.

This research followed the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board of the University of Arizona and by the Tohono O'odham Nation. Parents provided written informed consent prior to testing.

Data Analysis

Anisometropia was calculated in terms of clinical notation, for difference between eyes in SE and difference between eyes in cylinder power. In addition, vector methods were used to calculate astigmatic anisometropia. Using the Thibos method (M [equivalent to SE], J0, J45),[26] we determined difference between eyes in J0 (power in the vertical/horizontal meridia) and difference between eyes in J45 (power in the oblique meridia). Using the Harris method,[25,32] we determined the VDD between eyes, which results in a single number representing the vector distance between two refractions. In calculating the VDD, we used 3 methods: (1) the scalar difference in M between eyes, irrespective of cylinder; (2) two dimensional VDD (VDD_2), in which cylinder and axis vector difference is calculated irrespective of M; and (3) three dimensional VDD (VDD_3), the traditional method, which incorporates sphere, cylinder, and axis. Additional details and comparison of methods is provided in the Appendix.

For analysis of vector differences between eyes, anisometropia cutoffs were set to correspond to values comparable to 1.00 D SE or 1.00 D cylinder, the most commonly-used cut-off criteria for anisometropia (Table 1). Thus, for J0 and for J45, anisometropia was defined as a difference between eyes of 0.50 D, because a J0 value of 0.50 D is equivalent to a cylinder value of 1.00 D at 90° and a J45 value of 0.50 D is equivalent to a cylinder value of 1.00 D at 45°.[32] For VDD, anisometropia was defined as a difference between eyes of ≥ 1.41 VDD for SE VDD and a difference of 0.707 for cylinder VDD. The value of ≥ 1.41 VDD was chosen for SE because it is equivalent to a sphere difference of ≥ 1.00 D in eyes with no astigmatism.[32] For cylinder VDD (VDD_2), a value of 0.707 (1.4142/2) was chosen, because that difference is equivalent to a cylinder difference of 1.00 D in clinical notation

RESULTS

Data were excluded from six children who were unable to be refracted in one or both eyes due to cataract or pseudophakia (3), refusal of dilating drops (2), or traumatic eye injury (1), leaving a sample of 1,041 children whose data are included in the analyses.

Although the estimate of refractive error used in the analyses was based on retinoscopic confirmation of Retinomax measurements, aided by subjective refinement when possible, the final estimate of sphere was identical to the Retinomax reading in 75% of right eyes (RE) and 73% of left eyes (LE), and differed by no more than 0.5 D from the Retinomax reading, for both RE and LE, in 97% of subjects. Only three subjects (LE only) had a change in sphere ≥ 1.00 D, with a maximum change of 1.50 D (one subject). The final estimate of cylinder and axis was identical to that provided by the Retinomax in over 99% of RE and over 99% of LE measurements. Only one subject had a change in cylinder >1.00 D (1.50 D in LE) and only one subject had a change in axis >10 degrees (14 degrees in LE).

Prevalence of Astigmatism

Astigmatism ≥ 1.00 D was present in one or both eyes in 462 children (44.4% of the population). Table 2 provides a summary of amount of astigmatism present in the RE and in the LE of the children. Axis of astigmatism was with-the-rule (plus cylinder axis ≥ 60° and ≤ 120°) in 402/402 (100%) right eyes with ≥ 1.00 D of astigmatism. In left eyes ≥ 1.00 D of astigmatism, axis was with-the-rule in 391/393 (99.5%) and against-the-rule in 2/393 (0.5%). There were no astigmatic eyes with oblique axis (>30° and <60° or >120° and <150°) astigmatism.

Although most children had with-the-rule astigmatism, as defined above, none had plus cylinder axis at exactly 90° in both eyes. The pattern of astigmatism axis for RE and LE among the 333 children with astigmatism ≥ 1.00 D in both eyes is presented in Table 3. Almost half of the children (140, 42.0%) had plus cylinder axis >90° in the RE and <90° in the LE, and an additional 20.7% had plus cylinder axis <90° in the RE and >90° in the LE. When both RE and LE axis measurements differed from 90° in the same direction, the direction was three times more likely to be <90° (21.9%) than >90° (7.2%). We do not know if this was due to a possible tendency of the testers (all righthanded) to tilt the Retinomax in this direction, or to a truly higher frequency of cylinder axis in the <90° direction. However, all axis measurements were checked by the retinoscopist's assessment, which was conducted using a phoropter.

Prevalence of Anisometropia

Overall prevalence of anisometropia for the study population is provided in the last row of Table 1, based on definitions of anisometropia used in previous studies.

Table 4 provides age-related prevalence data for anisometropia, based on an interocular difference of ≥ 1.00 D SE, which is the most frequently reported definition of anisometropia

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in previous studies (Table 1), and on a cylinder difference between eyes of ≥ 1.00 D, which is the only between-eye cylinder difference for which prevalence data have been previously reported in school-based and population-based studies of school-aged children (Table 1). Chi square analyses, with Bonferroni correction for multiple comparisons, showed no statistically significant difference across age groups in the proportion of children who had anisometropia by any of the three definitions shown in Table 4 ([1] ≥ 1.0 D SE only, [2] ≥ 1.0 D cylinder only, and [3] ≥ 1.0 D SE & ≥ 1.0 D cylinder).

There was no significant difference in the proportion of girls (52.1%) in the 188 children who had anisometropia ≥ 1.00 D SE and/or ≥ 1.00 D cylinder, versus the proportion of girls (50.3%) in the group of 853 non-anisometropic children.

Table 5 shows data on prevalence of anisometropia, based on vector differences between eyes, presented in terms of different combinations of between-eye differences in M, J0, and J45.[26]

Table 6 provides a summary of the overall prevalence of anisometropia in terms of clinical notation, and both the Thibos et al.[26] and the Harris[25] forms of vector notation. For all three types of notation, the proportion of children who had astigmatic anisometropia was greater than the proportion who had M (SE) anisometropia. However, chi square analyses, with Bonferroni correction for multiple comparisons, indicated that the overall prevalence of anisometropia was less for the standard clinical notation (18.1%) than for either the Thibos et al.[26] notation (25.3%) ($X^2(1) = 15.5$, $p<0.003$) or the Harris[25] notation (28.2%) ($X^2(1) = 29.8$, $p<0.003$). Prevalence of anisometropia based on the Thibos et al.[26] notation did not differ significantly from prevalence based on the Harris[25] notation.

The Relation between SE and Astigmatic Anisometropia

Table 7 presents prevalence of astigmatic anisometropia with respect to presence of M (SE) anisometropia. Prevalence of astigmatic anisometropia was associated with an increased prevalence of M anisometropia, irrespective of whether the astigmatic anisometropia was calculated using clinical notation ($X^2(1) = 91.0$, $p<0.001$), J0 and J45 ($X^2(1) = 82.2$, $p<0.001$), or VDD_2 ($X^2(1) = 83.8$, $p<0.001$).

Prevalence of Anisometropia among Astigmatic Children

Cylinder anisometropia ≥ 1.00 D (clinical notation, based on differences in cylinder magnitude irrespective of axis differences) was present in 156 (33.8%) of the 462 children with astigmatism ≥ 1.00 D in one or both eyes and in 146 (39.2%) of the 372 children (35.7% of the population) with ≥ 1.50 D of astigmatism in one or both eyes. Among the group of 372 children with ≥ 1.50 D of astigmatism in one or both eyes, cylinder anisometropia ≥ 0.75 D was present in 199 (53.5%).

DISCUSSION

This is the first detailed report of prevalence of anisometropia among school-aged members of a Native American tribe in which a high prevalence of astigmatism has been documented. Results show that the prevalence of anisometropia calculated in terms of difference in SE between eyes is similar to that reported previously for other populations (Table 1). However, prevalence of anisometropia calculated in terms of difference in astigmatism between eyes is over four times greater than that reported in any previous study. This is likely related to the fact that the prevalence of astigmatism (≥ 1.00 D) in the present population (44%) is considerably higher than that reported for school-aged Caucasian (26%)[35] and Asian (34%)[35] populations, the only ethnic groups for which prevalence of astigmatic anisometropia has been previously reported.[6,10,15,19] In agreement with many previous studies, no relation was found between gender and prevalence of anisometropia,[9,10,16,19] nor between age and prevalence of anisometropia,[10,17,19] across the age range from 4 to 13 years.

Although no data have been reported previously for overall prevalence of anisometropia among Native American populations, Garber[23] reported a high prevalence (49%) of 0.75 D or more of astigmatic anisometropia among 296 Navajo children with ≥ 1.50 D of astigmatism in one or both eyes. Similarly, the results of the present study showed astigmatic anisometropia ≥ 0.75 D to be present in over half (54%) of 372 Tohono O'odham children with ≥ 1.50 D of astigmatism in one or both eyes.

Another study, in which both Native American adults and children were included as subjects, reported that anisometropia due to either spherical or cylindrical differences between eyes was more prevalent among Native Americans (primarily Cherokee) with any astigmatism (≥ 0.25 D) than among Native Americans with no astigmatism.[24] However, data were not provided to indicate whether the higher prevalence among astigmats was due solely to an increase in astigmatic anisometropia or to an increase in both SE and astigmatic anisometropia. The high prevalence of astigmatic anisometropia among astigmatic children in the present study suggests that the increase in prevalence of anisometropia reported in the previous study was likely due primarily to an increase in prevalence of astigmatic anisometropia.

The present study is the first to report prevalence of anisometropia in terms of vector analysis, which takes into account both the power and the axis of the astigmatism. In addition, the present study allows comparison of anisometropia prevalence data across the three methods for specifying interocular differences in refractive error (i.e., traditional clinical notation and two forms of vector notation), through the use of equivalent criteria for defining anisometropia (clinical notation: ≥ 1.00 D SE or cylinder; Thibos et al.[26] vector notation: J0, J45 ≥ 0.5 D; Harris[25] vector notation: VDD ≥ 1.41 D, VDD_2 ≥ 0.707) (Table 6). The ability to equate magnitudes for different calculations of anisometropia, as well as the ability to take axis differences into account, may prove to be particularly useful in future examination of the relation between anisometropia and the risk of amblyopia.

As shown in Tables 1 and 6, astigmatic anisometropia, whether described in terms of cylinder power, J0/J45, or VDD, was more prevalent than was SE anisometropia in this highly astigmatic population. Somewhat surprising, in light of the fact that almost all eyes with significant astigmatism had with-the-rule astigmatism, is the finding that significant oblique-axis anisometropic astigmatism (J45) occurred more often than did horizontal/vertical anisometropic astigmatism (J0), regardless of whether the comparison was made between all cases of J45 versus J0 anisometropia (15.2% versus 12.8%, Table 6) or between cases with J45-only anisometropia versus J0-only anisometropia (10.3% versus 7.9%, Table 5). As shown in Table 3, many of the children who were classified as having with-the-rule astigmatism (defined liberally as plus cylinder axes within 30° of vertical in both eyes), nevertheless had axis measurements that differed from vertical in both eyes, and the direction in which the axes tilted away from vertical was more likely to be different between eyes than to be similar between eyes. This would contribute an oblique-axis component to the cylinder difference between eyes, which might affect the likelihood of development of anisometropic amblyopia in these children.[27,28]

Overall, the present study has both strengths and limitations. One strength is the large sample size (n=1,041), consisting of approximately 85% of children in the targeted grades (K-2 and 4-6) attending school on the Tohono O'odham reservation. Another strength is the use of a rigorous method for determination of refractive error, including cycloplegia to eliminate accommodation-related variability in measurements of sphere, initial determination of refractive error using an unbiased, objective instrument (the Retinomax autorefractor), and implementation of a protocol in which all autorefractor measurement were verified by an experienced retinoscopist (JMM) and, when possible, by subjective refraction. The Retinomax autorefractor has been shown to be both accurate[32,36-39] and reliable[32,36,40] for measurement of cycloplegic refractive error in children. However, because the Retinomax autorefractor occasionally provides measurements that deviate by more than 1.00 D from cycloplegic retinoscopy[41] or from subjective refraction,[42] all measurements were checked by retinoscopy and, in older children, by subjective refraction. This protocol resulted in a change in sphere by >0.50 D in only 3% of children and a change in cylinder or axis in <1% of children. A final strength of the present study is the use of two forms of vector notation for determination of prevalence of anisometropia, which is, to our knowledge, the first report of prevalence of anisometropia in children using this method.

Limitations of the present study lie in three areas. First, use of the handheld autorefractor in children whose head position was not stabilized may have resulted in more variability in cylinder axis measurements than would have occurred had a tabletop autorefractor been used. However, the retinoscopy check of the autorefractor measurements, which was conducted using a phoropter, resulted in a change of >10 degrees in the final measurement of axis in only one eye of one child. The final two limitations relate to data not reported in this study. First, no data relating axial length to refractive errors were obtained, due to the lack of availability of portable equipment for measurement of axial length. Second, data relating presence of anisometropia to presence of amblyopia are not reported. As part of the prospective study in which all children were enrolled, best-corrected acuity data were obtained from all subjects at a separate study visit; and a manuscript reporting results of these measurements in anisometropic and nonanisometropic children is in preparation.

CONCLUSIONS

In summary, the main findings of the study were: (1) prevalence of SE anisometropia in Tohono O'odham children is similar to that reported for other school-aged populations; (2) prevalence of astigmatic anisometropia is higher among Tohono O'odham children than that reported for other school-aged populations; (3) presence of SE anisometropia was associated with presence of astigmatic anisometropia in this population; and (4) many children had astigmatic anisometropia in the absence of SE anisometropia. The high prevalence of astigmatic anisometropia suggests that this population may be at significant risk for anisometropic amblyopia. It will be of interest to compare the relation between astigmatic anisometropia and amblyopia, with astigmatic anisometropia characterized in terms of the three methods used in the present paper: (1) clinical notation (cylinder power), (2) the Thibos et al.[26] vector notation, and (3) the Harris[25] vector notation. The results of such a comparison could aid clinicians in knowing which method of calculating astigmatic anisometropia best predicts which children will develop amblyopia.

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APPENDIX: COMPARISON OF TWO METHODS FOR CALCULATION OF BETWEEN-EYE VECTOR DIFFERENCES IN CYLINDER POWER AND AXIS

Clinical notation represents cylinder power and axis as two separate numbers, and typically characterizes astigmatic anisometropia only in terms of the difference in cylinder power between eyes, ignoring the anisometropia that arises from axis differences between eyes.

Two methods have been developed that incorporate both cylinder power and axis information into between-eye comparisons of astigmatism. The first method, developed by Thibos and colleagues,[26] describes refractive error in terms of a spherical lens (the power of which is equal to the SE of the refractive error) and two Jackson-Cross cylinder lenses, one with axis at 0° and one with axis at 45°. Differences in astigmatism between eyes are characterized in terms of both the power difference at J0 and the power difference at J45.

The other method, developed by Harris,[25] represents a refractive error as a point in three-dimensional space, i.e., as a vector representation of power. Difference in astigmatism between eyes is represented as a vector between the two points in space that represent the refractive errors of the two eyes, with magnitude of blur represented by the length of the vector (termed Vector Dioptric Difference, or VDD). A comparison of the calculations used for both methods is presented in our previous publication.[32]

Table 8 provides a comparison of Thibos et al notation[26] versus Harris notation[25] for between-eye differences in astigmatism. In examples 1-4, astigmatism difference is represented by a single number in both the Thibos et al notation (J0 in examples 1 and 3, J45 in examples 2 and 4) and the Harris notation (VDD). However, in examples 5 and 6, in which cylinder axes are not at 90°/180° or 45°/135°, two numbers – J0 and J45 – are required in the Thibos et al notation to characterize between-eye differences in astigmatism. The two numbers provide characterization of the portion of the between-eye astigmatism difference that is on the vertical/horizontal axis (J0) versus the oblique axis (J45), but having two numbers makes it difficult to know how to calculate prevalence of astigmatic anisometropia. In the Harris method, between-eye differences in astigmatism are represented by a single number, VDD, which is identical when the power difference (e.g., 2.00 D) and the axis difference (e.g., 90°) are identical, regardless of the orientation of the axes (examples 3, 4, and 5 in Table 8).

In the present study, we were interested in comparing SE anisometropia and astigmatic anisometropia. In order to do this, we incorporated two modifications to the Harris method. In one, VDD was determined for SE differences only. In this calculation, termed MSD (scalar difference for M), cylinder differences are ignored. In a second modification, VDD was determined for cylinder and axis differences only. In this calculation, termed VDD_2 (two-dimensional VDD), any difference in M is ignored. In addition, we included the original VDD, which we refer to in the text and tables as VDD_3 (three-dimensional VDD), and which includes M, J0, and J45 in its calculations. Formulas used for these calculations are as follows:

$$MSD = 1.4142 * \mathrm{sqrt}[(REM - LEM)^2]$$

$$VDD_2 = 1.4142 * \mathrm{sqrt}[(REJ0 - LEJ0)^2 + (REJ45 - LEJ45)^2]$$

$$VDD_3 = 1.4142 * \mathrm{sqrt}[(REM - LEM)^2 + (REJ0 - LEJ0)^2 + (REJ45 - LEJ45)^2]$$

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Table 1

Prevalence of anisometropia in school-aged children, as reported in school-based and population-based studies. Prevalence values provided are based on the study-defined definitions of anisometropia.

Study	Age (Yrs)	Sample Size	Ethnicity/ Nationality	Difference in Refractive Error Between Eyes							
				≥ 0.5 D SE	≥ 1.0 D SE	> 1.0 D SE	≥ 1.5 D SE	≥ 2.0 D SE	> 2.0 D SE	≥ 1.0 D cyl	Combined*
Woodruff & Samek[3](1977)	1-90+	3,722	Ontario Indians		7.2%						
Laatikanen & Erkkilä[4](1980)	7-15	411	Finnish			3.6%					
Aine[5](1984)	6-85	602	Finnish			7.1%			3.1%		
Woodruff[6](1986)	6	10,464	New Brunswick		2.7%					1.5%	3.6%[a]
Almeder et al[7](1990)	3-8	374	Head Start & 1st grade (New York)								1.6%[a]
Preslan & Novak[8](1996)	4-7	680	Baltimore, MD			2.6%					
Lin et al[9](1999)	7-18	11,178	Taiwanese						2.6%		
Yamashita et al[10](1999)	6-11	350	Japanese		2.1%			1.7%		3.3%	
Zhang et al[11](2000)	6-7	382	Chinese (Singapore/China)			3.1%					
Hashemi et al[12](2004)	5-14	~1,000	Iranian		2.8%						
Tong et al[13](2004)	7-9	1,979	Primarily Chinese (Singapore)	14.5%	3.8%		1.6%	1.0%			
Amorim Garcia et al[14](2005)	7-24	1,024	Brazilian								2.1%[b]
Donnelly et al[15](2005)	8-9	1,582	Northern Ireland							1.1%	2.3%[c]
Shih et al[16](2005)	7-18	10,878	Taiwanese		9.3%			3.0%			
Thorn et al[17](2005)	12-59	259	Indigenous Brazilians		8.2%						
Grönlund et al[18](2006)	4-15	143	Swedish		2.8%						
Huynh et al[19](2006)	5-8	1,724	Caucasian & East Asian (Australia)		1.6%					1.0%	
Robaei et al[20](2007)	12	2,353	Australian		4.1%						
Present study	4-13	1,041	Tohono O'odham	24.7%	6.7%	4.8%	2.6%	0.8%	0.7%	15.0%	18.1%[d]

D = diopters; SE = spherical equivalent; cyl = cylinder

* "Combined" values include both sphere and cyl inter-eye differences, or both SE and cyl inter-eye differences, in the definition of anisometropia. Specifics are as follows

[a] Difference between eyes ≥ 1.0 D sphere or cyl

[b] Difference between eyes ≥ 2.0 D sphere or cyl

[c] Difference between eyes ≥ 1.5 D sphere of hyperopia or myopia, or ≥ 1.0 D cyl

[d] Difference between eyes ≥ 1.0 D SE or ≥ 1.0 D cyl

Table 2

Distribution of amount of astigmatism present in the right eyes and in the left eyes of the 1,041 children in the study.

Eye	Amount of Astigmatism						Total
	0 to < 1D	1 to <2 D	2 to <3 D	3 to <4 D	4 to <5 D	≥ 5 D	
Right	639 (61%)	163 (16%)	83 (8%)	74 (7%)	54 (5%)	28 (3%)	1,041 (100%)
Left	648 (62%)	135 (13%)	100 (10%)	81 (8%)	49 (5%)	28 (3%)	1,041 (100%)

Table 3

Pattern of differences in plus cylinder astigmatism axis between eyes for 333 children with astigmatism ≥ 1.00 D in both eyes.

Pattern of Plus Cylinder Axis Differences Between Eyes	Prevalence (N = 333)		Axis Difference (Degrees) Mean	SD
RE > 90°, LE < 90°	140	(42.0%)	15.4	9.0
RE < 90°, LE > 90°	69	(20.7%)	12.9	7.2
RE and LE < 90°	73	(21.9%)	4.6	3.6
RE and LE > 90°	24	(7.2%)	4.4	3.6
RE @ 90°, LE < 90° or > 90° RE < 90° or > 90°, LE @ 90°	27	(8.1%)	6.0	5.0
Overall	333	(100%)	11.0	8.6

Table 4

Prevalence and type of anisometropia at different ages in children tested cross-sectionally.

Anisometropia Type (IOD definition)	Age (Years) 4 - <6 (N = 215)	6 - <8 (N = 298)	8 - <10 (N = 180)	10 - <12 (N = 264)	12 - <14 (N = 84)	Total (N = 1,041)
≥ 1.0 D SE only	7 (3.3%)	8 (2.7%)	8 (4.4%)	8 (3.0%)	1 (1.2%)	32 (3.1%)
≥ 1.0 D cyl only	18 (8.4%)	43 (14.4%)	25 (13.9%)	18 (6.8%)	14 (16.7%)	118 (11.3%)
≥ 1.0 D SE & ≥ 1.0 D cyl	5 (2.3%)	7 (2.3%)	5 (2.8%)	17 (6.4%)	4 (4.8%)	38 (3.7%)
None (<1.00 D SE & <1.00 D cyl)	185 (86.0%)	240 (80.5%)	142 (78.9%)	221 (83.7%)	65 (77.4%)	853 (81.9%)

IOD = interocular difference; SE = spherical equivalent; cyl = cylinder

Table 5

Prevalence and type of anisometropia, in terms of vector notation,[26] showing the prevalence of anisometropia for M, J0, J45, and for combinations of M, J0, and J45. Each child is represented only once in the Table.

	ΔM <1.0 D (N = 971)		**ΔM ≥ 1.0 D (N = 70)**	
	ΔJ0 <0.5 D N (%)	**ΔJ0 ≥ 0.5 D N (%)**	**ΔJ0 <0.5 D N (%)**	**ΔJ0 ≥ 0.5 D N (%)**
ΔJ45 <0.5 D	778 (80.2*, 74.7‡)	62 (6.4*, 6.0‡)	23 (32.9†, 2.2‡)	20 (28.6†, 1.9‡)
ΔJ45 ≥ 0.5 D	95 (9.8*, 9.1‡)	36 (3.7*, 3.5‡)	12 (17.1†, 1.2‡)	15 (21.4†, 1.4‡)

Δ = difference between eyes; M = spherical equivalent; J0 = power at axis 0°/180°; J45 = power at axis 45°/135°

*denominator = children with M < 1.0 D (N = 971)

†denominator = children with M = 1.0 D (N = 70)

‡denominator = total sample (N = 1,041)

Table 6

Prevalence and type of anisometropia, in terms of standard clinical and vector[25,26,32] notation.

Anisometropia Type (IOD definition)	Prevalence of Anisometropia (N = 1,041)
≥ 1.00 D SE*	70 (6.7%)
≥ 1.00 D cylinder*	156 (15.0%)
None (< 1.00 D SE & cylinder)	853 (81.9%)
≥ 1.0 D M**	70 (6.7%)
≥ 0.5 D J0**	133 (12.8%)
≥ 0.5 D J45**	158 (15.2%)
None (< 0.50 D J0 & J45 & M < 1.00 D)	778 (74.7%)
≥ 1.41 MSD (difference for M, irrespective of cylinder) †	70 (6.7%)
≥ 0.70 VDD_2 (VDD for cylinder & axis, irrespective of M) †	274 (26.3%)
≥ 1.41 VDD_3 (traditional calculation using M, cylinder, & axis) †	169 (16.2%)
None (< 1.41 MSD, <0.70 VDD_2, & < 1.41 VDD_3)	747 (71.8%)

IOD = interocular difference; SE = spherical equivalent; M = spherical equivalent; J0 = power at axis 0°/180°; J45 = power at axis 45°/135°; MSD = scalar difference for M; VDD = vector dioptric difference

* Categories for SE and cylinder anisometropia are not mutually exclusive

** Nor are categories for J0, J45, and M anisometropia

† Nor are categories for MSD, VDD_2, and VDD_3 anisometropia.

Table 7

Prevalence of spherical equivalent anisometropia and astigmatic anisometropia, with astigmatic anisometropia calculated in (a) clinical notation (cylinder power), (b) J0 and J45 vector notation,[26] and (c) vector dioptric difference (VDD).[25,32]

		ΔM <1.0 D (N = 971)	ΔM ≥ 1.0 D (N = 70)	Overall Sample (N = 1,041)
Clinical Notation (Cylinder Power)	Δ cylinder < 1.00 D	853 (87.8%)	32 (45.7%)	885 (85.0%)
	Δ cylinder ≥ 1.00 D	118 (12.2%)	38 (54.3%)	156 (15.0%)
Vector Notation (J0 and J45)	ΔJ0 and ΔJ45 <0.5 D	778 (80.1%)	23 (32.9%)	801 (76.9%)
	ΔJ0 or ΔJ45 ≥ 0.5 D	193 (19.9%)	47 (67.1%)	240 (23.1%)
Vector Notation (VDD_2)	VDD_2 <0.70 D	748 (77.0%)	19 (27.1%)	767 (73.7%)
	VDD_2 ≥ 0.70 D	223 (23.0%)	51 (72.9%)	274 (26.3%)

Δ = difference between eyes; M = spherical equivalent; J0 = power at axis 0°/180°; J45 = power at axis 45°/135°; VDD2 = VDD for cylinder and axis

Table 8

Between-eye differences in astigmatism, calculated in terms of J0 and J45[26]versus vector dioptric difference (VDD_3).[25,32] All examplesassume equal sphere power in fellow eyes, with axis in plus cylinder notation.

Example	RE Cyl (D)	RE Axis (°)	LE Cyl (D)	LE Axis (°)	J0 RE-LE (D)	J45 RE-LE (D)	VDD_3 RE-LE
1*	2.00	90	4.00	90	1.00	0.00	2.00
2*	2.00	45	4.00	45	0.00	1.00	2.00
3†	2.00	90	4.00	180	3.00	0.00	4.47
4†	2.00	45	4.00	135	0.00	3.00	4.47
5†	2.00	67	4.00	157	2.10	2.13	4.47
6	2.00	95	4.00	85	0.99	0.52	2.12

RE = right eye; LE = left eye; cyl = cylinder

* Axis same in both eyes

† 90° between-eye difference in axis