The Pattern of Astigmatism in a Canadian Preschool Population

Laura Cowen and William R. Bobier

PURPOSE. To measure magnitude, type, and central tendency of astigmatism found in a county-wide population of Canadian preschool children (mean age, 48.1 months).

METHODS. Noncycloplegic autorefractive measures were taken in 1179 children attending a preschool health fair operated by their county board of health. Spherocylinder measures were transformed into three independent components.

RESULTS. The equivalent sphere showed considerable variation between retinoscopy and autorefraction that was attributed to the variable overaccommodation induced by the autorefractor. Astigmatic components were not affected. Small discrepancies between the two techniques were similar to those in adults and were not of sufficient magnitude to affect validity. With-the-rule (WTR) astigmatism of at least 0.25 D was the most frequent form (45%) followed by against-the-rule (ATR: 40%) and oblique (15%). The 95th percentile for cylinder magnitude was found at 1.25 D. Astigmatisms beyond this value were predominately WTR. The mean (negative) cylinder magnitude was 0.08 D x 0.15°.

CONCLUSIONS. When spherocylinder values are transformed into a mathematical continuum rather than WTR and ATR classifications, the true central tendency of the population is better defined and is close to zero. Astigmatisms of more than 1.25 D in the preschool child exceed the 95th percentile in this population and were more frequently WTR. (Invest Ophthalmol Vis Sci. 2003;44:4593–4600) DOI:10.1167/iovs.02-0730

Population information on astigmatism in preschool children is limited. It is well accepted that astigmatism declines from its original levels in infancy. This has been confirmed in a number of differing demographic locations in the United Kingdom, the United States, and Sweden. Defining the dominant form of astigmatism in populations is better defined and is close to zero. Astigmatisms of more than 1.25 D in the preschool child exceed the 95th percentile in this population and were more frequently WTR. (Invest Ophthalmol Vis Sci. 2003;44:4593–4600) DOI:10.1167/iovs.02-0730

Measurement of refractive errors in preschool children is bedeviled by the fact that children at this age typically have 1 to 2 D of hyperopia and readily overcome their hyperopia through accommodation, unless a cycloplegic is instilled. We have shown that the varying capacity of autorefractors to manifest refractive errors in young children appears dependent on the design of the instrument and both the viewing distance and spatial composition of the targets selected. Even conducting retinoscopy through “fogging lenses” does not fully manifest refractive error. Unfortunately, large-scale screenings do not offer the opportunity for testing with cycloplegia.

In this study, we used the Retinomax K-Plus (Nikon, Inc., Tokyo, Japan) autorefractor to provide noncycloplegic measures of refractive error. The Retinomax has been well studied in populations of adults and children. The measures in adults show good agreement where small biases on the order of 0.25 D are found between the Retinomax and conventional retinoscopy for both the equivalent sphere and cylinder values. The small Retinomax bias is toward hyperopia. Measurements in preschool children and younger have been performed with and without cycloplegia. It appears that the close working distance of the Retinomax (5 cm) induces considerable but variable “instrument myopia” in these children, in whom, without cycloplegia, the equivalent sphere measures are consistently inaccurate and hyperopia is underestimated. However, cylinder measures are not affected by this overaccommodation. Any differences in cylinder components were not thought to be clinically important. In a screening situation the Retinomax has had a 99.5% success rate in detecting refractive astigmatism and there is little bias.

When cycloplegia is used with preschool children, accuracy in equivalent sphere is restored to adult levels. Both cylinder and axis measures show good agreement with those of retinoscopy.

Although it can be concluded that preschool children exhibit less astigmatism than they exhibited at birth, the exact...
central tendency of the preschool population's astigmatism has been difficult to define. The standard spherocylinder format (sphere/cylinder/axis) does not allow the central tendency of a population to be defined. Only the magnitude of astigmatism (cylinder) can be averaged, while the orientation (axis, varying over 180°) must be ignored. Values of orthogonally oriented astigmatisms (e.g., with [WTR] and against [ATR] the rule) do not cancel but rather add, thus rendering an absolute cylinder value. If a true measure of central tendency is to be defined, then a mathematical continuum must be defined for astigmatisms of all orientations. Recent mathematical treatments have transposed the spherocylinder values into more mathematically workable formats. In particular, a format has been designed that decomposes different forms of astigmatism (ATR, WTR, and oblique) into continuums in which astigmatisms at orthogonal orientations are given opposite signs. In this way, a central tendency of the astigmatism of the population can be defined. This can serve as a metric of the extent to which astigmatic errors have emmetropized. Furthermore, this format allows cylinder components to be isolated from the equivalent sphere, thus allowing variations in accommodation to be independent from astigmatic measures.

**METHODS**

**Preschool Population**

An annual preschool health fair screening of vision, audition, and speech in kindergarten registrants takes place in Oxford County (Ontario, Canada) over a 4-month period. Public health nurses of the Oxford County Health Unit perform the screenings. Research is limited to the vision-screening component. A child's inclusion in the research component of the screening requires parental consent. The research was approved by the Human Research Ethics Committee of the University of Waterloo and adhered to the tenets of the Declaration of Helsinki.

In the spring of 1999, 1179 children participated in the screening. Their mean age was 48.1 months, (range, 38–86 months). Boys constituted 52% of the population. Calculations by the Board of Health indicated that this population represented close to 87% of the eligible school entrants that year. To ensure that nonattendees were not overly represented by individuals lacking the means to attend the health fair, the public health board supplied free transportation to the health fair to those in need. Figure 1 provides a flow chart representation of the screening.

**Oxford County**

Oxford County comprises 2032 km² located in southwestern Ontario, Canada. The demographics of the area, provided by the Statistics Canada 1996 census, show that 88% of the population are primarily English speaking and only 2% fall into the category of “visible minority.”

**Screening Tests**

The vision-screening program tested visual and stereo acuities. Specifically, visual acuity was tested with a single letter-matching test (Cambridge Crowding Cards; Clement Clarke, London, UK), and stereoacuity was tested with the Stereo Fly (Titmus Optical Co, Petersburg, VA). Children who scored poorer than 6/6 visual acuity and/or poorer than 100 seconds of arc of stereoacuity were referred to an eye care practitioner, normally within Oxford County. Failure of either or both of the screening components or failure to complete any component of the screening resulted in referrals of 369 of the 1179 children screened to eye care practitioners. The practitioners reported examination findings back to the Oxford County Board of Health. A printed form was used that specifically required retinoscopic measures.

**Autorefractive Measures**

During the vision testing, noncycloplegic refractive error measures were taken in 1162 preschool children with the Retinomax K-Plus autorefractor (Nikon). This instrument has been described in detail elsewhere. Briefly, the child was seated and the instrument was aligned for the child's right eye. The child was asked to fixate on the

![Flow chart of the Oxford County vision screening program.](https://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933434/ on 08/21/2018)
instrument’s Christmas tree target, set along the optical axis of the instrument. During fixation, the instrument averaged eight readings for each eye and supplied a confidence value based on the consistency of the repeated readings. Both the right and left eyes were measured; however, only the right eye was used for analysis purposes. Measurements were repeated until the confidence readings reached the manufacturer’s recommendations of at least 8 of a possible 10. In 5% of the measurements, a reading of 7 had to be accepted. In all cases, the fogging option was used in lieu of the ‘quick mode’ in an attempt to relax the child’s accommodation as much as possible.

Validation of Measures
To ensure that the measures of astigmatism were valid using the Retinomax without cycloplegia we conducted two investigations. The first compared the Retinomax readings with clinical measures of refraction taken in a subset of children whose practitioner reports were available to us. Second, we conducted a study on an adult sample, because Retinomax-induced overaccommodation has not been found to be significant in adults.

Clinical Measures of Preschoolers
A total of 155 of the practitioner reports were returned for this analysis. Of these, 154 had complete Retinomax measures. Refractive error measures were taken using the Retinomax and retinoscopy. All clinical findings were reported to the Oxford County Health Unit. These refractive error measurements provided the means to validate the Retinomax autorefractor measures.

Adult Study
Adult subjects (n = 144; mean age, 42 years; range, 19–79) were recruited from the patient population attending the Eye Care Clinic of the School of Optometry, University of Waterloo. Refractive error measures were taken using the Retinomax and retinoscopy. All refractive measures were reviewed from the clinical file and found to be within 0.50 D of the subjective along either refractive meridian. Further, measures were assessed for the presence of any confounding problems, such as media opacities. Again, ethics committee approval and informed consent were obtained before subject participation.

Refractive Error Analysis
Refractive error measurements were decomposed into three independent components using the following Fourier transformation:

\[ M = S + C \cos(2\alpha) \]  
\[ J_0 = -\frac{C}{2} \sin(2\alpha) \]  
\[ J_{45} = -\frac{C}{2} \sin(2\alpha)\]  

where S is the sphere, C is the negative cylinder, and \( \alpha \) is the axis in radians.

This transformation produces three well-understood optical components: M, the equivalent sphere (equation 1) and two Jackson cross cylinders (equations 2 and 3). \( J_0 \) represents cylinder powers set orthogonally approximately 90° and 180° meridians, representing WTR and ATR astigmatism, respectively. \( J_{45} \) represents a cross cylinder set at 45° and 135°, which represents oblique astigmatism.

Accommodation acts isotropically, where astigmatic changes with increased accommodation are small; specifically, they are rarely more than 0.1 to 0.2 D. Astigmatism was defined to be nonzero cylinder measurements starting at 0.25 D.

### Table 1. Mean Measurements for Retinoscopy and the Retinomax

<table>
<thead>
<tr>
<th>Eye</th>
<th>Retinoscopy</th>
<th>Retinomax</th>
<th>Difference</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>0.97 ± 1.40</td>
<td>0.08 ± 1.28</td>
<td>0.88 ± 1.50</td>
<td>0.0001</td>
</tr>
<tr>
<td>( J_0 )</td>
<td>0.12 ± 0.32</td>
<td>0.13 ± 0.41</td>
<td>-0.007 ± 0.28</td>
<td>0.77</td>
</tr>
<tr>
<td>( J_{45} )</td>
<td>0.003 ± 0.11</td>
<td>0.04 ± 0.17</td>
<td>-0.004 ± 0.16</td>
<td>0.003</td>
</tr>
<tr>
<td>Left</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>1.02 ± 1.45</td>
<td>0.18 ± 1.35</td>
<td>0.85 ± 1.46</td>
<td>0.0001</td>
</tr>
<tr>
<td>( J_0 )</td>
<td>0.14 ± 0.35</td>
<td>0.18 ± 0.37</td>
<td>0.003 ± 0.26</td>
<td>0.90</td>
</tr>
<tr>
<td>( J_{45} )</td>
<td>-0.02 ± 0.11</td>
<td>0.05 ± 0.16</td>
<td>-0.006 ± 0.15</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Data are mean diopters ± SD. Significance determined by paired \( t \)-test.

Results
Measurement Validation

Preschool Measures. The refractive measures of the Retinomax taken at the screening were compared to the retinoscopic measures reported by the eye-care practitioners. Refractive measures were transposed into the three components described earlier. For each subject, the Retinomax finding was subtracted from the clinical refractive measure (Table 1). Paired \( t \)-tests were performed independently on all components for the preschool sample (Table 1). The equivalent sphere of the Retinomax was found to be more myopic on average by 0.88 D. However, the difference was highly variable among subjects. The cylinder components showed smaller biases and less variation. Although the \( J_{45} \) component was significantly different, the bias was small (0.04) and 99% of those differences were less than 0.5 D. Multivariate differences between retinoscopy and Retinomax were significantly different (Hotelling’s \( T^2 \), \( F = 15.50, \ P < 0.0001 \)); however, when equivalent sphere was removed there were no significant differences (\( F = 2.88, \ P = 0.058 \)). Correlation between the Retinomax and the retinoscopy was weak in the equivalent sphere (\( r = 0.38 \), but stronger in \( J_0 \) (\( r = 0.72 \)) and \( J_{45} \) (\( r = 0.47 \)). However, all correlations were significantly different from 0 with \( P < 0.0001 \).

Analysis was restricted to the right eye to ensure independent measures. Inclusion of the left eye measurements without correcting for the correlation between eyes would lead to dependency among observations, invalidating statistical tests. Table 1 shows a similar pattern of results between right and left eyes.

As noted in the Methods section, 55 preschoolers underwent cycloplegia and 113 did not. Thus, the effects of cycloplegia on the components had to be determined. There were five preschoolers whose cycloplegic status was unknown and one who did not have a Retinomax measurement. Cycloplegia, which fully relaxes the child’s accommodation, provides the most accurate measure of equivalent sphere. We find an even greater discrepancy between the retinoscopy and the Retinomax (Table 2); however, this discrepancy did not vary with the magnitude of equivalent sphere. Thus, the overaccommodation induced by the Retinomax is probably underestimated by the noncycloplegic findings. Because retinoscopy in young children may also introduce overaccommodation, the variation in equivalent sphere cannot be attributed solely to the Retinomax.

The Hotelling multivariate \( T^2 \) test shows that cycloplegic refractions are significantly more hyperopic than noncycloplegic refractions (\( F = 8.58, \ P < 0.001 \)). However, when we only look at the astigmatic components, there is no significant
difference between groups (\( F = 0.89, P = 0.4123 \)). The difference in equivalent sphere is evident in Figure 2A. This disparity is not seen in the \( J_0 \) and \( J_{45} \) measures of astigmatism (Fig. 2B, 2C).

**Adult Measures.** A similar analysis was performed on the adult sample, shown in Table 3. An inspection of these results reveals that the differences in equivalent sphere are smaller and less variable than those found in the preschool sample. The equivalent sphere of the Retinomax in this case was found to be slightly more hyperopic on average (\(-0.37\) D), but with considerably less variation (0.75 D). In addition, small but significant differences were found in cylinder measures for \( J_0 \) and \( J_{45} \). Multivariate differences between retinoscopy and Retinomax for all components (\( M, J_0 \) and \( J_{45} \)) are significant (Hoelter \( T^2 \); \( F = 4.03, P = 0.0079 \)). When the equivalent sphere was removed, significant differences were retained. This indicates that in the adult sample, differences between retinoscopy and Retinomax measurements are not due to differences in equivalent sphere alone. However, these differences are small and not optically significant. Although the equivalent sphere is still significantly different, the Retinomax measure in the adults has strong correlation with the retinoscopy (\( r = 0.97, P < 0.0001 \)). The small differences in the astigmatism components between retinoscopy and Retinomax in the adult sample have results similar to those in the preschool sample. Correlation for \( J_0 \) and \( J_{45} \) was 0.59 (\( P < 0.0001 \)) and 0.45 (\( P < 0.0001 \)) respectively.

Transposition from the Fourier form back to the spherocylinder form for the mean differences found in Table 1 gives an overcorrection of 0.92 \(-0.08 \times 130^\circ\). A similar transformation for the adult study gives an overcorrection of \(-0.26 \times 21 \times 167^\circ\). An ANOVA split-plot design in which the whole-plot factor is measurement (Retinomax or retinoscopy) and the subplot factor is population (adult or preschool), showed that population had a significant effect; however, only when the equivalent sphere was considered (\( F = 111.42, P = 0.0001 \)). Because population does not have a significant effect on \( J_0 \) and \( J_{45} \), this implies that small differences in the cylinder components come from the same source in the two populations. It may be that the Retinomax provides a more accurate measure of small cylinders and axes than the reported clinical measures.

**Post Hoc Cylinder Analysis**

After completing our analysis and finding that many of the retinoscopy cylinders were zero, while the Retinomax showed small astigmatisms close to zero, we performed a post hoc analysis on this phenomenon. Small cylinder values (< 0.5 D) were removed from the preschool sample resulting in a sample size of 77. Correlations for \( M, J_0 \) and \( J_{45} \) were found to be 0.41 (\( P = 0.0002 \)), 0.72 (\( P < 0.0001 \)), and 0.52 (\( P < 0.0001 \)) respectively. Correlations for those preschoolers with small cylinders (< 0.5D) were low 0.19 (\( P = 0.09 \)), 0.28 (\( P = 0.01 \)), and 0.05 (\( P = 0.63 \)), respectively.

A similar analysis was performed on the adult sample where the reduced sample size was 74. Correlations were found to be 0.97, 0.62, and 0.50 for \( M, J_0 \) and \( J_{45} \), all of which had \( P < 0.0001 \). To find out whether the practice of setting small cylinder values to zero accounts for the differences in astigmatic components, paired t-tests on this adult sample were performed. We find that the mean differences in \( M, J_0 \) and \( J_{45} \) are \(-0.31 (P = 0.005), 0.11 (P = 0.08), \) and \(-0.09 (P = 0.02) \), respectively. Thus small differences in each component remain.

**Astigmatism in the Preschool Population**

The negative cylinder axes produced by the Retinomax were broken down into WTR (0-30° and 151-180°), ATR (61-120°) and oblique (31-60° and 121-150°) forms, in accordance with Borish.\(^{32}\) There were 278 (23.9%) preschoolers who had a cylinder of 0. Figure 3A–C shows the distribution of the three types of astigmatism. Of the children with astigmatism, WTR was most dominant in this preschool population (45%), followed by ATR (40%), and then oblique (15%). Within each astigmatism type, most children had very small cylinder errors (Fig. 3). The mean astigmatism values for WTR, ATR, and oblique are \(-0.33 \text{Dx} \; 004^\circ, -0.41 \text{Dx} \; 091^\circ, \) and \(-0.13\text{Dx} \; 041^\circ \), respectively. The range of WTR astigmatism spanned the interval \(-4, -0.25 \), whereas ATR and oblique spanned a smaller interval \((-1.75, -0.25) \).

The distribution of all astigmatic cylinder magnitudes is provided in Figure 4A. Cylinders ranged from 0.25 to 4 D, with most of the cylinders between 0.25 and 1 D. A cumulative distribution of all cylinder magnitudes (Fig. 4B) allowed the 95th percentile of cylinder magnitude to be calculated. Cylinders were ordered from 1 to \( n \) by magnitude and assigned \( l/n \times 100\% \) to each magnitude, where \( n \) is the total number of magnitudes and \( l \) is the order of the magnitude. For example, in the preschool data, the first magnitude would be assigned \( l/1 \times 100\% \), the second \( l/2 \times 100\% \) and so forth, until the 95th percentile is reached. The cylinder magnitude that corresponded to the 95th percentile was found to be 1.25 D. The 95th cylinder-magnitude percentiles for WTR, ATR, and oblique astigmatism distributions were 2.25 D, 1 D, and 0.75 D respectively. WTR astigmatism was the most frequent form found above 1.25 D.

The difference in cylinders between the right and left eyes was examined. In cases of right-eye astigmatism larger than 1.25 D, 18 of 43 showed a right–left eye difference of at least 1 D. Thus in 42% of high astigmatism cases, anisometropia was present. In 15 of the 18 anisometropia cases, the astigmatism was lower in the left eye. The 95th percentile for the absolute cylinder differences between the eyes of all 1159 subjects is 0.75 D.

### Table 2. Mean Measurements for Retinoscopy and Retinomax and Differences between the Measures of M, J0, and J45 in the Preschool Children Who Underwent Cycloplegia and Those Who Did Not

<table>
<thead>
<tr>
<th></th>
<th>Retinoscopy</th>
<th>Retinomax</th>
<th>Difference</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cycloplegic</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>2.17 ± 2.13</td>
<td>1.00 ± 1.74</td>
<td>2.06 ± 2.02</td>
<td>0.0001</td>
</tr>
<tr>
<td>( J_0 )</td>
<td>0.27 ± 0.37</td>
<td>0.25 ± 0.52</td>
<td>0.02 ± 0.34</td>
<td>0.70</td>
</tr>
<tr>
<td>( J_{45} )</td>
<td>0.0007 ± 0.18</td>
<td>0.06 ± 0.23</td>
<td>-0.06 ± 0.22</td>
<td>0.14</td>
</tr>
<tr>
<td><strong>Noncycloplegic</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>0.59 ± 0.81</td>
<td>0.05 ± 1.13</td>
<td>0.54 ± 1.09</td>
<td>0.0001</td>
</tr>
<tr>
<td>( J_0 )</td>
<td>0.07 ± 0.28</td>
<td>0.09 ± 0.36</td>
<td>-0.02 ± 0.27</td>
<td>0.44</td>
</tr>
<tr>
<td>( J_{45} )</td>
<td>0.0002 ± 0.06</td>
<td>0.03 ± 0.16</td>
<td>-0.03 ± 0.14</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Data are as described in Table 1. Cycloplegia, \( n = 35 \); noncycloplegia, \( n = 113 \).
Age Stratification

The Retinomax data set were stratified into two groups. Those children less than 48 months were deemed 3-year-olds (n = 475) and those 48 months or older were deemed 4-year-olds (n = 409). These groups were also stratified by gender. There were no significant differences found between age-groups, or between age-gender groups in the distributions of astigmatism. Specifically, the marginal distribution of astigmatism in 3-year-olds can be broken down into 47% WTR, 38% ATR, and 16% oblique. Similarly, the distribution was 42% WTR, 43% ATR, and 15% oblique in 4-year-olds.

Central Tendency

Overall mean magnitude of the cylinder components were −0.08 Dx 015° and −0.08 D 028° for the right and left eyes respectively. These measures take into account astigmatism direction, as they come from the back transformation of the mean Fourier components and are in the direction of WTR astigmatism. This value is smaller than the average cylinder value of 0.38 D, which was determined by considering only the absolute astigmatism without reference to the position of the axis.

Figure 5 plots J 45 against J0. From observation of this scatterplot a symmetrical clustering is found to orbit approximately 0 astigmatism. Part of the distinct pattern is because the Retinomax provided measurements in 0.25-D intervals, which rendered continuous data into discrete data. As the astigmatism values became larger, there was a loss of symmetry where astigmatism became clearly positive along J0 and, to a lesser degree, along J45. This would lead to astigmatism of a WTR format, with an axis between 0° and 45°, which is consistent with the overall mean axis of 15°.

ATR and WTR astigmatism split the J0 axis into positive and negative values. The range of J0 included (−0.83,−0.06) and (0, 1.78) for ATR and WTR, respectively. The J45 axis was split into positive and negative values by the axis of oblique astigmatism: those at 45° (Fig. 5, OBx 45) and those at 135° (Fig. 5, OBx 135). J45 ranged from −0.49 to 0.88.

DISCUSSION

Verification of the Retinomax

Retinomax comparisons with retinoscopy were comparable to previous studies for both adult and child populations.19–21 Close agreement was again found with astigmatic (cylinder) components in both populations, but only in the adult case was there agreement between spherical equivalents (a small but significant difference was found in the spherical equivalents where the Retinomax read more hyperopically). The poor agreement of the spherical equivalent in the preschool children would be expected to be remedied by the use of a cycloplegia.19–21 However, this is neither feasible and is probably impossible in a population study of mostly visually normal children.

It is important to recognize that simply correcting the bias of 0.88 D of overaccommodation (Table 1) will not provide a

| Table 3. Mean Retinoscopy and Retinomax Measures and Differences in Measures of M, J0, and J45 for 144 Adults |
|---|---|---|---|
| Retinoscopy | Retinomax | Difference | P |
| M | −1.43 ± 3.01 | −1.06 ± 2.97 | −0.37 ± 0.73 | 0.0001 |
| J0 | 0.13 ± 0.48 | 0.05 ± 0.37 | 0.09 ± 0.40 | 0.004 |
| J45 | −0.01 ± 0.19 | 0.04 ± 0.25 | −0.05 ± 0.24 | 0.02 |

Data are as described in Table 1.
suitable calibration of the Retinomax due to the high SD. Furthermore, calibrations based on regression analysis were thwarted by the considerable intersubject variation. It appears that when children overaccommodate in response to the Retinomax, the response is variable and cannot be easily calibrated.

Clinical retinoscopies are often taken to be the gold standard for refractive error measurements. Despite this, it appeared that many of the retinoscopy cylinder and/or axis measurements when close to zero were rounded off to zero by the practitioners. This practice of rounding off increases the measurement differences between retinoscopy and the Retinomax. The post hoc analysis showed that when small cylinders were removed, improvements in the correlations for J45 were found despite a halving of the sample size. This change in correlation values associated with very small percentages (e.g., cylinder −4 D; 0.25%) which do not show up as histograms in Figure 3 because the percentages are small.

**Figure 3.** Right-eye cylinder magnitude distribution of (A) WTR (n = 395, 45%), (B) ATR (n = 354, 40%), and (C) oblique (n = 137, 15%) astigmatism in the preschool population. There were 278 preschoolers without astigmatism. It is noted that there were some large cylinder values associated with very small percentages (e.g., cylinder −4 D; 0.25%) which do not show up as histograms in Figure 3 because the percentages are small.

**Figure 4.** (A) Distribution of cylinder magnitudes in the preschool population. (B) Cumulative density of the cylinder magnitudes for the preschool population. Ninety-five percent of the cylinder values lie between 0 and 1.25 D.
supports the idea that practitioners may not be measuring small astigmatisms as closely as the Retinomax.

This pattern was also found in adult studies. The retinoscopy set cylinder values to 0 twice as often as the Retinomax did. However, the removal of small cylinders did not remove the small differences found between retinoscopy and the Retinomax. The small hyperopic bias in the equivalent sphere has been found in other adult studies, and this small bias (0.29 D) was confirmed by the manufacturer (Nikon). However, other studies in which children underwent cycloplegia showed very little bias between retinoscopy and the Retinomax. It is possible that the calibration of the Retinomax is closer to the retinoscopy results taken from the eye of a child than that of an adult.

From these findings, we conclude that the variability of noncycloplegic equivalent sphere measures of the Retinomax K-Plus preclude an accurate measure of the degree of hyperopia and myopia present. This variance in equivalent sphere measures of the Retinomax preclude an accurate measure of the degree of hyperopia and myopia present. This variance in equivalent sphere measures of the Retinomax preclude an accurate measure of the degree of hyperopia and myopia present.

**Astigmatism in the Preschool Population**

The Oxford County preschool population’s distribution of astigmatism can be broken down into 45% WTR, 40% ATR, and 15% oblique, falling into a general pattern in which WTR astigmatism is most prevalent, especially in high astigmatisms. This pattern is consistent between 3- and 4-year-olds. When the sphero-cylinder data are transposed into two independent components (Fig. 5), the mean cylinder magnitude approaches zero. It appears that most of the data points cluster symmetrically about zero (Fig. 5). This suggests that in this population the small astigmatisms are random fluctuations about zero. It appears that a second and distinct subpopulation shows significant WTR astigmatism. It is important to note that native North American preschool populations show much higher levels of astigmatism, that WTR forms represent well over 90% of the astigmatism, and that the origin appears to be corneal.

Prescribing guidelines have not been well established for preschool children. Consideration of emmetropization suggests caution before spectacle prescription is undertaken, whereas consideration of amblyopia suggests intervention. Understandably, clinicians vary in their thresholds at which astigmatism should be corrected. However, on average, pediatric eye care practitioners start to correct astigmatism in 4- to 5-year-olds, once it has reached levels of 1.50 D — close to the 95th percentile of 1.25 D calculated from this study. Prescribing for astigmatism in clinical practice has defined critical levels that represent values falling just outside the population norms.

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**References**


