The Pattern of Astigmatism in a Canadian Pre-School Population

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ABSTRACT

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

METHODS. Non-cycloplegic autorefractive measures (Nikon Retinomax K-Plus) were taken on 1179 children attending a pre-school health fair operated by their county board of health. Sphero-cylinder measures were transformed into 3 independent components.

RESULTS. The equivalent sphere showed considerable variation between retinoscopy and autorefraction which was attributed to the variable over-accommodation induced by the autorefractor. Astigmatic components were not affected. Small discrepancies found between the two techniques were similar to those found in adults and were not of sufficient magnitude to affect validity. With-the-rule astigmatism (WTR) of at least 0.25D 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 1.25D. Astigmatisms beyond this value were predominately WTR. The mean (negative) cylinder magnitude was 0.08Dx 015°.

CONCLUSIONS. When sphero-cylinder values are transformed into a mathematical continuum rather than WTR and ATR classifications, the true central tendency of the population is better defined and was close to zero. Astigmatisms over 1.25D in the pre-school child exceed the 95th percentile in this population and were more frequently with-the-rule.
INTRODUCTION

Population information on astigmatism in pre-school 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 UK, the United States and Sweden. Defining the dominant form of astigmatism in populations is less clear. Perhaps the clearest population pattern is found in pre-school populations of many native North American tribes where abnormally high levels of with-the-rule (WTR) astigmatism are found. This pattern appears to remain into adulthood. Apparently this predisposition of Native Americans to WTR astigmatism, where the vertical meridian of the eye shows the greatest optical power, is found across differing demographic locations. However, the form of astigmatism, in other pre-school populations is less clear. Some reviews have concluded that infants have high amounts of against-the-rule (ATR) astigmatism, where the greatest optical power is along the horizontal meridian in infancy, which then reduces to mild levels of WTR astigmatism in pre-schoolers. However, the results of three studies in the United States, show that for astigmatisms greater than 1D there is a pattern where the predominant ATR form in infancy changes to a more equal distribution between these forms in the ages 3.5 to 5.5 years.

Knowledge as to what size of refractive error should be treated in a pre-school child is not clear cut. One source of information was a survey of a sample of pediatric ophthalmologists in regards to the dioptric thresholds at which spectacle corrections would be prescribed for refractive errors of myopia, hyperopia and astigmatism found in
infants and children of specific age groups \(^{16}\). Given that these thresholds are implicitly defining abnormally high levels of refractive error it is important to add credence to such information by defining population norms for a given refractive error.

The development of ‘child-friendly’ autorefractors which can be employed in county-wide pre-school health screenings have provided the means by which refractive measures can be determined on a county-wide population of pre-school children.

Measurement of refractive errors in pre-school children is bedevilled by the fact that children at this age are typically 1-2 D hyperopic 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 upon the design of the instrument and both the viewing distance and spatial composition of the targets selected \(^{17}\). Even conducting retinoscopy through ‘fogging lenses’ does not fully manifest refractive error \(^{17}\). Unfortunately, large-scale screenings do not offer the opportunity for testing with cycloplegia.

In this study, we use the Nikon Retinomax K-Plus (Nikon Inc, Japan) autorefractor to provide non-cycloplegic measures of refractive error. The Retinomax has been well studied in populations both of adults and children \(^{18-23}\). The measures in adults show good agreement where small biases in the order of 0.25D are found between the Retinomax and conventional retinoscopy for both the equivalent sphere and cylinder values. The small Retinomax bias is towards hyperopia \(^{23}\). Measurements on pre-school children and
younger have been done with and without cycloplegia. It appears that the close working distance of the Retinomax (5cm) induces considerable but variable ‘instrument myopia’ in these children where without a cycloplegia the equivalent sphere measures are consistently inaccurate and hyperopia was underestimated. However, cylinder measures were not affected by this over-accommodation\textsuperscript{23-25}. Any differences in cylinder components found were not thought to be clinically important\textsuperscript{18}. In a screening situation the Retinomax has had a 99.5\% success rate in detecting refractive astigmatism\textsuperscript{8} and there was little bias.

When cycloplegia was used with pre-school children, accuracy in equivalent sphere is restored to adult levels. Both cylinder and axis measures show good agreement with those of retinoscopy\textsuperscript{20, 21, 23, 25}.

While it can be concluded that pre-school children exhibit less astigmatism than what they exhibited at birth, the exact central tendency of the pre-school population’s astigmatism has been difficult to define. The standard sphero-cylinder format (sphere/cylinder x 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 degrees) must be ignored. Values of orthogonally orientated astigmatisms (e.g. ‘with’ and ‘against’ 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\textsuperscript{26,27} have transposed the sphero-cylinder values into more mathematically workable formats. In particular, a format has been
designed which decomposes different forms of astigmatism (ATR, WTR and oblique) into continuums where astigmatisms at orthogonal orientations are given opposite signs\textsuperscript{27}. 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.

This research measures the astigmatism in a county-wide population of pre-school children. Using the above analysis a central tendency of astigmatism is defined.

**METHODS**

**Pre-school population**

An annual “Pre School Health Fair” screening of vision, audition, and speech in kindergarten registrants takes place in Oxford County (Ontario, Canada) over a 4-month period\textsuperscript{28}. Public Health Nurses of the Oxford County Health Unit carry out the screenings. Research was limited to the vision-screening component. A child’s inclusion in the research component of the screening required parental consent. The research was approved by the Human Research Ethics Committee of the University of Waterloo, and followed 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 to 86 months). Males 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 non-attendees 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.

**FIGURE 1.** Flow chart of the Oxford County vision screening programme.

**Oxford County**

Oxford County comprises 2032 km² located in south-western 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". Thus Oxford County is predominantly Caucasian.
Screening tests

The vision-screening programme 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 secs 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 which specifically required ‘retinoscopic measures’.

Autorefractive Measures

During the vision testing, non-cycloplegic refractive error measures were taken on 1162 pre-school children using the Nikon Retinomax K-Plus autorefractor. 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 instrument’s Christmas tree target, set along the optical axis of the instrument. During fixation, the instrument averaged 8 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
out of a possible 10. In 3% 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 was possible.

Validation of Measures

In order to ensure that the measures of astigmatism were valid using the Retinomax without cycloplegia we conducted two investigations. The first compared the Retinomax readings to clinical measures of refraction taken on a subset of children whose practitioner reports were available to us. Secondly, we conducted a study on an adult sample, since Retinomax-induced over-accommodation has not been found to be significant in adult ages.\(^{30}\)

Clinical Measures of Pre-schoolers

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 retinoscopy. In 24% of the cases, cycloplegic drugs were employed; however, for the majority, retinoscopy had been conducted without a cycloplegic. All clinical findings were reported to the Oxford County Health Unit. These refractive error measurements provided the means to validate the Retinomax autorefractor measurements.

Adult Study

Adult subjects (n=144, mean age=42 years, range= 19-78) 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 retinoscopic measures were reviewed from the clinical file and found to be within 0.50D of the subjective along either refractive meridian. Further, measures were assessed for the presence of any confounding problems such as media opacities. Again, ethics approval and informed consent were obtained prior to subject participation.

**Refractive Error Analysis**

Refractive error measurements were decomposed into 3 independent components using the following Fourier transformation $^{27}$:

\[ M = S + \frac{C}{2} \quad (1) \]

\[ J_0 = -\frac{C}{2} \cos(2\alpha) \quad (2) \]

\[ J_{45} = -\frac{C}{2} \sin(2\alpha) \quad (3) \]

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: equivalent sphere (1) and two Jackson cross cylinders (2 and 3). $J_0$ represents cylinder powers set orthogonally about 90 and 180 degree meridians, representing ‘with’ and ‘against-the-rule’ astigmatism, respectively. $J_{45}$ represents a cross cylinder set at 45 and 135 degrees, which represents oblique astigmatism.
Accommodation acts isotropically, where astigmatic changes with increased accommodation are small; specifically, they are rarely more than 0.1 to 0.2D\textsuperscript{32}. Astigmatism was defined to be non-zero cylinder measures starting at 0.25D.

**RESULTS**

**Measurement Validation**

*Pre-school 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 3 components described above. 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 pre-school sample (table 1). The equivalent sphere of the Retinomax was found to be more myopic on average by 0.88D. 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 $T^2$, $F=15.50$, $p<0.0001$)\textsuperscript{32}; 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-values less than 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.

**TABLE 1.** Mean values for the retinoscopy and the Retinomax and differences between retinoscopy and Retinomax measures (diopters) of $M$, $J_0$ and $J_{45}$ for right and left eyes of 154 pre-school children. Mean, standard deviation and significance level of paired t-tests are shown.

<table>
<thead>
<tr>
<th>Eye</th>
<th>Retinoscopy Mean</th>
<th>Retinoscopy S. D.</th>
<th>Retinomax Mean</th>
<th>Retinomax S. D.</th>
<th>Difference in Retinoscopy and Retinomax Mean</th>
<th>Difference in Retinoscopy and Retinomax S. D.</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>$M$</td>
<td>0.97</td>
<td>1.40</td>
<td>0.08</td>
<td>1.28</td>
<td>0.88</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>$J_0$</td>
<td>0.12</td>
<td>0.32</td>
<td>0.13</td>
<td>0.41</td>
<td>-0.007</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>$J_{45}$</td>
<td>0.003</td>
<td>0.11</td>
<td>0.04</td>
<td>0.17</td>
<td>-0.04</td>
<td>0.16</td>
</tr>
<tr>
<td>Left</td>
<td>$M$</td>
<td>1.02</td>
<td>1.45</td>
<td>0.18</td>
<td>1.35</td>
<td>0.83</td>
<td>1.46</td>
</tr>
<tr>
<td></td>
<td>$J_0$</td>
<td>0.14</td>
<td>0.35</td>
<td>0.18</td>
<td>0.37</td>
<td>0.003</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>$J_{45}$</td>
<td>-0.02</td>
<td>0.11</td>
<td>0.05</td>
<td>0.16</td>
<td>-0.06</td>
<td>0.15</td>
</tr>
</tbody>
</table>
As noted in the methods, 35 pre-schoolers received cycloplegia from the practitioners and 113 did not. Thus the effects of cycloplegia on the components had to be determined. There were 5 pre-schoolers whose cycloplegic status was unknown and 1 who did not have a Retinomax measurement. The 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 does not vary with the magnitude of equivalent sphere. Thus the over accommodation induced by the Retinomax is likely underestimated by the non-cycloplegic findings. As retinoscopy in young children may also introduce over accommodation, the variation in equivalent sphere cannot be attributed solely to the Retinomax.
TABLE 2. Mean values for retinoscopy and Retinomax measures and differences in retinoscopy and Retinomax measures of $M$, $J_0$ and $J_{45}$ for the pre-school children who received cycloplegia (n=35) and those who did not (n=113). Mean, standard deviation and significance level of paired $t$-tests are shown.

<table>
<thead>
<tr>
<th></th>
<th>Retinoscopy</th>
<th>Retinomax</th>
<th>Difference in Retinoscopy and Retinomax</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean  S.D.</td>
<td>Mean  S.D.</td>
<td>Mean  S. D.  P-Value</td>
</tr>
<tr>
<td>Cycloplegic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M$</td>
<td>2.17 2.13</td>
<td>0.10 1.74</td>
<td>2.06 2.02 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 0.70</td>
</tr>
<tr>
<td>$J_{45}$</td>
<td>0.007 0.18</td>
<td>0.06 0.23</td>
<td>-0.06 0.22 0.14</td>
</tr>
<tr>
<td>Non-cycloplegic</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 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 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 0.01</td>
</tr>
</tbody>
</table>

Hotelling’s multivariate $T^2$ test shows that cycloplegic refractions are significantly more hyperopic than non-cycloplegic 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 2 (a). This disparity is not seen in the $J_0$ and $J_{45}$ measures of astigmatism (figure 2 b & c).

A)

![Graph A]

B)

![Graph B]

C)

![Graph C]
**FIGURE 2.** Difference between retinoscopy and Retinomax versus mean plots of A) $M$, B) $J_0$ and C) $J_{45}$ for the cycloplegic (+) and non-cycloplegic (o) pre-school groups.

**Adult Measures**

A similar analysis was carried out 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 pre-school sample. The equivalent sphere of the Retinomax in this case was found to be slightly more hyperopic on average (-0.37D), but with considerably less variation (0.73D). 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 (Hotelling's $T^2$: $F=4.03$, $p=0.0079$). When the equivalent sphere is removed, significant differences are 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 similar results to those in the pre-school sample. Correlation for $J_0$ and $J_{45}$ was 0.59 ($p<0.0001$) and 0.45 ($p<0.0001$) respectively.
**TABLE 3.** Mean values for retinoscopy and Retinomax measures and differences in retinoscopy and Retinomax measures of $M$, $J_0$ and $J_{45}$ for 144 adults. Mean, standard deviation and significance level of paired $t$-tests are shown.

<table>
<thead>
<tr>
<th></th>
<th>Retinoscopy</th>
<th>Retinomax</th>
<th>Difference in Retinoscopy and Retinomax</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
</tr>
<tr>
<td>$M$</td>
<td>-1.43</td>
<td>3.01</td>
<td>-1.06</td>
</tr>
<tr>
<td>$J_0$</td>
<td>0.13</td>
<td>0.48</td>
<td>0.03</td>
</tr>
<tr>
<td>$J_{45}$</td>
<td>-0.01</td>
<td>0.19</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Transposition from Fourier form back to sphero-cylinder form for the mean differences found in table 1 gives an ‘over-correction’ of $0.92 - 0.08 \times 130^\circ$. A similar transformation for the adult study gives an ‘over-correction’ of $-0.26 - 0.21 \times 167^\circ$. An ANOVA split-plot design where the whole-plot factor is measurement (Retinomax or retinoscopy) and the sub-plot factor is population (adult or pre-school), showed that population had a significant effect; however, only when considering the equivalent sphere ($F=111.42$, $p=0.0001$). As ‘population’ does not have a significant effect on $J_0$ and $J_{45}$, this implies that small differences in the cylinder components are coming from the same source in the
two populations. It may be that the Retinomax is providing 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 did a post-hoc analysis on this phenomenon. Small cylinder values (less than 0.5D) were removed from the pre-school sample resulting in a sample size of 77. Correlations for M, J₀ and J₄₅ were found to be 0.41 (p=0.0002), 0.72 (p<0.0001) and 0.52 (p<0.0001) respectively. Correlations for those pre-schoolers with small cylinders (less than 0.5D) were 0.19 (p=0.09), 0.28 (p=0.01) and 0.05 (p=0.63) for M, J₀ and J₄₅ 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, J₀ and J₄₅ all of which had p-values less than 0.0001. To find out if 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, J₀ and J₄₅ are -0.31 (p=0.003), 0.11 (p=0.08) and -0.09 (p=0.02) respectively.

**Astigmatism in the Pre-school 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. There were 278 (23.9%) pre-schoolers who had a cylinder value of 0. Figure 3 (a-c) shows the distribution of the 3 types of astigmatism. Of the
children with astigmatism, WTR is most dominant in this pre-school population (45%), followed by ATR (40%) and then oblique (15%). Within each astigmatism type, most children have very small cylinder errors (Figure 3). The mean astigmatism values for WTR, ATR and oblique are -0.33Dx 004º, -0.41Dx 091º, and -0.13Dx 041º respectively. The range of WTR astigmatism spans the interval (-4, -0.25) whereas ATR and oblique span a smaller interval (-1.75, -0.25).

A)

![Graph A]

B)

![Graph B]
FIGURE 3. Right-eye cylinder magnitude distribution of A) with-the-rule (n=393, 45%), B) against-the-rule (n=354, 40%) and C) oblique (n=137, 15%) astigmatisms for the pre-school population. There were 278 pre-schoolers without astigmatism. It is noted that there were some large cylinder values associated with very small percentages (e.g. cylinder=-4D, percentage=0.25%) which do not show up as bars in Figure 3 as the percentages are small.

The distribution of all astigmatic cylinder magnitudes is provided in figure 4(a). Cylinders ranged from 0.25 to 4D with the majority of the cylinders between 0.25 and 1D. A cumulative distribution of all cylinder magnitudes (figure 4(b)) allowed the 95th percentile of cylinder magnitude to be calculated. Cylinders were ordered from 1 to N by magnitude and assigned $i/N \times 100\%$ to each magnitude, where $N$ is the total number of magnitudes and $i$ is the order of the magnitude. For example, in the pre-school data, the first magnitude would be assigned $1/1162 \times 100\%$, the second $2/1162 \times 100\%$ and so forth until the 95th percentile was reached. The cylinder magnitude that corresponded to the 95th percentile was found to be 1.25D. The 95th cylinder-magnitude percentiles for WTR,
ATR and oblique astigmatism distributions were 2.25D, 1D and 0.75D respectively. WTR astigmatism was the most frequent form found above 1.25D.

**A)**

![Distribution of cylinder magnitudes in the pre-school population.](image)

**B)**

![Cumulative density of the cylinder magnitudes for the pre-school population.](image)

**FIGURE 4.** A) Distribution of cylinder magnitudes in the pre-school population. B) Cumulative density of the cylinder magnitudes for the pre-school population.

Ninety-five percent of the cylinder values lie between 0 and 1.25 diopters.

The difference in cylinders between the right and left eyes was examined. In cases of right-eye astigmatism larger than 1.25D, 18 of 43 showed a right-left eye difference of at
least 1D. 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 0.75D.

**Age Stratification**

The Retinomax data set was stratified into 2 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 for 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 for 4-year-olds.

**Central Tendency**

Overall mean magnitude of the cylinder components were -0.08Dx 015° and -0.08x 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 0.38D which was determined by considering only the absolute astigmatism without reference to the position of the axis.

Figure 5 plots $J_{45}$ against $J_0$. From observation of this scatter plot a symmetrical clustering is found to ‘orbit’ about 0 astigmatism. Part of the distinct pattern is due to the
Retinomax providing measurements in 0.25D intervals, which renders continuous data into discrete data. As the astigmatism values become larger there is a loss of symmetry where astigmatism becomes clearly positive along $J_0$ and to a lesser degree along $J_{45}$. This would lead to astigmatism of a WTR format, with an axis between 0 and 45 degrees, which is consistent with the overall mean axis of 15 degrees.

ATR and WTR astigmatism split the $J_0$ axis into positive and negative values. The range of $J_0$ includes (-0.83, -0.06) and (0, 1.78) for ATR and WTR respectively. The $J_{45}$ axis is split into positive and negative values by the axis of oblique astigmatism: those at 45° (OBx 45) and those at 135° (OBx 135). $J_{45}$ ranges from -0.49 to 0.88.

**FIGURE 5.** $J_{45}$ plotted against $J_0$ for the pre-school population. With-the-rule (WTR) and against-the-rule (ATR) astigmatisms are opposite signs on the $J_0$ axis. Ranges of $J_0$ include: WTR (0, 1.78), ATR (-0.83, -0.06), Oblique astigmatism can be separated into astigmatisms axis 45° (OBx45) and those at axis 135° (OBx135) (range of $J_{45}$= -0.49, 0.88); these are of opposite signs on the $J_{45}$ axis as shown.
DISCUSSION

Verification of the Retinomax

Retinomax comparisons with retinoscopy were comparable to previous studies for both adult and child populations. Close agreement is again found with astigmatic (cylinder) components in both populations but only in the adult case is 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 pre-school children would be expected to be remedied by the use of a cycloplegia. However, this is neither feasible nor likely possible in a population study of mostly visually-normal children.

It is important to recognise that simply correcting the bias of 0.88D of over-accommodation (table 1) will not provide a suitable calibration of the Retinomax due to the high standard deviation. Furthermore, calibrations based upon regression analysis were thwarted by the considerable inter-subject variation. It appears that when children over-accommodate 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. In spite of 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 found between retinoscopy and the Retinomax. To test this point, small cylinders were removed resulting
in improvements in the correlations; however, this resulted in a halving of the sample size. This change in correlation supports the idea that practitioners may not be measuring small astigmatisms as closely as the Retinomax.

Rounding off the astigmatism components to zero was also found in adult studies. This explains the small but significant differences in $J_{45}$ findings in the adult sample (table 2) but not in $J_0$. The retinoscopists set cylinder values to 0 twice as often as the Retinomax did. The small hyperopic bias found in the equivalent sphere has been found in other adult studies; this small bias (0.29D) was confirmed by the manufacturer. However, other studies where children were cyclopleged, 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 non-cycloplegic 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 (tables 1 and 2) further precludes measurement of anisometropia. Nevertheless, the Retinomax K-Plus provided a valid measure of astigmatism in this pre-school population.

**Astigmatism in the Pre-School Population**

The Oxford County pre-school population's distribution of astigmatism can be broken down into 45% WTR, 40% ATR and 15% oblique. This pattern falls into the general pattern where 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 (figure 5), the mean cylinder magnitude
approaches zero. It would appear that the majority of data points cluster symmetrically
about zero (figure 5). This suggests that in this population the small astigmatisms are
random fluctuations about zero. It would appear that a second and distinct sub-population
show significant WTR astigmatism. It is important to note that native North American
pre-school populations show much higher levels of astigmatism where with-the-rule
forms represent well over 90% of the astigmatism\(^6,8\) and the origin appears to be corneal
\(^8\).

Prescribing guidelines have not been well established for pre-school children.
Consideration of emmetropization suggests caution before spectacle treatment is
undertaken, while consideration of amblyopia suggests intervention. Understandably,
clinicians will vary in their thresholds at which astigmatism should be corrected\(^16\).
However, upon average, paediatric eye-care practitioners start to correct astigmatism in 4
to 7-year-olds once it has reached levels of 1.50D\(^16\). This is close to the 95\(^{th}\) percentile of
1.25D 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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