Normative Monocular Visual Acuity for Early Treatment Diabetic Retinopathy Study Charts in Emmetropic Children 5 to 12 Years of Age

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Objective: To provide normative data for children tested with Early Treatment Diabetic Retinopathy Study (ETDRS) charts.

Design: Cross-sectional study.

Participants: A total of 252 Native American (Tohono O’odham) children aged 5 to 12 years. On the basis of cycloplegic refraction conducted on the day of testing, all were emmetropic (myopia ≤0.25 diopter [D] spherical equivalent, hyperopia ≤1.00 D spherical equivalent, and astigmatism ≤0.50 D in both eyes).

Methods: Monocular visual acuity was tested at 4 m, using 1 ETDRS chart for the right eye (RE) and another for the left eye (LE).

Main Outcome Measures: Visual acuity was scored as the total number of letters correctly identified, by naming or matching to letters on a lap card, and as the smallest letter size for which the child identified 3 of 5 letters correctly.

Results: Visual acuity results did not differ for the RE versus the LE, so data are reported for the RE only. Mean visual acuity for 5-year-olds (0.16 logarithm of the minimum angle of resolution [logMAR] [20/29]) was significantly worse than for 8-, 9-, 10-, 11-, and 12-year-olds (0.05 logMAR [20/22] or better at each age). The lower 95% prediction limit for determining whether a child has visual acuity within the normal range was 0.38 (20/48) for 5-year-olds and 0.30 (20/40) for 6- to 12-year-olds, which was reduced to 0.32 (20/42) for 5-year-olds and 0.21 (20/32) for 6- to 12-year-olds when recalculated with outlying data points removed. Mean interocular acuity difference did not vary by age, averaging less than 1 logMAR line at each age, with a lower 95% prediction limit of 0.17 log unit (1.7 logMAR lines) across all ages.

Conclusions: For monocular visual acuity based on ETDRS charts to be in the normal range, it must be better than 20/50 for 5-year-olds and better than 20/40 for 6- to 12-year-olds. Normal interocular acuity difference includes values of less than 2 logMAR lines. Normative ETDRS visual acuity values are not as good as norms reported for adults, suggesting that a child’s visual acuity results should be compared with norms based on data from children, not with adult norms.

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southern Arizona. Children in grades K-2 were examined during the 2003/2004 academic school year, and children in grades 4-6 were examined during the 2001/2002 academic school year. Data are reported for the first study-related eye examination conducted on each child.

The research followed the tenets of the Declaration of Helsinki, was Health Insurance Portability and Accountability Act compliant, and was approved by the Tohono O’odham Nation and by the institutional review board of the University of Arizona. Parents provided written, informed consent before testing.

**Procedures**

All children underwent an eye examination that was conducted at their school. Initially, monocular distance visual acuity was assessed at 4 m, using ETDRS logMAR charts (Precision Vision, Inc., La Salle, IL) mounted in a chart illuminator box (Precision Vision, La Salle, IL). An adhesive eye patch of 5-cm-wide adhesive paper tape (3M Micropore, Minneapolis, MN) was placed over the child’s left eye (LE), and the visual acuity of the right eye (RE) was tested using ETDRS chart 1 (Precision Vision catalog item no. 2121). Testing began with the top line on the chart (20/200), and the child was asked to name, or to match to letters on a lap card, all letters on each line until they reached a line on which they could not correctly identify any of the 5 letters. Masking of adjacent lines or letters was not allowed, but the tester was permitted to place a pointer beneath a letter to direct the child’s attention to the letter. Visual acuity was recorded as the total number of letters correctly identified (letter by letter scoring) and as the smallest letter size at which the child identified at least 3 of the 5 letters correctly (line by line scoring). Testing of the RE was followed by testing of the LE with ETDRS chart 2 (Precision Vision catalog item no. 2122). Visual acuity scores were converted to logMAR values before analyses.

Visual acuity testing was followed by assessment of eye alignment using the cover–uncover test at distance and near, measurement of refractive error 40 to 60 minutes after instillation of 1 drop of proparacaine (0.5%) and 2 drops of cyclopentolate (1%) in each eye, and examination of the external eye and the fundus for abnormalities. 0.25 D of myopia (spherical equivalent), ≤0.50 D of hyperopia (spherical equivalent), and ≤0.25 D cylinder in both eyes.

**Data Analysis**

The primary analyses were conducted with visual acuity data scored on the basis of the total number of letters identified correctly. By using the following formula, which assigns a value of 0.02 log unit to each letter identified, scores were transformed to logMAR values:

\[
\text{logMAR} = 1.10 - 0.02T_c
\]

where \(T_c\) = the total number of letters identified correctly. This letter-by-letter scoring method provides better reliability of scores than does the line-by-line scoring. 15 However, because in clinical settings visual acuity is often scored as the last line on which the patient identifies 3 letters correctly we also provide, in Tables 1 and 2 and Figure 1, data based on this line-by-line scoring method.

Separate repeated-measures analyses of variance were conducted to determine whether there was a difference in acuity across age (separate analyses for RE [tested first] and LE) and in interocular acuity difference across age.

For visual acuity results and interocular acuity difference results, 95% prediction limits were calculated to determine the visual acuity or interocular acuity difference value that would indicate that a newly tested individual’s score was within normal limits with 95% probability. A visual acuity score less than the lower 95% prediction limit would indicate a below-normal acuity score, and an interocular acuity difference greater than the lower 95% prediction limit would indicate an abnormally large difference in visual acuity between eyes. The formula used for the 95% prediction limits was as follows:

\[
\text{Mean} + t_{\alpha/2} \left( \sqrt{1 + 1/n \times SD} \right)
\]

where \(t_{\alpha/2} = 2\text{-tailed value for alpha of 0.05 from the Student }t\text{ distribution, }n = \text{number of subjects, and }SD = \text{standard deviation.}

### Table 1. Mean and Standard Deviation of the Logarithm of the Minimum Angle of Resolution Recognition Visual Acuity and Snellen Equivalent for Testing with Early Treatment Diabetic Retinopathy Study Charts in the Present Study

<table>
<thead>
<tr>
<th>Age Group</th>
<th>5 to &lt;6 yrs</th>
<th>6 to &lt;7 yrs</th>
<th>7 to &lt;8 yrs</th>
<th>8 to &lt;9 yrs</th>
<th>9 to &lt;10 yrs</th>
<th>10 to &lt;11 yrs</th>
<th>11 to &lt;12 yrs</th>
<th>12 to &lt;13 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>27</td>
<td>28</td>
<td>35</td>
<td>25</td>
<td>28</td>
<td>50</td>
<td>39</td>
<td>20</td>
</tr>
<tr>
<td>Present study (letter by letter scoring)*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.16</td>
<td>0.09</td>
<td>0.06</td>
<td>0.03</td>
<td>−0.01</td>
<td>0.05</td>
<td>0.04</td>
<td>-0.00</td>
</tr>
<tr>
<td>SD</td>
<td>0.10</td>
<td>0.08</td>
<td>0.10</td>
<td>0.08</td>
<td>0.19</td>
<td>0.13</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Snellen equivalent</td>
<td>[20/29]</td>
<td>[20/25]</td>
<td>[20/23]</td>
<td>[20/21]</td>
<td>[20/20]</td>
<td>[20/22]</td>
<td>[20/22]</td>
<td>[20/22]</td>
</tr>
<tr>
<td>Present study (line by line scoring†)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.13</td>
<td>0.07</td>
<td>0.04</td>
<td>0.01</td>
<td>−0.05</td>
<td>0.02</td>
<td>0.00</td>
<td>−0.02</td>
</tr>
<tr>
<td>SD</td>
<td>0.11</td>
<td>0.08</td>
<td>0.10</td>
<td>0.09</td>
<td>0.08</td>
<td>0.20</td>
<td>0.13</td>
<td>0.19</td>
</tr>
<tr>
<td>Snellen equivalent</td>
<td>[20/27]</td>
<td>[20/24]</td>
<td>[20/22]</td>
<td>[20/20]</td>
<td>[20/18]</td>
<td>[20/21]</td>
<td>[20/20]</td>
<td>[20/19]</td>
</tr>
</tbody>
</table>

SD = standard deviation.

Subjects were emmetropic children who had ≤0.25 D of myopia (spherical equivalent), ≤1.00 D of hyperopia (spherical equivalent), and ≤0.50 D cylinder in both eyes.

*Letter by letter scoring based on number of letters correctly identified.

†Line by line scoring based on smallest line on which child identified at least 3 letters correctly.
Table 2. Median, Mean, and Standard Deviation for the Interocular Acuity Difference (Absolute Value of Right Eye logMAR Visual Acuity – Left Eye logMAR visual acuity) in Log Units for Emmetropic Children Who Had $\leq 0.25$ D of Myopia (Spherical Equivalent), $\leq 1.00$ D of Hyperopia (Spherical Equivalent), and $\leq 0.50$ D Cylinder in Both Eyes

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Age (yrs)</th>
<th>logMAR</th>
<th>logMAR SD</th>
<th>Snellen Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chen et al. 2006&lt;sup&gt;11&lt;/sup&gt;</td>
<td>11</td>
<td>3.6–11</td>
<td>0.10</td>
<td>0.09</td>
<td>20/25</td>
</tr>
<tr>
<td>Harvey et al. 2007&lt;sup&gt;7&lt;/sup&gt;</td>
<td>44</td>
<td>4–13</td>
<td>0.04</td>
<td>0.15</td>
<td>20/22</td>
</tr>
<tr>
<td>Stewart et al. 2006&lt;sup&gt;12&lt;/sup&gt;</td>
<td>27</td>
<td>6.05±0.63</td>
<td>0.02</td>
<td>0.05</td>
<td>20/21</td>
</tr>
<tr>
<td>Myers et al. 1999&lt;sup&gt;10&lt;/sup&gt;</td>
<td>106</td>
<td>9.7±10.9</td>
<td>$-0.01$</td>
<td>0.08</td>
<td>20/20</td>
</tr>
<tr>
<td>Elliott and Whitaker 1991&lt;sup&gt;4&lt;/sup&gt;</td>
<td>20</td>
<td>20–30</td>
<td>$-0.13$</td>
<td>—</td>
<td>20/15</td>
</tr>
<tr>
<td>Beck et al. 1993&lt;sup&gt;3&lt;/sup&gt;</td>
<td>140</td>
<td>18–46</td>
<td>$-0.12$</td>
<td>0.10</td>
<td>20/15</td>
</tr>
<tr>
<td>Ohlsson and Villarreal 2005&lt;sup&gt;5&lt;/sup&gt;</td>
<td>107</td>
<td>17–18</td>
<td>$-0.12$</td>
<td>0.07</td>
<td>20/15</td>
</tr>
</tbody>
</table>

logMAR = logarithm of the minimum angle of resolution; SD = standard deviation.

Results

Monocular Visual Acuity

Repeated-measures analyses of variance revealed no significant difference in visual acuity between RE (tested first) and LE (tested second) as a function of the child’s age and no interaction between eye and age (all $P>0.05$). There was also no systematic tendency for acuity to be better in the RE or the LE, with mean differences between eyes of 0.03, $-0.01$, $-0.01$, $-0.01$, $-0.03$, 0, $-0.01$, and $-0.04$ log unit (positive numbers indicate better LE acuity and negative numbers indicate better RE acuity) at 5 to $<6$, 6 to $<7$, 7 to $<8$, 8 to $<9$, 9 to $<10$, 10 to $<11$, 11 to $<12$, and 12 to $<13$ years, respectively. Therefore, visual acuity data are presented for RE only.

Table 1 and Figure 1 present VA results, grouped by age. Analysis of variance showed a significant effect of age on mean visual acuity ($F[7,244]=4.42$, $P<0.001$). Post hoc analysis (with Bonferroni correction) indicated a significant difference between visual acuity in the 5-year age group and visual acuity in the 8-year ($P<0.02$), 9-year ($P<0.001$), 10-year ($P<0.02$), 11-year ($P<0.008$), and 12-year ($P<0.002$) age groups, but no other significant age differences.

The lower 95% prediction limit was 0.38 (20/48) for 5-year-olds and 0.30 (20/40) for 6- to 12-year-olds, the age range for which there was no variation in visual acuity by age group. Recalculation of the lower 95% prediction limits with data removed from outliers (indicated as circles and asterisks in Fig 1) resulted in a value of 0.32 (20/42) for 5-year-olds and 0.21 (20/32) for 6- to 12-year-olds.

Interocular Acuity Difference

Table 2 presents interocular acuity difference results, grouped by age. Analysis of variance showed no effect of age on interocular acuity difference. At all ages, the mean absolute difference between eyes was $<1$ line (0.10 log unit) on the logMAR chart, and the median difference was $\leq 1$ line. The lower 95% prediction limit for the entire sample is 0.17 log unit (1.7 logMAR lines).

Discussion

The results of the present study provide normative data in 1-year age groups for visual acuity measured with ETDRS charts in children 5 to 12 years of age. The data indicate a developmental trend, with 5-year-olds showing, on average, visual acuity that is 1 logMAR line poorer than visual acuity of children 8 years of age and older. In contrast, there were no age differences in mean acuity for children aged 6 to 12 years, which suggests that a single normative value can be used across this age range.

Data from the present study (presented in Table 1) agree well with data previously published for ETDRS visual acuity testing of children between ages 5 and 12 years (shown in Table 3). With the exception of the high variability in visual acuity results in 10-year-olds in the present study, variability of visual acuity results was similar in the present study to that reported previously for children between 5 and 12 years of age, as indicated by similarity in the standard deviation values shown in Tables 1 and 3. Data from studies of adults (summarized in Table 3) indicate that the mean ETDRS visual acuity of adults 17 to 46 years of age is, on average, at least 1 line better than that of children aged less than 13 years. It is unclear whether the poorer visual acuity scores shown by the youngest children and the difference in mean visual acuity between children and adults are due to acuity development during childhood or to behavioral causes, for example, children’s difficulty...
attending to the visual acuity task or their reluctance to
guess the identity of letters that are difficult to see.

Clinically, it is useful to know the visual acuity score that
would indicate that a child’s visual acuity is below the
normal range for age. For 5-year-olds, the lower 95% pre-
diction limit was 0.38 logMAR (20/48), indicating that a
child would be within the normal range if he/she passed the
20/50 line on the ETDRS chart. For 6- to 12-year-olds, it
was 0.30 logMAR (~20/40), indicating that children 6 to 12
years of age would be within the normal range if they pass
the 20/40 line. Recalculation of these values with outlying
data points removed tightened the values and indicated that
a 5-year-old child with acuity of 20/40 or better would be
within the normal range and that a 6- to 12-year-old child
with acuity of 20/32 or better would be within the normal
range.

In contrast with the age-related findings seen for visual
acuity scores, there was no relation between age and the
difference in visual acuity between eyes (Table 2). Overall,
the average absolute difference in visual acuity between
eyes was 0.06 log unit, or less than 1 logMAR line. Adults
tested with ETDRS charts also show, on average, an intero-
cular acuity difference of less than 1 logMAR line, although
the mean difference between eyes of 0.04 log unit for adults is smaller than that shown by children, perhaps
because of more variability in visual acuity data obtained
from children. Important for clinical testing and screening is
the finding that, on the basis of the 95% prediction limit, an
interocular acuity difference greater than 0.17 log unit (i.e.,
>1.7 logMAR lines) would be considered abnormal.

Strengths and Limitations

The present study has a number of strengths. First, the
sample is large enough to include at least 20 children in
each of 8 one-year age groups. Second, the sample is
school-based, which is more representative of the general
population than one would expect with a patient-based
population. Third, all children had a cycloplegic refrac-
tion on the same day on which the visual acuity test was
conducted, so that the data indicating that the children were
emmetropic were concurrent. Fourth, visual acuity testing
was conducted using a standardized protocol by testers who
were unaware of the refractive error status of the children
and who were therefore unlikely to have biased the visual
acuity outcomes that were obtained.

The study also has several limitations. First, the sample
is ethnically based, in that the participants are members of
a Native American tribe. There is no evidence, however,
that visual acuity in emmetropic individuals varies with
ethnicity. Second, order of testing of eyes was not varied;
the RE was always first. However, the fact that there was no
significant difference in RE versus LE visual acuity sug-
gests that neither learning nor fatigue affected visual acuity
results for the second eye. Third, no adults were tested in the
present study, so that comparison of the present results with
those of adults (Tables 2 and 3) requires comparison with
other published data.

The present study provides the first normative ETDRS
monocular visual acuity data from emmetropic children
with no ocular pathology, categorized in 1-year age groups,
between 5 and 12 years of age. The results suggest that an age-specific visual acuity norm should be used for 5-year-olds, but that a single normative value can be used for children between 6 and 12 years of age, because mean visual acuity is similar across this age range. There was no age-based variation in interocular acuity difference across the age range tested, suggesting that there is no need for specific, age-based norms for interocular acuity difference in children 5 to 12 years of age.

Comparison of the present data with previously published normative ETDRS visual acuity data from adults indicates that there is a 1 logMAR line improvement in acuity between the child and adult years. In addition, mean interocular acuity difference in adults has been reported to be smaller than mean interocular acuity difference in the 5-12 year-old children tested in the present study. These findings emphasize the importance of using child-based rather than adult-based norms for acuity and interocular acuity difference.

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References


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