Objective: To measure monocular distance visual acuity, near visual acuity, contrast sensitivity, and visual field extent in full-term, 10-year-old children tested according to the protocol used to test 10-year-old preterm children in the Cryotherapy for Retinopathy of Prematurity study.

Subjects and Methods: Subjects were 106 healthy, full-term children, 9.8 to 10.9 years of age, who had no ocular abnormalities other than ametropia. All were tested monocularly using Early Treatment and Diabetic Retinopathy Study distance and near visual acuity charts and Pelli-Robson contrast sensitivity charts, with refractive error corrected according to Cryotherapy for Retinopathy of Prematurity study criteria. Goldmann perimetry was tested without correction using the V-4-e and III-4-e stimuli along 8 meridia. A standard pediatric eye examination was performed on each subject.

Results: Mean (SD) distance visual acuity was 20/19.6 OD (0.082 log unit [lu]) and mean near visual acuity was 20/19.5 OD (0.100 lu). Mean (SD) contrast sensitivity was 1.69 OD (0.12 lu), with a mean (SD) of 36.4 (2.2) letters read. Visual field extent was larger for the V-4-e stimulus than for the III-4-e stimulus.

Conclusions: The results provide the first monocular normative data from a large sample of 10-year-old children tested with Early Treatment and Diabetic Retinopathy Study distance and near visual acuity charts and the Pelli-Robson contrast sensitivity charts, and add to the literature on Goldmann perimetry in children.


In 1980, the Committee on Vision of the National Academy of Science–National Research Council recommended that visual acuity charts should be constructed using a similar number of letters on each line of the chart, logarithmic scaling of the distance between letters on successive lines on the chart, and logarithmic spacing between lines on the chart. These recommendations were published almost 20 years ago, and several visual acuity charts are available that follow these recommendations, eg, the Bailey-Lovie logMAR chart and the visual acuity charts used in the Early Treatment Diabetic Retinopathy Study (ETDRS). Nevertheless, recent studies of distance and near visual acuity in children in the 9- to 11-year age range reported different results. Visual acuity testing provides a measure of a patient’s ability to discriminate fine detail (high spatial frequencies). However, it does not provide information on a patient’s ability to detect the lower spatial frequencies that also contribute to overall pattern vision, and that may be selectively affected by some diseases, including optic neuritis and cataract. As a result, many clinicians supplement visual acuity measurement with assessment of contrast sensitivity, which provides information on visual function across a wide range of spatial frequencies. One of the most frequently used clinical measures of contrast sensitivity is the Pelli-Robson contrast sensitivity chart (Clement Clark Inc, Columbus, Ohio). One study has reported normative binocular values for children in the 9- to 11-year age range tested with the Pelli-Robson contrast sensitivity charts. However, monocular norms have not been reported for children in this age range.

One aspect of visual function for which data are available in normal 9- to 11-year-old children is visual field extent, as measured with the Goldmann perimeter. However, there is considerable variability among these studies in the stimuli used, the number and specific meridia tested, and the results obtained.

The Outcome Study for Cryotherapy for Retinopathy of Prematurity (CRYO-ROP)
SUBJECTS AND METHODS

SUBJECTS

Subjects were 106 children (41 boys and 65 girls) between 9 years 9 months and 10 years 11 months of age. Children were primarily white (61%) or African American (33%); the remaining 6% were of Asian or mixed descent. By the parent's report, none of the children were born prematurely, had a history of ocular disease other than ametropia, had a history of major illness or disease, or had a diagnosis of learning disorder. Subjects were recruited from family practice, orthopedic, and ear, nose, and throat clinics at the Children's Hospital of Philadelphia, Philadelphia, Pa, as well as from nearby schools. Subjects were reimbursed $20 for travel expenses.

A standard eye examination was performed on each child, including cycloplegic refraction, identical to that performed for participants in the CRYO-ROP study. The cycloplegic agent was 1 drop (approximately 20 µL) of 1% cyclopentolate hydrochloride and 1 drop of 1% tropicamide. No subjects had ocular abnormalities other than ametropia. Mean (SD) spherical equivalent was 0.06 diopters (D) OD (1.33) and 0.09 D OS (1.38), with a range from −5.00 to +2.00 D OD and from −5.50 to +3.25 D OS. Mean (SD) cylindrical refractive error was was 0.14 D OD (0.32) and 0.16 D OS (0.36), with a range from 0.00 to +2.25 D OD and from 0.00 to +2.50 D OS. Twenty-six children were tested with spectacle correction. This included the 18 children who had myopia of 0.62 D or more, 1 child with hyperopia of 3.00 D or more, and 1 child with astigmatism of 1.00 D or more. Thus, all children met the CRYO-ROP criteria of having refractive error corrected if it exceeded −1.00 D of myopia, +3.00 D of hyperopia, or 1.50 D of astigmatism.

PROCEDURE

Testing was conducted at the Children's Hospital of Philadelphia by the 2 vision testers (V.S.M., N.G.) who performed all visual acuity and contrast sensitivity testing and most of the visual field testing of 10-year-old, CRYO-ROP participants. Informed written consent was obtained from parents and verbal assent was obtained from the child prior to testing.

Distance Visual Acuity Testing

Each child's monocular distance visual acuity was tested with the Distance ETDRS modified Snellen charts (Lighthouse Inc, New York, NY). Luminance of the charts was 24 candelas per meter, squared (cd/m²) or more, as measured with a light meter (Sekonic Auto-Iumi L-158 light meter; Precision Vision, Chicago, Ill) calibrated to a photometer (Tektronix)17 photometer; Tektronix, Beaverton, Ore) with a luminance head (J1823 luminance head; Tektronix). Initially, each child was asked to identify 10 large, individual ETDRS letters that were held by the vision tester at a distance of 1.5 m. Following this pretest, an adhesive eye patch was placed over the left eye and distance visual acuity of the right eye was tested at the standard distance of 4 m, using 1 of the 3 ETDRS charts. Children were asked to identify the first 3 letters on each line. If the child incorrectly identified 1 or more of the letters, he or she was asked to identify the remaining letters on that line. Visual acuity was estimated as the Snellen value of the last line on which the child identified 3 or more letters correctly. Distance acuity of the left eye was measured using a different ETDRS chart.

Near Visual Acuity Testing

Following distance visual acuity assessment, each child's monocular near visual acuity was tested with the Near ETDRS modified Snellen charts (Lighthouse Inc) at the standard test distance of 40 cm and luminance 24 cd/m² or more. The left eye was tested first, followed by the right eye. The procedure and scoring used were identical to that used for distance visual acuity testing.

Contrast Sensitivity Testing

Following near visual acuity testing, each child's monocular contrast sensitivity was tested using 2 Pelli-Robson contrast sensitivity charts. Test distance was 1 m, and the contrast sensitivity charts were illuminated uniformly to a luminance of 64 cd/m² or more. The right eye was tested first using the Pelli-Robson contrast sensitivity chart, followed by testing of the left eye using the other Pelli-Robson contrast sensitivity chart. Subjects were asked to make a single attempt to identify each letter on the chart, starting with the high contrast letters in the upper left corner of the chart and reading across each line. Subjects were asked to guess even when they indicated that they thought that the letters were invisible. Contrast sensitivity was estimated by the log contrast value of the last triplet on which the subject identified at least 2 of the 3 letters correctly, and also by the total number of letters identified by the subject.

Visual Field Testing

Monocular visual field extent was measured first in the right eye and then in the left eye using a Goldmann perimeter with a radius of 300 mm and a background luminance of 31.5 apostilb. Testing was conducted first with the V-4-e stimulus and then with the III-4-e stimulus along the 15°, 60°, 105°, 150°, 195°, 240°, 285°, and 330° meridia. For each stimulus, the order of testing the 8 meridia was quasi-random, and the stimulus was moved at approximately 3° per second. In all but 6 children, testing was performed after dilation using 1% cyclopentolate hydrochloride and 1% tropicamide, and in all children testing was performed without spectacle correction. The child was instructed to maintain fixation on the black dot at the center of the perimeter and to press the buzzer as soon as the stimulus was visible in the periphery. One presentation was made on each meridian for each target size. However, the tester was permitted to repeat a presentation if her confidence in the validity of the trial was low (eg, the child showed poor fixation).
Snellen charts,\textsuperscript{3} monocular contrast sensitivity is measured with the Pelli-Robson contrast sensitivity charts,\textsuperscript{11} and monocular visual field extent is measured with III-4-e and the V-4-e targets of the Goldmann perimeter. For comparison, monocular visual acuity, contrast sensitivity, and visual field extent are being assessed with the same protocol in 100 ten-year-old children with birth weights less than 1251 g who were enrolled in the CRYO-ROP study but did not develop retinopathy of prematurity in either eye. However, full-term children were not enrolled in the CRYO-ROP study.

The purpose of this study was to measure monocular distance and near visual acuity, contrast sensitivity, and visual field extent in 100 healthy, full-term, 10-year-old children, tested according the protocol used to test 10-year-old preterm children in the CRYO-ROP study.\textsuperscript{17} The results will provide normative data for 10-year-old children for several recently developed measures of visual function, and will also provide comparison data for the 10-year follow-up results from the CRYO-ROP study.

## RESULTS

### DISTANCE VISUAL ACUITY

Table 1 gives the distance visual acuity results for the right eyes and left eyes of the 106 subjects. Mean (SD) acuity (calculated using log acuity scores) was −0.009 logMAR, 20/19.6 OD (0.082 log unit [lu]) and −0.004 logMAR, 20/19.8 OS (0.090 lu). Intercocular acuity difference results indicated equal acuity in both eyes in 60 subjects (57%), a difference of 1 line in 39 subjects (37%), a difference of 2 lines in 6 subjects (6%), and a difference of 3 lines in 1 subject (1%).

### NEAR VISUAL ACUITY

Table 1 gives the near visual acuity results. Mean (SD) visual acuity was −0.011 logMAR, 20/19.5 OD (0.100 lu) and −0.018 logMAR, 20/19.2 OS (0.108 lu). Intercocular acuity difference results indicated equal near visual acuity in both eyes in 48 subjects (45%), a difference of 1 line in 51 subjects (48%), a difference of 2 lines in 6 subjects (6%), and a difference of 4 lines in 1 subject (1%).

### CONTRAST SENSITIVITY

Contrast sensitivity results are given in Table 2 for log contrast sensitivity and in Table 3 for number of letters correctly identified. Mean contrast sensitivity was 1.69 OD (0.12 lu) and 1.66 OS (0.11 lu). Mean (SD) number of letters correctly identified was 36.4 OD (2.2) and 35.8 OS (2.0).

### VISUAL FIELDS

Visual field results are given in Table 4 and plotted in Figure 1. Measurement of pupil size following visual field testing indicated that 92% of subjects whose pupils were dilated prior to visual field testing had a pupil size of 5 mm or more and the 6 subjects whose pupils were not dilated prior to visual field testing had a pupil size of 2 mm or more. Average (SD) test time was 3 minutes (1) for each eye.

### COMMENT

The results of this study add to the literature on vision in 9- to 11-year-old children by providing normative data for several recently developed measures of visual function.

---

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
\textbf{Snellen Equivalent} & \textbf{LogMAR} & \textbf{Right Eye, No. (%)} & \textbf{Left Eye, No. (%)} \\
\hline
\textbf{Distance Visual Acuity} & & & \\
20/13 & −0.2 & 1 (1) & 3 (3) \\
20/16 & −0.1 & 31 (29) & 32 (30) \\
20/20 & 0.0 & 58 (55) & 45 (42) \\
20/25 & 0.1 & 10 (9) & 21 (20) \\
20/32 & 0.2 & 5 (5) & 4 (4) \\
20/40 & 0.3 & 1 (1) & 1 (1) \\
\hline
\textbf{Near Visual Acuity} & & & \\
20/15 & −0.1 & 38 (36) & 43 (41) \\
20/20 & 0.0 & 36 (34) & 37 (35) \\
20/25 & 0.1 & 27 (25) & 19 (18) \\
20/30 & 0.2 & 4 (4) & 5 (5) \\
20/40 & 0.3 & 1 (1) & 1 (1) \\
20/50 & 0.4 & 0 (0) & 1 (1) \\
\hline
\end{tabular}
\caption{Distance and Near Visual Acuity Results Using ETDRS Charts*}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
\textbf{Log Contrast Sensitivity} & \textbf{Right Eye, No. (%)} & \textbf{Left Eye, No. (%)} \\
\hline
1.95 & 3 (3) & 3 (3) \\
1.80 & 31 (29) & 18 (17) \\
1.65 & 64 (60) & 74 (70) \\
1.50 & 6 (6) & 10 (9) \\
1.35 & 1 (1) & 0 (0) \\
1.20 & 0 (0) & 0 (0) \\
1.05 & 1 (1) & 1 (1) \\
\hline
\end{tabular}
\caption{Contrast Sensitivity Using Pelli-Robson Chart}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
\textbf{No. of Letters Correct} & \textbf{Right Eye, No. (%)} & \textbf{Left Eye, No. (%)} \\
\hline
41 & 1 (1) & 2 (2) \\
40 & 2 (2) & 2 (2) \\
39 & 13 (12) & 5 (5) \\
38 & 17 (16) & 9 (8) \\
37 & 14 (13) & 8 (8) \\
36 & 32 (30) & 37 (35) \\
35 & 14 (13) & 22 (21) \\
34 & 8 (8) & 12 (11) \\
33 & 1 (1) & 5 (6) \\
32 & 1 (1) & 3 (3) \\
31 & 1 (1) & 0 (0) \\
30 & 1 (1) & 0 (0) \\
26 & 0 (0) & 1 (1) \\
25 & 1 (1) & 0 (0) \\
\hline
\end{tabular}
\caption{Number of Letters Correct on Contrast Sensitivity Using Pelli-Robson Chart}
\end{table}

*ETDRS indicates Early Treatment Diabetic Retinopathy Study.
distance and near visual acuity data obtained using the ETDRS logMAR modified Snellen charts, contrast sensitivity data using the Pelli-Robson contrast sensitivity chart, and visual field data using the Goldmann perimeter.

Although there are no other studies in which ETDRS logMAR acuity charts have been used to measure either distance or near visual acuity in 9- to 11-year-olds, several recent studies have provided normative acuity data for 9- to 11-year-old children tested with other optotype charts. As given in Table 5, these studies report that almost all children had both distance and near visual acuity of 20/32 or better and most had visual acuities of 20/20 or better. The results of this study are consistent with those of previous studies for percentage of eyes with distance and near visual acuity of 20/32 or better. However, the percentage of eyes with distance and near visual acuity of 20/20 or better in this study is lower than previously reported. This may be due to differences in the visual acuity charts used, as well as to differences in criteria used to estimate visual acuity threshold.

While no other distance or near visual acuity data have been reported for 10-year-old children tested with the ETDRS logMAR charts, Dowdeswell et al recently reported distance and near visual acuity results for a group of children aged 5.5 to 7 years who were tested with the Bailey-Lovie logMAR acuity chart. In the study by Dowdeswell et al, the mean distance visual acuity of the eyes was 0.10 logMAR, 20/25.2, which is approximately 1 line worse than the mean distance visual acuity of the eyes, −0.0065, 20/19.7, found in this study. In contrast, the mean near visual acuity of the eyes reported by Dowdeswell et al, decreased by only one third of a line from the mean near visual acuity value averaged across eyes found in this study, −0.0145, 20/19.3. A possible explanation for the difference between distance visual acuity but not near visual acuity results in children in these 2 studies is that it was more

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**Table 4. Visual Field Extent in Degrees as Measured With the Goldmann Perimeter**

<table>
<thead>
<tr>
<th>Meridian</th>
<th>V-4-e Mean (SD)</th>
<th>III-4-e Mean (SD)</th>
<th>V-4-e Mean (SD)</th>
<th>III-4-e Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15° (temporal)</td>
<td>86° (60)</td>
<td>81° (70)</td>
<td>15° (nasal)</td>
<td>57° (70)</td>
</tr>
<tr>
<td>60° (temporal)</td>
<td>60° (60)</td>
<td>56° (90)</td>
<td>60° (nasal)</td>
<td>50° (70)</td>
</tr>
<tr>
<td>105° (nasal)</td>
<td>49° (60)</td>
<td>46° (70)</td>
<td>105° (temporal)</td>
<td>53° (70)</td>
</tr>
<tr>
<td>150° (nasal)</td>
<td>51° (60)</td>
<td>51° (80)</td>
<td>150° (temporal)</td>
<td>78° (80)</td>
</tr>
<tr>
<td>195° (nasal)</td>
<td>51° (70)</td>
<td>50° (80)</td>
<td>195° (temporal)</td>
<td>85° (60)</td>
</tr>
<tr>
<td>240° (nasal)</td>
<td>52° (60)</td>
<td>50° (70)</td>
<td>240° (temporal)</td>
<td>72° (70)</td>
</tr>
<tr>
<td>285° (temporal)</td>
<td>70° (70)</td>
<td>67° (80)</td>
<td>285° (nasal)</td>
<td>58° (80)</td>
</tr>
<tr>
<td>330° (temporal)</td>
<td>86° (50)</td>
<td>82° (80)</td>
<td>330° (nasal)</td>
<td>52° (70)</td>
</tr>
</tbody>
</table>

**Figure 1.** Measured visual field extent for right and left eyes, tested using Goldmann kinetic perimetry with the V-4-e and III-4-e stimuli.
difficult for the younger children in the study by Dowdeswell et al to attend to visual acuity charts presented at distance. It is also possible that there was more residual myopia in the children in the study by Dowdeswell et al, even though children in both studies were tested with correction.

Although several studies have reported contrast sensitivity data for 9- to 11-year-old children, only 2 of the studies used the Pelli-Robson contrast sensitivity charts. The first study tested a small group of 10-year-old children, but their data were not reported separate from data of older subjects. In the second study, Fitzgerald et al reported a mean (SD) contrast sensitivity of 1.89 lu (0.97) in a group of 49 children aged 8 to 12. This value is better than that found in this study (1.68 lu, averaged across eyes). However, the children in the study by Fitzgerald et al were tested binocularly, while children in this study were tested monocularly. Dowdeswell et al tested children aged 5.5 to 7 years with the Pelli-Robson contrast sensitivity charts. The mean monocular contrast sensitivity found for these younger children was 1.62 lu, which is only slightly lower than the value of 1.68 lu found in this study.

While several studies have reported kinetic perimetry values in normal children aged 9 to 11 years using the Goldmann apparatus, there is variability among stimuli sizes used and the number of meridia tested. Figure 2 compares the results of this study with results of the earlier studies for the largest target size used. The results of this study showed measured visual field extent that was similar to that reported in the 2 other studies that used the V-4 stimulus and was larger than visual field extent reported in the study that used the smaller Goldmann I stimulus. The finding of larger measured visual field extent with larger Goldmann stimuli is consistent with the study by Matsuo et al and this study, both of which tested children with more than one stimulus size.

In this study, results for distance visual acuity, near visual acuity, and contrast sensitivity indicated higher values for the eye tested first than for the eye tested second. For distance visual acuity, more right eyes than left eyes have an acuity of 20/20 or better. For near visual acuity, in which left eyes were tested first, more left eyes have a visual acuity of 20/20 or better. For contrast sensitivity, in which the right eye was tested first, more right eyes than left eyes have values of 1.80 lu or better. While the difference between eyes was not significant for acuity results, it was significant for contrast sensitivity, regardless of whether contrast sensitivity was scored by contrast level (Wilcoxon signed rank test, \( P = .01 \)) or by number of letters read (Wilcoxon signed rank test,

### Table 5. Monocular Distance and Near Visual Acuity Results

<table>
<thead>
<tr>
<th>Source</th>
<th>No. of Eyes</th>
<th>Age, y</th>
<th>Test Used</th>
<th>Percentage of Eyes With Visual Acuity Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( \geq 20/20 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( \geq 20/20 )</td>
</tr>
<tr>
<td>Present study*</td>
<td>106</td>
<td>9.8-10</td>
<td>ETDRS$ charts</td>
<td>OD: 85</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OS: 75</td>
</tr>
</tbody>
</table>

### Table 6. Goldmann Perimetry Results

<table>
<thead>
<tr>
<th>Study</th>
<th>No. of Eyes</th>
<th>Age, y</th>
<th>Stimuli</th>
<th>Meridians, Degrees</th>
<th>Means, Degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liao</td>
<td>33</td>
<td>10-10.5</td>
<td>I</td>
<td>0, 45, 90, 135, 180, 225, 270, 315</td>
<td>75, 48, 40, 45, 52, 52, 56, 71 (ODs)</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>10.5-10.9</td>
<td>I</td>
<td>0, 45, 90, 135, 180, 225, 270, 315</td>
<td>72, 50, 42, 48, 53, 54, 56, 69 (ODs)</td>
</tr>
<tr>
<td>Matsuo et al</td>
<td>18 (eyes)</td>
<td>10</td>
<td>V-4, I4, I3</td>
<td>0, 45, 135, 180, 225, 315</td>
<td>–60, 60, 70, 90, 80, 60 (V-4, OS)</td>
</tr>
<tr>
<td>Quinn et al</td>
<td>56</td>
<td>4-10</td>
<td>V-4-e</td>
<td>45, 135, 225, 315</td>
<td>58, 48, 50, 76 (ODs, medians)</td>
</tr>
<tr>
<td>Present study</td>
<td>106</td>
<td>9-10</td>
<td>V-4-e, III-4-e</td>
<td>15, 60, 105, 150, 195, 240, 285, 330</td>
<td>86, 60, 49, 51, 51, 52, 70, 86 (V-4-e, ODs)</td>
</tr>
</tbody>
</table>
Figure 2. Measured visual field extent for the V-4-e stimulus for right eyes tested in this study, compared with results of Quinn et al\textsuperscript{16} for 4- to 10-year-old children (V-4-e stimulus), Liao\textsuperscript{14} for 10- to 17-year-old children (I stimulus), and Matsuo et al\textsuperscript{15} for 10-year-old children (V-4 stimulus).

P<.001). The significant difference obtained for contrast sensitivity results may be related to the fact that contrast sensitivity was always tested after completion of distance and near visual acuity testing, and therefore, the children may have been less attentive for testing of contrast sensitivity of the second eye.

The goal of this study was to obtain data from full-term children tested with distance visual acuity, near visual acuity, contrast sensitivity, and visual field tests that were identical to those used to assess vision in low-birth-weight children in the CRYO-ROP study. A strength of this study is that all children were tested with an identical, well-established protocol by 2 carefully trained vision testers. Another strength is that the population base for children in this study was similar to that for children who participated in the CRYO-ROP study at The Children's Hospital of Philadelphia. Weaknesses of the study include the relatively small sample size (N = 106) and the fact that subjects were not selected from the entire population of all 10-year-old children in the Philadelphia area. Thus, future studies are needed to provide large-scale normative data on these new tests of visual function.

Accepted for publication September 3, 1998.

This study was supported by Cooperative Agreements 5U10 EY06363 (Dr Quinn) and 5U10 EY08176 (Dr Dobson) from the National Institutes of Health, National Eye Institute, Bethesda, Md.


We thank Erin M. Harvey, MA, for assistance with statistics and graphics, and for comments on the manuscript.

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