Monocular Acuity and Stereopsis in Infantile Esotropia

Eileen E. Birch and David R. Stager

Monocular acuity and stereopsis were assessed by preferential-looking procedures in untreated infantile esotropes. Results were compared to an age-matched normal population. Monocular PL acuity was not significantly different from normal during months 3–14 for infantile esotropes who freely alternated fixation and for the preferred eyes of unilateral infantile esotropes. PL acuity of the non-preferred eyes of unilateral esotropes was significantly below normal during months 9–14, but not during months 3–8. The percentage of normal and esotropic infants who demonstrated PL stereopsis was approximately equal at 3–5 months but, unlike normal infants, the percentage of esotropic infants demonstrating stereopsis was lower in the older age groups. Taken together, the acuity results support previous reports that deficits in PL acuity develop after the onset of fixation preference. The results of PL stereopsis testing are consistent with the hypothesis that stereoscopic pathways are present and potentially functional in at least some esotropic infants. Invest Ophthalmol Vis Sci 26:1624–1630, 1985

Early anomalous binocular experience is known to lead to absence of binocular function, including stereopsis, and may lead to monocular acuity deficits (amblyopia) in both animals and humans.1–5 There are few prospective data available to determine whether the functional deficits associated with infantile esotropia become manifest at a particular age or whether the deficits are congenital. Preliminary results suggest that stereoblindness and PL acuity deficits are first detectable at a later age than the age of onset of esotropia6,7 and have been cited in support of the hypothesis that amblyopia is not congenital.8 It is not known precisely in humans how periods of susceptibility to deficits from anomalous visual experience correspond to periods of visual development. Since the time courses over which acuity and stereopsis normally develop differ greatly,8–16 deficits in these two capacities may begin to develop at different ages in infantile esotropes.

The present study utilized preferential-looking (PL) procedures for the assessment of acuity and stereopsis in a cross-sectional sample of untreated infantile esotropes in order to determine the relationships among the duration of binocular imbalance, the degree of amblyopia, and binocular function. Acuity differences between the eyes and stereopsis of esotropic infants were compared with data from a normal, age-matched population12,17 in order to define the time courses over which visual deficits may develop.

Materials and Methods

Subjects

Eighty-eight esotropic infants aged 3–14 months participated in the study. Two esotropic infants failed to complete testing and their data were not included in the analyses. Infants were referred by their ophthalmologists at the time of their initial visit and had not received prior treatment. All infants received a complete ophthalmological exam prior to participation. None of the patients had associated neurological or neuromuscular disease, retinal disease, cataract, anisometropia (>1 D), and/or optic nerve disorders. The age at which esotropia was diagnosed by a pediatric ophthalmologist ranged from 3 to 7 months. Each of the nine infants who were diagnosed at 7 months had their esotropia noted by their pediatrician prior to 6 months. Twenty-one of the infants had significant (>2 D) bilateral hyperopia.8 Fifty-nine of the infants had a preferred eye (28 preferred OD, 31 preferred OS) while the remaining 29 infants freely alternated fixation. Angle of esotropia as assessed by prism and cover...
test ranged from 30 to 120 p.d. (Mean = 46.9 p.d.; s.e. = 1.8 p.d.). All participants were born within 3 wk of 40 wk gestation. Informed consent was obtained from a parent after the testing procedures had been fully explained.

**Fixation Preference**

Fixation preference was assessed by the cover-uncover test. Infants were assigned to one of the following categories: (1) poor fixation of non-preferred eye, (2) failure to maintain fixation with non-preferred eye, (3) central, maintained fixation of each eye with preference for fixing with one eye, or (4) freely alternating fixation.

**Monocular Acuity**

The stimuli and procedure for obtaining estimates of monocular acuity were identical to those previously employed in a study of normal development. The infant was held over its parent’s shoulder at eye level with two Polacoat (3M; St. Paul, MN) lenscreens (11.5 deg diameter; 36 deg center-to-center separation) which were located 50 cm away in a dark room. The parent faced away from the screens and was unable to prejudice the infant’s response. Two red light-emitting diodes located midway between the screens were flashed between trials to center the infant’s gaze. High contrast (>90%) vertical square-wave gratings and paired gray fields were rear-projected onto the screens by means of Kodak (Eastman Kodak; Rochester, NY) slide projectors. The gratings and gray fields were photometrically matched in space-averaged luminance (2.5 log cd/m²).

On each trial, the infant was confronted with a grating versus gray held stimulus pair. An observer, located behind the screens, viewed the infant through a peephole and, without knowledge of the position of the grating, made a forced-choice judgment about which side the infant preferred. Each test consisted of a 60 trial series per eye using the method of constant stimuli: 5 spatial frequencies presented 12 times each in pseudo-random order and on a randomly chosen side. The five spatial frequencies employed were separated by one octave steps.* That is, each grating step was composed of stripes one-half as wide as the previous one. The range of spatial frequencies employed depended upon the infants’ age: 3–6 months: 0.75 to 12 c/deg (20/800 to 20/50), 7–14 months: 1.5 to 24 c/deg (20/400 to 20/25).

* Spatial frequency describes the width of vertical stripes which compose the grating in terms of cycles per degree of visual angle (where one cycle is defined as one black and one white stripe). An octave difference in spatial frequency corresponds to a doubling or halving of stripe width. Although all testing was conducted at 50 cm rather than 20 ft, Snellen equivalents are provided throughout the text for convenience of comparison.

In each session, the right eye was tested first, followed by the left eye and, when possible, a retest of the right eye. Occlusion was achieved by covering one eye with an orthoptic patch (Opticlude, 3M Co.). Hyperopic infants were tested with appropriate corrective lenses.

Acuity for each eye was determined graphically from the psychometric function relating percent preference for gratings to spatial frequency. Eighty-two percent of the psychometric functions were monotonic and, for these functions, acuity was defined as the spatial frequency corresponding to preference for gratings on 75% of trials. Since only preference for gratings (and not for gray fields) was considered as evidence of discrimination, the one-tailed binomial probability associated with this criterion was \( P < 0.07 \). The remaining 18% of functions were non-monotonic; ie, there existed two spatial frequencies corresponding to 75% preference for gratings with less than 75% preference for an intermediate spatial frequency. For these functions, acuity was defined as the geometric mean of the two criterion spatial frequencies.

**Stereopsis**

The infant was held by its parent at a distance of 50 cm from two Polacoat Lenscreens (25.8 deg square, 34 deg center-to-center separation) which were located at eye level in a dark room. Two light-emitting diodes located between the screens flashed at the start of each trial to center the infant’s gaze. Two half-fields of a stereogram (one for each eye) were rear-projected onto each screen. The views of the eyes were separated by means of crossed polarizers (extinction ratio = 10⁻⁴) mounted in the stereoprojector (Hawk Mk V, Agar Aides, Ltd.; Essex, England) and in goggles worn by the infant. A zero disparity stereogram on one screen was always paired with a crossed disparity stereogram on the other screen. Mean luminance of both screens was 2.3 log cd/m² (contrast = 92%).

All but one of the esotropes were tested with prismatic correction (as determined by prism and cover test) placed in the goggles. The remaining esotrope had a deviation of 120 p.d. and was not tested. Since completely accurate prismatic correction was difficult to obtain, the stereograms employed were specifically designed to minimize the effects of the remaining vergence error on performance. In this way, we attempted to evaluate sensory capacity even in the presence of motor fusion error. Each stereogram was composed of seven 2.0-deg wide black bars separated by six 2.0-wide white bars. To create horizontal binocular disparity, alternate black bars in one half-field were shifted laterally (in the same direction). These periodic stimuli allow for multiple fusion loci determined by the periodicity of the bars; as long as parts of the pattern fall on corresponding retinal areas, the...
maximum absolute disparity is 2.0 deg. This type of stereogram produces what has been described as ‘the wallpaper phenomenon’. In an earlier study with 1.4 deg wide bars, results from normal infants with simulated motor fusion errors (base-in prisms) suggested that stereopsis remained demonstrable in this paradigm until misalignment was so great that almost no stimulation of corresponding retinal areas occurred (approximately 40 p.d.). For purposes of direct comparison with the present study, 10 additional normal infants aged 5–10 months were tested with the larger, 2 deg-wide black bars while wearing 20 p.d. base in. These infants continued to demonstrate stereopsis, as did the infants in the prior study.

The testing room was dark so that the primary cues for accommodation and convergence were located in the plane of the screen. On each trial, a stimulus pair (zero versus non-zero disparity) was presented, and an observer, without knowledge of the position of the disparate stimulus, made a forced-choice judgment as to which side the infant preferred. The position of the disparate stimulus was randomized differently for each subject. Twelve trials were obtained with 45-min crossed disparity. As a control, 12 trials were obtained with 90-min crossed disparity. This disparity is too large to support stereopsis in adults (producing rivalry) and is either not preferred or avoided by normal infants. However, this stimulus pair does contain all of the other monocular and non-stereoscopic binocular cues on which an infant may base preference.

Passing the test for stereopsis required that the infant prefer 45 min crossed disparity to zero disparity on at least 9 of 12 trials. Since only preference for the disparate stimulus was taken as evidence of stereopsis (and not preference for zero disparity), the one-tailed binomial probability associated with this criterion is P < 0.074. However, if the infant reached criterion for both the 90-min and 45-min disparity stereogram (by preferring the disparate stimulus on 9 or more of 12 trials), discrimination was attributed to non-stereoscopic cues, and the result was considered a failure to demonstrate stereopsis.

### Normative Acuity and Stereopsis Data

In an earlier study, monocular acuity development and the range of normal differences in acuity between the two eyes during months 0–11 were described. These results, along with monocular acuity data from five additional normal infants aged 12–14 months, are summarized in Table 1 and comprise the baseline for comparison with data from esotropic infants. The mean interocular difference in acuity was obtained by calculating the absolute value of the difference between right eye and left eye acuity for each infant (in octaves) and determining the means of these difference scores for each age group. The distribution of difference scores in each age group did not significantly deviate from a normal distribution (Kolgomorov-Smirnov tests). On the assumption of the best fitting normal distribution for each age group, the range of acuity differences between the eyes within which 95% of normal infants would be expected to occur was determined. Test-retest reliability was assessed both by computing the Pearson product moment correlation coefficient for the sample as a whole and by calculating the absolute value of the difference between test and re-test acuity in each eye and the means of the difference scores for each age group.

Also shown in Table 1 are the percentages of infants in each age group who demonstrated stereopsis with a 45-min disparity stimulus in an earlier study. These results are consistent with those of other studies using a wide variety of stimuli and measurement procedures.

### Results

Mean PL acuity of preferred and non-preferred eyes of unilateral infantile esotropes is compared with mean normal monocular acuity in Figure 1. Mean preferred eye acuity increased from 4.1 cyc/deg (20/150) at 3–5 months to 8.5 cyc/deg (20/70) at 12–14 months. Within each age group, preferred eye acuity was not significantly different from the mean monocular acuity of

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**Table 1. Normative monocular acuity* and stereopsis† data**

<table>
<thead>
<tr>
<th>Age (months)</th>
<th>3–5</th>
<th>6–8</th>
<th>9–11</th>
<th>12–14‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>49</td>
<td>21</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>Mean monocular acuity (cyc/deg)</td>
<td>4.9</td>
<td>5.9</td>
<td>9.6</td>
<td>10.8</td>
</tr>
<tr>
<td>Mean acuity of better eyes (cyc/deg)</td>
<td>6.3</td>
<td>6.8</td>
<td>11.5</td>
<td>13.6</td>
</tr>
<tr>
<td>Mean acuity of worse eyes (cyc/deg)</td>
<td>3.4</td>
<td>4.7</td>
<td>7.7</td>
<td>8.5</td>
</tr>
<tr>
<td>Mean interocular difference (octaves)</td>
<td>0.96</td>
<td>0.64</td>
<td>0.55</td>
<td>0.53</td>
</tr>
<tr>
<td>Upper limit of normal interocular acuity difference (octaves)</td>
<td>2.17</td>
<td>1.45</td>
<td>1.14</td>
<td>1.18</td>
</tr>
<tr>
<td>Test-retest reliability (octaves)§</td>
<td>0.56</td>
<td>0.37</td>
<td>0.55</td>
<td>0.48</td>
</tr>
<tr>
<td>% infants demonstrating stereopsis</td>
<td>62</td>
<td>98</td>
<td>96</td>
<td>—</td>
</tr>
</tbody>
</table>

* Birch (1985).
† Birch, Gwiazda, and Held (1982).
‡ These data were obtained by the procedures described in Birch (1985).
§ Test-retest reliability overall was r = 0.81. On the average, test-retest reliability was 0.49 octaves. This is approximately equivalent to one line on a Snellen acuity chart (e.g., ±0.5 octaves for 20/20 are 20/14 and 20/28).
age matched normals ($t_{100} = 0.99, t_{56} = 1.83, t_{52} = 0.47, t_{14} = 1.01$, respectively; note: all t-tests in this report are two-tailed). Mean PL acuity of the non-preferred eye showed little improvement over months 3–14 and was significantly below normal during months 9–11 ($t_{52} = 2.75, P < 0.01$) and 12–14 ($t_{14} = 3.03, P < 0.01$).

Mean PL acuity of infantile esotropes who were clinically judged to freely alternate fixation is shown in Figure 2. Mean monocular acuity of the better and worse eyes of normal infants over the same age range is shown for comparison. Mean PL acuity of the better eye of alternate esotropes increased from 5.9 cyc/deg (20/100) to 10.6 cyc/deg (20/60) over months 3–14 and was never significantly different from the PL acuity of the better eyes of normals ($t_{50} = 0.23, t_{26} = 1.03, t_{25} = 1.68, t_{8} = 1.65$, respectively). Mean PL acuity of the worse eyes of alternate esotropes increased from 4.7 cyc/deg (20/130) at 3–5 months to 8.9 cyc/deg (20/70) at 12–14 months and was never significantly different from the PL acuity of the worse eyes of normals ($t_{50} = 1.38, t_{26} = 0.38, t_{25} = 1.79, t_{8} = 0.20$, respectively).

For each infant, the difference in acuity between eyes was calculated (in octaves). The mean difference in acuity for each age group is shown in Figure 3. The mean acuity difference for unilateral esotropic infants (preferred eye-nonpreferred eye) increased from 0.53 octaves at 3–5 months to 1.37 octaves at 12–14 months. The mean acuity difference was significantly above normal during months 9–11 ($t_{52} = 3.04, P < 0.01$) and 12–14 ($t_{14} = 2.26, P < 0.05$). For infantile esotropes who freely alternated fixation, the mean acuity difference (better eye-worse eye) ranged from 1.08 to 0.27 octaves but was never significantly different from normal ($t_{50} = 1.82, t_{26} = 1.86, t_{19} = 0.42, t_{9} = 0.26$, respectively).

The PL criterion for amblyopia in each age group was based on the range of PL acuity differences between eyes within which 95% of the normal population would be expected to occur (see Normative Data and Table 1). Esotropic infants with PL acuity differences between eyes which exceeded the upper limit of the normal range were considered amblyopic. The percentage of esotropic infants with PL amblyopia in each age group is shown in Figure 4. None of the esotropic infants who freely alternated fixation was found to be amblyopic by the PL criteria. The percentage of unilateral esotropic infants with PL amblyopia increased from 0% at 3–5 months to 67% at 12–14 months.
with amblyopia as determined by the PL criteria defined in the text.

Table 2.

<table>
<thead>
<tr>
<th>Age (months)</th>
<th>Unilateral esotropia preferred eyes</th>
<th>Unilateral esotropia non-preferred eyes</th>
<th>Alternate esotropia</th>
<th>Normals</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-5</td>
<td>60.4</td>
<td>57.9</td>
<td>61.8*</td>
<td>51.0</td>
</tr>
<tr>
<td>6-8</td>
<td>53.0</td>
<td>53.4</td>
<td>56.8</td>
<td>45.7</td>
</tr>
<tr>
<td>9-11</td>
<td>52.9</td>
<td>47.5</td>
<td>52.7</td>
<td>43.8</td>
</tr>
<tr>
<td>12-14</td>
<td>57.7</td>
<td>55.0</td>
<td>50.8</td>
<td>52.0</td>
</tr>
</tbody>
</table>

* Above the 95% confidence limit for normals.

Fig. 4. Percentage of esotropic infants in each of four age groups with amblyopia as determined by the PL criteria defined in the text.

Two possible non-sensory causes of low PL acuity in non-preferred eyes of unilateral infantile esotropes (aged 9–14 months) were evaluated. First, it is possible that PL tests of non-preferred eyes are less reliable than PL tests of preferred eyes. In order to address this issue, test-retest reliability was measured in 15 infantile esotropes aged 8–14 months. The absolute value of the difference between test and retest acuity (in octaves) was computed for each child. The mean difference between test and retest was 0.33 octaves overall, 0.38 octaves for 7 non-preferred eyes, and 0.29 octaves for 8 preferred eyes. These results indicate that the reliability of the test is comparable for non-preferred and preferred eyes (t_{13} = 0.78, n.s.) and for non-preferred eyes and normals (t_{46} = 0.02, n.s.). Overall, test-retest reliability was r = 0.85 (For normals, r = 0.81).

Second, possible performance deficits related to limited abduction were also evaluated. It is possible that unilateral esotropic infants may become progressively more unwilling or unable to abduct the non-preferred eye and, therefore, do not readily fixate stimuli which are presented in the temporal visual field. Although subjectively there were no difficulties associated with tests of the non-preferred eyes, limited abduction might have led to a bias for the observer who scored the infants’ visual preferences to make judgments of nasalward fixation. The percentage of trials on which each eye of each infant fixated the stimulus in the nasal visual field (regardless of the position of the grating) was calculated.* The mean percentage of trials resulting in fixation of the nasal visual field for each age group is shown in Table 2. The percentage of trials on which infantile esotropes showed nasalward fixation preference is within the 95% confidence interval for normals in both the non-preferred and preferred eyes for all age groups. Only the 3–5 month old alternate esotropes showed a significantly greater preference for fixation of stimuli in the nasal visual field than normals.

A comparison of diagnosis of amblyopia by clinical assessment of fixation and by PL criteria is given in Table 3. None of the infants who freely alternated fixation were found to be amblyopic by PL criteria. In addition, 23 of 24 infants who were capable of central, maintained fixation with each eye despite preference for fixing with one eye were non-amblyopic by PL criteria. Of 35 infants having poor fixation or failure to maintain fixation with one eye, only 13 (37%) were found to be amblyopic by PL criteria. In order to fulfill the requirements regarding minimum expected frequencies for a chi-square test, clinical categories were combined into two categories, unilateral (poor fixation and failure to maintain fixation) and alternate esotropia (freely alternates and maintains fixation). For the resulting 2 × 2 table, $\chi^2 = 7.67, P < 0.02$.

Table 3. Comparison of clinical and PL criteria for amblyopia

<table>
<thead>
<tr>
<th>Clinical assessment of fixation*</th>
<th>PL acuity result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor fixation in non-preferred eye</td>
<td>Amblyopia</td>
</tr>
<tr>
<td>Failure to maintain fixation in non-preferred eye</td>
<td>8</td>
</tr>
<tr>
<td>Central maintained fixation with preference for one eye</td>
<td>5</td>
</tr>
<tr>
<td>Freely alternates fixation</td>
<td>1</td>
</tr>
</tbody>
</table>

* Fixation was assessed by the cover-uncover test.

The percentage of normal and esotropic infants (both unilateral and alternate) who demonstrated PL stereopsis is shown as a function of age in Figure 5. Approximately equal percentages of normal and esotropic
monocular acuity and stereopsis in infantile esotropia

infants reached criterion at 3–5 months of age. While most normal infants demonstrate stereopsis after 6 months of age, few esotropic infants aged 6–14 months reached criterion (two of these infants showed preference for both 45 min and 90 min stereograms).

A comparison of results obtained with esotropic infants in the PL acuity and PL stereopsis procedures is given in Table 4. Most esotropic infants (71%) failed to show evidence of stereopsis. Of the esotropic infants who did demonstrate stereopsis, 76% were in the 3–5 month age group. Overall, approximately equal proportions of PL amblyopic and PL non-amblyopic infants demonstrated stereopsis ($\chi^2 = 1.83$, n.s.).

**Discussion**

Monocular PL acuity was not significantly different from normal during months 3–14 for infantile esotropes who freely alternated fixation and for the preferred eyes of unilateral infantile esotropes. PL acuity of the non-preferred eyes of unilateral infantile esotropes was significantly below normal only during months 9–14. This result is in general agreement with previous studies of a limited number of esotropic infants which suggested that deficits in PL acuity develop after the onset of fixation preference. Over 50% of unilateral infantile esotropes aged 9–14 months had significantly greater than normal differences between the acuities of the two eyes. Two possible non-sensory factors which might have affected the measured PL acuity of the non-preferred eye were directly evaluated; the poor PL acuity of non-preferred eyes in the older age groups is unlikely to be due to lower reliability of the test or to abduction defect.

While criteria for determining amblyopia clearly differ for the two methods, there exists general agreement between the diagnosis of amblyopia by PL criteria and by clinical assessment of fixation. Infants with maintained fixation for both eyes were found non-amblyopic by PL in 98% of cases. However, the percentage of infants with poor fixation of one eye or failure to maintain fixation identified as amblyopic by PL criteria was relatively low (37%). A similar pattern of results was recently reported by Mayer, et al; there was 88% agreement for alternate esotropes but, in 32% of unilateral esotropes, acuity was equal in the two eyes. One possible explanation, which has been advanced by other authors, is that amblyopia may have a later age of onset than the age at which fixation preference develops. While the clinical judgment of amblyopia based on fixation preference may include infants who are at risk for developing amblyopia in the future, it is also possible that differences between the two methods of evaluation lead to the clinical identification of amblyopia in infants whose amblyopia is not deep enough to be detected by the PL technique. For example, one factor which is likely to contribute to discrepancy in diagnosis is the difference in retinal area tested (foveal vs. large-field stimuli). Both of these suggestions are consistent with the increase in the percentage of infants with poor fixation or failure to maintain fixation identified as amblyopic by PL criteria, as the present sample is limited to progressively older age groups: 6–14 months: 52%; 9–14 months: 71%; 12–14 months: 83%.

Previous studies of PL acuity in esotropic infants have employed a criterion for amblyopia based on test reliability; differences between PL acuity of the two eyes which exceeded test reliability were considered evidence of amblyopia. Use of this criterion leads to frequent disagreement between PL and clinical assessment of which eye was amblyopic. The more strict criterion for amblyopia employed in the present study takes into account the finding that many normal infants have acuity differences between the eyes which exceed test reliability. Using this criterion for amblyopia resulted in only one disagreement between PL and clinical assessment of which eye was amblyopic. Some of the previously reported disagreements may have resulted from a less stringent criterion for PL amblyopia.

The percentage of normal and esotropic infants who demonstrated stereopsis in the PL procedure is nearly equal at 3–5 months. Since these infants did not pre-

**Table 4.** Comparison of results from PL acuity and stereopsis tests

<table>
<thead>
<tr>
<th>PL amblyopia</th>
<th>yes</th>
<th>no</th>
</tr>
</thead>
<tbody>
<tr>
<td>PL stereopsis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>yes</td>
<td>2</td>
<td>23</td>
</tr>
<tr>
<td>no</td>
<td>12</td>
<td>48</td>
</tr>
</tbody>
</table>
erentially fixate a stimulus with horizontal disparity too large to support stereopsis (90 min), it is unlikely that discrimination was based on non-stereoscopic cues. These data suggest that stereoscopic pathways are present and potentially functional in at least some esotropic infants. A similar result based on a very different methodology for assessing stereopsis has been previously reported. At later ages, virtually all normal infants demonstrate stereopsis. In contrast, a smaller percentage of esotropes aged 6–14 months demonstrated stereopsis. Whether this represents a sensory loss or other developmental factors is unknown. Despite the prism correction worn during stereopsis testing and the use of stimuli which limited the effect of vergence error on performance, some fusional effort on the part of the infants was probably required. It is possible that the ability to fuse disparate stimuli decreases with age. Alternately, it may be that some esotropic infants who initially develop stereopsis at 3–5 months subsequently lose this visual capacity.

Key words: esotropia, infants, acuity, stereopsis, preferential-looking

References