Stereopsis After Congenital Cataract

Milan E. Tytla, Terri L. Lewis, Daphne Maurer, and Henry P. Brent

**Purpose.** The authors determined whether stereopsis can be demonstrated in children treated for congenital cataract after compensating for their amblyopia and strabismus.

**Methods.** A custom-made set of large stereograms was used to compensate for amblyopia and presented in a synoptophore to facilitate motor fusion. Each pair of stereograms contained five wide vertical bars of high contrast, of which two or three were in crossed disparity. The authors aligned the stimuli in the synoptophore, then decreased the disparity until the child could no longer identify which bars appeared to be “in front.”

**Results.** In normal children (n = 25), stereo acuity on this test (Tytla-Lewis-Maurer-Brent [TLMB] test) correlated well with the Titmus and Randot results within the ranges measured by those tests. Seven children in whom a traumatic cataract had developed after 6 yr of age (four with no clinical stereopsis) had TLMB test stereo acuities ranging from 225 to 28 arc-sec. Of 30 children treated for congenital cataract with no clinical stereopsis, 5 regularly achieved a TLMB stereo acuity of up to 225 arc-sec, and 2 with Titmus stereo acuities up to 200 arc-sec, each had a TLMB stereo acuity of 112 arc-sec. These seven congenital cases (two unilateral and five bilateral) with measurable TLMB acuities are among those with the shortest deprivation, the highest minimum resolvable acuity, and the highest contrast sensitivity.

**Conclusions.** By compensating for amblyopia and strabismus, stereopsis can be demonstrated in some form-deprived amblyopic patients. Invest Ophthalmol Vis Sci. 1993;34:1767-1773.

Virtually all children treated for congenital cataracts fail clinical tests of stereo vision. Entirely consistent with this fact is the large body of research on cats and monkeys reared with early form deprivation. These animals show both a shift in the ocular dominance histogram from its normal binocular form to domination by the nondeprived eye and a loss of neurons tuned to binocular disparity.1-3 Presumably, the stereo blindness is a manifestation of these cortical changes.

Consider, however, that populations of binocular cortical neurons have been found in lid-sutured cats after bilateral deprivation,4,5 very short unilateral deprivation,6-9 and distributed reverse occlusion after unilateral deprivation,10 especially if followed by binocular visual experience.11 With the steady decline in the age of congenital cataract extraction, along with greater emphasis on occlusion therapy in unilateral cases, there has been considerable improvement in the acuity achieved after treatment for congenital cataract.12-14 Perhaps some of these children also have the neural substratum required for stereopsis.

Consider further that, although failures on standard stereo tests like the Titmus or Randot may reflect a genuine absence of stereo vision, a negative result also may be caused by two factors commonly associated with congenital cataract: (1) secondary strabismus and (2) amblyopia. Children with a strabismus whose deviation exceeds Panum’s area of single binoc-
ular vision, will consistently fail stereo tests employing only vectograph or anaglyph means of dissociation, simply because of their inability to align the stereoscopic stimuli on corresponding points on the two retinas. Tests designed for the synoptophore can compensate for the strabismus, but the commercially available stereograms consist of small and finely detailed contours, which are imperceptible to most amblyopic eyes.

Therefore, it is possible that some children treated for congenital cataract have stereopsis and, by implication, a population of binocular cortical neurons. We examined this possibility using stereograms sufficiently large to be seen by amblyopic eyes and presented in a synoptophore to facilitate motor fusion.

METHODS

This research followed the tenets of the Declaration of Helsinki. Informed consent was obtained from each parent or guardian and informed assent from each child after the nature and possible consequences of the study were explained. The research was approved by the human experimentation committee at The Hospital for Sick Children.

Subjects

Three groups of children participated in the study: congenital cataract, traumatic cataract, and normal control.

Congenital Cataract. This group consisted of 32 children treated for a dense and central cataract in one (n = 14) or both (n = 18) eyes diagnosed before 5 mo of age. All had had the cataract(s) removed surgically and had worn regularly a contact lens over the aphakic eye(s). In every case, the retina, including the macula, appeared normal postsurgically. The duration of deprivation (age of first contact lens fitting) ranged from 2–19 mo (mean, 7.2 mo). Among the unilateral cases, the unaffected fellow eyes were clinically normal and had been patched for periods ranging from 0–50% of waking time during early childhood. Ages at the time of the test ranged from 5–17 yr (mean, 7.3 yr). At that time, none had a secondary membrane covering the optic axis. All these children had amblyopia and secondary strabismus, with Snellen acuity in the aphakic eyes ranging from 6/9–6/240 (mean, 6/95).

Traumatic Cataract. This group consisted of seven children, aged 7–17 yr, with normal early histories until a dense and central cataract had developed after the age of 6 yr. Like the congenital cases, they had surgery to remove the cataract (within days of the trauma) and, subsequently, wore a suitable contact lens. The period of deprivation (age of diagnosis to the age of contact lens fitting) ranged from 4–5 weeks. In four, an exotropia developed posttrauma; the remaining three children were orthotropia. The fellow eyes were normal. Acuities ranged from 6/6–6/12 in the aphakic eyes and from 6/5–6/6 in the unaffected fellow eyes.

Normal Control. This group consisted of 25 children, aged 4.3–16 yr (mean, 8.1 yr), with no history of eye problems and with a Snellen acuity of at least 6/6 in each eye.

Stimuli and Procedure

To circumvent the problems posed by amblyopia and strabismus, we designed a set of stereograms employing targets large enough to be seen by amblyopic eyes and presented them in a synoptophore, which permits alignment on corresponding points on the two retinas. Figure 1 depicts the mirror-reversed members of one stereo pair. Only the circles and their contents are visible in the synoptophore. All stimuli are in perfect register for the two eyes except for the vertical and horizontal lines beneath the letter C and, in this example, the bars above the letters B and C. When fused, all binocularly registered stimuli appear to lie in the same frontoparallel plane. The lines beneath the letter C are used to differentiate suppressors from those with simultaneous binocular vision. Thus, for example, patients who suppress the left eye only see the horizontal bar, whereas those capable of fusion see an intersection of the vertical and horizontal bars. The bars above the letters B and C are displaced nasally in each frame of this example. This crossed disparity when fused stereoscopically results in Bars B and C appearing in front of the plane of the display. To mask position as a

FIGURE 1. Example of mirror-reversed stereo pair taken from the TLMB stereo test with exaggerated disparity (225 sec). Only the circle and its contents are visible when viewed in the Synoptophore. The lines below the letter C intersect when the stereo pairs are fused. The bars above the letters B and C are displaced nasally (crossed disparity) and, when fused, appear to be closer to the observer than the rest of the display, all elements of which are in perfect register (zero disparity) and lie on the horopter. We suggest free fusion be attempted with relaxed vergence and a close viewing distance to produce crossed disparity easily. If successful, notice the foreshortening of bars B and C experienced by many subjects.
The data presented in Figure 2 plot stereo acuity on our test (Tylala-Lewis-Maurer-Brent [TLMB]) against clinical stereo acuity. Each point represents the median of three threshold determinations for the normal control group and the median of at least six thresholds for the aphakic patients. All normal children exhibited stereopsis on all tests, with a mean TLMB stereo acuity of 29.3 arc-sec (range, 14–112 sec). The proximity of the control data to the unity line indicates that our test and the clinical stereo tests measure similar functions. The five normal children with the poorest stereo acuity (112 arc-sec on TLMB and a median of 100 arc-sec on the Titmus) were also the youngest of the control group; each was 4–5 yr old. This finding agrees with previous reports that stereo acuity is not yet mature in children younger than 5 yr of age.16–18 In the other control subjects, who were older than 5.8 yr of age, there was no relationship between age and stereo acuity.

All seven patients treated for traumatic cataract also exhibited TLMB stereopsis, ranging from 28–112 arc-sec. Four of these showed no clinical stereopsis probably because an exotropia, which had developed after the trauma, prevented motor fusion. However, of these latter four, three had TLMB stereo acuities (112 arc-sec) that were outside the 99% confidence interval defined by the normal sample. If their pre-trauma stereo acuities were normal, it is possible that their current mild stereo deficit reflected an imperfect alignment of the stimuli caused by small inaccuracies in the subjective reports of our young patients.

Of the 32 children treated for congenital cataract, 30 have never exhibited stereopsis on any clinical test. In 25 of these 30, no stereoscopic response could be elicited on the TLMB test. These 25 children exhibited constant suppression of one eye, both clinically on the Worth four-dot test and during our test. The seven remaining congenital cases, two unilateral and five bilateral, consistently showed TLMB stereo acuities ranging from 450 to 112 arc-sec. Their clinical histories and stereo acuities are shown in Table 1. Only two of these children had clinically measurable stereo vision, with median Titmus scores of 400 and 200 arc-sec, respectively. Although these two children are capable of simultaneous binocular vision, this performance may not represent stereopsis, but rather, it may be the discrimination of the larger horizontal displacements...
of the stereo circles or animals of the Titmus. We have often seen normal children achieve comparable or better results using only one eye.

By contrast, extraneous cues cannot account for positive results on the TLMB test. The normal control group tested monocularly performed randomly, a result indicating that monocular cues were not the basis of correct identification in the binocular TLMB task. Additional evidence that stereopsis was involved comes from the spontaneous reports by many of the control subjects and five of the seven congenital cases with TLMB stereo acuity that the nearer bars also appeared smaller. Such illusory size or distance foreshortening indicates that stereo depth was indeed being processed because the only cue to depth available in the display is retinal disparity. Finally, when Janine, a child treated for unilateral congenital cataract, was retested with the vertical bars, she replicated her previous result of 112 arc-sec of stereo acuity. However, with the bars oriented horizontally, she did not detect even the largest disparity. Together, these results exclude explanations other than stereo vision in patients with positive results on our test.

DISCUSSION

By compensating for amblyopia and problems with ocular alignment, a degree of stereopsis could be demonstrated in 7 of 32 (22%) form-deprived amblyopic eyes. These seven were among the congenital cases with the
TABLE 1. Clinical Details for Congenital Patients With Positive Results on the TLMB Stereotest

<table>
<thead>
<tr>
<th>Name</th>
<th>Age (mo) of Diagnosis/Contact Lens</th>
<th>Median Snellen Acuity</th>
<th>Alignment</th>
<th>Nystagmus</th>
<th>Additional Information</th>
<th>Titmus/ Randot (arc sec)</th>
<th>TLMB (arc sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unilateral patients</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>David</td>
<td>OD plano</td>
<td>6/6</td>
<td>6/6</td>
<td>2 pd LXP</td>
<td>No</td>
<td>Strabismus surgery OS at 4.8 yr; excellent patching from 0.5 to 5.5 yr (50% of waking time)</td>
<td>400</td>
</tr>
<tr>
<td>(11)</td>
<td>OS +12.00</td>
<td>6/12</td>
<td>8 pd LHP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Janine</td>
<td>OD plano</td>
<td>3.5/4.9</td>
<td>6/6</td>
<td>2 pd LXT</td>
<td>No</td>
<td>Excellent patching from 0.4 to 7.4 yr (tapered from 50 to 30% of waking time at 4.4 yr)</td>
<td>200</td>
</tr>
<tr>
<td>(17)</td>
<td>OS +13.25</td>
<td>6/12</td>
<td>14 pd LXT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bilateral patients</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caitlin</td>
<td>OD +8.50</td>
<td>1.1/3.0</td>
<td>6/12</td>
<td>35 pd LET</td>
<td>Latent</td>
<td>Strabismus surgery OU at 1.5 yr</td>
<td>No stereo</td>
</tr>
<tr>
<td>(5)</td>
<td>OS +8.50</td>
<td>1.1/3.0</td>
<td>6/18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adam</td>
<td>OD +15.25</td>
<td>4.0/6.4</td>
<td>6/10</td>
<td>10 pd LXT</td>
<td>Manifest</td>
<td>Surgery: Secondary membrane OS at 0.8 yr; strabismus OS at 3.7 yr</td>
<td>No stereo</td>
</tr>
<tr>
<td>(9)</td>
<td>OS +14.25</td>
<td>4.0/5.3</td>
<td>6/15</td>
<td>10 pd LHT</td>
<td>OU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lindsay</td>
<td>OD +11.50</td>
<td>3.3/5.2</td>
<td>6/8</td>
<td>10 pd LXT</td>
<td>Manifest</td>
<td>No additional surgery; microphthalmos OD</td>
<td>No stereo</td>
</tr>
<tr>
<td>(6)</td>
<td>OS +13.50</td>
<td>3.3/5.2</td>
<td>6/24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grant</td>
<td>OD +31.75</td>
<td>2.7/6.1</td>
<td>6/27</td>
<td>14 pd RET</td>
<td>Manifest</td>
<td>Surgery: Secondary membrane OD at 0.6 and 2.2 yr; strabismus OD at 0.8 yr</td>
<td>No stereo</td>
</tr>
<tr>
<td>(8)</td>
<td>OS +27.75</td>
<td>2.7/6.1</td>
<td>6/30</td>
<td>4 pd LHT</td>
<td>OU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iain</td>
<td>OD +14.00</td>
<td>2.5/5.9</td>
<td>6/30</td>
<td>14 pd RET</td>
<td>Manifest</td>
<td>Strabismus surgery OD at 3.3 and 6.0 yr</td>
<td>No stereo</td>
</tr>
<tr>
<td>(8)</td>
<td>OS +16.50</td>
<td>2.5/9.6</td>
<td>6/9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

pd, prism diopter. ET, esotropia. XT, exotropia. XP, exophoria. HT, hypertropia. HP, hyperphoria. R, right. L, left. OU, both eyes.

shortest deprivation (3.2 and 4.9 mo for the unilateral and 3.0–9.6 mo for the bilateral cases) and had the best spatial resolution. By comparison, the 25 children treated for congenital cataract without measurable stereopsis had endured periods of deprivation ranging from 4.7–19.4 mo for the unilateral cases and 9.6–18 mo for the bilateral cases. Thus, among children deprived from birth, short deprivation appears to have the least destructive influence on visual development. In unilateral cases, however, the extent of occlusion may also be an important factor. For example, of the unilateral congenital cases, David and Janine, whose affected eyes were deprived for 3.2 and 4.9 mo, respectively, were the only ones to demonstrate any stereo acuity (112 arc-sec, Table 1). They also had the best visual resolution we have measured in children treated for congenital cataract. Their nearly normal contrast sensitivities are depicted in Figure 3, and at the time of the contrast sensitivity test, their Snellen acuities in the amblyopic eye were 6/15 and 6/12, respectively. (David’s Snellen acuity has since improved to 6/12, likely because he was only 5.5 yr old at the time of the contrast sensitivity test.) Only two other unilateral cases had endured periods of deprivation as short as those of David and Janine. Sandra, deprived 4.7 mo, and Krista, deprived 5.7 mo, exhibited no stereopsis and, as shown in Figure 3, had profoundly abnormal contrast sensitivity. David and Janine were exceptional in that they complied with their 50% patching regimens throughout early childhood, whereas Sandra and Krista complied barely, if at all. Thus, among unilateral cases, short pattern deprivation and rigorous patching can promote good spatial vision and, perhaps as a consequence, preserve a degree of binocularity. Unfortunately, we cannot comment on the influence of rigorous patching after longer periods of deprivation because none of those children followed the prescribed patching regimen, and all had poor visual acuity.

Of course, we do not suggest that the seven children with positive TLMB results can appreciate stereopsis in everyday life, but the presence of stereopsis in these children implies the existence of a population of binocular cortical neurons with disparity selectivity. As
stereo acuities of 40-500 arc-sec were found in 20 of 35% of children treated early for infantile stereograms. However, the remaining small-angle tropia.21 With the same stereoscopic stimuli, 35% of children treated early for infantile esotropia demonstrated stereopsis. Other studies have not detected stereopsis in potentially amblyopic infants, perhaps because the prismatic corrections were too inaccurate to permit fusion of the random-dot stereograms.25,26

Although disparity detectors tuned to any spatial frequency can support stereopsis, only disparity detectors tuned to high spatial frequencies can support fine stereo acuity.25 It is noteworthy that the seven patients with TLMB stereopsis showed the least loss in Snellen acuity, the least loss in contrast sensitivity at medium and high spatial frequencies, and normal contrast sensitivity for gratings coarser than 2–3 cycles/degree (e.g., David and Janine, Fig. 3). Among the 25 without stereopsis, all had marked losses in Snellen acuity and all but five exhibited losses in contrast sensitivity that extended down to the lowest tested spatial frequency (0.33 cycles/degree) (e.g., Sandra and Krista, Fig. 3). Thus, the reduced stereo acuity in the seven patients with positive TLMB stereopsis likely represents reduced sensitivity in the requisite high spatial frequency neurons. An absence of stereopsis in the remaining patients likely represents reduced sensitivity in both the high and low spatial frequency neurons.25

An obvious inference is that children treated for congenital cataract with no measurable stereopsis have no binocular cortical neurons (or that, if they do, these neurons have exceedingly poor disparity selectivity). However, there are alternatives not controlled for by our stereo test. Foremost among these is aniseikonia. Although stereopsis from random-dot stereograms can tolerate up to a 15% difference in interocular image size,26 the maximum aniseikonia consistent with fine stereopsis for line stimuli like ours is 5–8%.27–29 Among our unilateral congenital cases, for example, the aniseikonia produced by the contact lens required to bring a typical aphakic eye to an infinity focus is in the range of 4–10%.30 Thus, it is possible that some of the congenital cases failed the TLMB task because of aniseikonia. Stereo acuity declines with greater degrees of aniseikonia up to the limit of 18–20%.31 Therefore, aniseikonia also may have diminished the stereo acuity of some of the congenital and traumatic cases who demonstrated TLMB stereopsis. A large reduction in the luminance contrast of one or both members of a stereo pair also may hinder stereopsis.26,30 Finally, we might have underestimated stereo acuity because any small inaccuracies in the subjective reports of our young patients would result in an imperfect alignment of the stimuli.

Although we suspect that few, if any, of the children treated for congenital cataract experience stereopsis in everyday seeing, the TLMB test may nonetheless have clinical utility for children old enough to perform the task. A positive response on the TLMB stereo test may portend a favorable outcome from strabismus surgery because it suggests that the neural substratum for stereopsis is present, perhaps to a degree sufficient to promote and maintain fusion after the globes have been surgically realigned. This possibility could be evaluated easily by examining clinical and TLMB stereo acuities and ocular alignment pre- and postoperatively in school-aged children slated for strabismus surgery.
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Key Words
congenital cataract, amblyopia, stereopsis, strabismus

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References