Sensitivity in the Nasal and Temporal Hemifields in Children Treated for Cataract

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Purpose. To determine if form-deprived aphakes, like normal infants, show especially poor sensitivity in the nasal visual field. The purpose of this article was also to examine the influence on their peripheral sensitivity of the timing and duration of deprivation, of whether deprivation was monocular or binocular, and of having patched the fellow nondeprived eye.

Methods. Static perimetry was used to measure intensity thresholds at 20° in the nasal visual field and at 30° in the temporal visual field in normal subjects (n = 20 7-year-old children, 20 8-year-old children, 12 9-year-old children, and 20 adults) and in 46 children treated for a dense and central cataract in one (n = 21) or both (n = 25) eyes. The deprivation began either at birth or after a normal early history, and the duration of deprivation varied widely among patients. Also tested were two adults who had been treated promptly for unilateral cataracts that had developed after the age of 40 years.

Results. In normal subjects, sensitivity was slightly higher at 20° nasally than at 30° temporally, with no developmental changes in sensitivity at either location. The deprived eyes of the children had losses in sensitivity at both locations but only children treated for unilateral congenital cataract had larger losses at 20° nasally than at 30° temporally. There were no significant effects on their sensitivity of the duration of deprivation or, in children treated for unilateral cataract, of patching of the nondeprived eye. In contrast, the two patients in whom cataracts did not develop until adulthood had normal sensitivity.

Conclusions. Pattern deprivation interferes with the development of peripheral sensitivity at both 30° temporally and 20° nasally. Nasal sensitivity, which is slow to mature, is affected more by early monocular deprivation than by early binocular deprivation. The results are consistent with the hypothesis that unfair interocular competition during early infancy especially affects visual functions that are slow to mature. Invest Ophthalmol Vis Sci. 1993;34:3501-3509.

Adults' sensitivity decreases with eccentricity with only a slight difference in sensitivity between comparable locations in the temporal and nasal visual fields.1-6 For example, adults are slightly less sensitive to a stimulus at 20° in the nasal field than at 20° in the temporal field; but they are more sensitive at 20° nasally than at 30° temporally.1 In contrast, 1-month-old infants are more than eight times less sensitive to stimuli at 20° nasally than at 30° temporally.7 Similarly, during early infancy the extent of the nasal field expands more slowly than does the extent of the temporal field, at least under some testing conditions.8-13

For several other aspects of vision, children treated for monocular deprivation that began early in life have been found to show patterns similar to those shown by young normal infants, and patterns different from those found in children treated for early binocular deprivation. Three examples of the different effects of monocular versus binocular deprivation will be presented, each of which is evident even in comparisons between children treated optimally for monocular deprivation who developed good visual acuity and children treated for binocular deprivation with much poorer visual acuity. First, normal adults demonstrate much better vernier than grating acuity.14 Children treated for bilateral congenital cataracts exhibit nearly equal losses in vernier and grating acuity so that, as in
normal adults, their vernier acuity is almost three times better than their grating acuity. In contrast, children treated for unilateral congenital cataract show much larger losses in vernier acuity than in grating acuity so that, like normal infants, they have nearly equal vernier and grating acuities. Second, normal adults' contrast sensitivity declines with eccentricity. Children treated for congenital cataract show reduced contrast sensitivity, especially of high spatial frequencies. In children treated for bilateral congenital cataracts, contrast sensitivity declines normally with eccentricity so that their loss is constant across the retina. Instead, children treated for unilateral congenital cataract show less decline than normal in contrast sensitivity with increasing eccentricity, so that their loss decreases in the periphery. Similarly, the grating acuity of normal 5- and 12-month-old infants differs less from that of normal adults when stripes are presented more peripherally. Third, the contrast sensitivity of normal adults is degraded by flicker at higher spatial frequencies. Children treated for bilateral congenital cataracts show a similar degradation of contrast sensitivity with flicker such that their sensitivity relative to normal is constant across conditions. Instead, children treated for unilateral congenital cataract exhibit improved contrast sensitivity at higher spatial frequencies as the flicker rate of gratings increases up to 8 Hz, so that their loss is less for flickering than static gratings. Like children treated for unilateral congenital cataract, infants aged 3 to 24 months exhibit better sensitivity to spatial frequencies near their acuity limit when tested with patterns flickering on and off up to 7 times per second than when tested with stationary patterns, so that their sensitivity is closer to that of normal adults with flickering than with static gratings. Together, these results suggest that children who are monoclonally deprived from birth exhibit infantile patterns of visual behavior and, therefore, also might be expected to exhibit larger losses of sensitivity in the nasal than in the temporal field.

To date, there have been four studies examining the effects of visual deprivation on peripheral sensitivity along the horizontal meridian. The first three were case studies in which static perimetry was used to test two patients monocularly deprived from birth to either 5 months or 19 years of age, one patient binocularly deprived from birth to 11 months of age, and one patient binocularly deprived from 11 months until 3 years of age. The results indicate that the deprived eyes have decreased sensitivity throughout the horizontal visual field, with only the patients monocularly deprived from birth exhibiting the infantile pattern of especially large losses in the nasal visual field. However, the samples have been too small to statistically evaluate the effects of the timing and duration of deprivation, the effects of whether the deprivation was monocular or binocular, and the effects of patching the nondeprived eye in unilateral cases. In the fourth study, Tylka et al. assessed contrast sensitivity in the periphery of deprived eyes. Children treated for unilateral congenital cataract, but not those treated for bilateral congenital or traumatic cataracts, showed larger losses of contrast sensitivity in the nasal field than in the temporal field. However, the patient sample was small and possibly unrepresentative because only children with fairly steady fixation were assessed.

The purpose of our study was to use static perimetry to examine in a larger sample whether form-deprived aphakes, like normal infants, show especially poor sensitivity in the nasal visual field. We also examined the influence on peripheral vision of the timing and duration of deprivation, of whether deprivation was monocular or binocular, and of having patched the fellow nondeprived eye. In cats and monkeys, peripheral vision is abnormal after deprivation from lid suture with the magnitude of the effect dependent on the timing and duration of deprivation and whether it was monocular or binocular. There is controversy about the possible benefits of suturing the fellow eye after monocular deprivation. In humans, all of these variables also affect the consequences of visual deprivation on the development of other visual functions.

We used the Octopus perimeter to assess monocular sensitivity at 20° nasally and at 30° temporally, the same locations tested in normal infants. We assessed children aged 7 years or older who had been treated for cataracts in one or both eyes with the onset of deprivation either at birth (congenital groups) or after an early normal history (noncongenital groups). We defined deprivation as lasting from birth (in congenital cases) or from the time of diagnosis of a dense and central cataract (in noncongenital cases) until fitting of the optical correction after surgery. To distinguish the effects of aphakia and its optical correction from the effects of early deprivation, we also tested two adults who had normal vision until they developed a unilateral cataract after the age of 40 years, which was subsequently removed. For comparison, we tested a group of normal adults and, because there are no published norms for children tested with the Octopus perimeter, we also tested groups of normal 7-, 8-, and 9-year-old children. For each of the normative groups, we assessed reliability of responding and interocular differences.

MATERIALS AND METHODS
This research followed the tenets of the Declaration of Helsinki and was approved by the human experimentation committee of The Hospital for Sick Children.
Subjects

Normal subjects. The final sample consisted of 20 7-year-old children (mean age = 7 years, range = 6.9–7.2 years), 20 8-year-old children (mean age = 8.0 years, range = 7.8–8.2 years), 12 9-year-old children (mean age = 9 years, range = 8.8–9.2 years), and 20 adults (mean age = 26.5 years, range = 16.9–37.7 years). To be included in the final sample, subjects had to pass a screening examination and produce valid data on tests of the visual field. Subjects passed the screening examination if they had a Snellen acuity of at least 20/20 in each eye, poorer acuity for each eye with a 3 diopter lens than without it (to control for hyperopia greater than 3 D), fusion at 6 m on the Worth Four Dot Test, and a stereoacuity of at least 20/20. Subjects with a Snellen acuity of at least 20/20 in each eye, poorer acuity for each eye with a 3 diopter lens than without it (to control for hyperopia greater than 3 D), fusion at 6 m on the Worth Four Dot Test, and a stereoacuity of at least 20/20 were included in the sample.

Deprived subjects. The final sample consisted of 62 deprived eyes from 46 children treated for dense and central cataracts in one or both eyes (see Table 1). The cataracts had been removed surgically and then evaluated by small or partial cataracts would result in our underestimating the duration of deprivation and overestimating the age at which it began. cataract in one (n = 3) or both (n = 18) eyes or sustained an injury that led to the formation of a cataract in one eye (n = 6). Children in the “short duration” groups all had deprivation lasting more than 6 months and those in the “long duration” groups all had deprivation lasting more than 6 months.

Adult aphakes. The sample consisted of two adults with a normal history until unilateral cataracts developed at ages 41 and 46 years, which were removed shortly thereafter. Like the treated children, their aphakic eyes had been fitted with a contact lens. The Snellen acuity for each eye of each adult was 20/20.

Stimuli and Apparatus

Subjects were tested by a normal bracketing procedure (program 62) using an Octopus 500 perimeter with 0.43° lights of varying intensity presented for 0.1 second against a background of 1.3 cd/m². Tests were at 21 locations: the primary location (20° nasally or temporally) and 20 nearby locations, all within a 12° square surrounding the primary location. For data analyses, we calculated the threshold for 20° nasally and temporally as the average of five thresholds: the primary location, ± 3° displaced horizontally, and ± 3° displaced vertically. Because we were interested in measuring sensitivity at only 20° nasally and temporally, we discarded the data from the remaining 16 locations.

Procedure

The examiner explained procedures to subjects and their consent, or in the case of children, parental consent was obtained. The subject had one eye patched and, if the eye was aphakic, it was fitted with a contact lens designed to focus the eye for the testing distance of 43 cm. The subject sat in front of the Octopus perimeter with the chin resting on the adjustable chin rest and the forehead against the forehead bar. After he or she had adapted to the lighting conditions of the perimeter for 5 minutes, the subject was instructed to maintain fixation on the central fixation aid, to listen for the beep that would signal the onset of a new trial, and to push a button if he or she was aware of a flash of light in the bowl. Central fixation was monitored by the Octopus perimeter, which is accurate to within 2° to 3°. Subjects were informed that some trials were

We have labeled these cataracts congenital because on the first eye examination, which was always before 6 months of age, the cataract was sufficiently dense that the fundus could not be visualized, there was no red reflex, the child did not fixate or follow with that eye, or the ophthalmologist described the cataract as dense and central. Thus, they were likely present from birth. If some were not, we will have overestimated the duration of deprivation in those cases.
TABLE 1. Characteristics of the Deprived Eyes

<table>
<thead>
<tr>
<th>Condition</th>
<th>Onset of Deprivation [mean age (yr), range]</th>
<th>Duration of Deprivation [mean (mo), range]</th>
<th>No. of Deprived Eyes</th>
<th>Snellen Acuity of Deprived Eyes* (mean, range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unilateral congenital</td>
<td>0</td>
<td>4.9</td>
<td>7</td>
<td>20/250</td>
</tr>
<tr>
<td>Short duration</td>
<td></td>
<td>4.1-5.8</td>
<td></td>
<td>20/40-20/650</td>
</tr>
<tr>
<td>Unilateral congenital</td>
<td>0</td>
<td>13.1</td>
<td>5</td>
<td>20/1513</td>
</tr>
<tr>
<td>Long duration</td>
<td></td>
<td>8.2-19.0</td>
<td></td>
<td>20/200-CF</td>
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<tr>
<td>Unilateral noncongenital</td>
<td>7.6</td>
<td>3.2</td>
<td>7</td>
<td>20/123</td>
</tr>
<tr>
<td>Short duration</td>
<td>3.0-12.1</td>
<td>1.6-5.1</td>
<td></td>
<td>20/27-20/400</td>
</tr>
<tr>
<td>Unilateral noncongenital</td>
<td>7.3</td>
<td>13.4</td>
<td>2</td>
<td></td>
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<tr>
<td>Long duration</td>
<td>1.5-13.0</td>
<td>11.5-15.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilateral congenital</td>
<td>0</td>
<td>5.5</td>
<td>11</td>
<td>20/103</td>
</tr>
<tr>
<td>Short duration</td>
<td></td>
<td>4.2-6.1</td>
<td></td>
<td>20/30-20/200</td>
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<tr>
<td>Bilateral congenital</td>
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<td></td>
<td>6.4-17.8</td>
<td></td>
<td>20/37-20/233</td>
</tr>
<tr>
<td>Bilateral noncongenital</td>
<td>4.1</td>
<td>3.9</td>
<td>13</td>
<td>20/35</td>
</tr>
<tr>
<td>Short duration</td>
<td>0.6-10.2</td>
<td>1.4-6.2</td>
<td></td>
<td>20/20-20/60</td>
</tr>
<tr>
<td>Bilateral noncongenital</td>
<td>4.2</td>
<td>29.4</td>
<td>5</td>
<td>20/690</td>
</tr>
<tr>
<td>Long duration</td>
<td>1.1-8.8</td>
<td>8.0-74.1</td>
<td></td>
<td>20/25-CF</td>
</tr>
</tbody>
</table>

CF = counting fingers.
* When a patient’s Snellen acuity was counting fingers, then the value of 20/1000 was used in the analysis.

RESULTS

Normal Subjects

Development of sensitivity. We used a three-way analysis of variance to compare sensitivity across four ages (7-, 8-, 9-year-olds, and adults) at two locations (20° nasally, 30° temporally) and three tests (first eye, second eye, reliability test of first eye). Sensitivity was higher at 20° nasally than at 30° temporally (F[1,68] = 6.84, P = 0.01). There were no significant differences across age or across tests and no significant interactions (P for all > 0.10) (see Fig. 1).

There was much variability in sensitivity within an age. The range of sensitivity for the best 95% of the sample for the first test of 20° nasally was 7.6, 10.6, 4.4, and 5.2 db for 7-, 8-, and 9-year-old children and adults, respectively. For 30° temporally, the range for the best 95% was 16, 6.4, 7.6, and 5.4 db for 7-, 8-, and 9-year-old children and adults, respectively.

Test–retest reliability. Reliability at each location was calculated as the difference in sensitivity between the two tests of the same eye. Test–retest reliability was high: for 20° nasally, the mean difference score was 0.19, -0.26, -0.27, and -0.87 db for 7-, 8-, and 9-year-old children and adults, respectively, with standard errors of 0.51, 0.48, 0.44, and 0.31 db. For 30° temporally, the mean difference score was -1.08, -0.51, -0.30, and -0.21 db for 7-, 8-, and 9-year-old children and adults, respectively, with standard errors of 0.94, 0.42, 0.74, and 0.22 db. In summary, repeated tests of the same eye usually gave results within 1 db (i.e., within 0.1 log unit) of each other.

catch trials during which there either would be no stimulus (positive catch trials) or a stimulus of high intensity (negative catch trials).

The tests for the adult aphakes were as described for the younger patients with two exceptions. First, the operated eye was tested with the patient’s own contact lens and a spherical add to focus the eye for the testing distance. Second, because of the possibility of failing accommodation, the fellow eye was given a spherical add to focus it for the testing distance.

We measured sensitivity at each location using a staircase procedure that crossed the subject’s threshold twice (see description of program 62 in reference 35). For normal subjects at each age, we began testing with the right eye in half the cases, followed by a test of the other eye, then an assessment of reliability based on retesting the first eye either on the same day (8- and 9-year-olds) or on a subsequent day (7-year-olds and adults). In each case, the location tested first (20° nasally or 30° temporally) was counterbalanced across subjects with this order of testing of locations repeated for all subsequent tests. In patients treated for unilateral cataract, we tested first the deprived eye, then whenever possible (18 out of 21 cases), the fellow eye. (In one of the three remaining cases, the fellow eye was not tested because it is not normal.) In patients treated for bilateral cataracts, we tested first the eye with the better acuity because we wanted to increase the likelihood of a completed test. In 16 of the 17 cases in which the second eye also met the criteria for eligibility, we then were able to test the second eye. We counterbalanced the location that was tested first in patients.
Deprivational Effects on Peripheral Sensitivity

FIGURE 1. Development of sensitivity (db) at 20° nasally (■) and at 30° temporally (□) for normal 7-, 8-, and 9-year-old children and adults during Test 1. Error bars indicate standard errors.

Interocular differences. An interocular difference score at each location was calculated as the difference in sensitivity between the tests of the right and left eye. The mean interocular difference scores were small. For 20° nasally, the mean difference score was 0.37, −0.09, −0.30, and −0.03 db for 7-, 8-, and 9-year-old children and adults, respectively, with standard errors of 0.48, 0.44, 0.27, and 0.29 db. For 30° temporally, the mean difference score was −0.10, −0.90, 0.03, and 0.10 db for 7-, 8-, and 9-year-old children and adults, respectively, with standard errors of 0.92, 0.53, 0.70, and 0.53 db.

The smaller variability across subjects within an age in interocular differences than in sensitivity suggests that assessment of the performance of the deprived eye in children treated for unilateral cataract likely will be most accurate when comparisons are made to the fellow nondeprived eye. Note, however, that there was much variability in interocular difference scores within an age. The largest interocular difference score for the best 95% of the sample at 20° nasally was −4.4, −3.8, −1.6, and 2.0 db for 7-, 8-, and 9-year-old children and adults, respectively. At 30° temporally, the largest interocular difference score was −8.4, −3.2, 2.8, and 5.6 db for 7-, 8-, and 9-year-old children and adults, respectively.

Nondeprived Eye of Monocularly Deprived Subjects

The parents of children treated for a unilateral cataract had been instructed repeatedly by the ophthalmologist to patch the fellow nondeprived eye 50% of the waking time during the first 5 years of life to force usage of the previously deprived eye. Of the children treated for a unilateral cataract, compliance with the patching regimen varied from excellent (patching of the fellow nondeprived eye 40% to 50% of the time, n = 4 children) to fair (patching 20% to 39% of the time, n = 11 children) to poor (patching 0% to 19% of the time, n = 6 children).

To determine if occlusion affected sensitivity of the fellow nondeprived eye and, therefore, if the nondeprived eye could serve as a standard by which to evaluate the performance of the deprived eye, the following analysis was carried out. We used a two-way analysis of variance to compare sensitivity at the two locations (20° nasally, 30° temporally) for normal volunteers and for the nondeprived eye of three groups of monocularly deprived subjects: those whose compliance with the patching regimen was excellent, fair, or poor. (Because of an insufficient number of subjects, we could not compare children treated for unilateral congenital vs unilateral noncongenital cataract.)

Regardless of the patching regimen, the fellow eye of monocularly deprived subjects did not differ significantly in sensitivity from that of normal volunteers (P > 0.10 for all). Thus, we could use the nondeprived eye as a standard by which to evaluate the data of the deprived eye in cases of monocular deprivation.

Deprived Eyes

In unilateral cases, we calculated loss scores by subtracting the sensitivity of the deprived eye from that of the fellow nondeprived eye for each location assessed. (The results remained the same when the comparison data were from the group of normal children of the same age.) In bilateral cases and in unilateral cases for which the nondeprived eye was not tested (n = 9), the comparison data were from the group of normal children of the same age. For patients older than 9 years, the comparison group was the normal adults.

The deprived eyes of every group of patients showed a loss of sensitivity at each location (see Fig. 2). The performance of the deprived eyes was analyzed with a four-way analysis of variance comparing type of deprivation (monocular vs binocular), timing of deprivation (congenital vs noncongenital), duration of deprivation (short vs long), and location (20° nasally, 30° temporally).

The only significant outcome was a three-way interaction of location with condition (monocular/binocular) with timing (F[1,54] = 9.63, P = 0.003; Fig. 2). Analyses of simple effects revealed that the children treated for unilateral congenital cataract had significantly larger losses of sensitivity at 20° nasally than at 30° temporally (F[1,54] = 16.65, P = 0.0001). All other groups showed equal losses in sensitivity at the
two locations and there were no other significant interactions (P > 0.10 for all).

To evaluate the influence on the deprived eye in unilateral cases of patching the fellow eye, we used a two-way analysis of variance to compare sensitivity at two locations (20° nasally, 30° temporally) for children who were excellent, fair, or poor patchers. We were unable to simultaneously analyze the variable of the timing of deprivation because of an insufficient number of unilateral congenital subjects who were poor patchers. There was no significant influence of patching of the nondeprived eye on the sensitivity of the deprived eye (P = 0.20 to 0.77).

To investigate the possibility that patching may be more effective when started earlier in life, we used a two-way analysis of variance to examine the performance of the deprived eye in children treated for a unilateral congenital cataract who were excellent vs fair patchers. (There was an insufficient number of these patients to also evaluate the influence of poor patching.) There was no significant influence of patching of the nondeprived eye on the sensitivity of the deprived eye (P = 0.32 to 0.60).

One possible explanation for reduced sensitivity may be that the typically poorer visual acuity of a deprived eye, relative to a normal eye, limits peripheral detection. To evaluate this possibility, we calculated Pearson correlations between the log 2 value of the deprived eye’s median Snellen acuity and its loss scores in the periphery (n = 46 eyes). For patients who contributed data from two deprived eyes, only the acuity of the right eye was used. There was no significant correlation at 20° nasally (r = 0.26, P > 0.10) nor at 30° temporally (r = -0.21, P > 0.10).

**DISCUSSION**

**Normal Development**

When tested with a small stimulus, normal children as young as 7 years were as sensitive as adults at 20° in the nasal field and at 30° in the temporal field. Moreover, we found higher sensitivity at 20° nasally than at 30° temporally, good test-retest reliability, and small average interocular differences (see Fig. 1). This suggests little improvement with practice, at least for a limited number of tests, and that our results can be used as a baseline for assessment of clinical cases.

Our finding of higher sensitivity at 20° nasally than at 30° temporally in normal children and adults agrees with previous findings. Because our pilot data indicated that it was not possible to test children younger than 7 years of age on the Octopus perimeter, we cannot identify when sensitivity at these locations first becomes adultlike. Our results indicate that adultlike sensitivity for some stimuli is achieved both at 20° nasally and at 30° temporally by 7 years of age (also see reference 36). However, studies using a smaller stimulus of lower controls suggest that peripheral sensitivity continues to develop after that age.

**Deprived Sample**

Relative to the fellow nondeprived eye or to normal volunteers, deprived eyes were less sensitive both at 20° nasally and at 30° temporally (see Fig. 2). This was true even in the five children whose deprivation began after 10 years of age: they showed mean losses of 9.0 db at 20° nasally and 8.8 db at 30° temporally. This finding suggests either that the sensitive period for

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4 The same pattern of results was obtained when only the eye with the worse acuity was included for children treated for bilateral cataracts.

5 The duration of deprivation was similar across groups (6.8, 7.8, and 5.9 months for the excellent, fair, and poor patchers, respectively). However, the onset of deprivation varied widely across groups (15, 8, and 111.1 months for the excellent, fair, and poor patchers, respectively). It was not possible to match the onset of deprivation across groups given the small sample.

6 When a patient’s Snellen acuity was counting fingers, the value of 20/1000 was used in the analysis.
Deprivational Effects on Peripheral Sensitivity

Peripheral vision lasts for many years after birth or that aphakia per se is largely responsible for the observed losses in sensitivity.

To evaluate the role of aphakia per se, we examined thresholds at 20° nasally and at 30° temporally in two aphakic subjects with normal histories until adulthood. Although the thresholds of the operated eye of both adults were within normal limits at each location, their fellow unaffected eyes were more sensitive by 1.6 db to 2.4 db, values that are larger than the interocular differences typically found in normal young adults (see Results). Thus, there may be a small deleterious effect of aphakia per se on threshold sensitivity at each location. Nonetheless, the loss of sensitivity at each location was much larger in children treated for a cataract (see Fig. 2), even in children who developed a cataract after 10 years of age. Overall, these results suggest that losses of sensitivity at 20° nasally and at 30° temporally in deprived children largely reflect the effects of deprivation on the visual system and not the effects of aphakia per se. Moreover, they support the hypothesis that the sensitive period for peripheral vision lasts for many years after birth.

The loss of sensitivity observed in the deprived eyes is also unlikely to result from the strabismus or poor visual acuity that commonly occur in children treated for cataracts. First, there are no systematic effects of primary strabismus on peripheral vision in humans or monkeys.37-45 Second, there was a large range of visual acuity in the deprived eyes (20/20 to the ability to only count fingers) and we found no significant correlations between visual acuity and the loss of peripheral sensitivity.

We found that only children treated for unilateral congenital cataract exhibited larger losses at 20° nasally than at 30° temporally. The finding of greater loss at 20° nasally was true even in patients with good visual acuity. Our finding that the nasal visual field is particularly affected only in children treated for unilateral congenital cataract agrees with previous studies of a few human patients.23-25

The special vulnerability of the nasal visual field is congruent with reports that the nasal field is slow to develop in normal young infants. For example, studies of normal infants reveal that 1-month-olds have poorer sensitivity at 20° nasally than at 30° temporally but that 2-month-olds, like normal older children and adults, have better sensitivity at 20° nasally.34,40 Moreover, our results parallel the results from assessment of peripheral contrast sensitivity in children treated for cataracts. Children treated for unilateral congenital cataract exhibit larger losses of contrast sensitivity in the nasal visual field than in the temporal field, unlike children treated for bilateral congenital cataracts or for traumatic cataract.17,21

Our finding that losses at 20° nasally are greatest in children treated for unilateral deprivation that began at birth suggests that competition very early in life from the nondeprived fellow eye influences peripheral vision. As such, it was surprising that the history of patching of the nondeprived eye did not affect the peripheral vision of the deprived eye in children treated for unilateral cataract. Note, however, that the groups of monocularly deprived children with different patching histories, although well matched for the duration of deprivation, were not well matched for the age of onset of deprivation and that the sample of children treated for unilateral congenital cataract was small. Therefore, the influence of occlusion of the nondeprived eye should be further evaluated in a larger sample of children who are matched for both the age of onset and the duration of deprivation.

This experiment indicated that children with deprivation of less than 6 months were as impaired at 20° nasally and 30° temporally as children with longer deprivation. Similarly, deprivation reduces sensitivity in the far periphery comparably in children with short or long periods of deprivation.46 These results are surprising because longer duration of deprivation has been shown to have more deleterious effects on the extent of the field in monocularly lid-sutured monkeys27,28 and in dark-reared cats.47,48 (lid-sutured cats have not been studied systematically). Examination of other visual abilities in humans indicates that longer duration of deprivation more severely affects visual acuity44 and contrast sensitivity22 but not the asymmetry of optokinetic nystagmus.21,40 These findings indicate that the effects of the duration of deprivation may vary for different visual functions and across species. Of course, periods of deprivation shorter or longer than those we studied might lead to smaller or larger losses of peripheral sensitivity than those we observed.

As in our patients, deprivation alters peripheral vision in the deprived eye but not in the nondeprived eye of cats and monkeys.27,28,30-32 In cats, monocular or binocular deprivation for several months from the time of normal eye-opening leads to poor detection in the nasal field and either loss in the extent of, or decreased responsiveness at the edge of, the temporal field of the deprived eye.26,29-31,33,31,52 In monkeys, monocular deprivation, in the best case, leaves the visual field intact and, in the worst case, leaves the eye blind.27

Although deprivation affects peripheral vision in cats, monkeys, and humans, the effects in deprived animals are not identical to those in humans. We found larger losses in the nasal than in the temporal field only in children treated for a unilateral congenital cataract. In contrast, either monocular or binocular deprivation from birth in cats particularly affects the nasal visual field.30 As well, in monkeys monocularly
deprived early in life, the nasal field is not always most vulnerable.27

The losses in sensitivity shown by the children treated for cataract are likely to reflect neural losses because the sensitivity losses are much larger than those observed after treatment of adult cataracts and because they vary systematically with the timing of deprivation and whether it was monocular or binocular. Because cells of the lateral geniculate nucleus of monocularly deprived monkeys exhibit normal spatial resolution,58 sensitivity losses may reflect damage to the geniculo-striate pathway, which projects to the superior colliculus, a projection that has been implicated in peripheral vision.54-56 Moreover, monocular deprivation in monkeys has more severe effects on the visual cortex than does binocular deprivation (reviewed in reference 57). If visual deprivation exerts similar effects on the cortex of children as in monkeys then differences in the visual field of monocularly vs binocularly deprived children may be at least partially explained by differences at the cortical level.

In summary, sensitivity to stimuli in the nasal visual field is known to be especially slow to develop in normal young infants.7 Although the deprived eyes exhibited losses of sensitivity at both tested locations, we found that only children unilaterally deprived from birth exhibited larger losses of sensitivity at 20° nasally than at 30° temporally. As such, our results provide further evidence that during early infancy the visual system is especially vulnerable to unfair interocular competition.

**Key Words**

peripheral vision, development, deprivation, static perimetry, children

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