Cortical Binocularity and Monocular Optokinetic Asymmetry in Early-Onset Esotropia

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Purpose. To investigate the correlation between directional asymmetry in ocular responses to monocularly viewed optokinetic stimuli (monocular optokinetic nystagmus, MOKN) and sensory fusion in infants and toddlers with early-onset esotropia.

Methods. Subjects were 14 infants and toddlers with early-onset esotropia (7–26 months old; median, 10 months), and 16 with no esotropia (6–22 months; median, 11 months) who provided control data. Monocular optokinetic nystagmus in response to a 30°/sec square-wave grating (0.25 cycles/°) was measured by electro-oculogram. Sensory fusion was assessed with visual evoked potentials (VEPs) to random-dot correlograms after correction of the strabismus angle with Fresnel prisms.

Results. All subjects with early-onset esotropia had MOKN with a faster slow-phase component for temporal-to-nasalward (TN) than nasal-to-temporalward (NT) motion. Ninety-three percent of subjects had MOKN asymmetry higher than the 95th percentile of the control group. Of subjects who cooperated with VEP fusion testing, 5 subjects with early-onset esotropia (45%) and 11 control subjects (92%) showed evidence of sensory fusion.

Conclusions. Symmetrical MOKN did not develop in infants and toddlers with early-onset esotropia. This deficit existed in most infants who showed sensory-cortical fusion. These results are consistent with the belief that optokinetic nystagmus asymmetry may not be associated with a deficit in the cortical fusion facility, but rather with deficits in binocular pathways projecting to MOKN control centers. These deficits may be associated with abnormal processing subsequent to sensory fusion or with abnormal processing in motion pathways, which run parallel to sensory fusion pathways. (*Invest Ophthalmol Vis Sci.* 1998;39:1352–1360)

Early-onset esotropia, also known as infantile esotropia, is a fairly common clinical disorder; estimates of prevalence have varied from 0.09% to 0.5%.[1] Early-onset esotropia occurs within the first 6 months of life.[2]

When visual development is normal, binocular single vision and stereopsis develop quickly during a critical period within the first few months of life.[3–9] The development of binocular single vision is accompanied by the development of oculomotor systems that function to keep images from the two eyes aligned. As part of this system, the vergence control system receives fusion and disparity information to align the binocular fixation point to different depth planes,[10] whereas the optokinetic control system receives fusion and disparity information to stabilize moving images of binocularly fused stimuli.[11–13] This interaction undergoes considerable refinement during development. If any part of this sensory-oculomotor feedback loop is defective or absent, it impedes the ability to maintain alignment of the eyes, and strabismus may result.

The development of fusion and stereopsis is sensitive to the effects of deprivation. Children who experience various forms of disruption of monocular or binocular vision during the first 6 months of life may not develop binocular single vision,[2] and optokinetic and pursuit eye-movement control systems may not develop normally.[14] For example, in strabismus, under monocular viewing conditions, target movements in the temporal-to-nasal (TN) direction tend to elicit higher ocular following-eye velocities than do movements in the nasal-to-temporal (NT) direction.[15–24] These deficits in optokinetic and pursuit stimuli are more prevalent when the esotropia manifests in infants less than 6 months old.[18,20,21,23,24]

Investigators have[16,25] suggested that monocular deficits in oculomotor responses to monocularly viewed optokinetic stimuli are related to deficits in binocularity, namely stereopsis[16] and interocular transfer of threshold elevation.[25] The purpose of the present study was to investigate the correlation between the asymmetry of monocular optokinetic nystagmus (MOKN) and sensory fusion in neurologically normal infants and toddlers with early-onset esotropia. We assessed the oculomotor and sensory functions of our subjects while they were still infants and toddlers. This allowed us to be more confident that the esotropia was of early onset and to gain knowledge of

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TABLE 1. Clinical Characteristics of Infants with Early-Onset Esotropia

Infant No.	*Refractive Error*		*Pre-Operative Prism Cover Test*	*Latent Nystagmus*
	Right Eye	*Left Eye*		
1	PL +0.75 × 180	+0.50 +0.75 × 180	65^ RtoAET	No
2	+4.50	+3.75	35^ AET	No
3	+0.50	+0.50	65^ AET	Yes
4	+0.50 +0.75 × 90	+0.25 +0.50 × 90	35^ AET	Yes
5	+2.00	+2.00	45^ AET 5^ RHT	No
6	+1.75	+0.75	45^ AET	No
7	+4.50	+5.00	60^ AET	Yes
8	+4.25	+3.75 +0.25 × 90	40-45^ LtoAET	Yes
9	+1.75	+2.00	40^ AET	No
10	+2.00 +0.50 × 90	+2.25 +0.50 × 90	35^ AET	No
11	+0.75 +0.50 × 90	+1.00 +0.75 × 90	45^ AET	Yes
12	+1.50 +1.00 × 90	+2.00 +1.00 × 90	40^ AET	No
13	+0.50	+0.50	45-50^ RtoAET	No
14	+0.50	+0.50	45^ RtoAET 8^ RHT	No

AET, alternating esotropia; LtoAET, left-to-alternating esotropia; PL, plano; ^, prism diopter; RHT, right hypertropia; RtoAET, right-to-alternating esotropia.

motor and sensory functions within months, rather than years, of the time when the strabismus developed.

METHODS

Fourteen full-term infants and toddlers (7-26 months; median age, 10 months) with early-onset esotropia (less than 6 months onset) but with no ocular or neurologic disease were recruited (Table 1) from the strabismus service at The Hospital for Sick Children, Toronto, Canada. All underwent a complete ophthalmologic examination by a pediatric ophthalmologist (SK or DS), with appropriate refractive errors corrected. In 5 of these 14 children (36%), latent nystagmus was detected clinically in the primary position. It is possible that more patients with infantile esotropia had latent nystagmus, but the amplitude was too low to be detected clinically. All 14 infants and toddlers had received occlusion therapy. Monocular occlusion for half of waking hours was used to treat amblyopia. Once equal fixation was achieved, the infants and toddlers then underwent half-time alternate occlusion. They had been treated with occlusion for several weeks (range, 2 weeks to 2 months) before they were accepted as subjects in the present study. Sensory fusion and MOKN were tested within 2 weeks of the other in nine infants and toddlers, and within 2 to 5 months of the other in the remaining five. All infants and toddlers were less than 26 months old at testing. All who had esotropia underwent strabismus surgery within 5 months of testing.

Sixteen infants and toddlers who had no strabismus (6-22 months; median age, 11 months) served as control subjects. The control subjects were recruited through a newspaper advertisement. After the procedures were explained to the parents, they volunteered their infants and toddlers to participate in the study.

This research followed the tenets of the Declaration of Helsinki. Parents signed a consent form for their child's participation that acknowledged that research procedures had been described, questions had been answered, and harms and benefits had been adequately explained. Approval for the study was obtained from the Research Ethics Board at The Hospital for Sick Children (file 85/581).

Optokinetic Response

The stimulus for optokinetic nystagmus (OKN) was a horizontally moving, 100% contrast, black-and-white vertical square-wave grating, viewed on a computer screen positioned 50 cm from the subject (software from Vision Research Graphics, Durham, NH). The computer screen subtended 45° × 35° and the 0.25-cycle/° stripes moved at 30°/sec (equivalent to a movement of 7.5 cycles/sec). This choice of stimulus is sufficient to evoke OKN in adults.[26] Using similar stimulus parameters, Roy et al.[27] found that stimulus speeds between 36°/sec and 42°/sec successfully evoked OKN in visually normal infants and toddlers 8 to 20 months old.

Eye movements were recorded with two silver-silver chloride recording electrodes (Neuromedical Supplies, Herndon, VA) and placed bitemporally. A third ground electrode was placed on the forehead. The skin at each electrode position was cleaned with a mild abrasive (Nu-prep; DO Weaver, Aurora, CO) before electrode placement. Adhesive electrode washers held electrodes in place. The electrodes were plugged into an isolated direct-current preamplifier (P16 AC/DC microelectrode preamplifier; Grass Instrument, Quincy, MA). The analog signal was captured (sample rate 300 Hz) and digitized with a CED 1401 laboratory interface (Cambridge Electronic Design, Cambridge, UK) with software (Spike2; Cambridge). Data were filtered off-line (low pass; 0-30 Hz).

Optokinetic nystagmus testing was monocular. The first eye to be tested and the initial direction of motion (right or left) were deliberately varied. Once the subject was watching the television monitor, data were collected in the absence of the moving target. These data were subsequently analyzed to identify the presence of latent nystagmus. After this, movement of the vertical grating was initiated. The subject's looking responses were monitored at all times. If the subject watched

the target for more than 5 consecutive seconds, the trial was accepted for later analysis. Subsequent trials consisted of moving the target two or three times in each direction, the number of times depending on the child's looking behaviors. This procedure was repeated for the other eye. The parents were asked to hold the child and to keep his or her head as still as possible during testing. We calibrated the eye movements by recording horizontal eye movements to a 12° saccadic target (a colored disc moving between two known positions on the screen).

If the expected repeated pattern of slow-fast-phase eye movements was apparent, we derived the slow-phase nystagmus velocity from the raw data by calculating the slope of the eye-position trace per unit of time. We did this by marking the beginning and end of each slow-phase eye movement and dividing the amplitude of the slow phase in degrees by the time interval. If eye-movement traces revealed no evidence of the expected slow-fast-phase eye-movement response, then the velocity was taken as 0°/sec. When latent nystagmus was observed in the trials with no target motion, we adjusted the slow-phase eye velocities in response to target motion by subtracting the eye velocities in trials with no target motion from velocities calculated in the presence of target motion.

Analysis of Monocular Optokinetic Nystagmus

Because Schor et al.[24] found MOKN asymmetry to be greater in the nondominant than in the dominant eye of subjects with early-onset esotropia, we analyzed the MOKN data from the dominant and the nondominant eye separately. The dominant eye was classified according to the referring ophthalmologist's report of fixation preference: If fixation was equal, the data were classified according to left or right eye.

The MOKN asymmetry ratio was defined according to Schor et al.[24]:

$$\mathrm{MOKN_{asym}} = \frac{\mathrm{TN_{MOKN}}}{\mathrm{TN_{MOKN}} + \mathrm{NT_{MOKN}}}$$

where TN is temporal-to-nasal slow-phase velocity, NT is nasal-to-temporal slow-phase velocity, and $\mathrm{MOKN_{asym}}$ is the monocular optokinetic nystagmus asymmetry ratio.

An MOKN asymmetry ratio of 0.5 represents perfect symmetry; ratios greater than 0.5 mean that the slow-phase velocity was higher in the TN than in the NT direction. To determine the normal range for OKN ratios, the 95th percentile was calculated for the left and right eyes of infants and toddlers in the control group. Monocular optokinetic nystagmus asymmetry ratios from nondominant and dominant eyes of infants and toddlers with esotropia were considered abnormal if they exceeded the 95th percentile of data from the left and right eyes, respectively, in the control group.

Sensory Fusion

Sensory fusion was assessed by the detection of VEP responses to dynamic random-dot correlograms (DRDCs).[28] These stimuli are devoid of monocular cues and contain cues that can be perceived only by subjects with fusion, which provides unequivocal evidence of binocular single vision.[29] Visual evoked potential responses using DRDCs and stereograms have been used in many studies to establish the properties of sensory fusion and stereopsis.[5,6,29] The presentation of the DRDC requires the separation of images perceived by the left and right eyes, which is achieved by the alternating field stereoscopy method,[28] in which binocular stimuli are separated by time-multiplexing the images to the two eyes as follows.

In our alternating field stereoscopy binocular VEP stimulator, the right and left images of a binocular pair were displayed sequentially (at a rate of 30 Hz) on the screen of a microcomputer (Atari, Sunnyvale, CA). Liquid crystal (LC) shutters in front of the infant's eyes multiplexed the images to the two eyes. The LC shutters were synchronized with the computer monitor so that the left or right shutter was only "open" (92% transmission) when the corresponding left-right image of the binocular pair was displayed on the screen. During the occluding ("closed") phase, the LC shutters scattered incident light that resulted in a uniformly luminous, milky texture that blocked form vision. The LC shutters could alternate between the closed and open states in less than 1 msec. The left- and right-eye shutters were synchronized so that one shutter was opened only 1.5 msec after the start of the open-to-closed transition of the other shutter. In this way, the images to the right and left eyes were never visible simultaneously, and only subjects with sensory fusion could create binocular single images.

The dynamic random-dot patterns (dot size, 30 × 25 minutes of arc at a distance of 50 cm) presented to each eye alternated between two phases: correlated and anticorrelated. In the correlated phase, the random-dot patterns presented to each eye were identical. In the anticorrelated phase, the dot patterns were inverted: a dark dot in the field of one eye corresponded to a bright dot in the field of the other eye, and vice versa. To mask the changes between the correlated and anticorrelated phases, the dynamic dot patterns to each eye were changed at a rate of 15 Hz, whereas the rate of change between the correlated and anticorrelated phases was 2.5 Hz. The alternation from correlated to anticorrelated states could only be detected in the cyclopean image—that is, the cortical image that contains the information from the two eyes.[30]

During the experiments, all subjects wore their full refractive correction. Subjects sat 50 cm from the computer screen on which the stimuli were displayed (field size, 22° × 13°). Fresnel prisms were placed on the LC shutters to compensate for the angle of deviation. The Fresnel prism steps were in 5 prism diopters; we assumed that the angle of deviation was corrected within 5 prism diopters. Although Fresnel prisms blur the image, random-dot correlograms are insensitive to blur.[5] We tested the effects of blur from Fresnel prisms in a cooperative adult. We found detectable DRDC responses with a 30-prism diopter Fresnel lens in front of one eye (22-D glass lens in front of the other eye to compensate for vergence stress), and with a 20-prism diopter Fresnel lens in front of each eye (prism base in the same direction).

Visual evoked potentials were recorded with a gold-disc electrode positioned over the occiput, 2 cm above the inion along the midline. A gold-clip electrode was attached to each earlobe, one serving as a reference electrode and the other as a ground. The electrodes were attached with electrode paste and tape after the surface of the scalp and earlobes were abraded.

An amplifier with a gain of 50,000 (Grass) amplified VEP signals with a band-pass filter from 1 Hz to 25 Hz. The amplified

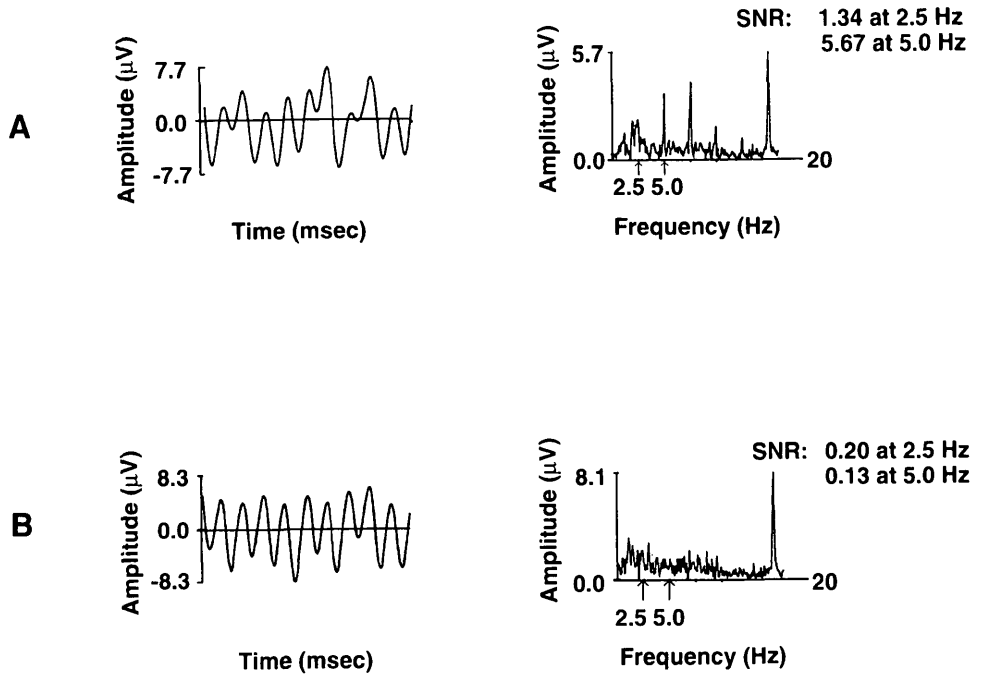

FIGURE 1. Visual evoked potentials (VEPs) to a dynamic random-dot correlogram recorded in a child with normal binocular vision. The *left traces* are VEPs as a function of time; the *right traces* are VEP amplitudes as a function of frequency. In both *right traces*, a prominent peak at 15 Hz was generated by changes in the random-dot patterns presented to each eye. *Arrows* identify the alternation frequency of the correlogram and its second harmonic. (**A**) Visual evoked potentials recorded with both eyes open. Prominent responses were seen at 5 Hz, the second harmonic of the stimulus frequency. (**B**) Visual evoked potentials recorded with the right eye occluded. No prominent VEP responses were seen at the harmonics of the stimulus frequency. SNR, signal-to-noise ratio.

signal was collected in seven 10-second intervals, for a total recording time of 70 seconds. For each interval, the amplitude at each frequency was calculated with a fast Fourier transform (frequency resolution 0.1 Hz). The averaged fast Fourier transform response was calculated for all seven intervals.

The power was determined at the alternating frequency of the DRDC (2.5 Hz) and its second harmonic (5 Hz). For a detectable response (with a 5% probability of false detection), Eizenman et al.[31] determined that the power at the signal frequencies has to exceed, by a factor of more than 6, the average power of the adjacent noise frequencies—that is, the signal-to-noise ratio (SNR) must exceed 6. To calculate the average noise power, the power of the 10 frequencies adjacent to the signal frequency was ordered (from low to high), and the two highest and two lowest values were discarded. Then the remaining six noise power measurements were averaged to get an estimate of the background noise power.[31] In this study, instead of using the power SNR, we used the amplitude SNR. The amplitude SNR is the ratio of the amplitude of the signal to that of the noise and is equal to the square root of the power SNR. A VEP response was considered to be detectable if the SNR exceeded 2.45.

Figure 1 is an example of a VEP response to DRDC, recorded from a child with normal binocular function, with both eyes open (Fig. 1A) and with one eye occluded (Fig. 1B). The VEP correlogram response is shown in the time domain (left) and frequency domain (right). The stimulus alternated between binocularly correlated and anticorrelated phases five times per second (2.5 Hz). The arrows in Figure 2 identify the frequency of the binocular alternation (2.5 Hz) and its second harmonic (5 Hz). Signals at the harmonics of the alternation frequency (2.5 Hz) are detectable in Figure 1A only. A prominent peak (at 5 Hz, in response to the purely binocular DRDC) is missing from Figure 1B. These traces demonstrate that the presence of a detectable response to DRDC depends on visual input from both eyes. Using the detection criterion of amplitude SNR greater than 2.45 (SNR power of 6) with more than 200 infants and toddlers who viewed the DRDC display, we have never detected a fusion response when the DRDC stimuli were viewed monocularly.

RESULTS

Figure 2 shows an example of MOKN eye-movement traces (Fig. 2A) and VEP correlogram data (Fig. 2B) from a control subject (C12, 21 months) with no strabismus. Monocular optokinetic nystagmus asymmetry ratios were close to 0.5 in both eyes. The VEP correlogram response is shown in the time domain (left) and frequency domain (right). The stimulus alternated between correlated and anticorrelated phases five times per second (2.5 Hz). The arrows in Figure 2 identify the frequency of alternation (2.5 Hz) and its second harmonic (5 Hz). This SNR was higher than 2.45 at the alternation frequency and at its first harmonic and therefore demonstrated detectable sensory fusion.

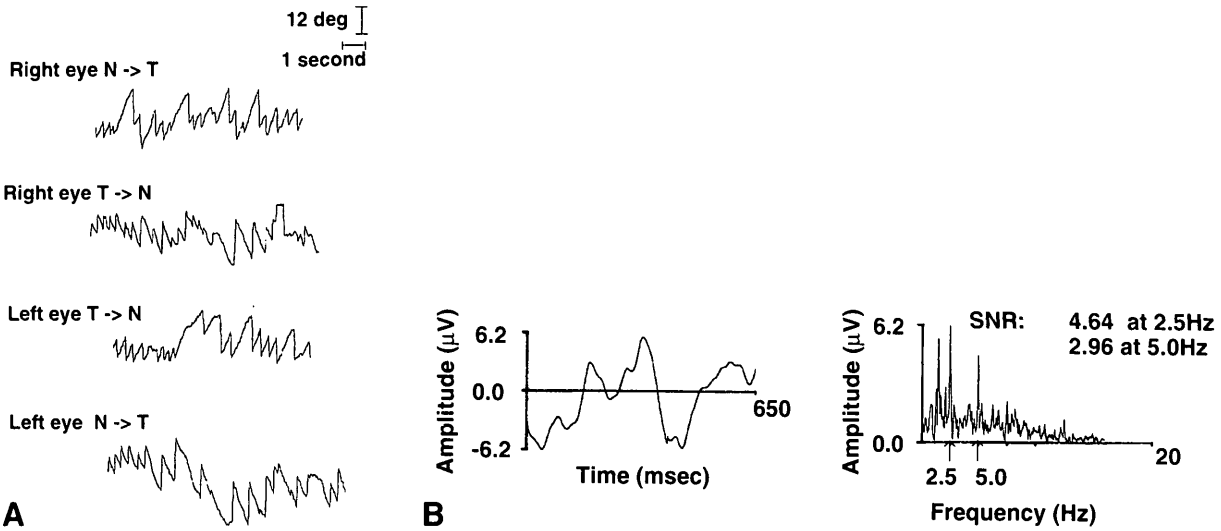

Figure 2. (**A**) Monocular optokinetic nystagmus (MOKN) recorded from a toddler with no strabismus (subject C12). Scale shows the amount of horizontal displacement representing 1 second and the amplitude of 12° of eye movement derived from calibration. N→T, motion in the nasal-to-temporal direction; T→N, motion in the temporal-to-nasal direction. (**B**) VEPs to a dynamic random-dot correlogram in an infant (subject C12) with normal binocular vision. *Left traces* are the visual evoked potentials (VEPs) as a function of time; *right traces* are VEP amplitudes as a function of frequency. *Arrows* identify the alternation frequency of the correlogram and its second harmonic. There were prominent detectable responses at first (2.5 Hz) and second harmonics (5 Hz) of the alternation frequency. SNR, signal-to-noise ratio.

Figure 3 shows examples of MOKN eye movement traces (Fig. 3A) and VEP correlogram data (Fig. 3B) of an infant (subject 6, 9 months) with early-onset esotropia. Monocular optokinetic nystagmus asymmetry ratios were 1 in both eyes. The SNR at the alternation frequency of the DRDC was 3.5, demonstrating evidence of cortical sensory fusion.

Monocular optokinetic nystagmus asymmetry ratios of the control group and the group with esotropia are shown in Table 2. The 5th and 95th percentiles of MOKN asymmetry ratios recorded from subjects with esotropia were 0.59 and 1, respectively, in the dominant eyes and 0.64 and 1.04, respectively, in the nondominant eyes. Monocular optokinetic nystagmus asymmetry ratios of the group with esotropia were higher in the nondominant than in the dominant eyes ($P = 0.01$; two tail, paired t-test). Figure 4 contrasts the 5th, 50th, and 95th percentiles of MOKN asymmetry ratios in the control group with those from the group with early-onset esotropia. Of the 14 infants and toddlers with early-onset esotropia, 13 had OKN ratios exceeding the 95th percentile of the control group.

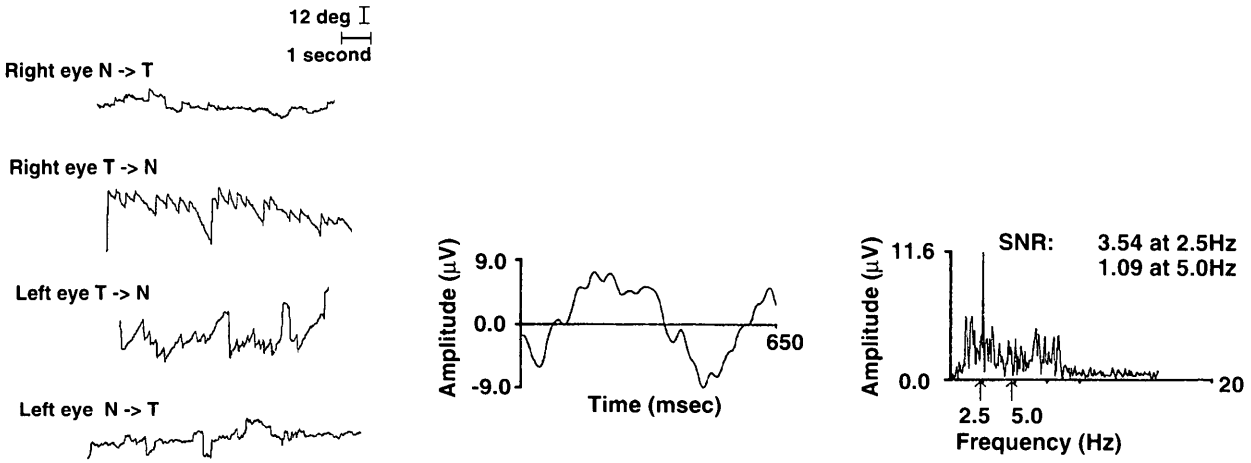

Figure 3. (**A**) Monocular optokinetic response (MOKN) recorded from an infant (subject 6) with early-onset esotropia. Scale shows the amount of horizontal displacement that represents 1 second and the amplitude of 12° of eye movement derived from calibration. N→T, motion in the nasal-to-temporal direction; T→N, motion in the temporal-to-nasal direction. (**B**) Visual evoked potentials (VEPs) to a dynamic random-dot correlogram in an infant with early-onset esotropia. *Left traces* are VEPs as a function of time; *right traces* are VEP amplitudes as a function of frequency. *Arrows* identify the alternation frequency of the correlogram and its harmonics. There were detectable responses at the frequency of alternation (2.5 Hz). Note: Signal-to-noise ratio is from different trial from most significant SNR reported in table 6.

TABLE 2. Results of Visual Evoked Potential Testing with Dynamic Random-Dot Correlogram and Monocular Optokinetic Nystagmus Asymmetry Ratios

		DRDC		*MOKN Asymmetry Ratio*	
Infant No.	*Age (mo)*	*SNR*	*Amplitude (μV)*	*Right Eye (dominant)*	*Left Eye (nondominant)*
Infants with Early-Onset Esotropia					
1	9	1.75		1.00	1.00
2	9	0.20		0.64	0.82
3	7	2.66*	1.96	1.00	1.00
4	9	na		1.00	0.95
5	26	3.00*	3.90	0.61	0.60
6	9	4.75*	11.60	1.00	1.00
7	11	2.90*	4.10	1.00	1.00
8	11	1.17		0.85	1.00
9	14	na		0.55	0.66
10	8	1.38		0.86	1.00
11	7	7.50*	5.40	1.00	1.00
12	14	2.17		1.00	1.10
13	18	na		0.80	0.84
14	11	1.92		0.98	1.0
Percentiles					
5th				0.59	0.64
50th	10†		4.10‡	0.99	1.00
95th				1.00	1.04
Control Infants					
C1	18	2.79*	4.90	0.54	0.47
C2	9	na		0.42	0.52
C3	11	2.40	3.90	0.35	0.55
C4	6	2.47*	5.12	0.48	0.53
C5	14	2.60*	6.50	0.50	0.56
C6	9	2.75*	7.20	0.47	0.62
C7	6	3.81*	10.30	0.53	0.49
C8	6	4.28*	6.90	0.52	0.64
C9	9	4.19*	6.50	0.54	0.56
C10	6	3.50*	30.00	0.53	0.54
C11	20	5.30*	3.50	0.55	0.38
C12	21	4.64*	6.60	0.55	0.54
C13	22	2.50*	5.80	0.50	0.50
C14	14	na		0.42	0.49
C16	13	na		0.50	0.59
Percentiles					
5th				0.40	0.44
50th	11†	3.14‡	6.50‡	0.50	0.54
95th				0.55	0.63

Age at the first test.

* Detectable response (sensory fusion).

† Median age.

‡ Median SNR (column 3) or median amplitude (column 4).

DRDC, dynamic random-dot correlogram; MOKN, monocular optokinetic nystagmus; SNR, signal-to-noise amplitude ratio (most significant trial); na, not available (infant did not cooperate with testing).

The SNRs of each child's most significant VEP correlogram responses are shown in Table 2. The most significant SNR could be at the first or the second harmonic of the alternation frequency. In infants and toddlers with no esotropia (the control group), the correlogram response SNR varied from 2.4 (not considered a detectable response) to 5.3, with a median of 3.14. Twelve out of 13 infants and toddlers with no esotropia (92%) produced a detectable correlogram response. Five out of 11 of subjects with esotropia (45%) had a detectable correlogram response (range, 2.66–7.5; median, 3). The median amplitude of detectable VEPs in subjects with esotropia was 4.1 (range, 1.96–11.6) and in the control group, 6.5 (range, 3.5–30).

DISCUSSION

Monocular optokinetic nystagmus is asymmetrical in neonates and normally becomes symmetrical by 3 to 6 months of age.[27,32,33] Wattam-Bell et al.[34] showed that in some infants, MOKN becomes symmetrical, although early-onset esotropia subsequently developed, whereas in other infants who had esotropia, MOKN remained asymmetrical.

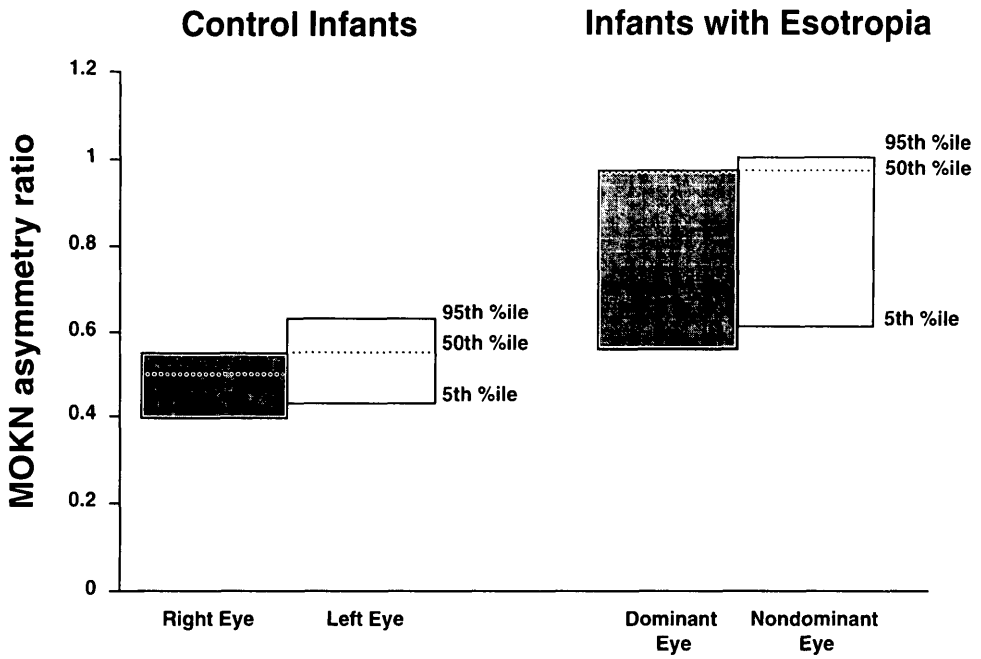

FIGURE 4. The 5th to 95th percentiles (with the 50th percentiles as *dotted lines*) of monocular optokinetic response ratios in infants, comparing the right eyes of control subjects with the dominant eyes of infants and toddlers with esotropia (*gray columns*), and the left eyes of control subjects with the nondominant eyes of infants and toddlers with esotropia (*white columns*). %ile, percentile.

In our study, 13 (93%) of the 14 infants and toddlers with early-onset esotropia had asymmetries of MOKN, with MOKN asymmetry ratios higher than the 95th percentile of the age-matched control subjects. Asymmetries were present in each eye of subjects with esotropia, and MOKN asymmetry ratios were higher in the nondominant than in the dominant eyes—a finding consistent with the data of Schor et al.[24] Our data were also consistent with those of a study of Bourron-Madignier et al.[22] who observed eye movements in 145 children (3 months to 7 years old) with early-onset esotropia, by using an OKN drum. They found that approximately 93% of children in whom esotropia developed in the first 6 months of life had asymmetrical OKN.

Using a hand-held optokinetic drum, Demer and von Noorden[23] found MOKN asymmetry in 58% of a group of adults and children more than 3 years old in whom esotropia had developed before the age of 6 months. When Schor et al.[24] measured MOKN in 50 people more than 8 years old who had esotropia that had occurred in the first 12 months of life, they found that 48% had MOKN asymmetry ratios that exceeded the 95th percentile of the control group. Using identical methods to those used in the current study, Westall et al.[35] also found a reduction in MOKN asymmetry in children with early-onset esotropia who were more than 3 years old, compared with children less than 3 years old. The reduction in the prevalence of MOKN asymmetry in older children with early-onset esotropia may be related to decreased motion asymmetry after surgical correction of esotropia,[36] or after alternate occlusion therapy.[37] However, in a limited number of children, we found that MOKN asymmetry was not affected by surgical correction of strabismus.[35] The difference in prevalence of MOKN asymmetry between the present study and the above studies may be associated with the difference in age of subjects tested. We suggest that MOKN asymmetry may be related to learning or delayed maturation of the visual pathways that are responsive to motion.

In the present study, cortical sensory fusion was found in 5 of 11 infants and toddlers with early-onset esotropia. Although the VEP detection system in this study was designed to optimize the detection of small-amplitude VEPs in response to DRDC, the following reasons suggest that the percentage of subjects with esotropia who have sensory cortical fusion may have been higher. First, the system used a conservative criterion for VEP detection so that detectable responses were not always seen in subjects with normal visual systems (e.g., subject C3). Second, infants and toddlers with esotropia may not have generated detectable responses to DRDC because of the imperfect alignment with Fresnel prisms and the reduced ability to use fusional vergence to compensate for this imperfect alignment.[2]

We found that 45% of subjects with uncorrected esotropia between ages 7 and 26 months showed sensory fusion. The presence of detectable VEP fusion responses in infants and toddlers of these ages is higher than the percentage of children with early-onset esotropia who show stereopsis. Using preferential-looking techniques and prism correction, Birch and Stager[38] found that the percentage of infants with early-onset esotropia who had stereopsis declined from more than 50% at 3 to 5 months old to 10% to 30% between 6 and 14 months old. Our data and data from Birch and Stager[38] show that a significant proportion of infants and toddlers with early-onset esotropia have fusion, stereopsis, or both.

The link between optokinetic nystagmus and binocular vision has been established previously.[11-13] Howard and Simp-

son[12] demonstrated that the slow-phase velocity of OKN is inversely proportional to the binocular disparity of the stimulus, with disparities of 0° (fusion) producing higher slow-phase OKN velocities than stimuli with disparities of as much as 3°. In other studies, investigators have found that subjects who have no stereopsis have greater MOKN deficits than do those who have reduced or normal stereopsis[16] and that binocularly dependent interocular transfer of threshold elevation is poorer in adults with greater MOKN deficits than in those with lesser or no MOKN deficits.[25] Our results indicated that some infants and toddlers with early-onset esotropia who showed asymmetrical responses to monocularly viewed optokinetic stimuli could also have had sensory fusion—that is, MOKN asymmetry was not correlated with cortical sensory fusion. These data are consistent with those from studies by Aiello et al.,[39] who showed that three children who had had surgical correction for esotropia by age 20 weeks had normal stereopsis in childhood, yet their MOKN was still asymmetrical. Taken together, our results and results of other studies[11-13,25,39] show that although binocular vision contributes to OKN, MOKN asymmetry can still occur in the presence of sensory fusion.

Our results show that infants and toddlers with early-onset esotropia who had detectable VEP correlogram responses may have had asymmetrical MOKN. These data could be explained by abnormality in binocular pathways projecting to monocular OKN control centers according to either of the following models: Processing subsequent to sensory fusion may be abnormal; or binocular motion pathways, which may run parallel to sensory fusion pathways, may be abnormal. As suggested by results of VEP studies in human infants[40] and primates[41] with early-onset esotropia, the hypothesis that malfunctioning motion pathways in early-onset esotropia results in asymmetrical MOKN is still consistent with our data.

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