Motion VEPRs, Stereopsis, and Bifoveal Fusion in Children with Strabismus

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PURPOSE. The link between nasal-temporal motion asymmetries and anomalous binocular sensory function in infantile esotropia (ET) has led to the idea that visual evoked potential responses to horizontal motion (mVEP) is an alternative measure of sensory binocularity to stereopsis. A second hypothesis is that the mVEP response is a marker for bifoveal fusion. The purpose of this study was to directly evaluate these two hypotheses by examining the correspondence between the mVEP response and both stereoaucity and bifoveal fusion in a cohort of strabismic patients with variable binocular sensory function.

METHODS. Motion VEPRs, random dot stereopsis, and bifoveal fusion were measured in 94 children: 20 with infantile ET, 16 with infantile accommodative ET, 22 with late-onset accommodative ET, 10 with intermittent infantile strabismus, and 26 normal control participants.

RESULTS. Patients with infantile ET and infantile accommodative ET had high concordance between mVEPR responses and stereoaucity and mVEPR responses and bifoveal fusion. Asymmetric mVEPR responses were highly concordant with both no measurable stereoaucity and an absence of fusional vergence. Patients with late-onset accommodative ET and intermittent infantile strabismus revealed discordance between the mVEP response and stereoaucity and high concordance between the mVEP response and bifoveal fusion. Asymmetric mVEPR responses were highly concordant with the absence of bifoveal fusion and the minimum-size prism to elicit fusional vergence.

CONCLUSIONS. The qualitative and quantitative relationship between the mVEP response and fusional vergence suggests that the mVEP response is an objective measure of bifoveal fusion. The availability of such a test will facilitate studies of normal development of bifoveal fusion and development of monofixation syndrome in strabismus. (Invest Ophthalmol Vis Sci. 2000;41: 411–416)

INFANTILE ET is a constant nasalward misalignment of the visual axes with an onset by 6 months of age. Infantile ET is associated with a pervasive nasal-temporal directional asymmetry of motion processing. Children and adults with a history of infantile ET have an absence or weakness of the temporalward slow phase of monocular optokinetic nystagmus (mOKN)1 and exhibit asymmetric horizontal smooth pursuit eye movements favoring the temporal-to-nasal direction.2,5 Sensory measures of motion processing in infantile ET also indicate a nasal-temporal directional asymmetry. Patients with infantile ET judge the velocity of nasalward targets as faster than temporalward targets3 and exhibit asymmetric monocular visual evoked potentials to horizontally jittering vertical gratings consistent with a nasaltemporal directional asymmetry.4

The mechanisms underlying the nasal-temporal motion processing asymmetry in infantile ET are poorly understood. One hypothesis, is that the nasal-temporal directional asymmetry in infantile ET is linked to the defect of binocularity commonly associated with infantile ET, measured by various tests of binocular function, including stereoaucity,5 interocular transfer9 and binocular summation.10–12 This hypothesis is supported by two findings. First, the time courses of the development of symmetric oculomotor11 and sensory12,13 responses to motion are similar to the time course of the development of stereopsis.13,15 Second, directional asymmetries in stereoblind patients with infantile ET are qualitatively similar to healthy pre-stereoscopic infants. Patients with infantile ET have asymmetric mVEPs4,12 indistinguishable from pre-stereoscopic infants, while patients with late onset accommodative ET, who typically have normal stereopsis, have symmetric mVEP responses.16 These observations are suggestive of a link between motion processing and binocular sensory function and have led to the hypothesis that mVEPRs may be an alternative measure of binocularity to stereoaucity tests.4,17 As there are no published studies in which stereoaucity and mVEP responses have been systematically measured in the same patients, this hypothesis has not been directly evaluated. The first aim of the present study was to directly evaluate this hypothesis by examining the link between mVEP responses and stereoaucity in the same patients. An alternative hypothesis is that mVEP asymmetry is a marker for the absence of bifoveal fusion, sometimes referred to as monofixation. Although not directly tested, there is some
Indirect support for this idea in the literature. Full-time alternate occlusion therapy is thought by some investigators to extend the critical period for the development of binocularity by eliminating binocular visual experience. As such, full-time alternate occlusion therapy has been advocated to maintain binocularity in children with infantile ET. Although full-time alternate occlusion therapy has not been shown to produce better stereoacuity outcomes in patients with infantile ET, it has been demonstrated to reduce the asymmetry of mVEP responses significantly in these patients. It is possible that the shift of the mVEP response that occurs subsequent to full-time alternate occlusion occurs because the occlusion therapy prevents or ameliorates binocular suppression. Following this rationale, we propose that mVEP responses are directly related to bifoveal fusion and not to stereopsis. This hypothesis is supported by a recent study showing better stereoacuity outcomes after early surgery for infantile ET without any shift in the mVEP response.

The second aim of the present study was to directly evaluate the link between mVEP asymmetry and bifoveal fusion by obtaining measures of the mVEP responses and a quantified measure of the minimum prism that elicits fusional vergence.

**METHODS**

**Participants**

Because infantile ET results in profoundly abnormal binocular visual experience during the critical period of development, many aspects of binocular function are severely disrupted, making it difficult to dissociate them. To dissociate different aspects of binocular vision and correlate their function, it is necessary to examine these functions in patients with a spectrum of binocular sensory function. Although patients with infantile ET invariably have little or no random dot stereopsis and lack bifoveal fusion post-treatment, patients with late onset accommodative ET or intermittent strabismus have more variable binocular sensory outcomes. In this study, we assessed mVEP asymmetry, random dot stereopsis, and bifoveal fusion in several subgroups of patients to examine whether mVEPs involve a binocular subsystem and whether mVEP asymmetry reveals a general or a distinct anomaly of binocularity.

Eighty-nine children ranging in age between 9 months and 9 years (mean age, 3 years) participated in the study. Sixty-eight study patients had tropia, and 21 binocular control participants had normal binocular vision. Study patients were referred to the Pediatric Eye Research Laboratory at the Retina Foundation of the Southwest by local pediatric ophthalmologists in Dallas, Texas. Normal volunteer participants were recruited from the Newborn Nursery of the Perot Women’s and Children’s Hospital at Presbyterian Medical Center, Dallas, Texas. Study exclusion criteria were neurologic abnormalities, developmental delay, muscle palsy, gestational age less than 37 weeks, low birth weight, or anisometropia greater than 1.5 diopters (D). Informed consent was obtained before testing from the parents of all participants. The procedures of the experiment were approved by the Institutional Review Board of the University of Texas Southwestern Medical Center, Dallas, Texas, and were performed according to the guidelines of the Declaration of Helsinki. Patient categorization was limited to the variables listed below.

**Infantile ET.** Patients with infantile ET (n = 20) ranged in age from 9 months to 5 years (mean age, 2.4 years). All had a constant ET between 35 and 50 prism diopters (PD) onset before 6 months of age. All were surgically corrected to between 0 to 8 PD before 2 years of age.

**Infantile Accommodative ET.** Patients with infantile accommodative ET (n = 16) ranged in age from 10 months to 9 years (mean age, 3.2 years). All had infantile ET with moderate to severe hyperopia treated with a combination of optical correction and surgery to achieve alignment of 0 to 8 PD before 2 years of age.

**Late-Onset Accommodative ET.** Patients with late-onset accommodative ET (n = 22) ranged in age from 2 to 7 years (mean age, 3.7 years). All had moderate to severe hyperopia with an onset of ET between 18 and 48 months of age and wore spectacles to achieve orthoposition.

**Intermittent Infantile Strabismus.** Patients with intermittent infantile strabismus (n = 10) ranged in age from 10 months to 5 years (mean age, 2.9 years). All had an onset of intermittent exotropia or ET before 6 months of age and may have had eye muscle surgery.

**Participants with Normal Binocular Vision.** Participants with normal binocular vision (n = 21) ranged in age from 12 months to 5 years (mean age, 2.5 years). Ten were normal control volunteers, and 11 were patients with normal binocular vision referred by an ophthalmologist. Control patients were chosen with no binocular vision deficits ruled out by stringent binocular sensory testing, including random dot stereopsis, bifoveal fusion testing, and monocular visual acuity testing. Of the 11 patients, 7 had mild ptosis, 3 had Duane’s syndrome, and 1 had a unilateral polar cataract. All had normal binocular vision defined as having equal monocular visual acuities within the normal range for their age, normal random dot stereocuity for their age, symmetric mOKN, and bifoveal fusion.

**mVEP Recordings**

Motion VEPs were measured monocularly using the NuDiva sweep-VEP system. From a viewing distance of 50 cm, vertical sinusoidal gratings (1 or 3 cyc/deg) were displayed on a 34° × 25° field using a high-resolution video monitor with a mean luminance of 161.6 cd/m² and a contrast of 80%. The gratings jittered between two positions separated by 90° of spatial phase. The temporal rate of positional jitter was 6 Hz (12 reversals/sec), depending on the age of the participant. The spatial frequency of the gratings was scaled to be at least five times lower than the child’s expected visual acuity. Infants and children younger than 2 years were tested only with 1 cyc/deg gratings presented at 6 Hz, and children older than 2 years also were tested using the 3 cyc/deg gratings presented at 10 Hz. During a single trial, the stimulus was displayed for 10 seconds. VEPs were recorded only when the child was calm and alert and when the corneal reflection of the video monitor was centered in their pupil. Recording was interrupted when the child was inattentive or when fixation was interrupted. Seven to 10 trials were recorded for each eye, depending on the cooperation of the child. After the initial series of trials, any trials with artifacts caused by head or body movements were eliminated from the analysis. For the most part, a minimum of five trials was included in the analysis of each motion VEP. However, under the least favorable circumstances, when children were excessively wiggly and we were unable to test long enough to obtain five trials free of artifacts, a minimum of three trials was included in the analysis.
Monocular viewing was achieved by occluding one of the eyes using an opaque Coverlet eye occlusor (Beiersdorf, Wilton, CT) in infants and toddlers or using monocular occluding spectacle frames in older children. A small toy was dangled immediately in front of the monitor to attract the child’s gaze. Infants, toddlers, and small children sat on a parent’s lap during testing. When necessary to maintain alertness or cooperation, infants enjoyed their pacifiers, bottles, or dry cereal.

The EEG was recorded from two bipolar derivations (0_1 and 0_2), 2.5 cm to the left and right of a common reference electrode (0_0) placed 1 cm above the inion on the midline. A ground electrode was placed 2.5 cm above the reference electrode. The potential differences were amplified (gain = 10,000; −3 dB cutoff at 1 and 100 Hz). The EEG was recorded from the two channels and adaptively digitally filtered at a sampling rate of 397 Hz to isolate the VEP.

**Fourier Method for Detecting Motion Asymmetry and VEP Data Analysis**

The EEG was subjected to Fourier analysis to extract the amplitude and phase of the VEP at 6 or 10 and 12 or 20 Hz. These peaks of activity represent the first (F_1) and second (F_2) harmonics of the stimulus presented at 6 or 10 Hz frequency, respectively. All analyses to determine the asymmetry index and the presence versus absence of a bowtie were based on vector averages of at least three trials for each eye. Significance tests and error estimates for each vector average were determined by the T^circ test of Victor and Mast. A vector average met the criteria for analysis if either or both of its F_1 and F_2 harmonics had a signal to noise ratio of greater than 3.00 and the T^circ statistic was significant at less than or equal to 0.05. Most vector averages included a minimum of five individual trials; however, a few averages included only three individual trials.

Symmetric and asymmetric mVEPs produce characteristic Fourier spectrum. A symmetric mVEP, in which the response to the two directions of motion is equal, yields a Fourier spectrum composed primarily of F_2 (where there is a peak of activity at twice the temporal frequency of the stimulus). A symmetric mVEP Fourier spectrum represents equal responses to both nasalward and temporalward horizontal motion. An asymmetric mVEP, in which the response is dominated by one direction of motion, yields a Fourier spectrum composed primarily of F_1 (where there is a peak of activity at the fundamental frequency of the stimulus). An asymmetric Fourier mVEP spectrum represents a stronger response to motion in one direction than the other. If opposite directions of motion produce large F_1 amplitudes in the two eyes, the phase of the F_1 response will differ by 180° between the two eyes. This provides an earmark for nasal-temporal asymmetry in the mVEP.

The symmetry of the mVEP response also was quantified by comparing the relative proportion of F_1 to F_2. This proportion, called the asymmetry index, was calculated by dividing the amplitude of F_1 by the sum of the amplitudes of F_1 and F_2. Values greater than 0.4 indicate a directional asymmetry.

**Stereopsis**

Stereacuity was measured in all participants using the Randot Preschool Stereocuity Test, the Randot, the Lang 1, and the Titmus. Children younger than 3 years, who were unable to cooperate using these tests, were tested using the Infant Randot Dot Stereocuity Cards. The Randot Preschool Stereocuity Test and the Infant Random Dot Stereocuity Cards are new random dot stereocuity tests that are quick and simple to use and provide accurate measures of gross, moderate, and fine random dot stereocuity.

**Bifoveal Fusion**

The 4-PD base-out prism test is a commonly used test to measure bifoveal sensory fusion in children unable to complete the simpler sensory fusion tests that require a voluntary verbal or tactile response by the patient, such as required by the Worth 4-dot test. In the presence of bifoveal fusion, a 4-PD base-out prism placed over one eye leads to a nasalward refixation response by that eye and a subsequent slow fusional vergence movement of the fellow eye. Absence of the refixation response indicates foveal suppression of the eye viewing through the prism, while absence of the slow fusional movement indicates foveal suppression of the fellow eye. A re-test is performed by placing the 4-PD prism over the other eye.

Bifoveal fusion was assessed in all participants using the 4-PD base-out prism test. The 4-PD base-out test was applied to both eyes. Bifoveal fusion was considered to be present in patients who produced a fusional vergence eye movement in response to 4 PD. In children who failed the 4-PD test, we also measured the minimum prism to elicit fusional vergence using 10- and 20-PD base-out prisms. Because the vergence response produced by the prism is dependent on the sensory appreciation of diplopia and the subsequent eye movement is made to restore bifoveal fusion, no response to a 10-PD prism was taken to indicate a binocular suppression region 5° or larger, whereas no response to 20-PD prism was taken to indicate a binocular suppression region 10° or larger. Note that it is possible that the 4-PD base-out prism test may not be completely reliable as a measure of bifoveal fusion. A binocular suppression region less than 2° may be present in children who pass the 4-PD base-out prism test.

**RESULTS**

All binocular control participants had normal random dot stereopsis, bifoveal fusion, and symmetric mVEP responses. The mVEP responses of all control participants were symmetric, composed primarily of F_2 with nonsignificant F_1. Motion VEPs by controls were also determined to be symmetric by an analysis of their asymmetry indices (0.23 ± 0.12; mean ± SD). These values are comparable to those reported by others (e.g., means of 0.20^{12} and 0.28^{17} and SDs of 0.13^{12} and 0.15^{17}).

The relationship among the three binocularity measures (mVEP responses, stereopsis, and bifoveal fusion) was examined by comparing the outcome measures among patients with infantile ET, infantile accommodative ET, late-onset accommodative ET, and intermittent tropia. In the first analysis, mVEP asymmetry was defined by a mVEP dominated by F_1 with a 180° interocular phase difference. The percent concordance between symmetric mVEP responses, the presence of stereopsis or bifoveal fusion and between asymmetric mVEP responses, and the absence of stereopsis or bifoveal fusion was calculated for each patient group. The data from patients with infantile ET and infantile accommodative ET are combined in Table 1. Within this cohort of
patients, there was 25% discordance between the presence of bifoveal fusion and measurable stereopsis. Of 11 patients who exhibited symmetric mVEP responses and bifoveal fusion, only 4 had measurable stereopsis (175, 550, 550, and 3000 seconds). Of 25 patients who exhibited asymmetric mVEP responses, all had an absence of bifoveal fusion (having no fusional vergence response to a 4-PD prism), and all but 2 (3000 and 800 seconds) had no measurable stereopsis.

To summarize, these patients demonstrated 100% concordance between mVEP responses and bifoveal fusion and only 75% concordance between mVEP responses and presence versus absence of stereopsis. The data from patients with late-onset accommodative ET are shown in Table 2. Within this cohort of patients, there was 36% discordance between the presence of bifoveal fusion and measurable stereopsis. Of 18 patients who exhibited symmetric mVEP responses, 17 had bifoveal fusion and 13 had stereopsis. Of four patients who exhibited motion asymmetry, all showed an absence of bifoveal fusion but maintained some measurable stereopsis. To summarize, patients with late-onset accommodative ET had 95% concordance between mVEP responses and bifoveal fusion and 59% concordance between mVEP responses and presence versus absence of stereopsis. The data from patients with intermittent infantile strabismus are presented in Table 3. Within this cohort of patients, there was 25% discordance between the presence of bifoveal fusion and measurable stereopsis. Of eight patients who had symmetric mVEP responses and bifoveal fusion, six had stereopsis. To summarize, patients with intermittent infantile strabismus had 100% concordance between their mVEP responses and bifoveal fusion and weaker concordance (80%) between their mVEP responses and the presence versus absence of stereopsis. The data from all experimental participants are summarized in Table 4. The overall discordance between the presence of bifoveal fusion and measurable stereopsis is 34%. The positive predictive value of motion asymmetry for an absence of a fusional vergence response to a 4-PD prism is 100% and the positive predictive value of motion asymmetry for an absence of stereopsis is 80% (z = 2.20, P = 0.028). The negative predictive values of motion asymmetry for bifoveal fusion and stereopsis are 97% and 62%, respectively (z = 3.44, P < 0.001).

The relationships between the mVEP response, stereopsis, and bifoveal fusion also were examined by comparing the size of the asymmetry index (e.g., the proportion of F1 to F2 in the mVEP) to stereoacuity outcomes and the size of the asymmetry index to the estimated size of the binocular suppression region determined by the minimum-sized prism to elicit fusional vergence. In the first analysis, we examined the relationship between the asymmetry index and stereoacuity. Patients were grouped as having fine to moderate stereopsis (40–550 sec), coarse stereopsis (800–3000 sec), and no stereopsis. The raw data for each category of stereoacuity are presented in Figure 1. A Kruskal–Wallis nonparametric one-way analysis of variance (ANOVA) on ranks revealed a significant relationship between the asymmetry index and stereoacuity (H = 11.916, P < 0.003). As shown in Figure 1, this effect is limited to a significant difference between patients with fine versus no stereopsis (Dunn’s Pairwise Comparisons,21 P < 0.05) and no difference between patients with fine versus moderate or coarse versus no stereopsis.

In the second analysis, we examined the relationship between the asymmetry index and bifoveal fusion by comparing the magnitude of the asymmetry index to the minimum-sized prism to elicit fusional vergence. The raw data are presented in Figure 2. Because the data passed tests of normality, a parametric one-way ANOVA was used to reveal a significant relationship between the asymmetry index and stereoacuity (H = 11.916, P < 0.003). As shown in Figure 2, this effect is limited to a significant difference between patients with fine versus no stereopsis (Dunn’s Pairwise Comparisons,21 P < 0.05) and no difference between patients with fine versus moderate or coarse versus no stereopsis.

To summarize, these patients demonstrated 100% concordance between the presence of bifoveal fusion and measurable stereopsis. Of eight patients who exhibited symmetric mVEP responses, 17 had bifoveal fusion and 13 had stereopsis. Of 25 patients who exhibited asymmetric mVEP responses, all had an absence of bifoveal fusion (having no fusional vergence response to a 4-PD prism), and all but 2 (3000 and 800 seconds) had no measurable stereopsis.

**Table 1. Stereopsis and Bifoveal Fusion Responses of Patients with Infantile Esotropia (Nonaccommodative and Accommodative) as a Function of mVEP Response**

<table>
<thead>
<tr>
<th>Motion Asymmetry</th>
<th>Motion Symmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stereopsis</td>
<td>4</td>
</tr>
<tr>
<td>No stereopsis</td>
<td>25</td>
</tr>
<tr>
<td>Bifoveal fusion</td>
<td>0</td>
</tr>
<tr>
<td>Monofixation</td>
<td>25</td>
</tr>
</tbody>
</table>

| Stereopsis       | 6              |
| No stereopsis    | 25 (80°)       |
| Bifoveal fusion  | 0              |
| Monofixation     | 31 (100°)      |

**Table 2. Stereopsis and Bifoveal Fusion Responses of Patients with Late-Onset Accommodative Esotropia as a Function of mVEP Response**

<table>
<thead>
<tr>
<th>Motion Asymmetry</th>
<th>Motion Symmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stereopsis</td>
<td>13</td>
</tr>
<tr>
<td>No stereopsis</td>
<td>5</td>
</tr>
<tr>
<td>Bifoveal fusion</td>
<td>17</td>
</tr>
<tr>
<td>Monofixation</td>
<td>1</td>
</tr>
</tbody>
</table>

| Stereopsis       | 23 (62%)       |
| No stereopsis    | 14             |
| Bifoveal fusion  | 36 (97%)       |
| Monofixation     | 1              |

**Table 3. Stereopsis and Bifoveal Fusion Responses of Patients with Intermittent Infantile Strabismus as a Function of mVEP Response**

<table>
<thead>
<tr>
<th>Motion Asymmetry</th>
<th>Motion Symmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stereopsis</td>
<td>0</td>
</tr>
<tr>
<td>No stereopsis</td>
<td>2</td>
</tr>
<tr>
<td>Bifoveal fusion</td>
<td>0</td>
</tr>
<tr>
<td>Monofixation</td>
<td>2</td>
</tr>
</tbody>
</table>

**Table 4. Stereopsis and Bifoveal Fusion of All Participants with Strabismus as a Function of mVEP Response**

<table>
<thead>
<tr>
<th>Motion Asymmetry</th>
<th>Motion Symmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stereopsis</td>
<td>6</td>
</tr>
<tr>
<td>No stereopsis</td>
<td>25 (80°)</td>
</tr>
<tr>
<td>Bifoveal fusion</td>
<td>0</td>
</tr>
<tr>
<td>Monofixation</td>
<td>31 (100°)</td>
</tr>
</tbody>
</table>

*Positive predictive value of motion asymmetry.
†Negative predictive value of motion symmetry.
produce fusional vergence to the 20 diopter prism (\( P < 0.05 \)). A Kruskal–Wallis nonparametric one-way ANOVA on ranks revealed the same finding (\( H = 40.777, P < 0.001 \)) with differences between patients with bifoveal fusion versus patients with monofixation syndrome classified according to the minimum-sized prism to elicit fusional vergence (Dunn’s Pairwise Comparisons, \( P < 0.05 \)).

**DISCUSSION**

In this study, we examined the relationship between the mVEP response and two different measures of binocularity: random dot stereopsis and bifoveal fusion. In brief, we found that in a population of patients with diverse binocular sensory outcomes, the symmetry of their mVEP responses are highly predictive of their performance on the 4-PD base-out prism test and less predictive of their random dot stereopsis outcomes. Within a diverse population of patients with variable stereopsis outcomes we found predictive values for mVEP response and bifoveal fusion versus no bifoveal fusion to range between 97% to 100%, whereas predictive values for mVEP response symmetry and stereopsis versus no stereopsis ranged between 57% and 80%. These findings suggest that the mVEP response is not a marker for stereopsis but is rather a marker for bifoveal fusion.

**FIGURE 1.** The relationship between the mVEP asymmetry index and random dot stereopsis in patients with infantile esotropia (○), infantile accommodative esotropia (●), late-onset accommodative esotropia (□), and intermittent infantile strabismus (■). As indicated by the arrow, patients with 40 to 550 arc sec stereoaucity had significantly lower asymmetry indices compared to patients with no measurable stereopsis (nil). The solid and dashed horizontal lines mark the normal mean asymmetry index (0.23) ± 1 SD (0.12), respectively.

**FIGURE 2.** The relationship between the mVEP asymmetry index and the minimum-sized prism to elicit fusional vergence in patients with infantile esotropia (○), infantile accommodative esotropia (●), late-onset accommodative esotropia (□), and intermittent infantile strabismus (■). As indicated by the asterisk, patients with bifoveal fusion (who produced fusional vergence to a 4 DP) had significantly lower asymmetry indices compared to all other patient groups. The solid and dashed horizontal lines mark the normal mean asymmetry index (0.23) ± 1 SD (0.12), respectively.
fusion. In addition, separate analyses of the asymmetry index and its relationship to stereocuity and to the minimum-sized prism to elicit fusional vergence indicate the asymmetry index may be a useful measure of the density of binocular suppression. As the size of the minimum prism able to elicit fusional vergence increases, so too does the magnitude of the asymmetry index. The relationship between the mVEP asymmetry index and stereocuity is not as clear and should be interpreted cautiously. As shown in Figure 1, patients with fine-to-moderate stereocuity tend to have asymmetry indices clustering within the normal range, whereas patients with no measurable stereocuity tend to have higher asymmetry indices clustering outside of the normal range. However, there are many patients within the groups with fine-to-moderate stereocuity and no stereocuity who fall outside of this simple description, providing a strong argument against any relationship between the mVEP response and stereocuity.

Furthermore, our finding that motion asymmetry is a marker of an absence of bifoveal fusion is consistent with the finding of less asymmetric mVEP responses in patients with infantile ET after full-time alternate occlusion therapy. Full-time alternate occlusion therapy treats abnormal binocular experience, alleviating the conditions that lead to the development of suppression and monofixation syndrome. Reduced asymmetry indices after full-time alternate occlusion treatment may reflect a reduction in the size of the minimum prism to elicit fusional vergence or in some instances the recovery of bifoveal fusion.

Together, these findings lead us to conclude that the mVEP response, though related to several aspects of binocular vision, is primarily a measure of bifoveal fusion. The high concordance between the mVEP response and bifoveal fixation or the absence of fusional vergence provides a distinct and objective measure of monofixation that can be used in infants as well as children and adults. This result is a promising one, providing an alternative measure of bifoveal fusion to the base-out prism test or other tests of fusion that require fixation or understanding and communication. The mVEP will facilitate studies of normal development of binocular vision, including the codevelopment of eye alignment, stereopsis, and bifoveal fusion. It will also facilitate studies of the disruption of binocular vision, including the development of monofixation syndrome and the influence of different treatments and their time courses on the recovery of bifoveal fusion in different patient groups, including infantile ET and late-onset accommodative ET.

Currently, we are investigating the progression of the mVEP response in children who acquire late onset accommodative ET and the influence of different factors on binocular sensory outcomes in this patient group. An understanding of the progression of the mVEP response in children with accommodative ET may facilitate early treatment to prevent monofixation and to facilitate the recovery of bifoveal fusion and fine stereocuity. Finally, existing theories regarding the underlying causes of infantile ET are vague. An objective measure of bifoveal fusion may provide a useful tool to investigate the causes of infantile ET. Different maturation patterns of mVEP responses by patients with congenital infantile ET (onset at birth) versus noncongenital infantile ET (onset between 2 and 4 months), may indicate subgroups of patients with different etiology.

References