Early Versus Delayed Repair of Infantile Strabismus in Macaque Monkeys: II. Effects on Motion Visually Evoked Responses

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Purpose. Infantile strabismus in humans and the monkey is associated with maldevelopment of visual motion responsiveness, one manifestation of which is directionally asymmetric motion visual evoked potentials (motion VEPs). Early repair of strabismus in infant monkeys has been shown to restore normal development of motion responsiveness for pursuit and optokinetic eye movements (optokinetic nystagmus [OKN]). The purpose of this study was to determine how early versus delayed repair of strabismus influences the development or maldevelopment of motion VEPs.

Methods. Optical strabismus was created in infant macaques by fitting them with prism goggles on day 1 of life. The Early Repair group wore the goggles for a period of 3 weeks (the equivalent of 3 months before surgical repair in humans), whereas the Delayed Repair group wore the goggles for a period of 3 to 6 months (the equivalent of 12–24 months before surgical repair in humans). Several months after the removal of the goggles, motion VEPs to horizontally oscillating grating stimuli were recorded during monocular viewing. An asymmetry index (AI) was measured for each animal by extracting an asymmetric (F1) and symmetric (F2) frequency component from the motion VEP. The AIs of the infant monkeys with Early versus Delayed Repair were also compared with that of a group of adult monkeys, who had unrepaired, natural strabismus.

Results. When tested with a 1-cyc/deg, 6-Hz stimulus, both control and Early Repair monkeys exhibited symmetric motion VEPs (AI $<$ 0.25). Mean AI was 0.15 $\pm$ 0.09 in control and 0.16 $\pm$ 0.13 in Early Repair monkeys. In contrast, both Delayed Repair and naturally strabismic monkeys had asymmetric motion VEP responses: AI = 0.57 $\pm$ 0.22 in the Delayed Repair and 0.49 $\pm$ 0.17 in the naturally strabismic monkeys ($P <$ 0.01). Delayed Repair and naturally strabismic monkeys also had motion VEP asymmetries of equivalent magnitude when tested using stimuli at higher (3 cyc/deg/11 Hz) spatial–temporal frequencies. The concordance between motion VEP symmetry and normal fusional vergence was significant ($P < 0.01$).

Conclusions. Early repair of optical strabismus in primates restores normal development of visual motion pathways in the cerebral cortex, measured as symmetric motion VEPs. Delayed repair causes permanent motion VEP maldevelopment. These results provide additional evidence that early strabismus repair is beneficial for brain development in infant primates. (*Invest Ophthalmol Vis Sci.* 2004;45:821–827) DOI:10.1167/iovs.03-0564

Infantile (congenital) esotropia is a convergent misalignment of the visual axes with onset in the first 6 months of life.[1,2] It represents more than 90% of all strabismus occurring in infancy.[3,4] In addition to subnormal fusion and stereopsis, children and adults with a history of infantile esotropia exhibit a nasotemporal directional asymmetry in response to visual motion.[2] Under conditions of monocular viewing, smooth pursuit is robust for nasally directed target motion and absent or weak for temporally directed motion.[5,6] Monocular optokinetic nystagmus (OKN) is characterized by strong nasalward but weak temporalward slow phases.[7–10] Patients with infantile esotropia may also misperceive the direction or speed of moving stimuli, generally with a bias favoring nasally directed motion.[6,11–13]

Motion VEPs provide evidence that the directional asymmetries of eye movement and perception are due to maldevelopment of visual motion circuits in the occipital cortex.[14,15] Motion VEPs are asymmetric in young normal human infants before onset of binocularity but systematically become symmetric as binocular function is established.[16] If esotropia develops during infancy, the motion VEP remains asymmetric.[15–17] The asymmetry is absent (or less prevalent) if onset of esotropia occurs after infancy.[18,19] Taken together, these findings indicate that the development of symmetric motion responsiveness in the visual cortex is dependent on normal binocular eye alignment in the first months of life.

The appropriate age at which to perform corrective eye muscle surgery for infantile strabismus is controversial.[20,21] In North America, the average age of repair ranges from 10 to 18 months.[2,4] Despite surgical repair at this age, deficits of stereoscopic perception and asymmetries of eye tracking persist into adulthood.[5,6] Recently, surgeries at or before age 4 to 6 months have been advocated. These very early surgeries often restore binocular fusion and stereopsis,[16,22–25] but little detailed information is available regarding improvement in ocular motor behavior or motion processing.

Behavioral studies have shown that the postnatal development of binocular sensory and motor functions in normal infant monkeys closely parallel those of normal infant humans, but on a compressed time scale (i.e., 1 week of monkey development is equivalent to 1 month of human development).[16,26–30] Macaque monkeys with infantile esotropia display the constellation of eye movement and VEP abnormalities found in strabismic humans, including defective fusional vergence, pursuit/OKN asymmetry, and motion VEP asymmetry.[10,31–33] Thus, infant macaques are an appropriate model to use in studies designed to test the efficacy of early strabismus repair.

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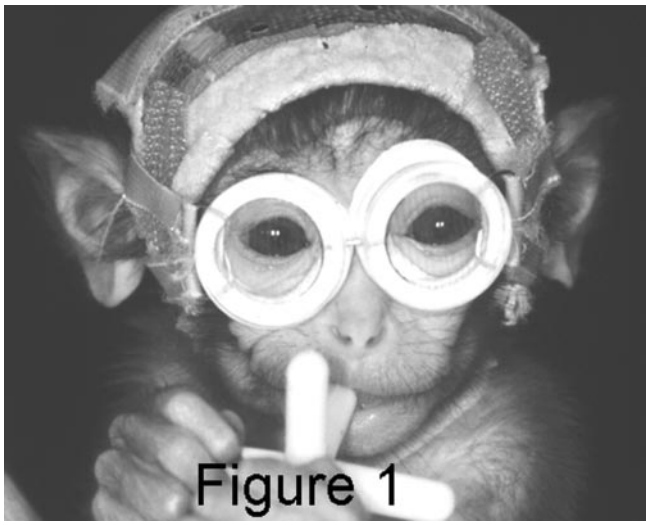

FIGURE 1. Infant monkey wearing prism goggles to induce optical strabismus—that is, image decorrelation between the right and left eyes.

We have recently reported the results of experiments designed to test the efficacy of early repair on pursuit/OKN eye tracking, using a model of optically induced infantile strabismus in infant monkeys.[34] The repair (i.e., removal of prism goggles) was deliberately timed to mimic early (before age 6 months) versus delayed (age 1–2 years) surgical repair of strabismus in human infants. Early repair restored symmetric tracking, whereas delayed repair caused permanent pursuit/OKN asymmetries. The purpose of the present study was to determine how the timing of repair influences the development of motion VEPs.

METHODS

Animals and Goggle Rearing Groups

Monkeys (*Macaca mulatta*) born at the Yerkes Primate Center (Atlanta, GA) were fitted with goggles on the first day of life (Fig. 1). The fitting procedure was an adaptation of that originally described by Crawford and von Noorden[35] and Crawford.[36] The procedure was not stressful to the newborn macaques and did not require anesthesia or fabrication of a head mold. Padded head straps held the goggles firmly in place and prevented the infant from removing the apparatus, which was custom fabricated for each monkey from light-weight plastic. The front piece consisted of two lens holders, which unscrewed so that ultra–light-weight, 2-mm thick Fresnel plastic prisms could be inserted. Animals were observed several times per day in the primate nursery and during bottle feedings to ensure that the goggles remained clear and in proper position. The goggles did not interfere noticeably with normal play or mingling with other infant macaques. The goggle helmet was removed daily from each monkey for cleaning. During cleaning and, if necessary, adjustment of the goggle, the animal was placed briefly in a dark (light-tight) enclosure to preclude normal binocular experience. Inspection of the infant monkeys during the brief periods when the goggles were removed for cleaning disclosed that each of the animals manifested esotropia. Those reared with goggles for longer periods did not manifest noticeably larger angles of strabismus during these inspections.

The monkeys were divided into two repair groups, Early and Delayed. In each group, experimental animals wore prism goggles to induce optical strabismus of at least 11.4° (20 prism diopters) in each eye. Four experimental animals (Table 1) wore 11.4° base-down in one eye, and 11.4° base-in in the other eye, causing a combined horizontal and vertical strabismus. A fifth experimental animal (SY), wore 11.4° base-in in each eye, causing a 22.8° (40-prism-diopter) horizontal strabismus. Normal control animals wore goggles with plano lenses (Table 1). The Early Repair group (two experimental and one normal control) wore the goggles for a period of 3 weeks (the equivalent of three months in humans[28]). The Delayed Repair group (three experimental and one normal control) wore the goggles for a period of 3 months

TABLE 1. Visual and Ocular Motor Characteristics of the 10 Macaque Monkeys Used in the Study

Animal/Sex/Age (yr) (Species)	Rearing Conditions	Eye Alignment at Testing	Latent Nystagmus	Pursuit/OKN Asymmetry	DVD	Visual Acuity SSVEP (cpd)
Early repair group						
TE/M/1.5 (*M. mulatta*)	3 weeks prism (11.4° BI OD; 11.4° BD OS)	Orthophoric	No	No	No	OD: 19.85 OS: 21.40
SY/M/1.7 (*M. mulatta*)	3 weeks prism (11.4° BI OU)	Orthophoric	No	No	No	OD: 17.95 OS: 22.80
WE/M/1.5 (normal control) (*M. mulatta*)	3 weeks plano lens (0°)	Orthophoric	No	No	No	OD: 22.85 OS: 20.50
Delayed repair group						
YO/M/2 (*M. mulatta*)	3 months prism (11.4° BI OD; 11.4° BD OS)	RET: 16° RHT: 5°	Yes	Yes	Yes	OD: 21.10 OS: 19.06
HA/F/2 (*M. mulatta*)	6 months prism (11.4° BD OD; 11.4° BI OS)	RET: 15° RHT: 4°	Yes	Yes	Yes	OD: 19.23 OS: 18.65
QN/F/2 (*M. mulatta*)	6 months prism (11.4° BI OD; 11.4° BD OS)	LET: 12° LHT: 4°	Yes	Yes	Yes	OD: 23.28 OS: 24.01
AY/M/2 (normal control) (*M. mulatta*)	3 months plano lens (0°)	Orthophoric	No	No	No	OD: 18.09 OS: 16.17
Unrepaired naturally strabismic group						
ZE/F/7 (*M. mulatta*)	Naturally strabismic	LET: 12° LHT:8°	Yes	Yes	Yes	OD: 16.80 OS: 18.67
HD/M/12.2 (*M. nemistrina*)	Naturally strabismic	LET: 13° LHT: 2°	Yes	Yes	Yes	OD: 19.06 OS: 19.52
TM/M/22 (*M. nemistrina*)	Naturally strabismic	RET: 22° RHT: 5°	Yes	Yes	Yes	OD: 17.68 OS: 19.33

DVD, dissociated vertical deviation; SSVEP, spatial sweep visually evoked potential; BI, base-in; BD, base-down; RHT, right hypertropia; LET left esotropia; RET, right esotropia.

(the equivalent of 12 months in humans), or for a period of 6 months (the equivalent of 24 months in humans). At 4 to 6 months of age, the monkeys were shipped to Washington University (St. Louis, MO) where they were trained to perform visual fixation and tracking tasks without prism goggles, using a positive-feedback reward (a small bolus of fruit juice).[37] Three adult monkeys who had naturally occurring esotropia with onset at 4 weeks of age or earlier were also studied (Table 1). Cycloplegic refractions revealed a refractive error of less than +3.00 spherical equivalent in each of the infant and adult animals. Monocular visual acuity was measured using spatial sweep VEPs[38,39] (without correction for refractive error), documenting approximately equal vision in both eyes of the control and experimental monkeys (Table 1).

All experiments were performed in compliance with the ARVO Statement for the Use of Animals in Ophthalmic and Vision Research and were approved by the Washington University Animal Care and Use Committee.

Motion VEP Recordings

Motion VEPs were measured using the NuDiva VEP program (Smith-Kettlewell, San Francisco, CA) developed by Norcia et al.[15,40] when the monkeys reached 1 to 2 years of age. Detailed descriptions of the visual fixation training used for the monkeys[37] and VEP recording methods used in both monkeys[31] and humans[13] have been published in reports from our laboratory, and for this reason only an abbreviated description is provided herein. The monkeys were placed in the primate chair with the head restrained and were rewarded with a bolus of fruit juice for maintaining fixation on an LED target (subtending 0.05°) at the center of the visual display. A plastic occluder affixed to the head restraint was used to ensure monocular viewing in successive trial blocks. Three-channel evoked potential recordings were obtained using a bipolar electrode configuration with the active (needle) electrodes 1 cm above the occipital ridge and 2 cm lateral to the sagittal midline, a postauricular reference electrode overlying the region of the mastoid, and a ground electrode near the brow. From a viewing distance of 50 cm, vertical sine-wave gratings (1–3 cyc/deg) were displayed on a high-resolution video monitor with a mean luminance of 76.4 cd and a contrast of 84% to stimulate the central 20° of the visual field. The oscillating gratings had the effect of presenting both leftward and rightward motion, each separated in the frequency domain by a 180° phase difference from the other. The animals were tested with 1-cyc/deg gratings presented at 6 Hz, and with 3-cyc/deg gratings presented at 11 Hz. Blocks of twenty 10-second trials per eye were recorded. In several of the infant and adult animals, recordings were also obtained with the animals deeply sedated (which eliminated all eye movement), using intravenous pentobarbital (10 to 30 mg/kg). Comparison of awake versus sedated recordings revealed no substantial intraindividual differences.

Data Analysis

Data were Fourier transformed to extract the amplitude and phase of the motion VEP at 6 or 12 and 11 or 22 Hz. These peaks of activity represent the first (F1) and second (F2) harmonics of the stimulus presented at the 6- or 11-Hz frequency, respectively. The presence of a significant F1 and/or F2 component in the response was determined using the t circ statistic.[40,41] A VEP in which the response to the two directions of motion is equal yields a response spectrum that is composed of even multiples of the stimulus frequency (larger F2). An asymmetric VEP contains additional response components at the odd harmonic multiples of the stimulation frequency (larger F1). If opposite directions of motion produce larger responses in each eye, as is presumed to be the case when nasalward versus temporalward asymmetries are seen, the temporal phase of the odd harmonic responses (F1) from each eye will be 180° out of phase (bow-tie appearance on a polar plot of amplitude and phase).

The symmetry of the motion VEP response was quantified by comparing the relative proportion of F1 to F2. This proportion, called the asymmetry index, was calculated by dividing the amplitude of F1 by the sum of the amplitudes of F1 and F2.[15,42] The asymmetry index can range from 1.0 (extremely asymmetric response dominated by F1) to 0.0 (extremely symmetric response dominated by F2). On the basis of testing a large number of normal human and nonhuman primates, an index greater than 0.25 at 6 Hz and 0.40 at 11 Hz indicates a directional asymmetry.[32,42,43]

Results

Ocular Motor and Visual Function

Early Repair and control monkeys had normal horizontal and vertical eye alignment when tested at age 1 to 2 years. Control and Early Repair monkeys also exhibited normal, stable fixation, symmetric horizontal pursuit/OKN eye movements when viewing monocularly, and normal fusional vergence movements when viewing binocularly. In contrast, each of the three Delayed Repair animals exhibited a constant, comitant, large angle esotropia (Table 1). The esotropia cannot be explained as an adaptive response of the vergence system to the prisms, because esotropia is opposite in direction to the exodeviation that would have been the expected fusional vergence response to chronic base-in prisms. Delayed Repair and naturally strabismic animals also displayed the constellation of eye movement abnormalities that typify infantile esotropia in humans: latent (fusion maldevelopment) nystagmus, nasotemporal asymmetries of both horizontal smooth pursuit and OKN during monocular viewing, and vertical deviations resembling DVD. The ocular motor behavior of these monkeys is the subject of an earlier report.[34]

Spatial sweep VEPs (Table 1) documented approximately equal vision in both eyes of the control and experimental monkeys. Normal acuity in the monkeys confirmed that amblyopia, which can be associated with VEP phase delays,[39] did not play a role in any measured interocular phase difference associated with the motion VEP asymmetries.

Motion VEP Polar Plots

Representative motion VEP responses for individual monkeys from each of the four study groups are shown in the polar plots of Figure 2. Each vector is an individual response from a 10-second trial, viewing 1-cyc/deg gratings that jittered at 6 Hz monocularly with the right or left eye. The length of the vector depicts amplitude (in microvolts) and the direction indicates phase (0–360°). The left column plots first harmonic (F1, asymmetric) responses and the second column the second harmonic (F2, symmetric) responses. Note that the control (AY) and Early Repair (SY) animals exhibited weak F1 but robust F2 amplitudes, with the phases of the responses congregating within similar angles for the right and left eyes. Comparable findings (not shown) were recorded in the other control (WE) and Early Repair (TE) monkeys. Interocular phase differences ranged from 3.3° to 73.3° in control and from 7.2° to 48.5° in Early Repair monkeys.

In contrast, the Delayed Repair and naturally strabismic monkeys showed a strikingly abnormal pattern of motion VEP response (Fig. 2). They exhibited strong F1 but weaker F2 amplitudes, and the responses were approximately 180° out of phase for the right versus left eye. This interocular phase difference produced a bow-tie appearance in the F1 polar plots, as illustrated by the responses of Delayed Repair monkey HA and naturally strabismic monkey TM in Figure 2. Similar findings (not shown) were recorded in Delayed Repair monkeys YO and QN and naturally strabismic monkeys ZE and HD. Interocular phase differences ranged from 149.4° to 225.6° in the Delayed Repair animals and from 140.0° to 220.2° in the naturally strabismic.

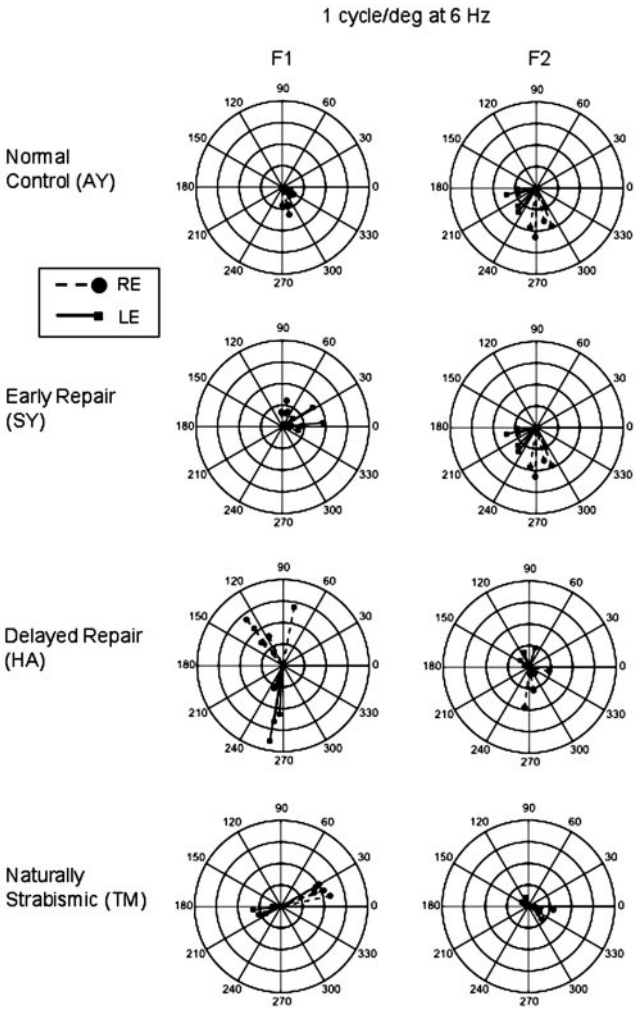

FIGURE 2. Polar plots of motion VEP amplitude (4 μV, full scale) and phase (0–360°) in control, Early Repair, Delayed Repair, and uncorrected naturally strabismic monkeys. The control and Early Repair animals had smaller F1 but larger F2 responses, with the phases of the responses for the right and left eyes congregated in roughly the same direction. The Delayed Repair and naturally strabismic animals had larger F1 but smaller F2 responses, with the phases of the response for the right and left eyes in opposite directions (approximately 180° out-of-phase). Each vector represents data averaged over a 10-second, 6 Hz, 1 cyc/deg trial. F1, first harmonic response; F2, second harmonic response.

Asymmetry Indices

Mean asymmetry indices for each of the four groups of monkeys are summarized in the histograms of Figures 3 and 4. When tested using 1-cyc/deg gratings that oscillated at 6 Hz (Fig. 3), mean asymmetry indices were less than 0.25 (indicated by the horizontal dashed line) for the control and Early Repair monkeys, but 0.57 ±0.22 in the Delayed Repair and 0.49 ±0.17 in the naturally strabismic animals ($P < 0.01$ by *t*-test).

Similar results were obtained when testing was performed with 3-cyc/deg gratings that oscillated at 11 Hz (Fig. 4). The mean asymmetry index was less than 0.40 (dashed line) in control (0.34 ± 0.05) and Early Repair (0.28 ± 0.03) monkeys, but measured 0.70 ± 0.21 in Delayed Repair and 0.57 ± 0.15 in naturally strabismic animals ($P < 0.01$ by *t*-test).

Concordance of Motion VEP Asymmetry and Strabismus

Previous work in human infants by Birch et al.[16] and Fawcett and Birch[19] has shown that the presence or absence of motion VEP asymmetry is strongly tied to ocular motor fusion. Motion VEPs are asymmetric in normal infants before the onset of binocular alignment and fusional eye movements, but symmetric once alignment and fusion are established. In infants with esotropia who were repaired by eye muscle surgery, the prevalence of asymmetric VEPs is significantly lower in those who regain fusion after surgery. Of the 10 monkeys used in this study, the four who had normal alignment and fusional vergence when tested at age 1 to 2 years had symmetric motion VEPs, and the six who manifested esotropia as well as absence of fusional vergence had motion VEP asymmetries. These proportions differ significantly, according to the Fisher exact test ($P < 0.01$).

Discussion

The major finding emerging from our results is that prism-induced strabismus imposed for a sufficient duration causes permanent asymmetries in motion VEPs. The findings of the current report and earlier reports from our laboratory also reinforce the utility of the macaque monkey as a model for exploring the critical period that dictates successful and unsuccessful repair of infantile strabismus in human. Each of the monkeys with alignment repaired by age 3 weeks regained binocular fusional eye movements and demonstrated symmetric motion VEPs. The critical factor in development of normal, symmetric motion VEP responses is therefore timely restoration of binocular image correlation for the development of fusion.

Prism-Induced Strabismus and Binocular Correlation

We have borrowed the short-hand moniker "repair" from the clinical literature to indicate correction of the binocular image decorrrelation produced by prisms. Removal of the prisms reduced or eliminated image decorrelation immediately, mimicking the effect achieved by surgical realignment of the visual axes in children. Goggle removal at the end of the prism-rearing interval delivered a fixed "dosage" of correction to each animal, analogous to performing equal quantities of eye muscle surgery on a group of esotropic human infants. This dosage of correction was highly efficacious if delivered by age 3 weeks, but was ineffective if delayed to age 3 to 6 months.

The animal model replicates in important ways the response of strabismus in children to surgical correction. Infants with identical magnitudes of esotropia—and identical dosages of eye muscle surgery—may respond in a significantly different ways, depending on the timeliness of the repair.[16,23,25,44] Infants who have surgery within 2 to 3 months of onset of a constant misalignment have a substantially greater chance of development of robust stereopsis and fusional vergence.[19,45] Repair delayed to age 12 to 18 months is more commonly associated with permanent deficits in, or absence of, stereopsis and fusion.[24,44,46] Our findings in the infant macaque are similar, taking into account the compressed 1:4 time scale of macaque visual development compared with human. When repair (goggle removal) was performed by age 3 weeks (3 months human) the monkeys also regained normal fusional vergence. Appropriate caution must be exercised in advocating very early surgery in human infants with esotropia (for a discussion of the pros and cons, see Ref. 34). Note also that the monkeys that we labeled Delayed Repair failed to respond to

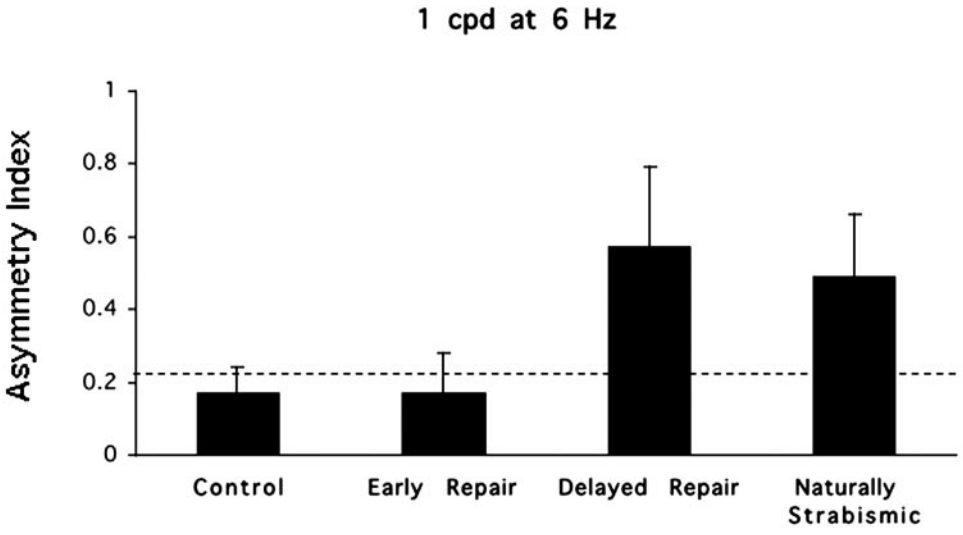

FIGURE 3. Mean ± SD motion VEP asymmetry indices for control, Early Repair, Delayed Repair, and naturally strabismic monkey groups in response to a 1-cyc/deg, 6-Hz stimulus. *Dashed line*: 0.25 or upper range for normal primate. Pooled data for viewing with right and left eyes in each animal.

the "treatment" delivered by prism goggle removal and therefore most appropriately model children who have undercorrected, persistent esotropia.

Development of Binocular Fusion and Motion VEP Symmetry

Motion VEPs are asymmetric in normal human infants before the onset of fusional eye movements and stereopsis, but symmetric once fusion and stereopsis are established.[16,19] The asymmetry in normal infants can be detected at age 2 months. It diminishes systematically by approximately 5 to 6 months of age, corresponding to the periods before (~2 months of age) and after (~6 months) establishment of stereoscopic fusion.[47,48] An analogous time course is evident in normal infant monkeys. Motion VEPs are asymmetric before approximately 6 weeks of age, but become symmetric within a few weeks after,[43] corresponding to the time in macaque visual development for onset of stereoscopic fusion.[30] In our study, motion VEPs were recorded in the monkeys at age 1 to 2 years (the equivalent of age 4 to 8 years in human), by which time motion VEP symmetry is well established.

Motion VEP Asymmetry as a Marker for Suppression (Absence of Fusion)

Motion VEPs remain asymmetric in human infants who have esotropia.[15–17] The asymmetry is reduced by alternate occlusion of the eyes, which minimizes interocular suppression caused by the esotropia.[42,49] When the esotropia is repaired by eye muscle surgery, the prevalence of asymmetric VEPs is significantly lower after surgery in those infants who regain fusion and demonstrate absence of suppression (as inferred from the response to the 4-D base-out prism test[4,50]).[16,19] Infants with alignment repaired before age 10 months have significantly lower postoperative asymmetry indices than those who undergo alignment after 1 year of age.[16,17] Older children and adults who have persistent eye misalignment and interocular suppression, due either to Delayed Repair, unsuccessful repair, or nonrepair, show permanent motion VEP asymmetries.[13,15,17] The responses of our nonrepaired (natural) and Delayed Repair esotropic monkeys were remarkably similar to those in these esotropic humans. The findings indicate that, in both human and nonhuman primates, motion VEP asymmetry is an electrophysiological marker for lack of fusion. If present

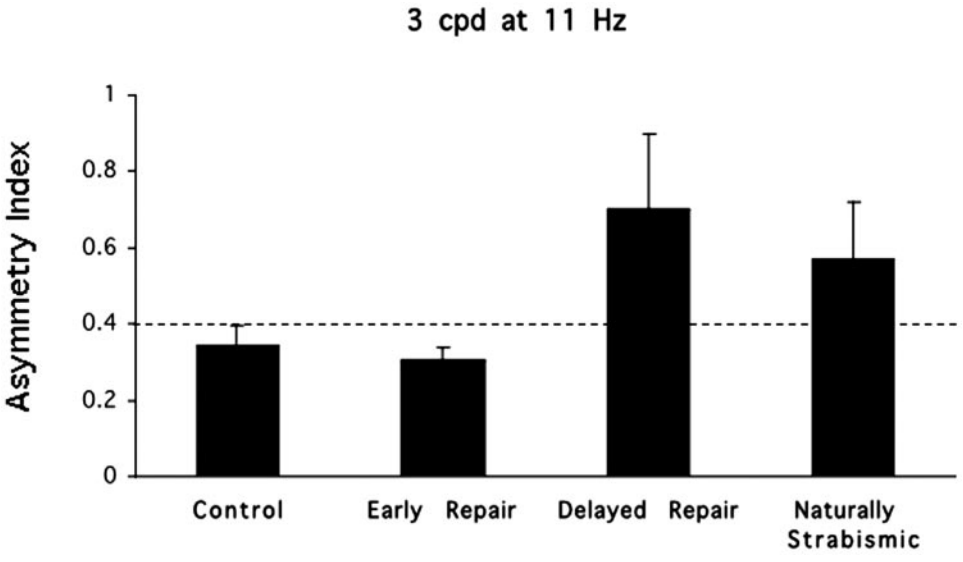

FIGURE 4. Mean ± SD motion VEP asymmetry indices for control, Early Repair, Delayed Repair, and naturally strabismic monkey groups in response to 3-cyc/deg, 11-Hz stimulus. *Dashed line*: 0.40 or upper range for normal primate. Pooled data for viewing with right and left eyes in each animal.

beyond age 6 months in human, the asymmetry is also a marker for interocular suppression.[16,19,42]

Cortical Mechanisms for the Motion VEP Asymmetry

The mechanism underlying the nasotemporal asymmetry of motion responsiveness in infantile esotropia is not well understood. Chandna et al. (*IOVS* 1993;43:ARVO Abstract 1054) have shown that the motion VEP taps binocular, direction-selective neurons in the visual cortex, and depth electrode recordings reveal that motion VEPs arise predominantly from neurons within area V1.[32,51] Neurons that are both directionally selective and sensitive to binocular disparity are present in area V1 of monkey,[52,53] as well as in cortical areas V2,[54,55] V3,[55,56] MT,[57–59] and MST.[60] Physiological recordings from monkey area V1 have shown that infantile-onset strabismus causes a lack of binocular responsiveness[61–64] and heightened interocular suppression.[65,66]

Neuroanatomic studies of V1 in macaques with infantile strabismus show both a paucity of binocular horizontal connections,[67–69] necessary for fusion, and the suppression of metabolic activity[70,71] between ocular dominance columns of opposite ocularity. These binocular maldevelopments, affecting directionally selective neurons at the earliest stage of visual motion processing (e.g., V1), would be expected also to have important downstream effects on the extrastriate regions (e.g., V3, MT, MST, VIP) involved in motion perception, vergence, stable fixation, and pursuit/OKN eye movement. Physiological recordings from area MT in artificially strabismic, paralyzed macaques have revealed abnormal binocularity but no overrepresentation of neurons selective for nasally directed motion.[72] One explanation may be that the overall number of nasally versus temporally directed neurons is unchanged, but subnormal binocularity, coupled with suppression, causes preferential activation of nasally directed subpopulations.[2]

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