Pursuit Eye Movements in Late-Onset Esotropia

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ABSTRACT

Horizontal, smooth pursuit eye movements were recorded from adults and children with infantile and late-onset esotropia using a remote, video-based, eye-movement recording system. Each subject monocularly tracked a 0.5-degree target moving back and forth on a video monitor at a constant velocity of 10°, over a range of 12°. Each subject's nasal and temporal gain (eye velocity/target velocity) was measured. Confirming the results of previous studies, we found that infantile esotropes had asymmetrical pursuit eye movements (nasal gain greater than temporal gain) while late-onset esotropes had symmetrical gains. However, unlike previous investigators, we found that half of the late-onset esotropes had impaired pursuit gain. The magnitude of the pursuit abnormality and the amount of refractive error were correlated—patients with the highest refractive error had the lowest pursuit gain.

INTRODUCTION

The horizontal smooth pursuit and optokinetic eye movements of infantile esotropes are asymmetric.[1-4] This asymmetry is characterized by a higher gain for nasally directed targets than for temporally directed targets. One explanation for the smooth pursuit asymmetry is based on the maldevelopment of binocular cortical mechanisms of visual motion processing.[5-7] Cortical binocular cells and cortical pathways for visual motion overlap and develop in parallel. If the eyes are misaligned, both binocular correspondence and motion-processing development are interrupted. Smooth pursuit eye movements are abnormal because they are driven by the same visual input from the cortical pathways that process motion information. This hypothesis leads to the prediction that patients with esotropia appearing after the critical period for binocular development, will have symmetrical, smooth pursuit eye movements.

The purpose of this study was twofold: first, to test this prediction by recording horizontal smooth pursuit eye movements from patients with a history of infantile and late-onset esotropia; second, to determine the feasibility of using a remote video-based recording system to record pediatric patients' eye movements rather than electro-oculography, which can be cumbersome, time-consuming, and anxiety producing for a child.

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METHODS

Subjects

A total of 42 subjects were tested; 25 children and 17 adults. All subjects received a complete visual and ocular motility examination. Criteria used to establish the presence of infantile esotropia were documented onset of esotropia occurring between 6 and 12 months of age, latent nystagmus, and dissociated vertical deviation (DVD).[8,9]

Infantile esotropes were tested for two reasons: (1) to replicate previous findings using video-based equipment; and (2) to assure the credibility of our data from late-onset esotropes. Criteria for late-onset esotropia were documented onset of esotropia after 2 years of age, no latent

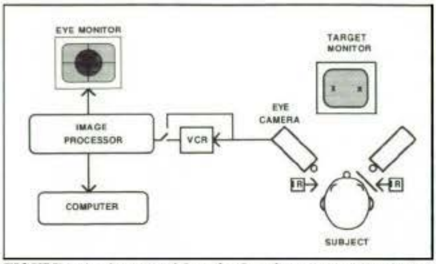

FIGURE 1: A schematic of the video-based eye movement recording system used in the present study. Eye movements were recorded using only one camera at a time; the fellow eye was patched.

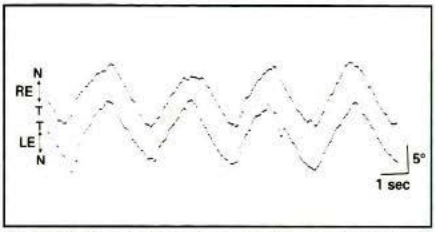

FIGURE 2: Pursuit eye movements recorded separately from each eye of an 11-year-old orthophoric subject. Nasal gain = 0.86; temporal gain = 0.86.

nystagmus, and no DVD. Of the 15 patients with late-onset esotropia, nine had an accommodative component. Patients with only DVD or nystagmus were excluded.

The children were 4 to 12 years of age and included 13 normal controls, 9 late-onset esotropes, and 3 late-onset exotropes. The Snellen acuities of the strabismic child were no worse than 20/25 when their eye movements were recorded, although most had a history of occlusion therapy for amblyopia. The adult subjects, all with at least 20/25 acuity in each eye, included five normal controls, four infantile esotropes, six late-onset esotropes, and two late-onset exotropes.

RECORDING CONDITIONS

A schematic of the system used to record pursuit eye movements is shown in Figure 1. Because of equipment limitations, eye movements were recorded from only one camera at a time, but in order to minimize the time required to position the patient's head, two cameras, a switch, and two illuminants were used. The eye was illuminated with infrared radiation. A low-light level change-coupled device video camera, equipped with an infrared filter, imaged the subject's dark pupil. The output of the camera was fed to a real-time digital image processor, which tracked the center of the pupil at a sampling rate of 60 Hz (ISCAN, Cambridge, Mass).[10,11] The camera output could also be fed to a video cassette recorder, for storage of the data on video-cassette tape for later analysis. The horizontal position of the center of the dark pupil was used as the measure of eye position. Software written for an Apple IIe digitized the tracker's analog output and stored the digitized records. The software also controlled the position of the pursuit target on a small video monitor located 75 cm in front of the patient.

DATA COLLECTION

Each subject was tested monocularly with his or her spectacle correction if required; the fellow eye was patched. A chin-and-forehead rest stabilized the subject's head. Prior to recording the pursuit eye movements, monocular calibration data were obtained by instructing the subject to look at the video screen, which displayed a center fixation target and two eccentric targets, one 8° to the left of the center target and the other 8° to the right. The subject made saccadic eye movements to the right and left of the center target. The pursuit target, a 0.5-degree spot of light, moved at a constant velocity of 10° per second over a span of 12°. At least 20 cycles of pursuit eye movement data were obtained from each eye.

DATA ANALYSIS

The average pursuit velocity of each nasally and temporally directed eye movement segment of at least 400-ms duration was measured directly from the digitized eye movement records. Gain (eye velocity/target velocity) was calculated for each segment. Using a paired *t*-test, each normal subject's temporal and nasal gain for 20 cycles of data were analyzed for right and left eye differences and none were found. On that basis, each normal subject's right and left eye nasal gains and right and left eye temporal gains were pooled. Analysis of these data showed no significant nasal-temporal asymmetries.

For each patient, the right and left eye temporal gains and the right and left eye nasal gains did not differ significantly. On this basis, each patient's right and left eye nasal gain and right and left eye temporal gain values were pooled.

RESULTS

Figure 2 shows pursuit movements recorded separately from each eye of an 11-year-old orthophoric subject. Figure 3 shows pursuit eye movements recorded separately from an adult with a history of infantile esotropia. The patient exhibits pursuit asymmetries. Temporally directed eye movements are characterized by large, interconnecting saccades. Nasally directed eye movements show small refixation saccades, which move in the opposite direction to the moving target. We assume that these patterns

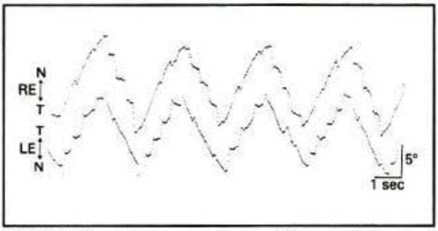

FIGURE 3: Pursuit eye movements recorded separately from each eye of an adult infantile esotrope. Nasal gain = 0.95; temporal gain = 0.24.

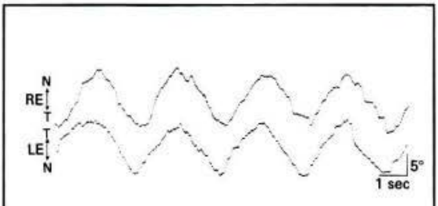

FIGURE 4: Pursuit eye movements recorded from each eye of a 10-year-old late-onset esotrope. Nasal gain = 0.67; temporal gain = 0.61. This gain difference was not significant.

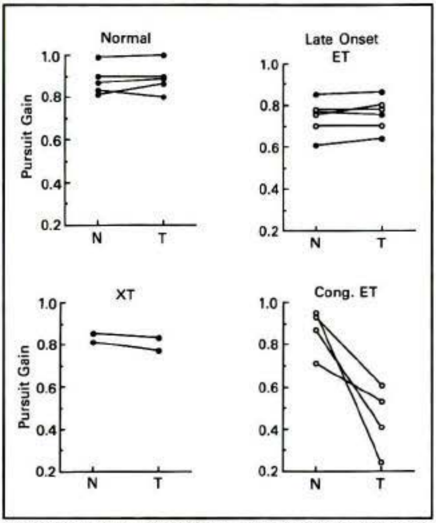

FIGURE 5: Mean temporal and mean nasal gains for adult normal controls and adult strabismic patients. Patients who had strabismus surgery are indicated by open circles.

indicate that compared with target velocity, nasal velocity was slightly faster and temporal velocity was slower. Actual verification of our assumption is impossible with our system because exact target position was not recorded. The difference in velocity could be the result of temporally beating nystagmus with the slow phase affecting the overall eye velocity. Figure 4 shows the monocularly recorded pursuit records of a 10-year-old late-onset esotrope. Small temporal/nasal asymmetries were seen in this sample of eye movements, but the patient's mean nasal gain (0.67) and mean temporal gain (0.61) did not differ significantly. The gains were, however, outside the range of the normal controls.

Figure 5 shows the mean nasal and temporal gains for each adult in the experimental and control groups. Pursuit tracking of the infantile esotropes was asymmetric; nasal gain was higher than temporal gain. The late-onset esotropes had symmetrical pursuit gains, but the temporal and nasal gains of five of the six late-onset adult esotropes were outside of the normal range. The mean nasal and temporal gains of the late-onset esotropes were significantly lower than the normal temporal and nasal means. (Mann-Whitney U test, $P<.05$).

Figure 6 shows the mean nasal and mean temporal gains for the pediatric group. The nasal and temporal gains of four of the nine late-onset esotropic children were outside the normal range. The mean nasal and temporal gains of the late-onset esotropes were significantly lower than the normal nasal and temporal means (Mann-Whitney U test, $P < .05$).

We found no correlation between the symmetrical gain reduction in late-onset esotropia and stereopsis, eye preference, surgery, or visual acuity. There was, however, a relationship between pursuit gain and refractive error. Figure 7 shows each patient's mean nasal/temporal pursuit gain plotted separately for the preferred and nonpreferred eyes as a function of spherical refractive error. A straight line, fit to the data by the method of least squares, showed a correlation of 0.67.

DISCUSSION

In agreement with the findings of Tychsen et al,[1] we found that infantile esotropes have asymmetrical smooth pursuit (nasal gain greater than temporal gain). However, unlike Tyschen et al, who reported that "subjects with strabismus acquired after the age of 2 years did not have impaired pursuit", we found that 50% of the late-onset esotropes whom we tested had impaired pursuit gain. Further, the magnitude of the gain reduction was associated with the magnitude of the patient's refractive error—

the higher the refractive error, the lower the gain, in either direction. This association could possibly be an artifact of optical magnification from the patient's spectacle correction. Because of magnification, the patient tracks a target with a velocity greater than 10° per second. Since pursuit gain decreases as target velocity increases,[12] the patient's gain might still be normal after correction for magnification. This possibility is unlikely since the effect we found for the late-onset esotropes is larger than predicted by magnification. For example, a +5.00 spherical lens causes a magnification of approximately 9%, which increases the velocity of the target on the retina from only 10° to 11° per second. The gain decrement associated with such a small change in target velocity is negligible. To confirm this, we recorded pursuit movements from a normal emmetropic subject with and without a +5.00 spherical lens and found only a 2% reduction in pursuit gain.

These data suggest that the mechanism responsible for symmetrically reduced pursuit gain develops after symmetrical pursuit matures but before normal absolute gain levels are reached. Because of increased accommodative demand, the hyperopic child is exposed intermittently to bilaterally defocused retinal images. This, in turn, may reduce retinal sensitivity to position and velocity information. For example, it is known that motion sensitivity decreases as visual acuity decreases.[13]

Directional eye movement asymmetries have been reported by some investigators[1-7,14-16] but not others.[17,18] One possible reason for this discrepancy is that the emphasis in most of these studies was on the eye movements of the amblyopic eyes of strabismic patients. Whether the patients had early or late-onset strabismus was usually not documented. In studies in which the age of onset to strabismus has been documented,[1-3,19] the age of onset and asymmetry of eye movements were correlated. For example, Demer and von Noorden[3] found that 58% of esotropic patients who developed strabismus before 6 months had asymmetric optokinetic nystagmus but only 5% of patients with esotropia developed under 24 months of age showed asymmetry.

Our study has also shown that in spite of some limitations, a video-based eye-movement recording system can be used effectively to record pediatric patients' eye movements.[20] A video system has the advantages of being noninvasive and rapid. Most of the children that we tested were comfortable with the test conditions, and the average time required to record each child's eye movements was 15 minutes. In this study, measures of horizontal eye position were based only on pupil measurements, which requires that the patient's head is stable. However, the system described here also monitors corneal reflection (the first Purkinje reflex) so that the pupil-cornea difference can be calculated as point of gaze, which compensates for small lateral head movements.

Aslin,[21,22] and Hainline and Lemerise[23] and Lemerise have used video-based systems to record normal infants' eye movements. The major difference between their systems and ours is that in contrast to our system, the light

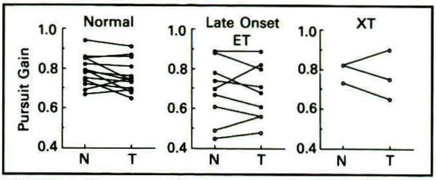

FIGURE 6: Mean temporal and mean nasal gains for the normal and strabismic children. Patients who had strabismus surgery are indicated by open circles.

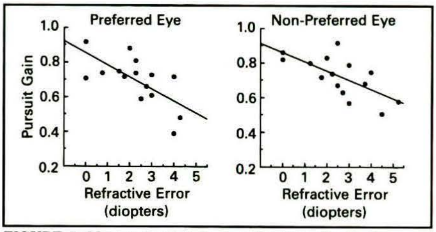

FIGURE 7: Mean pursuit gain as a function of refractive error (spherical equivalent) for the preferred and non-preferred eye of late-onset esotropes. Each data point represents the average nasal / temporal gain for each eye.

source used by these researchers is coaxial with the video camera lens, so that the image of the pupil is filled with light reflected from the retina, the so-called bright pupil. Since a bright pupil system requires a large pupil diameter, subjects must be tested under low ambient illumination. In our system, the light source is off the axis of the camera lens (1-2 inches below the lens) so the light is reflected from the front of the eye, the so called dark-pupil system. Although pupil diameter is not as critical with the dark-pupil system, light reflected off the lashes and sclera can "confuse" the tracker. The system described here can be modified to a bright-pupil system.

Disadvantages of the video system include a relatively slow sampling rate (60 Hz) and a small range of linearity (±15°). The electro-oculogram has a larger linear range than a video based system, (±30°) as well as higher temporal resolution. Because of these drawbacks, the video-system described here is limited to the study of slow velocity and long latency eye movements.

In summary, our data confirm previous reports that the magnitude of nasal-temporal eye movement asymmetry depends on the age of onset of strabismus. Nasal-temporal asymmetries are found in infantile esotropia but not in late-onset esotropia. In addition, we have found that late-onset esotropes have symmetric pursuit deficits which are related directly to the amount of hyperopia present.

We have also demonstrated that eye movements can be recorded effectively in pediatric patients using a video-based recording system which is rapid, comfortable for the patient, and a promising tool in studying eye movements of pediatric patients.

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