Oculomotor Control in Children Who Were Born Very Prematurely

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Purpose. Preterm infants are at increased risk of a variety of cerebral lesions, involving the white matter, cortex, cerebellum, thalamus, and caudate nucleus, many of which could compromise the control of eye movement. Visual problems and disorders of binocularity and alignment have been reported, but little if any quantitative assessment of oculomotor control has been undertaken. The purpose of this study was to extend the initial pilot study and quantitatively examine the control of saccades, smooth pursuit, and antisaccades in children who were born very prematurely.

Methods. A group of preterm (PT) children aged 8 to 11 years (<32 weeks' gestation), who had normal IQ (≥85) and were free of major disabilities (cerebral palsy, blindness, or deafness), and full-term (FT) control subjects of similar age were recruited from a geographically defined cohort. Antisaccades were examined in 36 preterm and 33 full-term subjects and smooth pursuit and saccades in 21 preterm and 19 full-term subjects, by using infrared oculography. Saccade and antisaccade targets were presented at an amplitude of 5° according to a standard synchronous paradigm, and pursuit was assessed by using a step–ramp paradigm with a target velocity of 14 deg/s.

Results. There were no statistically significant differences between the preterm and the full-term subjects in relation to saccade gain, latency, duration, peak velocity, or the proportion of express saccades. Smooth-pursuit latencies tended to be slightly longer in the preterm subjects (leftward: $P = 0.17$, rightward: $P = 0.02$), but there were no significant differences between them and the full-term subjects in pursuit acceleration, open-loop velocity, or peak slow-eye velocity. The main area of deficit in the preterm children occurred in the voluntary control of saccades, with significantly higher antisaccade directional error rates (PT: 73.3% ± 18.1%, FT: 54.2% ± 16.9%, mean ± SD; $P < 0.001$). The latency of the antisaccade error tended to be shorter in preterm subjects ($P = 0.065$), with a greater proportion of errors with latency in the express range ($P = 0.08$).

Conclusions. Despite the increased risk of cerebral lesions, the control of saccades and pursuit was largely normal in the preterm children, suggesting that pathways at the level of the brain stem were principally intact. However, the preterm children had difficulties with the voluntary control of saccades, particularly in the area of inhibition, which may be indicative of a deficit in the region of the dorsolateral prefrontal cortex. This finding is consistent with other reports in preterm children in whom executive function has been found to be compromised, and both these aspects of behavior are likely to share similar areas of cortical control. (*Invest Ophthalmol Vis Sci.* 2007;48:2595–2601) DOI:10.1167/iovs.06-1425

Advances in medical technology over the past 20 years have meant that a greater number of preterm infants are surviving.[1,2] Since the early 1980s, the incidence of preterm births has increased[3,4]: The proportion of spontaneous preterm deliveries in low-risk primiparous women rose by 51% between 1995 and 2004.[5] An increasing number of survivors, however, are at greater risk of having several types of cerebral lesion such as periventricular leukomalacia and intraventricular hemorrhage.[6,7] When compared with full-term control subjects, preterm children have consistently higher levels of problems in areas such as attention deficit and hyperactivity,[8,9] cognitive ability and academic achievement,[10,11] language and social skills,[12,13] and psychomotor skills.[14,15] Preterm children are a heterogeneous group, and cognitive difficulties are not exclusively experienced by preterm children with severe and multiple disabilities, who typically account for only 14% of preterm children[16] and 23% of extremely low birth weight children (<1000 g).[17] Preterm children are also at greater risk of having a variety of ophthalmic disorders that result from white matter damage[18] and retinopathy of prematurity.[19] Subsequent functional deficits have been reported to affect visual acuity, contrast sensitivity, and stereopsis,[19,20] with an increased incidence of strabismus.[21]

In addition to periventricular leukomalacia and intraventricular hemorrhage, preterm children are at risk of other cerebral lesions that can compromise oculomotor control. Cerebellar hemorrhages have been increasingly diagnosed because of improvements in neuroimaging techniques, with a recent estimated incidence of 4.5% in all preterm children and 14.6% in those weighing less than 750 g.[22] Cerebellar lesions have been shown to cause saccadic dysmetria,[23] reduced smooth-pursuit velocity at the end of the open-loop period,[24] and increased pursuit latency.[25] Thalamic lesions have been reported in 50% of preterm children (with the pulvinar being affected in 43% of cases) associated with periventricular leukomalacia, all of whom had spastic cerebral palsy.[26] Thalamic lesions, particularly affecting the pulvinar, may also cause deficits in saccades.[27] Choroid plexus hemorrhages have been found in the region of the caudate nucleus in 41% of preterm infants,[28] and the caudate nucleus may also be damaged due to infarcts of the lenticulostriate branch of the middle cerebral artery.[29] In addition, quantitative magnetic resonance imaging has shown the caudate to have reduced volume.[30] The caudate nucleus is involved in the saccadic pathway by contributing to the suppression and initiation of saccades, providing a tonic inhibitory signal to the superior colliculus.[31] In studies of regional brain volume in preterm subjects, a reduction in cortical volumes has been reported, including the premotor and parieto-occipital regions and the basal ganglia and cerebellum.[32] Similarly, the absolute volumes of cortical and deep nuclear gray matter have been reported to be reduced by 22% compared with that in full-term control subjects.[33] These structural differences may also lead to impairment of oculomotor control. Damage to the

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TABLE 1. Characteristics of the Study Subjects

	Saccades and Smooth Pursuit			Antisaccades		
	Preterm (*n* = 21)	**Full-Term (*n* = 19)**	***P***	**Preterm (*n* = 35)**	**Full-Term (*n* = 32)**	***P***
Sex	11 male 10 female	6 male 13 female	N/A	18 male 17 female	14 male 18 female	N/A
Mean gestation in weeks (range)	30.0 (24 to 32)	37+	N/A	29.9 (23 to 32)	37+	N/A
Mean birth weight in grams (range)	1388 (512 to 2220)	N/A	N/A	1421 (512 to 2300)	N/A	N/A
Mean age tested in months (range)	114.8 (101 to 131)	115.3 (100 to 140)	0.9	121.3 (101 to 143)	121.9 (100 to 142)	0.8
Mean full scale IQ (range)	97 (85 to 113)	105 (91 to 119)	0.004	98 (85 to 113)	105 (91 to 121)	0.001
Median (IQR) of near LogMAR, left eye	0.0 (0.0, 0.0)	0.0 (0.01, −0.01)	0.7	0.0 (0.0, −0.02)	0.0 (0.0, −0.02)	0.1
Median (IQR) of near LogMAR, right eye	0.0 (0.02, 0.01)	0.0 (0.0, 0.01)	0.5	0.0 (0.0, −0.02)	0.0 (0.0, −0.02)	0.4
Median (IQR) of stereopsis (secs of arc)	60.0 (60.0, 60.0)	60.0 (30.0, 120.0)	0.9	60.0 (60.0, 60.0)	60.0 (37.5, 120.0)	0.9

prefrontal cortex can cause difficulties with the suppression of reflexive saccades, resulting in poor control of antisaccades.[34] Lesions of the parieto-occipital region have been reported to result in the impairment of ipsilateral pursuit with superimposed cogwheel saccades.[35]

Given the nature and variety of anomalies affecting children born preterm, including behavioral, motor, cerebral, and ocular anomalies, these children appear to be a group at high risk of having oculomotor control deficits. However, very little if any, quantitative research[36,37] has been directed toward this area. Observations of difficulties with saccades have been made in preterm children,[38,39] but this occurrence has not been investigated systematically. The significance of intraventricular hemorrhage on the incidence of strabismus[40,41] and as a cause of gaze palsy[42] has been described but again without any quantitative examination of oculomotor control. Therefore, the purpose of this research was to extend the work of our pilot study[36] by investigating oculomotor control in preterm children.

METHODS

Subjects

With informed consent and local ethics approval, 36 preterm (<32 weeks gestation) children aged 8 to 11 years were recruited from a geographically defined cohort and compared to 33 full-term children of similar age (<1 year's difference). The investigation adhered to the tenets of the Declaration of Helsinki. Exclusion criteria were major disabilities (cerebral palsy, blindness, or deafness); low full-scale IQ (<85), assessed with the WISC-III test (Wechsler Intelligence Scale for Children); and reduced near logMAR (logarithm of the minimum angle of resolution) acuity (worse than 0.5). Acuity was important, as it ensured that the targets in the eye-movement experiments could be viewed without difficulty. All the children also had an orthoptic assessment that examined alignment (cover test), clinical ocular movements (with a pen torch), and stereopsis (TNO).

Eye-Movement Recording

Eye movements were recorded by infrared oculography (Iris Eye Tracker; Skalar Medical, Delft, The Netherlands), with spatial and temporal resolution of less than 0.1° and 1 ms, respectively. The output of the system was digitized with 16-bit precision at 1 kHz with a power interface (CED Power 1401 interface; Cambridge Electronic Design, Cambridge, UK), and data were written to hard disk for off-line analysis. Visual stimuli were generated by a visual stimulus generator (model 2/5; Cambridge Research Systems, Rochester, UK).

Oculomotor Tasks

The preterm children and full-term control subjects were tested on several standard saccade, antisaccade, and pursuit paradigms. Antisaccades were tested on all 36 preterm and 33 full-term subjects. Saccades and smooth pursuit were tested on 21 preterm children and 19 full-term subjects (the remainder completed a separate experiment, to be reported at a later date). Subjects sat, with their head stabilized by a chin rest and cheek pads, 57 cm from a visual display, which they viewed monocularly with the left eye; the right eye was occluded. For

TABLE 2. Comparison of Saccade Data

Eye Movement Measurement	Preterm (*n* = 21)	Full-Term (*n* = 19)	Significance (*P*)
Saccade gain, leftward	1.1 ± 0.2	1.1 ± 0.1	0.8
Saccade gain, rightward	1.1 ± 0.2	1.0 ± 0.1	0.3
Saccade latency (ms), leftward	206.2 ± 43.3	200.1 ± 30.0	0.6
Saccade latency (ms), rightward	210.4 ± 37.8	204.8 ± 33.5	0.6
Saccade duration (ms), leftward	45.8 ± 6.9	42.9 ± 4.5	0.1
Saccade duration (ms), rightward	44.3 ± 5.7	42.8 ± 3.9	0.3
Peak velocity (deg/s), leftward	−220.9 ± 44.1	−254.5 ± 49.8	0.1
Peak velocity (deg/s), rightward	243.0 ± 41.1	238.2 ± 37.6	0.7
Proportion of express saccades (%), leftward*	0 (0, 15.6)	4.3 (0, 15.7)	0.4
Proportion of express saccades (%), rightward*	4.3 (0, 10.6)	4.3 (0, 17.6)	1.0

Data are expressed as the mean ± SD, unless otherwise specified.
* Data were not normally distributed, values shown are the median (IQR).

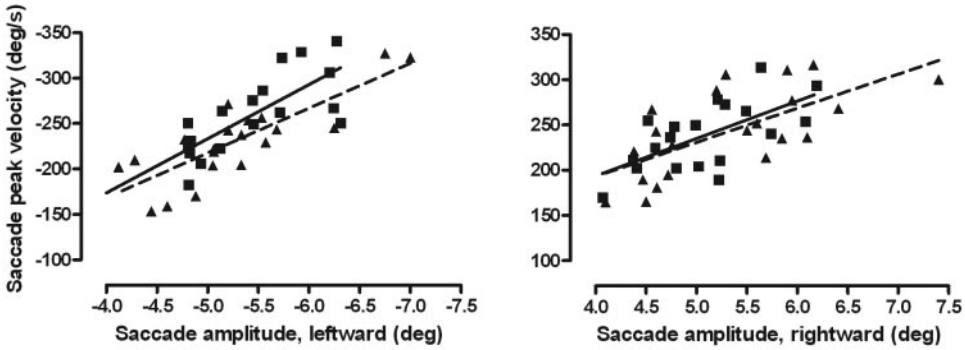

FIGURE 1. Main sequence relationship (peak velocity–amplitude) for leftward and rightward saccades in the preterm and full-term subjects (negative values indicate leftward amplitudes and velocities). Linear regression (*solid line*: full-term subjects; *dotted line*: preterm subjects). Leftward: full-term (■): saccade peak velocity = 64.9 + 59.6 × saccade amplitude, $R^2 = 0.66$, $P < 0.001$; preterm (▲): saccade peak velocity = 28.9 + 49.3 × saccade amplitude, $R^2 = 0.67$, $P < 0.001$. Rightward: full-term (■): saccade peak velocity = 28.3 + 41.4 × saccade amplitude, $R^2 = 0.41$, $P = 0.003$; preterm (▲): saccade peak velocity = 42.5 + 37.7 × saccade amplitude, $R^2 = 0.45$, $P = 0.001$.

all tasks the fixation, saccade, antisaccade, and pursuit targets were small dark squares (0.3° × 0.3°), presented on a light background (contrast 90%). Each trial commenced with a fixation target appearing in the center of the display for a random period of 0.5 to 1.5 seconds. In saccade and antisaccade tasks, a synchronous paradigm was used in which targets appeared randomly 5° to the left or right of fixation at the same time as the fixation target was extinguished. In the saccade task, subjects were instructed to view the eccentric target as soon as it appeared. For the antisaccade task, the instruction was to look in the direction opposite that from which the target appeared, but at the same eccentricity. In pursuit tasks a step–ramp paradigm was used.[43] Targets were randomly stepped 5° to the left or right, then were moved at 14 deg/s back through the center of the display. Subjects were exposed to 52 trials in each experimental run for visually guided saccade and pursuit tasks, and 96 trials for the antisaccade task. At the end of each task, 24 calibration trials were collected and the subject allowed to rest before the next task. In the calibration task, saccade targets appeared randomly 5° or 10° to the left or right of fixation and calibration factors calculated using linear regression.

Data Analysis

Data were analyzed with a specially written analysis program that for each trial displayed the eye position, eye velocity, and time of appearance of the target. Trials contaminated by blinks or head movements were discarded. To analyze saccades, the saccade amplitude, latency, peak velocity, and duration were measured by fitting cursors to the data and reading off the parameters. Saccade accuracy was determined by calculating the gain (actual saccade amplitude divided by the desired target amplitude). Saccade latency in each subject was examined in more detail to determine the proportion of saccades with latencies between 90 and 140 ms (express saccades).[44] Antisaccade directional error rates were calculated by dividing the number of trials on which a prosaccade (error) was made by the number of valid trials. In a manner similar to that used for the standard saccade analysis, the proportion of prosaccades (errors) made during the antisaccade task with short latency (90–140 ms) was calculated[45,46] and is referred to as express antisaccade errors. Smooth-pursuit latency was measured by using a regression technique from trials in which the first eye movement after target appearance was a smooth eye movement (i.e., for presaccadic smooth pursuit). A regression of eye velocity on time was calculated from approximately 50 ms before to 50 ms after the target appearance, where the velocity would be expected to be 0. A second regression was calculated for the acceleration phase of the pursuit response. The intercept between the two regression functions was taken as the time of pursuit initiation. Eye velocity was measured (averaged over 20 ms epochs) from 0 to 20 ms and 80 to 100 ms from the time of target appearance, from 80 to 100 ms after pursuit initiation (at the end of the open-loop period), and finally at 20 ms centered on the peak smooth eye-movement velocity.

RESULTS

Pursuit measurements were unavailable for one full-term subject because of a technical problem with the recording of the data. It was also not possible to record the antisaccade measurements in one preterm and one full-term subject, because they became distressed during testing, and recording had to be abandoned. Measurements were successfully recorded without difficulty in all other subjects, and their characteristics are summarized in Table 1.

There were no statistically significant differences between the preterm and full-term children in mean age when tested, logMAR acuity of the left and right eyes, or level of stereopsis. Neither the preterm nor the full-term subjects had any manifest strabismus or gross deficits of ocular movements during orthoptic assessment. The mean IQ, though well within normal limits, was lower in the preterm children than in the control subjects.

Saccades

A comparison of the control of saccades between the preterm and full-term subjects is provided in Table 2. The control of saccades was similar on all measures for both groups of subjects, with no statistically significant differences.

Assessment of the main sequence relationship[47] between peak velocity and amplitude (Fig. 1) demonstrated a strong association in both the preterm and full-term subjects. Statisti-

TABLE 3. Frequency of Dysmetria for Leftward and Rightward Saccades

Dysmetria	Preterm	Full-Term	Total
Leftward saccades			
Yes	6 (29%)	10 (53%)	16
No	15 (71%)	9 (47%)	24
Total	21	19	40
Rightward saccades			
Yes	11 (52%)	7 (37%)	18
No	10 (48%)	12 (63%)	22
Total	21	19	40

TABLE 4. Comparison of Smooth Pursuit Data

Eye Movement Measurement	Preterm (n = 21)	Full-Term (n = 19)	Significance (P)
Pursuit latency (ms), leftward	219.2 ± 33.2	204.5 ± 31.8	0.17
Pursuit latency (ms), rightward	203.3 ± 29.8	180.6 ± 27.4	0.02
Pursuit acceleration (deg/s/s), leftward	−204.9 ± 54.4	−197.3 ± 21.6	0.6
Pursuit acceleration (deg/s/s), rightward	202.2 ± 69.9	200.5 ± 90.1	0.9
Velocity (deg/s) 0–20 ms after target appearance, leftward	−0.7 ± 1.6	−0.2 ± 1.1	0.3
Velocity (deg/s) 0–20 ms after target appearance, rightward	1.1 ± 1.2	0.5 ± 1.1	0.1
Velocity (deg/s) 80–100 ms after target appearance, leftward	−1.0 ± 0.9	−0.6 ± 0.8	0.2
Velocity (deg/s) 80–100 ms after target appearance, rightward	1.1 ± 1.3	0.8 ± 1.1	0.4
Velocity at the end of the open loop (deg/s), leftward	−8.6 ± 2.1	−7.7 ± 1.9	0.2
Velocity at the end of the open loop (deg/s), rightward	8.0 ± 1.9	7.4 ± 2.0	0.3
Peak slow eye velocity (deg/s), leftward	−14.6 ± 4.2	−14.1 ± 3.4	0.7
Peak slow eye velocity (deg/s), rightward	15.8 ± 3.5	14.9 ± 4.1	0.5

Data are expressed as the mean ± SD.

cal comparison of the regressions[48] revealed no significant difference between the regression coefficient (leftward and rightward; $P > 0.1$), indicating that the peak velocity–amplitude relationship was similar in both the preterm and full-term subjects.

There was slightly greater variability in the preterm group than in the full-term group on most saccade measures. To determine whether there were more preterm children with saccadic dysmetria, the number of preterm and full-term subjects with a gain of more than 1 SD from the full-term mean was calculated and compared by using the χ^2 test (Table 3). The number of preterm children with saccadic dysmetria was not significantly different from that of full-term children for either leftward ($P = 0.1$) or rightward ($P = 0.3$) saccades.

Smooth Pursuit

The pursuit data are summarized in Table 4. Pursuit latencies tended to be longer in the preterm children and reached significance for rightward pursuit.

The acceleration of pursuit was similar in both groups. At 0 to 20 ms and 80 to 100 ms after the appearance of the target, as expected, velocities were close to 0 and were similar in both the preterm and the full-term children. Velocities at the end of the open-loop period were slightly higher in the preterm subjects, although the difference was not statistically significant. The maximum slow eye velocities were in the region of the target velocity (14 deg/s) in both groups.

Antisaccades

The preterm children made significantly more antisaccade directional errors than did the full-term children (Fig. 2). The mean latency of the antisaccade errors tended to be shorter in the preterm children, and the subjects tended to have a higher proportion of antisaccade errors with latencies in the express range (90–140 ms), in comparison to the full-term control subjects (Table 5). The antisaccade errors were corrected less frequently by the preterm children, though the difference between the groups was small. Antisaccade latencies were longer than the antisaccade error latencies, but were similar in both groups.

To assess whether there was any association between the increased antisaccade directional error rates in the preterm children and the degree of prematurity, the data were compared by linear regression (Fig. 3).

The degree of prematurity (completed weeks of gestation) was found to be neither associated with, nor predictive of, increased antisaccade directional error rates in the preterm children.

DISCUSSION

Both in comparisons between the groups of subjects and the proportion of subjects with dysmetria, there were no significant differences in the control of saccades between the preterm and full-term children. This result is surprising given the reports of lesions in preterm children that affect the cerebellum,[22] thalamus,[26] and caudate nucleus.[28–30] Cerebellar lesions if sufficiently serious can lead to dysmetria, particularly hypometria, and reduced saccadic velocity.[23,49] Thalamic lesions can also cause dysmetria and asymmetry due to disruption in the transmission of corollary discharge signals,[50] and caudate lesions can lead to an increase in latency and a reduction in both the amplitude and velocity of saccades.[51] The absence of notable saccade deficits in the preterm children in this study may be because the lesions that occur very early in life are compensated for by neural plasticity and development. In addition, severe lesions in preterm children are likely to be associated with cognitive deficits and reduced IQ,[52] which were excluded from the cohort that we examined and may also explain the absence of manifest strabismus found in the preterm group.

Comparisons with other studies is difficult due to the paucity of research—particularly qualitative studies—published in this area. Therefore, although it has been reported that a group of preterm children had difficulties performing normal saccadic eye movements, no specific data have been presented.[38] Further, the group studied was not typical of preterm children,

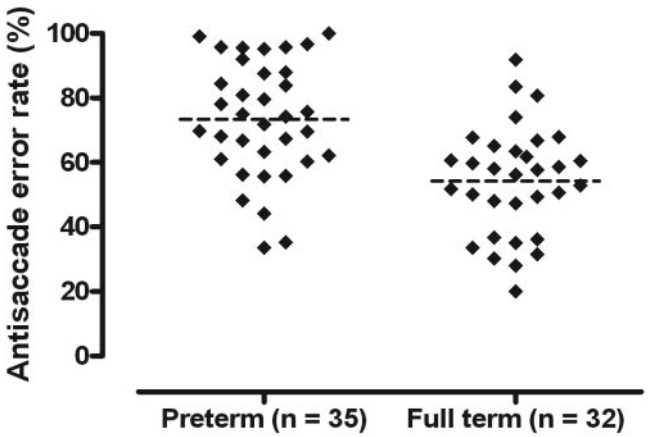

FIGURE 2. Dot plot of the antisaccade directional error rate in individual preterm and full-term subjects. *Dotted lines*: group means.

TABLE 5. Comparison of Antisaccade Data

Eye Movement Measurement	Preterm (n = 35)	Full-Term (n = 32)	Significance (P)
Antisaccade directional error rate (%)	73.3 ± 18.1	54.2 ± 16.9	<0.001
Latency of antisaccade error (ms)	197.2 ± 26.4	212.2 ± 38.1	0.065
Proportion of express antisaccade errors (%)	19.0 ± 18.9	11.8 ± 14.2	0.08
Antisaccade error correction rate (%)	89.1 ± 8.4	93.6 ± 8.2	0.03
Latency of antisaccade (ms)	358.1 ± 54.9	352.6 ± 73.5	0.7

Data are expressed as the mean ± SD.

as all had cerebral palsy, periventricular leukomalacia, and visual impairment, and most had nystagmus. Deficits of saccade initiation and coordination have also been reported in children with cerebral visual impairment after perinatal hypoxia, most of which were preterm.[53] The severity of visual deficits, cognitive problems, and presence of cerebral palsy again makes this cohort unrepresentative of preterm children in general and differs markedly from the subjects recruited in this study. Recently, saccade abnormalities were found in 10% of preterm subjects, though the nature of the abnormalities could not be quantified, as the eye movements were only assessed qualitatively.[39] This is comparable to our findings where the most extreme values of saccade gain occurred in two (10%) of the preterm subjects.

It could be argued that testing only a single saccade amplitude (5°) reduced our likelihood of detecting very subtle abnormalities, although these would be unlikely to be of clinical importance. The fairly small amplitude was specifically chosen, given that most naturally occurring saccades have amplitudes less than 15°, with more than 70% having amplitudes of less than 10°.[54] In addition, the technique we used to assess the eye movements was of a relatively high resolution, allowing identification of small differences. Use of a single amplitude, though, limited our ability to investigate the main-sequence relationships in detail—an area that needs further research.

Preterms had a modest increase in pursuit latency in comparison to full-term subjects, with the increase reaching significance for rightward pursuit. Increased pursuit latencies have been found in patients with degenerative cerebellar lesions,[55] though this increase is unlikely to be the cause in preterm infants, as it would also have caused more widespread saccadic dysmetria throughout the group. Cerebellar lesions have also been found to cause reduced acceleration during pursuit and reduced velocity at the end of the open-loop period.[24,55] We found no differences between the preterm and the full-term subjects in either of these areas, however, providing further evidence that the preterm children in this study were free of any notable deficits affecting the cerebellum. It is possible that the increased pursuit latency in preterm children may have occurred as a result of diffuse cortical damage, which has been shown to occur in other subjects in the area of the posterior parietal cortex[56] and could occur in preterm children because of a reduction in the cortical volume,[57] perhaps affecting the normal maturational process of the cortex.[58] The difference in significance in the pursuit latencies for leftward and rightward pursuit may be attributable to asymmetry of the deficit that has been reported particularly for lesions affecting either posterior cortical areas and underlying white matter[59] or frontal cortex and frontal eye field,[60] though some directional asymmetry was present for both preterm and full-term subjects. Again, there is very little research with which to compare our findings. Some pursuit deficits have been reported in the studies referred to previously in which saccade abnormalities were also noted,[38,39,53] but the assessments of pursuit were again qualitative and involved unrepresentative groups of preterm subjects. Only one other study appears to have involved quantitative assessment of pursuit,[37] finding a significantly reduced pursuit gain in a small group of eight preterm subjects who were free of major disabilities. The study did not measure latency or assess pursuit initiation.

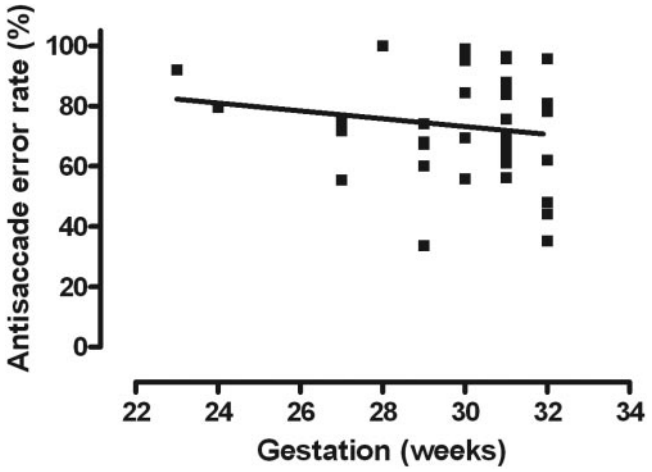

FIGURE 3. Relationship between the antisaccade directional error rate and gestation in preterm subjects. Linear regression: n = 35; R^2 = 0.02; antisaccade error (%) = 112.1 + (−1.3) × gestation; Pearson r = −0.16, P = 0.4.

Preterm children had impairment in the voluntary control of saccades, as demonstrated by the significantly increased antisaccade directional error rates in relation to those in the full-term control subjects. The reasonably high error rate in the full-term children, as found by others,[61,62] is likely to be as a result of incomplete maturation of the frontal cortex.[63,64] Successful execution of an antisaccade involves two components. The first is to suppress the reflexive prosaccade when a new target is introduced, and the second is to generate a voluntary saccade in the opposite direction. Antisaccade error correction rates, though slightly lower in the preterm children, were still at a high level, indicating that the preterm children did not have difficulty in generating the voluntary saccade. Their increased error rate was therefore most likely due to difficulties in inhibiting the reflexive saccade. This notion is suggestive of a deficit in the region of the dorsolateral prefrontal cortex (DLPC), which has an important inhibitory role with connections to the posterior parietal cortex and superior colliculus.[65] Lesions of the DLPC in other subjects have been shown to lead to increased error rates.[66] The high correction rate of the antisaccade errors also suggests that the frontal eye fields, responsible for the generation of voluntary saccades,[67] were relatively unaffected. This interpretation is also consistent with the saccade data that were fairly normal in the preterm subjects. The tendency in the preterm children toward shorter antisaccade error latencies and a higher proportion of errors with latencies in the express range could also be indicative of

a deficit in the region of the frontal cortex that causes a disruption in the balance between the inhibition and generation of saccades. Despite increased antisaccade error rates in preterm children, no association was found with respect to the degree of prematurity. This finding should be treated with caution, however, as the subjects in this study were selected with normal IQ and were free of major disabilities, resulting in a group of subjects with quite a small range of gestational age (most were between 29 to 32 completed weeks of gestation), making it difficult to identify an association.

In conclusion, although children born prematurely have been shown to be at increased risk of a variety of cerebral lesions involved in the control of eye movement and disorders affecting binocular vision and alignment, the control of saccades and, to a large extent, smooth pursuit was surprisingly normal. The voluntary control of saccades, however, as assessed by antisaccades, was significantly impaired in preterm children and suggests there may be deficits at a higher cortical level, particularly in the region of the dorsolateral prefrontal cortex. This has been reinforced recently by behavioral research that found that children born prematurely (with IQ in the normal range) had impaired executive function, a psychological process defined by the control of thought and behavior in which the frontal cortex plays a major role, in which one of the main deficits was in the area of inhibition.[68] Executive function is a key influence of ability in many academic and behavioral areas, and it is possible that the simple assessment of antisaccade control could be a useful predictor of a variety of behavioral difficulties. Antisaccade control is an area that would benefit from further research.

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