Frequency and Severity of Visual Sensory and Motor Deficits in Children with Cerebral Palsy: Gross Motor Function Classification Scale

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PURPOSE. Cerebral palsy (CP) is a permanent, nonprogressive disorder of movement and posture due to a lesion of the fetal or infant brain. The goal was to determine whether children with different severities of CP, as defined using the Gross Motor Function Classification System (GMFCS), had different degrees or types of visual dysfunction.

METHODS. An observational, cross-sectional–design study was conducted by using neurologic and masked ophthalmic measurements on a representative cohort of 50 children with CP. Mean age was 5.6 years (range, 2–19.5 years); mean gestational age was 31 weeks.

RESULTS. The likelihood of debilitating visual deficits was greater in children with higher GMFCS scores, independent of gestational age. Children with level 5 disease (most severe) were at greatest risk for high myopia, absence of binocular fusion, dyskinetic strabismus, severe gaze dysfunction, and optic neuropathy or cerebral visual impairment (CVI). These deficits were rare or absent in children with the mildest disease, level 1. When categorized by anatomic or physiologic CP subtype, diplegic and spastic children were more often hypotonic and ataxic, whereas quadriplegic children with mixed CP (dyskinetic, athetoid, hypotonic, and ataxic) were more often had high myopia, CVI, dyskinetic strabismus, and gaze dysfunction.

CONCLUSIONS. Visual deficits differ in children who have mild versus severe CP. Children with GMFCS level 1 to 2 have sensorimotor deficits resembling those of neurologically normal children with strabismus and amblyopia; children at level 3 to 5 have more severe deficits, not observed in neurologically normal children. (Invest Ophthalmol Vis Sci. 2008;49:572–580) DOI:10.1167/iovs.07-0525

Cerebral palsy (CP) is a permanent, nonprogressive disorder of movement and posture due to a lesion of the fetal or infant brain.1,2 It is the most common cause of physical disability in childhood, affecting ~3 infants per 1000 live births.2,3 To establish a standardized scale for grading CP severity, Palisano et al.4 introduced the Gross Motor Function Classification System (GMFCS). Children at GMFCS level 1 (mildest) can walk and perform all the activities of age-matched peers, albeit with limitations of speed, balance, and coordination.2 Children at level 5 (most severe) must be transported, have extreme difficulties with trunk posture, and have little voluntary control of limb movement. GMFCS grading has been shown to be reliable across observers and invariant with increasing age.5

Children with CP have abnormalities of the visual sensory and motor pathways at rates exceeding those detected in neurologically normal children.6–12 The rates vary considerably from study to study, depending on the selection criteria for the cohort, the sophistication of the clinical tests used, and the terms used to describe both the CP and the visual deficits. A small number of studies have addressed visual acuity as a function of GMFCS.13–15 In none was the GMFCS used to catalog a spectrum of sensory and ocular motor deficits. Accordingly, the first goal of our study was to determine whether children at different levels of GMFCS have different levels or types of visual disability. Because many CP studies describe trunk and limb dysfunction using alternative, anatomic (e.g., diplegic), and physiologic (e.g., spastic) descriptors,3,16,17 we also analyzed, as the second goal of our study, the findings for these descriptors. To aid in both tasks, we define in an Appendix the visual sensory and motor signs used to catalog each deficit.

METHODS

An observational, cross-sectional–design study was conducted by performing ophthalmic and neurologic measurements during the same interval (within days or weeks, often on the same day) on all patients referred to the Cerebral Palsy Center, St. Louis Children’s Hospital at Washington University Medical Center, from 2000 to 2006. The participants were enrolled, and informed consent was obtained from patients or their guardians in accordance with the guidelines of the Declaration of Helsinki. The patients entered into the study at their first neurologic evaluation. The representative cohort (see Data Analyses section) of 50 children and adolescents reported in this study (hereinafter referred to as children) had a mean age of 5.6 years (range, 2–19.5); 35 (66%) boys and 17 (34%) girls. Mean gestational age was 31 weeks (range, 24–40 weeks). Examiners were highly experienced in the care and assessment of children with CP. Family history, prenatal, pregnancy, and birth information was collected along with review of obstetric and neonatal records. The results of genetic, metabolic, and neuroimaging investigations were recorded to help confirm the diagnosis of CP and verify the absence of progressive/degenerative neurologic disease (correlation with neuroimaging findings is the subject of a separate report). In total, more than 200 items of information were reviewed for each child.

Neurologic Examination and Classification

To reduce any interobserver bias, a complete neurologic examination was conducted in the center on each child by attending neurologists...
and by pediatric nurse practitioners. Committee for the Definition of Cerebral Palsy criteria were used for motor function assessment and assignment to physiologic and anatomic subtypes. The GMFCS is used to grade patients in standardized fashion along a five-unit ordinal scale ranging from level 1 (mild) to level 5 (most severe) trunk and limb motor impairment (Table 1). The physiologic classification was dichotomous: either spastic or mixed (dyskinetic, athetoid, hypotonic, or ataxic features). Anatomic classification was trichotomous: diplegic (both lower limbs impaired), hemiplegic (one arm and leg on the same side of the body impaired), or quadriplegic (all four limbs impaired). These classifications follow those recommended in several recent large, multicenter studies of CP.

### Ophthalmic Examination and Classification

Ophthalmic and orthoptic assessments were conducted, including age-appropriate testing of best-corrected visual acuity in each eye, pupillary examination (for anisocoria, iris plica, or afferent defects), sensorimotor examination of eye alignment/eye movement/binocular fusion, cycloplegic refraction with manual, and, when feasible, automated retinoscopy, slit lamp biomicroscope evaluation of the anterior segment, measurement of intraocular pressure by application (Tonopen XL; Medtronic, Jacksonville, FL), indirect ophthalmoscopy with a 15D loupe for high-magnification assessment of optic disc/foveal anatomy, and a 2.2-D loupe for assessment of the peripheral fundus. Acuity (best corrected) was quantified by using optotype (Snellen letter, HOTV, or Allen-type figures) testing when feasible or, alternatively, spatial-sweep visually evoked potentials (SSVEPs). The criteria used for prescribing glasses adhered to the American Academy of Ophthalmology Preferred Practice Pattern, Pediatric Eye Evaluations, and Guidelines for Prescribing Eyeglasses for Young Children. Visual field perimetry was performed with Humphrey automated, Goldmann, or Stycar equivalent methods. Videographic (digital infrared) ocular motor recordings were obtained, under conditions of monocular and binocular viewing (with the head unrestrained), to supplement the clinical assessments of fixation,vergence, saccadic, smooth pursuit, and optokinetic eye movements. The presence, absence, and grade of sensory and visuomotor deficits in each child were determined according to the criteria defined in the Appendix.

### Data Analysis

The ophthalmic examiners were masked to the GMFCS, as well as the physiological and anatomic CP classification. The patients’ data were collated for analysis by unmasking for GMFCS. The database was then scanned and sorted in consecutive, rolling fashion for GMFCS levels 1 to 5, until 10 patients were identified in each class. The strategy ensured random assignment of patients to GMFCS bins of equal size, providing a representative study population of 50 patients. Gestational age and age at examination were compared across GMFCS levels by one-tailed analysis of variance (ANOVA). The \( \chi^2 \) test was used to assess differences among anatomic subtypes. The Fisher exact test was used to assess differences in deficits between physiologic subtypes and between GMFCS levels. For this analysis, GMFCS levels were collapsed into “mild” (levels 1–2) versus “severe” (levels 3–5). This convention was used because it has been used in previous studies of CP severity and logically divides children into those who retain the capacity to walk unassisted (Table 1, GMFCS levels 1 and 2) and those who require a supportive walking device or a transporter (GMFCS levels 3–5). Intellectual function was assessed in most of the children and did not vary in noteworthy fashion across groups. Significance was defined as \( P \leq 0.05 \).

### Results

#### Level of Gross Motor Function and Sensory or Motor Deficits

The first purpose of the study was to determine whether the severity of CP, as graded by GMFCS, was related to the frequency and severity of visual system deficits. By study design, the 50 children of this analysis distributed equally into the five levels of GMFCS. Across CP levels, the children did not differ in gestational age, birth weight, or age at examination (ANOVA, \( P = 0.24, 0.35, \) and 0.40, respectively). The disorders plotted in Figures 1 through 6 are divided into sensory and motor categories. The sensory figures are plots of the prevalence of refractive errors, deficits of binocular fusion, amblyopia, and other deficits of the afferent visual pathways (retinopathy of prematurity, optic neuropathy, visual field defect, or cerebral visual impairment). The motor figures are plots of the prevalence of strabismus and conjugate gaze abnormalities. The individual graphs within each figure are arranged in order of decreasing prevalence, with the most common disorders at the top left and the least common at the bottom right.

#### Sensory Deficits and GMFCS

As shown in Figure 1, most of the children across all levels of GMFCS had low-to-moderate degrees of ametropia, with hyperopes exceeding myopes by a ratio of 2.5:1. The most common type of ametropia was low-to-moderate hyperopia. A trend was evident toward high myopia in the children with severe CP (levels 3–5; \( P = 0.05 \)). The high myopia in levels 3 to 5 was not due to retinopathy of prematurity (ROP). Anisometropia was detected in 10% to 20% of the children across all levels of GMFCS.

Figure 2 shows that binocular vision was absent in 50% or more of the children at each GMFCS level. The children with severe CP tended to be more severely affected, with \( \geq 70\% \) of the children in levels 3 to 5 lacking any binocularuity; the retention of any fusion or stereopsis was greater in the children with mild CP (levels 1 and 2, \( P = 0.04 \)). Fifty percent of those with level 1 CP had intact motor fusion, and 20% to 30% had sensory fusion and at least gross stereopsis. None of the children with level 5 CP retained these binocular capacities.

The presence of fusion in the children with milder CP did not equate to the absence of amblyopia. Strabismic amblyopia (Fig. 3) was detected in 70% of the level-1 to -2 children. An unexpected finding was the lower prevalence of amblyopia in the children with severe CP (levels 3–5; \( P = 0.03 \)). The lower frequency of amblyopia in levels 3 to 5 may be explained in large part by 2 factors: the higher frequency of dyskinetic strabismus in these children (see below) and the greater difficulty in obtaining optotype as opposed to grating SSVEP acuities in these children. Inconstant direction and angles of dyskinetic strabismus would be less likely to promote chronic, amblyogenic suppression of vision from one eye. Grating acuity, when compared with optotype acuity, is less sensitive in detecting strabismic amblyopia.

Figure 4 displays the prevalence of other abnormalities of the afferent visual pathways. For level 1, 70% of the children had no abnormality. Conversely, 70% of the children with level 5 had one or more deficits (\( P = 0.02 \)). The most common afferent pathway deficits in the level-5 children were sectoral optic neuropathy (in 50%; \( P = 0.05 \)) and cerebral visual impairment (CVI; in 30%; \( P = 0.08 \)). Visual field scotomas were
present in ≤20% of the children in each GMFCS level. When the children with mild versus severe CP were compared for the presence of any afferent pathway deficit, the children with severe CP had a higher prevalence (P = 0.01). The children with severe CP also had a higher prevalence of any optic neuropathy (sectoral, axial, or hypoplastic; P = 0.02).

**Motor Deficits and GMFCS**

Horizontal strabismus prevalence (Fig. 5) was high in each level of GMFCS, with primary esotropia exceeding exotropia by a ratio 2.2:1. Primary esotropia ranged from a prevalence of 60% to 70% in levels 1 and 2 to 40% in levels 4 and 5. In levels 1 and 2, the esotropia was refractive (corrected with hyperopic spectacles) or intermittent in 32%; the other 68% had a constant, most commonly infantile-onset, deviation. In levels 3 to 5, more than 90% of the esotropic children had a constant deviation. Exotropic deviations were constant in all affected. Vertical misalignment (which included DVD) was also common, detected in 50% of the children in levels 1 to 4. Dyskinetic strabismus was distinct, in that it was present only in the children with severe CP (P = 0.01).

Gaze disorders (Fig. 6) that are features of infantile-onset strabismus—pursuit/OKN asymmetry and latent nystagmus—were common, evident in at least 20% of the children in all GMFCS levels, with the children in levels 2 to 5 showing the highest prevalence. Seventy percent of the children in level 1 had no gaze disorder. The highest rates of more severe gaze dysfunction (i.e., pendular-jerk nystagmus, gaze apraxia/palsy, and fixation impersistence) were detected in the children of CP level 5, affecting 30% to 40% (P = 0.03).
Sensorimotor Deficits in CP

The second purpose of the study was to determine how the anatomic or physiologic subtype of CP related to the severity of visual system deficits. The distribution of the children into CP subtypes and the prevalence of deficits are listed in Table 2. The subtype distribution is comparable to that of other CP studies.3,15,24,25

With respect to anatomic subtype and sensory deficits, the children with diplegic CP were distinguished by a substantially higher percentage of low-to-moderate hyperopia ($P = 0.005$), preserved gross (larger disparity) stereopsis ($P = 0.03$), strabismic amblyopia ($P = 0.04$), and stage 3 ROP ($P = 0.03$). The children with quadriplegic CP tended to have absence of amblyopia ($P = 0.001$) but a higher percentage of CVI ($P = 0.05$). For anatomic subtype and motor deficits, primary esotropia was more common in those with diplegic disease ($P = 0.01$).

The children with quadriplegic disease had more dyskinetic strabismus ($P = 0.05$) and more severe gaze dysfunction in the form of fixation impersistence ($P = 0.05$).

The physiologic subtypes of CP differed in several categories of visual sensory deficits. A higher percentage of the children with spastic CP had low-to-moderate hyperopia ($P = 0.01$), whereas a higher percentage of mixed CP had high myopia ($P = 0.02$). More spastic children with CP had strabismic amblyopia ($P = 0.05$), and more mixed CP had anisometropic amblyopia ($P = 0.02$). It is not clear why myopia occurred with greater frequency in the children with more severe levels or subtypes of CP. As noted earlier, it was not due to gestational age or ROP (distributed evenly across groups). Perhaps the cytokines implicated as the cause of cerebral damage also interfere with emmetropization by mechanisms that are currently unknown.

**DISCUSSION**

The purpose of this study was to determine the frequency and severity of visual system deficits in children with CP of different severity and type (extent). The first question we posed was whether children at different ends of the CP functional spectrum had different visual deficits. The answer was yes, with qualifications. The children in each level of the GMFCS had visual deficits detected at rates 10- to 70-fold higher than those reported in a general pediatric population of equivalent age.26-31 However, the likelihood of having debilitating visual...
deficits was substantially greater in children with more severe CP. The children with the most severe disease, level 5, were at greatest risk for high myopia, absence of any fusion, dyskinetic strabismus, more severe gaze dysfunction, and optic neuropathy or CVI. Each of these deficits was rare or absent in the children with the mildest disease, level 1.

The second question we posed was whether CP subtypes, defined by anatomic extent or physiologic features, were linked to distinct visual deficits. The answer to this was also a qualified yes. The children with diplegic and spastic CP were often hyperopic and esotropic, but retained the highest prevalence of fusion and stereopsis. In contrast, the children with quadriplegic and mixed (dyskinetic, athetoid, hypotonic, and ataxic) CP tended to have high myopia, CVI, dyskinetic strabismus, and severe gaze dysfunction. These findings are consonant generally with those of previous reports. \(^8,10,11,22,32–36\)

Taken together, both the GMFCS and the subtype results convey an important message. The children with milder or less extensive CP resemble the infants and children with bilateral optic neuropathy alone accounted for the low acuities in each eye. Level-1 children had prevalences of 4% to 9% and level-5 children, prevalences of 58% to 60%. Da Costa et al.\(^14\) found similar results using the SSVEP technique to measure acuities. These reports did not specify the etiology of the lowered acuities, or identify visual sensory or motor comorbidities that may have influenced acuity measurements.

Study Design and Methods

Two concerns, related to the design and methods of CP studies, deserve comment. The first concern is sampling bias. Is the CP sample we report here representative of the CP population as a whole? One might argue that children referred for evaluation to a CP unit within a metropolitan medical center are affected more severely than children with CP living in the community, not referred for evaluation. This concern would apply equally to CP studies of any kind in the literature. To minimize potential bias, we conducted masked examinations and then analyzed equal-sized GMFCS subgroups using an array of objective, ophthalmic measures. Our cohort contained children within each anatomic and physiologic category of CP; the distribution, average gestational age, birth weight, and age at examination overlap those of several, large multicenter surveys of CP.\(^3,5,16,18\)

A second concern is attempting to catalog and describe accurately the spectrum of visual deficits encountered. Even for skilled examiners, the examinations are labor intensive and time consuming, requiring repeated observations in subjects who cannot cooperate, supplemented by eye movement recordings, tedious perimetry, and when necessary, VEP measures of acuity. This explains why there are so few reports of similar scope. A related challenge posed by attempting to compare studies of visual deficits in CP, is that caused by an impoverished or nonstandardized ophthalmic CP nomenclature. This problem is especially true of CVI, optic neuropathies, and CP gaze dysfunction (described later). For this reason, we have defined each clinical entity in an Appendix. This catalog has been useful for standardization of clinical documentation across examiners in CP studies at our institution. We believe that it will be useful, at the very least, as a stimulus for discussion and supplementation, by other investigator groups.

Cerebral Visual Impairment in CP

Our results indicated a rate of CVI in children with CP of 16% (averaged across all GMFCS levels). These rates are approximately three to five times lower than those reported in several CP studies from Europe.\(^39–45\) For the present study, CVI was defined as bilateral, subnormal, best corrected visual acuity for age that could not be attributed to an ocular motor deficit (e.g., nystagmus) or a structural defect of the anterior afferent visual pathway (e.g., bilateral optic neuropathy)—the standard definition of CVI used in North America.\(^44–50\) Investigators in European centers tend to use a broad, inclusive definition, wherein any child with combined low acuity and cerebral damage may be labeled as CVI, though the acuity decrements could be ascribed to optic neuropathy and/or ocular motor impairments. For example, a recent report defined all children with bilateral optic neuropathy and CP as CVI, though the optic neuropathy alone accounted for the low acuities in each child.\(^51\)

Huo et al.\(^47\) and Good et al.,\(^49,50\) as well as Hoyt and Fredrick,\(^46\) have petitioned most notably for the conservative CVI definition used in the present study. A virtue of the conservative definition is that it requires that one tease out all

FIGURE 6. Conjugate gaze dysfunction as related to GMFCS level. Pursuit/OKN asymmetry: nasotemporal asymmetry of smooth pursuit or OKN when viewing monocularly; latent nystagmus: slow-phase fixation nystagmus when viewing monocularly; gaze apraxia/palsy: difficulty initiating saccades in response to a step change of target position when viewing binocularly. Pendular-jerk nystagmus: pendular or increasing-velocity, slow-phase oscillations when viewing binocularly; fixation insufficiency: noncyclical ≥5° saccadic or slow-phase instabilities when viewing binocularly. See the Appendix for details.

Vision Studies Involving GMFCS

In a small number of studies, investigators have examined subnormal vision in children with CP as a function of GMFCS.\(^13–15\) Nordmark et al.\(^12\) and Himmelmann et al.\(^15\) reported a systematic increase in severe visual impairment as the GMFCS level increased (defined as grating visual acuity in the better eye worse than 20/60, when measured by preferential-looking). Level-1 children had prevalences of 4% to 9% and level-5 children, prevalences of 58% to 60%. Da Costa et al.\(^14\) found similar results using the SSVEP technique to measure acuities. These reports did not specify the etiology of the lowered acuities, or identify visual sensory or motor comorbidities that may have influenced acuity measurements.
factors other than posterior, afferent visual pathway damage that could impair acuity. By defining and cataloging these factors, attention is directed to deficits other than CVI that may be amenable to treatment (e.g., nystagmus), or the implementation of strategies to help the child cope (e.g., minimizing vertical scanning tasks in school-age children with gaze apraxias). We concur with our European colleagues that the term “cerebral” is more accurate than “cortical” for the CVI acronym. The majority of children with CVI have white-matter (subcortical) lesions of the optic radiations. A minority have lesions of the calcarine or extrastriate cortices. Cerebral subsumes both subcortical and cortical.

Optic Neuropathy in CP

Ten percent of the children in our study with level 1 CP, compared to 60% with level 5, had some form of optic neuropathy. The optic neuropathy was defined by the number of quadrant optic disc sectors that showed pallor (sectoral), the number that showed an enlarged cup (axial), and the number that showed a reduced optic disc diameter (hypoplastic). The majority of reports of optic neuropathy in cerebral palsy have historically used the label “optic atrophy” to describe any disc pallor. However, atrophy connotes progressive loss after maturity. The optic neuropathy of CP is incurred from nonprogressive fetal or neonatal injury. The etiology is attributed to retrograde, transsynaptic loss of ganglion cell axons caused by postgeniculate lesions. Horizontal and vertical bands (sectors) of nonprogressive disc pallor, associated with fetal injury to the calcarine cortex on one side of the brain, were first described by Hoyt and later by Tychsen and Hoyt as, interchangeably, homonymous hemioptic hypoplasia or band atrophy (the patients had normal sized optic discs and no cerebral palsy).

Jacobson et al. proposed that the term “optic nerve hypoplasia” be extended to describe both small diameter optic discs and normal diameter discs with enlarged cups. These investigators hypothesized that small discs were the result of brain injury before the gestational age of 28 weeks, whereas enlarged cups were due to injury at 28 to 34 weeks. However, optic disc analysis in children with CP has shown recently that both types of neuropathy occur with equal frequency in those less than or greater than 34 weeks gestational age.

### Table 2. Prevalence of Visual System Deficits as a Function of Anatomic or Physiologic Subtype of CP

<table>
<thead>
<tr>
<th>Anatomic Subtype (%)</th>
<th>Physiologic Subtype (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diplegics</strong></td>
<td><strong>Hemiplegics</strong></td>
</tr>
<tr>
<td><em>n = 16</em></td>
<td><em>n = 8</em></td>
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<tr>
<td>Low/mod hyperopia</td>
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<tr>
<td>Low/mod myopia</td>
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<tr>
<td>High myopia</td>
<td>6</td>
</tr>
<tr>
<td>High hyperopia</td>
<td>6</td>
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<tr>
<td>Anisometropia</td>
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<tr>
<td>Emmetropia</td>
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<tr>
<td>Binocular vision</td>
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<tr>
<td>No binocular vision</td>
<td>50</td>
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<tr>
<td>Motor fusion</td>
<td>37</td>
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<tr>
<td>Sensory fusion</td>
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<td>Stereopsis</td>
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<tr>
<td>Amblyopia</td>
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<tr>
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<tr>
<td>Amblyopia-anisometropia</td>
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<td>Normal</td>
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<td>CVI</td>
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<td>Strabismus</td>
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<td>Primary exotropia</td>
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<tr>
<td>Dyskinetic strabismus</td>
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<td>Sensory strabismus</td>
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<td>Normal alignment</td>
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<td>Gaze disorders</td>
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<td>Pursuit/OKN asymmetry</td>
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<td>Normal</td>
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</tr>
<tr>
<td>Fixation impersistence</td>
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</table>

Arranged in descending order, most common first, least common last. Bold denotes significant difference.

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advantage of using the term hypoplasia is that it captures the early, nonprogressive nature of the insult (nonprogressive after the first months of infancy). The disadvantages are threefold (1) as noted earlier, hypoplasia could describe sectoral, axial, or small-diameter neuropathy ambiguously; (2) although the central nervous system (CNS) insult causing the neuropathy occurred before maturation, the appearance of the optic discs does change with maturation in early infancy; the enlarged cups of axial neuropathy, for example, are conspicuous at age 6 months but are distinctly rare during ROP screening at age 6 to 12 weeks (Tychsen L, unpublished observation, 2005); and (3) the term hypoplasia is entrenched in the bulk of the literature and clinical parlance as applying only to small nerves. The term “optic neuropathy,” with a subtype prefix, circumvents these controversies, unambiguously describes the funduscopic appearance, and acknowledges gaps in current knowledge of the underlying mechanisms.

Gaze Dysfunction in CP
Observations of gaze dysfunction in CP have been described using a variety of terms: uncoordinated saccades and pursuit; paroxysmal ocular deviations; stability of fixation inability; struggling with fixation and eye movement; complete disruption of ocular motor organization; dyskinetic eye movement disorder; and ocular motor apraxia. Jan et al. reported that one or more of these deficits was present in all 14 children chosen for study because of severe, dyskinetic CP. Salati et al. stated a prevalence ≥78% in children chosen for study using the broader definition of CVI, 77% of whom were categorized as having spastic or mixed, moderate-to-severe quadriplegia.

The results of our study indicate lower prevalences of gaze dysfunction: an average 22% in children with quadriplegic CP; an average 18% in children of CP levels 3 to 5; and an average 8% for levels 1 to 2. Irrespective of discrepancies in prevalence, conjugate gaze deficits deserve better recognition as significant components of visual impairment in children with CP, as they often masquerade as CVI. We were struck by the number of children in our cohort who had normal or mildly subnormal visual acuity, but who, on review of outside medical records, had been labeled as having “cortical blindness.” Parents, therapists, and other healthcare professionals described them variously as: “visually inattentive,” “unable to see or follow,” “no eye contact,” “looks away,” “looks over,” or “uses only peripheral vision.” Careful clinical observation and eye movement recordings revealed combined saccadic and smooth pursuit gaze apraxia/palsy, and fixation insufficiency. The children with these deficits who retained head and neck control used horizontal or vertical head thrusts to facilitate gaze shifts. Restraining head motion tended to exacerbate the impairments by prolonging latencies, reducing saccade amplitudes, and reducing pursuit/OKN velocity matching. The deficits impaired both horizontal and vertical gaze, but were often more pronounced for vertical target steps and target motion.

APPENDIX: DEFINITION OF VISUAL-SENSORY AND VISUAL-MOTOR DEFICITS

Sensory Deficits
Refractive Errors. Measured as spherical equivalent (SE, calculated as spherical error ± cylindrical error) and graded as:

- High myopia: > -4 D
- Low-moderate myopia: -4 to > -0.5 D
- Emmetropia: -0.5 to +1 D
- Low-moderate hyperopia: > +1 to +4 D
- High hyperopia: > +4 D

Anisometropia: > 1.5-D difference between the eyes for SE ≤ 6 D or 25% difference for SE > 6 D.

Binocular Vision Deficits. Binocular fusion was graded as “absent” to “most robust” according to the following scale:

- No binocular vision: absence of sensory or motor fusion.
- Motor fusion: convergence evoked by placing a 20-D base-out prism before one eye, followed by divergence when the prism was removed (i.e., fusional vergence elicited by prism-induced binocular disparity).
- Sensory fusion: perceptual report of “four dots” seen with red-green or Polaroid glasses and viewing the Worth or Polaroid four-dot target at a 33-cm (near) and/or a 6-mm (far) distance.
- Stereopsis: perceptual report of detection and elevation of the salient figure above the background using Polaroid glasses to view figures of the Stereo Fly or Randot preschool stereocuity tests (Stereo Optical Inc, Chicago, IL) at 33 cm.

Amblyopia. Subnormal, best-corrected visual acuity in the absence of a structural abnormality of the pre- or postgeniculate visual pathways. “Subnormal” was ≥2 optotype lines difference between the eyes or greater than octave grating acuity difference for SSVEP.

Strabismic amblyopia: presence of heterotropia.
Anisometropic amblyopia: ≥2 D of spherical or astigmatic anisometropia, independent of presence/absence of heterotropia.

Afferent Pathway Deficits
ROP3: macular distortion (ectopia or vessel traction), accompanied by dysversion of the optic disc, with a history of treated or regressed stage-3 or more ROP.
Sectoral optic neuropathy: a normal diameter disc with one or more quadrantic sectors (e.g., temporal) of neuroretinal rim pallor.
Axial optic neuropathy: a normal diameter optic disc, with normal color of the neuroretinal rim, but an enlarged, pale cup >50% of disc diameter.
Hypoplastic optic neuropathy: small diameter optic disc, estimated by funduscopy or measured from fundus photographs to have a CC/DD >3.5, where CC is the distance from the optic disc center to the fovea centralis, and DD is optic disc width (for myopia ≥5 D the CC/DD threshold was adjusted to 3.0)66—that is, diminished optic disc area, independent of the presence or absence of a hypopigmented ring or pallor.
Visual field defect: a scotoma, relative or absolute, on automated Humphrey or manual Goldmann perimetric testing when feasible; when not feasible, the presence of scotomata was assessed with an evoked saccade or evoked head-movement method with Stycar-equivalent stimuli presented at eccentricities or 0° to 60° in each monocular quadrant.
Cerebral visual impairment: bilateral, subnormal best corrected visual acuity for age that could not be attributed to a funduscopic abnormality or nystagmus and was accompanied by MRI/CT evidence of structural damage to the geniculostriate pathways in the form of periventricular leukomalacia, intraventricular hemorrhage, occipital encephalomalacia, parieto-occipital lobe atrophy, posterior ventriculomegaly, or occipital ulegra.
Motor Deficits

**Strabismus.** Misalignment of the visual axes under conditions of binocular viewing:

*Primary esotropia:* convergent heterotropia on cover testing before any treatment.

*Vertical strabismus/DVD:* hypertropia in one eye with corresponding hypotropia in the opposite eye, and/or dissociated vertical deviations (alternating hyperphorias).

*Primary exotropia:* divergent heterotropia on cover-testing before any treatment.

*Dysskinetic strabismus:* heterotropia that manifested unpredictably as both esotropia and exotropia during the examination.

*Sensory strabismus:* unilateral heterotropia of an eye with substantially lower acuity than in the preferred eye, due to an afferent pathway anatomic lesion or anisometropic amblyopia of the deviated eye.

**Gaze Disorders.** Abnormal conjugate eye movements denoted by the following features:

*Pursuit/OKN asymmetry:* measured under condition of monocular viewing with each eye alternately elicited by a 1° spot or 2° physical target; for pursuit, sustained horizontal smooth eye-tracking for nasallyward target motion, and subnormal tracking for temporallyward motion, evident as the eye-lagging target position and substitution of catch-up saccades; for OKN elicited by a 90° × 90° large field projected image of vertically oriented 80% contrast 5° stripes, a reduced number of sustained slow phases, and nystagmus fast phases for temporallyward stripe motion; the direction of the asymmetry inverts 180° instantaneously with a change of fixating eye; eye movement tracings reveal consistently lower smooth eye velocities for temporallyward motion.

*Latent nystagmus:* measured under conditions of monocular viewing while fixating a stationary 1° or 2° target, nasallyward slow-phase drifts of eye position with respect to the fixating eye, interrupted by temporallyward saccadic fast phases; the direction of the nystagmus inverts 180° instantaneously with a change of fixating eye; usually evident also, but more subtle, when viewing binocularly (manifest latent nystagmus); the slow-phase waveform is linear or of decreasing velocity on eye movement tracings.

*Gaze apraxia/palsy:* difficulty initiating saccades in response to a step change of target position, evident as abnormally long latencies and/or subnormal saccade amplitude; apraxia connotes disfacility more severe for performance on command, and less severe for spontaneous saccades, including persistent gaze deviations away from primary position in the orbits; supranuclear origin of the palsy is verified by demonstrating full eye rotations on vestibulo-ocular reflex testing (doll’s eyes).

*Pendular-jerk nystagmus:* oscillation of eye position under conditions of binocular viewing while fixating a stationary target, with pendular or increasing-velocity slow phases, depending on gaze position in the orbits; each cycle of increasing velocity slow phase is followed by an oppositely directed fast-phase saccade.

*Fixation impersistence:* noncyclical instabilities of eye position in subjects attempting to view a stationary target; manifested as ≥5° saccades directing the eyes away from target position, and/or slow-phase drifts, not followed by refocusing saccades.

**Acknowedgments**

The authors thank Jackie Foeller, BS (Visual Diagnostics Laboratory, St. Louis Children’s Hospital) for help with electrophysiological testing and eye-movement recordings.

**References**


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