Cognitive and Academic Consequences of Bronchopulmonary Dysplasia and Very Low Birth Weight: 8-Year-Old Outcomes

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ABSTRACT. *Objective.* **To examine the effects of bronchopulmonary dysplasia (BPD) and very low birth weight (VLBW) on the cognitive and academic achievement of a large sample of 8-year-old children.**

Methods. **Infants who were VLBW and had BPD (n = 98) or did not have BPD (n = 75) and term infants (n = 99) were followed prospectively to age 8. Groups were compared on measures assessing 4 broad areas of functioning: intelligence, achievement, gross motor, and attentional skills. Measures included the Wechsler Intelligence Scale for Children III, the Woodcock Johnson Test of Achievement-Revised, the Bruininks-Oseretsky Test of Motor Proficiency, the Tactual Performance Test (spatial memory), and the Continuous Performance Test (attention). School outcomes were assessed by parent and teacher report, as well as from school records. Groups were comparable on socioeconomic status, sex, and race. The total sample of BPD, VLBW, and term children was compared on all outcome measures. In addition, neurologic risk was assessed in the present sample and included the following: intraventricular hemorrhage, echodense lesions, porencephaly, hydrocephalus, ventriculoperitoneal shunt, meningitis, and periventricular leukomalacia. Individual difference analyses were conducted for neurologically intact children in all 3 groups. Finally, treatment effects were examined by comparing BPD children who had received steroids as part of their treatment with BPD children who had not.**

Results. **The BPD group demonstrated deficits compared with VLBW and term children in intelligence; reading, mathematics, and gross motor skills; and special education services. VLBW children differed from term children in all of the above areas, except reading recognition, comprehension, and occupational therapy. Attentional differences were obtained between BPD and term children only. The BPD group (54%) was more likely to be enrolled in special education classes than VLBW (37%) or term children (25%). In addition, more BPD children (20%) achieved full-scale IQ scores <70, in the mental retardation range, compared with either VLBW (11%) or term (3%) children, with all VLBW children significantly more likely than term children to achieve IQs in the subaverage category. After controlling for birth weight and neurologic problems, BPD and/or duration on oxygen predicted lower performance IQ, perceptual organization, full-scale IQ, motor and attentional skills, and special education placement. The qualitative classification of BPD (present or absent) was a significant predictor for lower scores on measures of applied problems; motor skills; and incidence of speech-language, occupational, and physical therapies. Individual difference analyses were performed to ascertain whether differences between the risk groups were primarily attributable to neurologic complications. Even with the neurologically intact sample of BPD and VLBW children, differences between the term comparison group and both the BPD and VLBW groups were found for many outcome measures. When birth weight and neurologic complications were controlled, BPD and severity of BPD were associated with lower performance and full-scale IQ, poorer perceptual organization, attention, and motor skills, as well as lower school achievement and greater participation in special education, including occupational, physical, and speech-language therapies. Treatment protocol may in part be responsible for differences observed in our BPD sample. Steroid and nonsteroid groups of BPD children differed significantly in performance IQ (72.8 vs 84.8) and full-scale IQ (77.0 vs 85.2); perceptual organization (74.0 vs 85.2); Bruininks-Oseretsky Test of Motor Proficiency score (36.6 vs 44.7); and participation in special education (78% vs 48%), occupational therapy (71% vs 44%), and physical therapy (71% vs 41%). In every instance, BPD children who received steroids fared more poorly than BPD children who did not receive steroids.**

Conclusions. **BPD and duration on oxygen have long-term adverse effects on cognitive and academic achievement above and beyond the effects of VLBW. The problems that have been identified at 8 years of age highlight the need for continued monitoring of the learning, behavior, and development of BPD children to intervene with children who are at risk for school problems.** *Pediatrics* **2003;112:e359–e366. URL: http://www.pediatrics.org/cgi/content/full/112/5/e359;** ***very low birth weight, intelligence, school performance.***

ABBREVIATIONS. BPD, bronchopulmonary dysplasia; VLBW, very low birth weight; NICU, neonatal intensive care unit; IVH, intraventricular hemorrhage; WISC-III, Wechsler Intelligence Scale for Children III; WJTA-R, Woodcock Johnson Test of Achievement-Revised; BOT, Bruininks-Oseretsky Test of Motor Proficiency-Short Form; TPT, Tactual Performance Test; CPT, Continuous Performance Test; MANOVA, multivariate analysis of variance; ANOVA, analysis of variance; ADHD, attention-deficit/hyperactivity disorder.

Bronchopulmonary dysplasia (BPD) is a serious, chronic pulmonary condition that has emerged in the past decade as the leading cause of chronic lung disease in infancy in the United States.[1]

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Medical and technical advances have enabled more infants with respiratory distress syndrome to survive and have reduced mortality for very low birth weight (VLBW) infants but resulted in a corollary increase in survivors with BPD.[2,3] Long-term neurodevelopmental outcomes of VLBW infants with BPD have become a growing concern because of the increased vulnerability of infants with BPD to the harmful effects of primary lung disease and its associated treatment-related insults and side effects.[3,4] The pathophysiology that leads to infants with BPD having greater developmental delay is probably multifactorial and may include chronic, intermittent hypoxia, growth deficiencies, and altered environmental stimulation.[5–8]

Poorer developmental outcomes have been reported in VLBW children with BPD compared with VLBW children without BPD. Both lower IQs at school age[9–11] and poorer fine and gross motor skills have been reported.[10,12,13] However, to date, most studies have had small sample sizes and therefore lack adequate statistical power to control for potential confounding factors, including socioeconomic status and neurologic complications, or have not reliably ascertained the presence of concomitant neurologic complications. Moreover, since the early 1990s, infants with respiratory distress have been treated with surfactant, which may alter the outcome for treated infants.[14]

In the present study, VLBW infants, with and without BPD, and normal-birth weight term children were followed prospectively from birth. Our purpose was to evaluate cognitive, academic achievement, motor, and attention skills at school age, with special attention directed toward identification of functional differences as a result of the presence or absence of BPD. Data are presented for the total sample of BPD, VLBW, and term children first, with separate subgroup analyses for children without neurologic complications presented subsequently.

METHODS

Participants

All infants who had VLBW and BPD and were admitted to the neonatal intensive care units (NICUs) of hospitals in the Cleveland region in 1989–1991 were eligible for the study and were recruited prospectively. All infants with BPD from a 4-county region were cared for in the NICU of the 3 participating hospitals that had a level 3 NICU. Infants with BPD were defined as infants who were <1500 g at birth, required supplemental oxygen for >28 days, and exhibited radiographic evidence of lung disease.[15] The Northway definition of BPD, which relies on the 28-day cutoff, was in use at the time of recruitment and has been shown to yield comparable results with Mental Development Index and Psychomotor Development Index when compared with newer definitions of BPD (oxygen dependence at 36 weeks). A partial stratification sample strategy was adopted to enroll adequate numbers of participants without socioeconomic disadvantage or severe neurologic risk. Infants who had a diagnosis of BPD were free of neurologic problems other than grades 1 to 2 intraventricular hemorrhage (IVH), and were not socially disadvantaged (ie, Hollingshead classification IV and V) were recruited exhaustively. The remainder were randomly recruited by approaching the family of the next available BPD infant diagnosed who could be accommodated in the follow-up schedule.

For each infant with BPD, the next VLBW infant who did not have BPD and was of the same race and socioeconomic status and born during the same time period and at the same hospital was recruited. Term infants were recruited from the newborn nurseries. Information about the study and return addressed postcards were left for all mothers in the nurseries. VLBW and term infants who met eligibility criteria and whose parents returned the postcard indicating their willingness to participate constituted the comparison groups. VLBW infants without BPD were <1500 g birth weight and required oxygen supplementation for <14 days. Term infants had no diagnosed medical illnesses or abnormalities at birth, were >36 weeks' gestational age, and were >2500 g birth weight. Infants with major congenital malformations or drug exposure; or whose mothers had major psychiatric or physical illness, human immunodeficiency virus, or mental retardation; or who lived >2 hours' driving distance were excluded.

During the recruitment period, 250 infants with BPD were identified, 89 of whom were excluded (35 for drug/alcohol exposure, 21 for all other exclusions, 33 who could not be accommodated into the testing schedule), leaving 161 eligible VLBW infants with BPD. Twenty (12%) refused the study, 14 (9%) died before enrollment, and 5 (3%) were unable to be contacted, leaving 122 infants enrolled at birth. Of those 122 enrolled infants, 7 died after enrollment, leaving 115 children with BPD. At 8 years of age, 2 had withdrawn, 9 were lost to follow-up, and 104 (90%) were seen. From this group, 6 were excluded from these analyses for the following reasons: 2 had significant genetic impairments, 2 had advanced forms of cancer, and 2 had moved out of state and only interview data were available, leaving 98 BPD children in the present cohort.

Of 214 VLBW infants without BPD, 24 were excluded for drug/alcohol exposure, 34 for oxygen supplementation for 21 to 28 days, and 46 for all other exclusions, leaving 110 eligible VLBW infants without BPD. Of these 110, 8 (7%) were unable to be contacted and 18 (16%) refused the study, leaving 84 VLBW children enrolled in the study at birth. Of these 84, 2 withdrew, 6 were lost to follow-up, and 1 died at 2 years, leaving 75 (90%)VLBW seen at 8 years.

Of 123 term infants enrolled at birth, 6 withdrew, 5 were lost, and 13 did not come for the visit, leaving 99 (80%) who were seen at 8 years. Groups did not differ by sex, race, socioeconomic status, maternal education, or marital status of parents at birth. At 8-year follow-up, group demographic and medical characteristics did not differ significantly from the sample recruited at birth.

All neonatal medical and demographic information was obtained from the hospital charts. Variables of interest in the present investigation included infant gestational age, birth weight, steroids, and days on oxygen. Cranial ultrasound studies were performed and reviewed by board-certified radiologists, typically at 3, 10, and 28 days, as well as before discharge. A system for rating the severity of IVH was devised on the basis of the extent of the lesion. A score of 0 was used to indicate no hemorrhage. Identifiable lesions were graded on a scale from 1 to 4, based on the criteria of Papile et al.[16] At least 1 ultrasound study was available for all infants; ratings were based on the most severe lesion diagnosed. In addition to IVH, the following neurologic abnormalities were coded: echodense lesions, porencephaly, hydrocephalus, ventriculoperitoneal shunt, meningitis, and periventricular leukomalacia. On the basis of these neurologic abnormalities, a total neurologic risk score was calculated wherein 0 was used to indicate absence and 1 was used to indicate presence. The validity of the summary score has been demonstrated in its significant relationship to IQ at 3 years of age in a previous study.[6] For the purposes of the individual difference analyses, all children with any of the known neurologic risk factors were excluded from the analyses.

Procedures

All children who were recruited at birth were invited to participate in the current study and scheduled for the 8-year visit. Assessments were completed in the behavioral laboratory of the project by an examiner who was unaware of the children's medical history. Families were reimbursed for transportation when needed or requested and given a stipend of $100. The Institutional Review Board of the hospital approved this study, and informed consent from parents/guardians and the child was obtained for all participants.

The measures used in this study were designed to assess 4 broad areas of functioning: cognitive functioning, academic achievement, attentional skills, and motor skills. Multiple sources of information were obtained to assess child functioning across the

TABLE 1. Maternal Demographic Factors

Characteristics	BPD (n = 98)		VLBW (n = 75)		Term (n = 99)		χ^2/F	P
	Mean	SD	Mean	SD	Mean	SD		
Maternal Education	13.6	2.1	13.4	2.1	14.2	2.4	3.41	.03*
SES (Hollingshead)								
1–3	48	49	29	39	40	40		
4	32	33	33	44	42	42		
5	18	18	13	17	17	17	3.11	.53
Married	62	64	41	55	58	59	1.32	.52
Mother Employed	69	70	57	76	64	65	2.63	.27

SD indicates standard deviation; SES, socioeconomic status.
* VLBW group differed from term group.

4 domains, including child, parent, and teacher data. School outcomes were obtained from multiple sources, including teacher and parent ratings and school records. Parent and teacher questionnaires and interviews were used to obtain information concerning school placements, grade retention, and enrollment in special education services.

Measures

The Wechsler Intelligence Scale for Children III (WISC-III)[17] was used to assess intelligence. Standard scores were obtained for verbal, performance, and full-scale IQ, as well as subscores for perceptual organization and verbal composites.

The Woodcock Johnson Test of Achievement-Revised (WJTA-R)[18] was used to ascertain current academic achievement in reading recognition and comprehension, as well as calculation and applied problem-solving skills. The 4 standard scores were used for data analysis purposes.

The Bruininks-Oseretsky Test of Motor Proficiency-Short Form (BOT)[19] was used to assess fine and gross motor skills. The short form consists of 14 items drawn from the 8 subtests that were found to correlate highly with both the subtest score and the total score. A T score was used for data analysis, with the mean of this instrument equal to 50.

The Tactual Performance Test (TPT)[20] assesses spatial memory and localization skills. Never given an opportunity to view the form board, children are asked to place objects into the board while blindfolded using only their tactual sense. The memory score for this task is derived from the child's spatial reconstruction of the board based on their free-form drawing. Their localization score is based on the accuracy of their drawings of the forms in relation to each other.

The Continuous Performance Test (CPT)[21] assesses children's attentional skills via a computerized presentation of letter stimuli. Children were asked to depress the space bar for all letters occurring on the screen except the letter X. Therefore, children were required to inhibit their behavior in the face of a designated target. Although numerous measures are available for this task, the overall attentional index was used in the current study as a measure of attentional impairment. Scores obtained at or above 10 are indicative of attentional impairment.

The Connors Teacher and Parent Rating Scales[22] are widely used instruments for assessment of attentional impairment. This 48-item parent version and 28-item teacher version of the Connors was used globally to ascertain whether attentional impairments observed in this research setting were also observed in the home and school environment. T scores were analyzed for Conduct Problem, Learning Problem, Psychosomatic, Impulsivity, Anxiety, and Hyper-Activity Index.

Data Analysis

The effects of BPD and VLBW on cognitive and achievement outcomes were analyzed using a multivariate analysis of variance (MANOVA) and/or univariate analysis of variance (ANOVA) strategy, with diagnostic group (BPD, VLBW, and term) as the between-subject variable. All significant multivariate and univariate effects were explored with post hoc analyses using a Duncan correction. χ^2 analyses and Fisher exact tests were performed to compare groups on demographic and medical characteristics at birth, special education services at age 8, and grade retention.

The 3 groups were also compared on the percentage of children who met clinical criteria for developmental disabilities. The percentage of children who scored 2 standard deviations below the mean on the WISC-III and WJTA-R was calculated for each group. χ^2 were used to compare the percentages of children with intellectual and learning impairments in each group.

Results for Total Population

Demographic Data From Birth

As shown in Table 1, BPD, VLBW, and term children were comparable in terms of maternal demographic characteristics. That is, the majority of children from this sample were from families in which mothers had completed high school and were married, employed, and of average social class. It should be noted that although the overall univariate analysis was significant for maternal education, the post hoc comparison on maternal education revealed that only mothers of VLBW children attained lower levels of education than did term mothers.

As can be seen in Table 2, whereas children with a history of BPD did not differ from their VLBW and term counterparts in race and sex, BPD children were significantly smaller and more immature at birth than VLBW and term control children. In addition, the BPD group had a higher number of days on oxygen and higher incidence of steroids and IVH in the perinatal period than either VLBW or term infants. Comparisons involving VLBW and term infants revealed that VLBW infants were significantly smaller and more immature, as well as more apt to be a multiple than term infants. In fact, VLBW infants were more likely than BPD infants to be a multiple. It should be noted that VLBW infants did not differ from term infants in days on oxygen or exposure to steroids.

Eight-Year Outcomes

Cognitive Outcomes

As can be seen in Table 3, the MANOVA performed on the WISC-III revealed a significant main effect for group. Follow-up univariate ANOVAs and pairwise comparisons revealed that BPD children performed more poorly than VLBW children on the verbal, performance, and full-scale IQs, with both BPD and VLBW children performing more poorly than term children on verbal, performance, and full-scale IQs ($P < .01$). The MANOVA conducted on the perceptual organization and verbal composite index scores revealed the same pattern. Taken together, 8-year-old children with a history of BPD demonstrated poorer cognitive skills, both verbal and per-

TABLE 2. Neonatal Characteristics ($N = 258$)

Characteristic	BPD ($n = 98$)		VLBW ($n = 75$)		Term ($n = 99$)		χ^2/F	P
	Mean	SD	Mean	SD	Mean	SD		
Birth weight (g)*	954	253	1256	176	3451	547	1267	.001†‡§
Gestational age (wk)*	27	2	30	2	40	1	1173	.001†‡§
Total Oxygen (d)*	101	157	5	5	0		30.7	.001†‡
	n (%)		*n* (%)		*n* (%)			
Race (white)	56 (57%)		35 (47%)		53 (54%)		1.9	.39
Sex (male)	54 (55%)		31 (41%)		48 (49%)		3.2	.20
Single birth	76 (78%)		39 (52%)		87 (88%)		29.6	.001†‡§
Steroids	28 (29%)		0		0		53.1	.001†‡
IVH								
1	17 (17%)		10 (13%)		0		69.8	.001†‡§
2	11 (11%)		1 (1%)		0			
3	12 (12%)		1 (1%)		0			
4	4 (4%)		1 (1%)		0			
none	54 (55%)		62 (83%)		99 (100%)			

* MANOVA neonatal characteristics: F (6,474) = 242.26, $P < .001$.
† BPD group differed from VLBW group.
‡ BPD group differed from term group.
§ VLBW group differed from term group.

ceptual, as compared with their VLBW counterparts, who in turn performed more poorly than their term counterparts.

Achievement Outcomes

The MANOVA of the WJTA-R data revealed a significant multivariate effect for group as well (Table 3). Univariate ANOVAs and pairwise comparisons revealed different patterns of performance in the reading and the mathematical domains. BPD children performed significantly more poorly than both the term control and VLBW children in both reading recognition and comprehension. VLBW children did not differ significantly from the term children in either aspect of reading performance. In the mathematical domain, BPD children performed significantly more poorly in both calculation skills and applied problems than both VLBW and term children. In addition, VLBW children performed more poorly than term control children on mathematical achievement.

Motor Outcomes

The univariate ANOVA of the BOT revealed significant main effects for group (Table 3). Consistent with the cognitive and achievement outcomes, BPD children scored more poorly on motor outcomes than the VLBW group without BPD, who scored more poorly than the term control group.

The TPT is an assessment of visual/fine motor performance and spatial memory. The MANOVA of the memory and localization data from the TPT revealed significant group effects (Table 3). Both BPD and VLBW children performed more poorly in memory for shapes and localization of shapes when compared with term children.

Attentional Outcomes

The ANOVA of the overall index score of the CPT revealed a significant main effect for group (Table 3). Children with a history of BPD scored more poorly than the term group; however, the VLBW children did not differ from either the BPD or the term children. Despite this evidence for attentional differences on the experimental task of attention between BPD and term children on the CPT, no parent and teacher differences were found on the global or subscales scores on the Conner's Rating scales.

Categorical Analyses of Educational Outcomes

Therapy and educational outcomes at 8 years of age are reported in Table 3. Although BPD children did not differ from VLBW or term children in age, significant differences were found for grade placement. BPD children were more likely to be enrolled in lower grades than VLBW or term children. Despite placement in lower grades, no differences in grade retention were observed among the 3 groups of children. In contrast, placement in special education services, regardless of type, differentiated the groups, with 54% of the BPD, 37% of the VLBW, and 25% of the term children participating in special education. A closer examination revealed that significantly more BPD children had a diagnosis of attention-deficit/hyperactivity disorder (ADHD) than either term or VLBW children. In addition, significantly more BPD children received speech-language, occupational, and physical therapy than either VLBW or term children, and significantly more VLBW children were receiving speech-language and physical therapies than term children at age 8. In an effort to determine whether differences in IQ and achievement placed children in the subaverage category, χ^2 analyses were performed. More BPD children (20%) achieved full-scale IQ scores <70, in the mental retardation range, compared with either VLBW (11%) or term (3%) children, with all VLBW children significantly more likely than term children to achieve IQs in the subaverage category. Differences between BPD and VLBW children approached significance ($P \leq .08$). Similarly, more BPD children were significantly below average (≤ 70) in their reading (17% recognition, 17% comprehension) and mathematics achievement (17% calculation, 14% applied prob-

TABLE 3. Cognitive and Academic Outcomes for Total Sample at 8 Years ($N = 272$)

	BPD ($N = 98$)		VLBW ($N = 75$)		Term ($N = 99$)		χ^2/F	P
	Mean	SD	Mean	SD	Mean	SD		
WISC-III*†								
Verbal	87.4	20	95.0	16	102.3	15	18.8	.001‖¶#
Performance	81.4	19	89.9	17	101.5	15	35.8	.001‖¶#
Full Scale	82.8	20	91.7	16	101.9	15	30.7	.001‖¶#
Verbal Composite	88.7	19	95.9	16	103.0	15	17.6	.001‖¶#
Perceptual Organization	82.0	18	90.3	17	101.5	15	33.4	.001‖¶#
Woodcock Johnson‡								
Letter Word Identification	92.1	23	98.2	19	102.6	18	6.7	.01‖¶
Passage Comprehension	93.9	24	102.3	17	107.6	18	11.1	.001‖¶
Calculations	84.8	23	94.0	18	106.4	19	27.2	.001‖¶#
Applied Problems	91.4	25	103.8	17	112.2	15	28.2	.001‖¶#
Motor outcomes§								
BOT	42.5 (15)		51.1 (13)		57.8 (12)		32.9	.001‖¶#
TPT								
Memory	3.6 (2)		3.7 (2)		4.3 (1)		5.9	.01¶#
Localization	2.1 (2)		2.3 (2)		2.9 (2)		5.4	.01¶#
Attentional outcomes								
CPT	10.5 (7)		8.7 (7)		7.8 (6)		3.8	.05¶
School outcomes								
Age (mo)	8.8 (.6)		8.8 (.6)		8.8 (.5)		0.75	.47
Grade in school	*n* (%)		*n* (%)		*n* (%)			
K-1st	10 (10)		1 (1)		0			
2nd	39 (40)		32 (43)		28 (28)			
3rd	39 (40)		36 (48)		56 (57)			
4th	10 (10)		6 (8)		15 (15)		20.9	.001¶
Repeated grade	18 (19)		9 (13)		12 (12)		2.2	.33
Special education	50 (54)		25 (37)		25 (25)		16.6	.01‖¶
ADHD diagnosis	15 (15)		5 (7)		4 (4)		8.3	.01‖¶
Psychological services	10 (10)		5 (7)		9 (9)		0.7	.71
Speech-language services	50 (51)		17 (23)		10 (10)		41.8	.001‖¶#
Occupational therapy	51 (52)		8 (11)		5 (5)		69.5	.001‖¶
Physical therapy	49 (50)		10 (13)		2 (2)		69.6	.001‖¶#

* MANOVA Overall WISC-III F (6,532) = 12.28, $P < .001$.
† Composite WISC-III F (4,534) = 15.90, $P < .001$.
‡ WJTA-R F (8,522) = 9.00, $P < .001$.
§ TPT F (4,456) = 3.35, $P < .01$.
‖ BPD group differed from VLBW group.
¶ BPD group differed from Term group.
# VLBW group differed from Term group.

lems) than term children (4% recognition, 5% comprehension, 4% calculation, 2% applied problems). Although term and VLBW children did not differ in their rates of subaverage achievement, VLBW children (5%) differed significantly in rates of subaverage applied mathematics than BPD children (14%).

Regression analyses were performed to assess whether these differences persisted after controlling for birth weight and severity of neurologic risk. Duration on oxygen predicted performance IQ, full-scale IQ, and perceptual organization deficits and all achievement test differences except calculation. Duration on oxygen also predicted poorer performance on the BOT and CPT, as well as higher use of speech-language, occupational, and physical therapies. The qualitative classification of BPD (present or absent) was a significant predictor for applied problems, BOT scores, and incidence of speech-language, occupational, and physical therapies.

Individual Difference Results

To ascertain whether differences between risk groups were attributable to differences in neurologic complications alone, we repeated data analyses for BPD ($n = 49$) and VLBW children ($n = 55$) without neurologic complications (total neurologic risk score: 0). None of the term children ($n = 99$) was neurologically compromised. An examination of Table 4 reveals that 45% of the BPD children and 27% of the VLBW children were neurologically compromised. As predicted, BPD children were born earlier, were smaller, and experienced more oxygen and steroids than did VLBW children, who, in turn, experienced more of these factors than term infants. In addition, VLBW infants were more likely to be a multiple birth than either BPD or term infants.

As can be seen in comparing results obtained in Tables 3 and 5, BPD and VLBW children without neurologic complications performed better as a group on all outcomes than their peers with complications. Even with the neurologically intact sample of BPD and VLBW children, differences between the term comparison group and both the BPD and VLBW groups were found for many outcome measures. When birth weight and neurologic complications were controlled, BPD and severity of BPD were associated with lower performance and full-scale IQ; poorer perceptual organization, attention, and motor skills; and lower school achievement and greater participation in special education, including occupational, physical, and speech-language therapies. Moreover, consistent with the findings for the total

TABLE 4. Neonatal Characteristics for Neurologically Intact Children ($N = 203$)

Characteristic	BPD ($n = 49$)		VLBW ($n = 55$)		Term ($n = 99$)		χ^2/F	P
	Mean	SD (%)	Mean	SD (%)	Mean	SD (%)		
Birth weight (g)*	958	273	1238	180	3451	547	810	.001†‡§
Gestational age (wk)*	27	2	30	2	40	1	886	.001†‡§
Total oxygen (d)*	96.2	122	4	4	0		30.7	.001†‡
Race (white; *n* [%])	30	61	25	46	53	54	2.6	.27
Sex (male; *n* [%])	22	45	22	40	48	49	1.0	.60
Single birth (*n* [%])	39	80	30	55	87	88	22.4	.001†§
Steroids (*n* [%])	13	27	0		0		34.4	.001†‡

* MANOVA neonatal characteristics F (6,350) = 184.39, $P < .001$.
† BPD group differed from VLBW group.
‡ BPD group differed from term group.
§ VLBW group differed from term group.

TABLE 5. Cognitive and Academic Outcomes at 8 Years for Neurologically Intact Children ($N = 203$)

Total Sample	BPD ($N = 49$)		VLBW ($N = 55$)		Term ($N = 99$)		χ^2/F	P
	Mean	SD	Mean	SD	Mean	SD		
WISC-III*†								
Verbal	93.1	17	96.1	15	102.3	15	6.7	.001¶#
Performance	85.0	16	92.2	14	101.5	15	20.7	.001‖¶#
Full Scale	88.0	16	93.6	14	101.9	15	15.0	.001‖¶#
Verbal Composite	94.3	17	97.0	15	103.0	15	5.8	.01¶#
Perceptual Organization	85.0	16	92.6	14	101.5	15	20.5	.001‖¶#
Woodcock Johnson‡								
Letter Word Identification	98.0	20	97.1	16	102.6	18	2.0	.14
Passage Comprehension	100.1	21	102.8	15	107.6	18	3.1	.05¶
Calculations	90.5	21	94.6	16	106.4	19	13.8	.001¶#
Applied Problems	96.9	23	104.7	16	112.2	15	13.1	.001‖¶#
Motor outcomes§								
BOT	47.1	13	52.9	12	57.8	12	12.5	.001‖¶#
TPT								
Memory	3.8	1	3.7	1	4.3	1	4.7	.01¶#
Localization	2.2	2	2.3	2	2.9	3	3.6	.03¶
Attentional outcomes								
CPT	10.1	7	8.2	6	7.8	7	1.8	.17¶
School outcomes								
Age	8.7	0.6	8.7	0.5	8.8	0.6	1.5	.23
Grade in school	*n* (%)		*n* (%)		*n* (%)			
K-1st	3 (6)		1 (2)		0			
2nd	21 (43)		25 (46)		28 (28)			
3rd	23 (48)		26 (47)		56 (57)			
4th	2 (4)		3 (6)		15 (15)		14.9	.01¶#
Repeated grade	6 (13)		8 (16)		12 (12)		.40	.81
Special education	20 (42)		15 (29)		25 (25)		4.1	.13‖¶
ADHD diagnosis	1 (2)		4 (7)		4 (4)		1.6	.42
Psychological services	2 (4)		4 (7)		9 (9)		1.1	.54
Speech-language services	20 (41)		12 (22)		10 (10)		18.6	.001‖¶#
Occupational therapy	22 (45)		3 (5)		5 (5)		46.2	.001‖¶
Physical therapy	19 (39)		4 (7)		2 (2)		42.5	.001‖¶

* MANOVA Overall WISC-III F (6,394) = 7.90, $P < .001$.
† Composite WISC-III F (4,396) = 10.01, $P < .001$.
‡ WJTA-R F (8,386) = 5.24, $P < .001$.
§ TPT F (4,360) = 2.55, $P < .05$.
‖ BPD group differed from VLBW group.
¶ BPD group differed from term group.
# VLBW group differed from term group.

sample, more neurologically intact BPD children (17%) than either VLBW (7%) or term (3%) children had IQs in the range of mental retardation. Despite the differences in IQ, no significant differences were found in the percentage of neurologically intact children achieving at the subaverage level on academic achievement tests from the 3 groups.

The group differences observed for the BPD children may be attributable in part to differences in treatment. That is, some of the BPD children ($n = 28$) received steroids early in their life, whereas others did not ($n = 70$). BPD children who received steroids did not differ from the BPD children who did not receive steroids in gestational age, birth weight, maternal education, incidence of IVH, or the neurologic risk score. Significant differences were observed for total oxygen delivered, with 2.5 times the amount of oxygen delivered to the steroid group (187.14) as compared with the nonsteroid BPD group (71.61). Steroid and nonsteroid groups of BPD children differed significantly in performance IQ (72.8 vs 84.8) and full-scale IQ (77.0 vs 85.2); perceptual organiza-

tion (74.0 vs 85.2); BOT score (36.6 vs 44.7); and participation in special education (78% vs 48%), occupational therapy (71% vs 44%), and physical therapy (71% vs 41%). In all cases, BPD children who received steroids as a part of their treatment performed more poorly on the outcome measures or received more therapy than their nonsteroid BPD counterparts.

DISCUSSION

This study longitudinally assessed from birth to early school age outcomes of a large sample of VLBW infants with BPD. Compared with VLBW infants without BPD and with term infants, VLBW children with BPD were more likely to receive special education services and had more difficulties in perceptual-motor, gross motor, reading, math, spatial memory, and attention skills relative to the comparison children. After controlling for birth weight and severity of neurologic complications, duration on oxygen predicted the majority of differences obtained in this sample. Differences could not be attributed to socioeconomic status, maternal education, race, or sex because groups did not differ on these factors. Controlling for neurologic complications, children with BPD had specific difficulties with perceptual organization, gross motor, mathematics, and attentional skills. Thus, consistent with previous research findings, VLBW children with BPD had significantly more difficulties at early school age than VLBW children without BPD or children of normal birth weight.[9,10,23,24]

The findings are consistent with 2 previous studies that found impairment in IQ at school age in children with BPD.[10,25] However, in these previous studies, neither cranial ultrasound findings nor screening for drug exposure was available. Thus, obtained differences may have resulted from confounding variables. Two other studies assessed the outcome of children with BPD to school age and found no differences between them and other VLBW children, but these studies had very small sample sizes and may have lacked adequate statistical power.[11,13] Although BPD was not a focus of inquiry, Robertson et al[23] found lower IQs associated with longer duration of supplemental oxygen in an 8-year follow-up. The findings are also consistent with outcomes found in this cohort at 3 years of age, which indicated that history of BPD predicted poor motor skills beyond the effects of other medical and demographic factors.[6]

The present findings suggest that BPD and duration on oxygen more specifically have long-term effects on the perceptual, motor, and processing speed components of cognitive abilities, beyond the effects of VLBW.[10,11] BPD children performed more poorly than VLBW and term comparison children on tests of reading and math abilities and had significantly lower scores than both comparison groups and were nearly 1 standard deviation below the mean on the calculation subtest. Thus, difficulties with mathematics seem to be even more pronounced for VLBW children with BPD than for children with VLBW only.[26]

Similarly, gross and fine motor problems have been described in several studies of VLBW children.[27,28] In this study, the BPD children scored more poorly than both VLBW and term comparison children on a measure of gross motor skills. Furthermore, VLBW children scored more poorly than term children. The gross motor difficulties experienced by the BPD children have been noted in previous, smaller studies.[12,13] Majnemer et al[12] found that, at 10 years of age, 50% of BPD children who had required home oxygen therapy had gross and fine motor skill deficits. The high rates of both occupational and physical therapies experienced by the BPD children underscore the clinical implications of this finding.

Infants with BPD have been demonstrated to have central nervous system pathology including brain atrophy and glions compatible with chronic hypoxia associated with prolonged oxygen dependence leading to hypoxic-ischemic cerebral injury.[29–31] Such injury may preferentially damage primary sensory and forebrain motor systems,[3] leading to deficits in cognitive, motor, and attentional function. Selective neuronal injury may also be correlated with the presence of BPD, as noted by Volpe,[7] consistent with abnormal axon and dendrite development and the structure of the medulla oblongata in ventilator-dependent preterm infants.

Reduced pulmonary function, increased airway resistance and reactivity, and decreased tolerance for exercise have been demonstrated in children with a history of BPD from preschool age through early adolescence and into adulthood.[31–35] These respiratory problems may limit opportunities for BPD children to engage in the physical activities necessary to develop gross motor skills, resulting in the discrepancies in motor skills noted in this cohort now and at 3 years of age.[6]

The finding that more BPD children were enrolled in lower grades may be explained by several factors. Many parents of children with a history of BPD and even VLBW without BPD have indicated that they chose to delay school entry for a variety of reasons, including small stature, history of repeated illness and hospitalizations, and perceptions of "increased vulnerability." In addition, given the multiplicity of difficulties experienced by both the child and the family during the early years of life, educational and clinical specialists may have advocated delayed entry into formal education.

More than 50% of BPD children were receiving some type of special educational services at the 8-year follow-up. Even when neurologically compromised BPD children were removed, >40% of children with a history of BPD were receiving special education services. Our finding that approximately one third of the VLBW children are receiving special education is consistent with those reported in earlier studies.[25,26] In addition, our findings suggest that even more VLBW and BPD children seem to be in need of special services, particularly occupational and physical therapy.

One striking finding regarding diagnosis and placement in special education pertained to the inci-

dence of ADHD in this sample. More BPD children received the diagnosis of ADHD than term or VLBW children. Although their teachers did not rate BPD children as having more attention problems in school than the VLBW or term children, BPD children had more attention problems as measured by the laboratory CPT. This measure of attention at 8 years may be an early indication of attention deficits that may increase over time. Because several of the BPD children were unable to complete the task and it was not administered to children with IQ scores <70, this average score may underestimate the severity of attention difficulties for children with a history of BPD.

Parents of children with a history of BPD reported that more of their children had occupational and physical therapy, including children who were without neurologic complications. The prolonged hospitalizations experienced by children with BPD and the frequent interactions of families with medical personnel may result in increased access and opportunities for services for parents of children with BPD.

These results suggest that BPD has adverse effects on academic achievement above and beyond the effects of VLBW. The medical complications experienced by this sample of BPD children[6,24] place these children at high risk for learning and related developmental difficulties, especially in conjunction with socioeconomic risk, which often coexists with VLBW and prematurity.[24,36] These school difficulties have the potential to become more severe over time as academic demands increase. The problems that have been identified at 8 years of age underscore the need for continued monitoring of the learning, behavior, and development of BPD children to identify, refer, and intervene with children who are most at risk for diagnosable school problems.

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