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Predicting school readiness from neurodevelopmental assessments at age 2 years after respiratory distress syndrome in infants born preterm

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Abstract

AIM—To determine whether neurodevelopmental outcomes at the age of 2 years accurately predict school readiness in children who survived respiratory distress syndrome after preterm birth.

METHOD—Our cohort included 121 preterm infants who received surfactant and ventilation and were enrolled in a randomized controlled study of inhaled nitric oxide for respiratory distress syndrome. Abnormal outcomes at the age of 2 years were defined as neurosensory disability (cerebral palsy, blindness, or bilateral hearing loss) or delay (no neurosensory disability but Bayley Scales of Infant Development mental or performance developmental index scores <70). School readiness (assessed at a mean age of 5y 6mo, SD 1y) was determined using neurodevelopmental assessments of motor, sensory, receptive vocabulary, perceptual, conceptual, and adaptive skills.

RESULTS—The mean birthweight of the cohort (57 males, 64 females) was 987g (SD 374), and the mean gestational age was 27.3 weeks (SD 2.6). At the age of 2 years, the neurodevelopmental classification was 'disabled' in 11% and 'delayed' in 23%. At the age of 5 years 6 months, intensive special education was required for 11% and some special education for 21%. Disability and delay at the age of 2 years were 92% and 50% predictive of lack of school readiness respectively, whereas only 15% of children who were normal at the age of 2 years were not school ready at the later assessment. Children with delay at 2 years were more likely to need special education if they were socially disadvantaged.

INTERPRETATION—Without preschool developmental supports, preterm survivors living in poverty will require more special education services.

Over the past decade, state systems for assessing children as they enter kindergarten have expanded rapidly. This occurred when the US government created the National Education Goals Panel, with the first goal being that 'all children in America will start school ready to learn'.¹ This panel broke new ground by defining the important dimensions of 'readiness' and the conditions that are critical for supporting these dimensions. The five dimensions were conceptualized as physical and motor, social and emotional, approaches toward learning, language and communication, and cognition and general knowledge. These domains have

become widely accepted for promoting developmental and learning competencies.² Three supporting conditions (having access to good-quality preschool programs, parents as children's first teachers, and appropriate nutrition and health status) and the avoidance of high-stakes single assessments (i.e. describing a child's performance based on one test that does not take into account the child's progress, response to interventions, or learning trajectory) have also been reviewed.³

With increased survival of very- and extremely-low-birth-weight infants there is also increased recognition of a spectrum of motor, cognitive, communicative, and behavioral disorders affecting school success.⁴ This recognition has led to heightened importance of longitudinal follow-up of infants whose treatment involved new technologies when critically ill. However, the literature in this area primarily involves assessing children at the ages of 18 to 24 months. There are concerns that evaluation during this time frame may not adequately sample developmental processes that can be directly linked to cognitive, communicative, coordination, and attention skills.⁵ It is well known that the results of neurodevelopmental assessments performed in the first 2 years of life may not reliably predict the full spectrum of disability at school age.⁶ For example, some children may be classified as having a mild form of cerebral palsy (CP: i.e. Gross Motor Functional Classification System [GMFCS] level I) at the age of 2 years but they may not retain that diagnosis in later childhood. Other children may test well on basic developmental processes but subsequently struggle with academic achievement. The goal of this study was to assess the impact of neurodevelopmental assessments at the age of 2 years on school readiness at the age of 5 years 6 months in a cohort of children who had participated in a randomized clinical trial of inhaled nitric oxide in the management of respiratory distress syndrome.⁷

METHOD

Participants

The study sample consisted of 121 children who were followed up, after discharge from the neonatal intensive care unit, at the ages of 2 years and 5 years 6 months. The original cohort consisted of 207 children born preterm with respiratory distress syndrome participating in a single-center, randomized, placebo-controlled trial at the University of Chicago (trial NCT00152542 registered at clinicaltrials.gov). All of the infants received surfactant-replacement therapy and mechanical ventilation and were treated with inhaled nitric oxide or placebo during the first week of life. Of the 207 infants in the original cohort, 168 (81%) survived through their first 2 years. At the age of 2 years, 138 (82%) of these 168 children were assessed for developmental delay and neurodevelopmental disability.⁸ Of the 138 children assessed, 121 (88%) were seen again at the age of 5 years 6 months.

Assessments at 2 years and at 5 years 6 months

At the age 2 years, children underwent an assessment battery using the Bayley Scales of Infant Development (2nd edition),⁹ as well as evaluation of health, growth, vision, hearing, and neuromotor status. These assessments were undertaken by individuals who were masked to neonatal treatments and complications.

Children and their parents or caregivers were reassessed in a single visit when the children were aged 5 years 6 months. At or before the visit, caregivers completed questionnaires regarding updated social and family information, the child's need for special education services, and his or her current health status. Detailed information on socioeconomic status, the child's independent functioning in daily living skills, and behavior was collected using standardized instruments. A multidimensional assessment at this age included the following: the Bracken School Readiness Assessment,¹⁰ Peabody Picture Vocabulary Test third edition,¹¹ and Beery–

Buktenica Developmental Test of Visual-Motor Integration.¹² The Bracken School Readiness Assessment¹⁰ was used to evaluate children's understanding of foundational concepts in the categories of colors, letters, numbers, sizes, comparisons, and shapes. The Peabody Picture Vocabulary Test¹¹ was used to assess children's receptive vocabulary. The Test of Visual-Motor Integration¹² was used to assess children's abilities to copy a progressively more difficult sequence of geometric forms. Raw scores were converted to standard scores (mean 100, SD 15) using test-specific criteria. Children scoring less than 70 on the Bracken School Readiness Assessment or Peabody Picture Vocabulary Test and those identified as potentially having socio-behavioral abnormalities were administered the Childhood Autism Rating Scale to identify autistic spectrum disorders.¹³ Socioeconomic status was determined using the Hollingshead Index of Social Position, a two-factor index based on the head of household's highest educational attainment and current occupation.¹⁴ Independent functioning in daily activities was determined using the Pediatric Functional Independence Measure.¹⁵ This 18-item instrument measures performance in basic daily skills across the domains of self-care, mobility, and social cognition. Behavior was assessed using the National Initiatives for Children's Healthcare Quality Vanderbilt Parent Assessment Scale, a screen for common pediatric behavior disorders involving attention, hyperactivity, oppositionality, social behaviors, and mood.¹⁶

At both visits, children with abnormalities of tone, posture, and motor skills were classified as having one of the CP syndromes using methods previously described.¹⁷ The GMFCS was used to describe the level of each child's mobility skills at the age of 5 years 6 months.¹⁸ By direct observation, children identified as having CP were assigned to a GMFCS level of I to V, with level I equivalent to mild, levels II and III equivalent to moderate, and levels IV and V equivalent to severe CP.

Also at both visits, children were screened for loss of hearing or vision. Recent audiograms were reviewed for those with hearing loss. The presence of a hearing aid constituted the criterion for hearing loss. Children with hearing aids who were unable to communicate were presumed deaf. Visual acuity was assessed with Lea symbols.¹⁹ Children with corrected visual acuity between 20/60 and 20/200 were considered visually impaired, and children with acuity worse than 20/200 were considered blind.

The protocol was reviewed and approved by the institutional review board of the University of Chicago. Informed consent was obtained from all of the caregivers of the children examined for this study.

Outcome classification

The outcome classification at the ages of 2 years and 5 years 6 months differed slightly and are highlighted in Table I. At the 2-year assessment, children were categorized as having normal or abnormal neurodevelopment; in the later category, children were categorized as having neurodevelopmental delay or disability. Normal neurodevelopment was defined as no disability or delay. Delay was defined as no disability and a Bayley mental developmental index (MDI) or performance developmental index (PDI) less than 70, which is 2 SD below the mean. Disability was defined as the presence of at least one of CP, bilateral blindness, or bilateral hearing loss.

At the age of 5 years 6 months children were assessed for their readiness for school. School readiness was defined as the ability to function at age-appropriate levels in a variety of cognitive, motor, sensory, and social domains, including functioning in activities of daily living, understanding of age-appropriate concepts, understanding language and the ability to communicate, visual-motor integration and gross motor functioning, and visual and auditory status. Accordingly, we used each child's standardized scores on the Pediatric Functional

Independence Measure, the Bracken School Readiness Assessment, the Peabody Picture Vocabulary Test, and the Test of Visual-Motor Integration, as well as the presence of sensory impairments or autism, to construct school-readiness levels. Children were assigned to one of four levels of school readiness based on the number of test scores below 85 and the presence of sensory or motor impairment using methods previously described and highlighted in Table I.²⁰ Levels 1 and 2 were assigned to children who were not ready for school, and levels 3 and 4 were assigned to children who were ready for school.

We considered children scoring above 85 on all assessments to have the highest school readiness (level 4) and to be unlikely to require special education support according to criteria used by local educational authorities. A child who scored 70 to 85 on only one assessment was also considered as being at level 4. We considered children who scored 70 to 85 on two assessments, but who were without impairments in multiple domains, also to be school ready (level 3), although less than children at level 4. Children scoring 70 to 85 on three or more assessments were considered to have impairments in several domains and were, therefore, considered to be unready for school (level 2), as were children scoring less than 70 on any single assessment and already receiving some special education, according to the criteria used by local education authorities. Children with autistic spectrum disorder, an inability to communicate, deafness, or blindness and requiring intensive special education services were classified as being at level 1 (lowest school-readiness level).

Statistical analysis

A generalized linear model with a log link was used to examine the association between 2-year-old neurodevelopmental outcome and lack of school readiness at the age of 5 years 6 months. Relative risks and 95% confidence intervals (CI) were calculated from the generalized linear model.²¹ We also analyzed the school readiness score as an ordinal variable using proportional odds models, in which odds ratios and 95% confidence intervals (CI) were derived. The joint effect of Bayley MDI and PDI scales on school-readiness level was examined, and the interaction was tested within the framework of proportional odds models. Receiver operating characteristic (ROC) curves were constructed by plotting the sensitivities against 1 minus specificities, using each value of MDI or PDI as a cut-off point. Global predictive ability was indicated by the area under the ROC curve, which can be interpreted in the current scenario as the probability that the test score (e.g., MDI) of a randomly selected school-ready child will be greater than the test score of a randomly selected child who is not school ready.

RESULTS

The demographic, social, and neonatal characteristics of the 121 children in our study cohort are summarized in Table II. Thirty children from the original neonatal intensive care unit trial were alive at 2 years but not available for the 2-year neurodevelopmental assessments. These children had greater birthweight (1255g [SD 445] vs 987g [SD 374], $p=0.001$) and gestational age (28.6wks [SD 2.9] vs 27.3wks [SD 2.6], $p=0.02$) than those seen at 2 years and 5 years 6 months. Seventeen children were seen at 2 years but were lost to follow-up before the assessment at the age of 5 years 6 months. The mean birthweight and gestational age of these 17 infants (1033g [SD 253], $p=0.64$, and 27.4wks [SD 2.1], $p=0.98$ respectively) were not significantly different from those of the children who were available at the later assessment. The children lost to follow-up could not be reached by phone or mail.

At the age of 2 years, 11% of children were categorized as disabled and 23% as delayed. At the age of 5 years 6 months, 32% of the children required some special education support. The proportion of children classified as normal at the age of 2 years was similar to the proportion classified as being school-ready at the age of 5 years 6 months. However, as shown in Figure

1, not all children maintained the same level of outcomes. In particular, 92% of children (12/13) who were disabled at the age of 2 years were not school-ready, compared with 50% of children (14/28) with delays at the age of 2 years, and 15% of children (12/80) who were assessed as neurodevelopmentally normal at the age of 2 years.

Figure 2 depicts the ROC analysis of MDI and PDI at the age of 2 years as a predictor of school readiness at the age of 5 years 6 months. For MDI, the area under the ROC curve is 0.81 (95% CI 0.73–0.90). The positive predictive value of an abnormal MDI (i.e. a score <85) was 0.58 (95% CI 0.44–0.71). For PDI, the area under the ROC curve is 0.75 (95% CI 0.64–0.86). The positive predictive value of an abnormal PDI (i.e., a score of <85) was 0.67 (95% CI 0.49–0.81).

The contribution of socioeconomic status to a classification of abnormal at the age of 2 years and of school-ready at the age of 5 years 6 months is shown in Figure 3. Among the children living in severe socioeconomic adversity (Hollingshead level 5) and with developmental delay at the age of 2 years, 75% were not ready for school at the age of 5 years 6 months. Among the children with developmental delay at the age of 2 years and higher socioeconomic status (Hollingshead levels 1–3), 64% were ready for school at the age of 5 years 6 months. In addition, among the children living in social disadvantage (Hollingshead level 5) and classified as being developmentally normal at the age of 2 years, 29% required special education resources at the age of 5 years 6 months. Among those living with advantaged socioeconomic status (Hollingshead levels 1–3) and with normal developmental status at the age of 2 years, only 8% required special education resources at the age of 5 years 6 months.

We examined the joint impact of MDI and PDI on the school-readiness score. No interactive effect was identified between MDI and PDI ($p=0.28$). We thus dropped the interaction term from the model and present the model with the main effect of PDI and MDI in Table III. Not only does an MDI or PDI more than 2SD below the mean increase the risk of lack of school readiness, but so do scores between 1- and 2SD below the mean increase the risk for special educational support needs at kindergarten entry.

DISCUSSION

The time of entry into kindergarten is a time of importance for children, as the combination of health status, developmental status, and social/emotional maturity are key determinants for subsequent school success.

A child's readiness for school requires age-appropriate physical, behavioral, communicative, visual-motor, adaptive, and conceptual skills.³ Accordingly, in designing our assessment of school readiness, we used a multidimensional battery of well-validated cognitive, language, visual-motor, functional, and behavioral assessments, supplemented with assessments of neuromotor disability (i.e. CP) and neurosensory disability to assign school-readiness levels. This model has not been routinely applied to recent US, Canadian, European, or Australian cohorts.

Regardless of preterm birth, a large percentage of the general US population is not ready for school. Data from three US national surveys have been reviewed by the Center for the Future of Children.²² These included the 1993 National Household Education Survey and the Kindergarten Teacher Survey on Student Readiness, both sponsored by the National Center for Education Statistics. In addition, the National Survey of Kindergarten Teachers was sampled by the Carnegie Foundation. The data from these three surveys were combined to determine the proportion of children in the general US population who were considered ready for school. These surveys demonstrated that as many as one-third of kindergarten children may not have been ready for school in the early 1990s.²² In a study by Reynolds, children who were

part of the Longitudinal Study of Children at Risk were evaluated at early school age; after controlling for socio demographic factors in these Chicago public school children, grade retention was seen in 26.2% of the children, and special education was needed for 8.9% of the children.²³ Grade retention and need for special education, which when combined total 35.1%, would be most comparable with school-readiness levels 1 and 2 (i.e. not school ready) in our cohort. In both our cohort of preterm children and Reynolds' cohort of all children at risk, the majority of the children were from the Chicago public school system.

A school-readiness measure has, to our knowledge, been used in only one previous study, in which risk factors associated with need for special education services in kindergarten were assessed in infants who had been born extremely preterm (23–28wks' gestation).²⁰ That cohort study occurred at the beginning of the surfactant era of neonatology and revealed that 50% of children were not ready for kindergarten.

Hack et al. examined the predictive validity of the Bayley MDI at the age of 20 months on the Kauffman Assessment Battery for Children, using the mental processing composite score at age 8 years.⁶ The positive predictive value of an MDI less than 70 at 20 months for a mental processing composite less than 70 at the age of 8 years was 0.37. Among the children with neurosensory disability, the positive predictive value was 0.67. When we construct ROC curves using the data from Hack et al., the area under the ROC curve for the Bayley MDI to predict 8-year mental processing composite is 0.81. This is similar to our ROC analysis. However, the purpose of the study by Hack et al. was to examine the predictive value of the Bayley MDI on an overall cognitive outcome score on the mental processing composite. Our analysis was designed to examine the impact of 2-year Bayley scales on school readiness at the age of 5 years 6 months using several dimensions.

Our finding of poverty and low socioeconomic status affecting preterm infants when they reach school age was dramatically shown in the Edinburgh follow-up study.²⁴ In that very early era of neonatology, children who survived very low birthweight and lived in advantaged households were not different from their siblings in terms of intellectual ability and educational achievement in the first grade of school. However, a combination of low socioeconomic status and very low birth-weight (<1500g) resulted in significant decreases in both intellectual ability and educational achievement.²⁴

Several investigators suggest that the suboptimal outcomes of poverty and socioeconomic status on child development have the most impact during preschool years.²⁵ It is in these areas between the ages of 18 months and 5 years that US children in poverty experience fragmented medical, developmental, and educational support.

In a prospective follow-up study of infants after they left the neonatal intensive care unit, Resnick et al. attempted to measure the effects of birthweight, medical conditions, and socioeconomic status on educational disabilities in a Florida state-wide sample of over 24 000 children.²⁶ The results suggest a correlation between birthweight and requirement for special education services: 40% of children with a birthweight of 500 to 750g, 35% of those with a birthweight of 750 to 999g, and 30% of those with a birthweight of 1000 to 1499g required special education services later in childhood, compared with 24% of those who weighed 2500g or more at birth. Mild mental retardation (IQ 55–69) was most related to male sex, black race, and mother's educational achievement of less than high-school completion. Specific learning disabilities, emotional challenges, and speech and language impairments were strongly tied to socio demographic factors, especially lower family income. With the current reduction of public funding for disadvantaged urban areas and the lack of human and community resources available to medical and educational professionals serving children in these neighborhoods,

the importance of comprehensive support for very- and extremely-low-birthweight children experiencing social adversity is critical.

Over 2 decades ago, Hille et al. undertook a collaborative follow-up study at the ages of 2, 5, and 9 years of 1338 Dutch infants born very preterm or with very low birthweight.²⁷ At the age of 5 years, 12% of the cohort were receiving intensive special education services. At the age of 9 years, approximately 19% of children were receiving special education, with almost half (47%) having already been in special education since the age of 5 years. Twice as many males as females were in special education, and children from low socioeconomic backgrounds were five times more likely to be in special education (35%) than their counterparts from high socioeconomic backgrounds (7%). Socioeconomic status and sex more substantially contributed to suboptimal school outcomes than very or extremely low birthweight.

A limitation of the present study is the difficulty in obtaining greater longitudinal follow-up at the ages of 2 years and 5 years 6 months. Great effort was made to remain in contact with the families over the years, but despite this, some of the families were unfortunately unable to be reached. In addition, this was a single-center study, and the numbers are small. Lastly, even though our center works closely with the Early Intervention, Ounce of Prevention, and Head Start programs, there is not universal access to these services for preterm children.

Our study revealed that 2-year neurodevelopmental assessments of preterm infants are good predictors of school readiness. We found that abnormal 2-year neurosensory disability or delay (MDI or PDI <70) predicted the need for special education services at the age of 5 years 6 months. We also found that children with MDI or PDI scores of less than 85 (1SD below the mean) had an increased risk of not being ready for school, especially if they were experiencing social disadvantage. Our results highlight the importance of ensuring access to good-quality preschool education experiences for children at the highest biomedical and social risks, so that they can enter kindergarten ready to learn. We believe that preterm infants should continue to be followed longitudinally with structured assessments beyond the age of 2 years to allow early interventional programs to be evaluated further and to help identify factors that promote developmental resilience and educational success.

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LIST OF ABBREVIATIONS

MDI	Mental developmental index
PDI	Performance developmental index
ROC	Receiver operating characteristic

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Figure 1.

Proportion of children by neurodevelopmental status at the age of 2 years who were not ready for school at the age of 5 years 6 months. Relative risks are given with 95% confidence intervals.

Figure 2. Receiver operating characteristic (ROC) analysis of (a) the Bayley Scales of Infant Development mental developmental index and (b) performance developmental index at the age of 2 years as predictors of school readiness at the age of 5 years 6 months.

Figure 3. Contribution of socioeconomic status, measured using the Hollingshead Index of Social Position (ISP), to the classification of neurodevelopmental status at the age of 2 years and school readiness at the age of 5 years 6 months.

Table I

Neurodevelopmental classification at age 2y and school-age assessment

2-year assessment (mean age at assessment 2y 4mo [SD 8mo])	
Normal	No disability and no delay
Abnormal	
Delay	No disability and MDI and/or PDI <70
Disability	Cerebral palsy and/or Bilateral blindness and/or Bilateral hearing loss
School-age assessment (mean age at assessment 5y 6mo [SD 1y])	
School ready	
Level 4	One domain 1–2SD below mean
Level 3	At risk for special education Two domains 1–2SD below mean
Not school ready	
Level 2	Requiring some special education Three domains 1–2SD below mean Any domain > 2SD below mean Visual impairment (sees letters/shapes) Hearing impairment requiring aids (hears/understands verbal language) GMFCS level I–III
Level 1	Requiring intense special education BSRA <50 Visual impairment (inability to see) Hearing impairment (inability to talk) GMFCS level IV–V Severe autism (CARS >36)

BSRA, Bracken School Readiness Assessment; CARS, Childhood Autism Rating Scale; GMFCS, Gross Motor Functional Classification System; MDI, Bayley Scales of Infant Development, mental developmental index; PDI, Bayley Scales of Infant Development, performance developmental index.

Table II

Participant characteristics

Characteristics	
Participants, <i>n</i>	121
Male:female ratio, <i>n</i> (%)	57:64 (47:53)
Birthweight mean (SD), g	987 (374)
Gestational age mean (SD), wks	27.3 (2.6)
Apgar scores, median (interquartile range)	
At 1min	5 (3–6)
At 5min	7 (6–8)
Ethnic group (self-reported), <i>n</i> (%)	
African–American	85 (70)
White	21 (17)
Hollingshead Index of Social Position, <i>n</i> (%)	
Levels 1–3	51 (42)
Levels 4–5	70 (58)
Neonatal morbidities, <i>n</i> (%)	
Chronic lung disease	56 (46)
Severe intraventricular hemorrhage or periventricular leukomalacia	20 (17)

Table III

Combined effect of Bayley Scales of Infant Development mental developmental index (MDI) and performance developmental index (PDI) on school readiness

	PDI normal (≥ 85)	PDI >1SD below mean (70–84)	PDI >2SD below mean (<70)
MDI normal (≥ 85)	1.0	3.12 (0.66–14.9)	41.7 (1.27–1363)
MDI >1SD below mean (70–84)	7.89 (2.45–25.4)	6.85 (0.41–114)	41.7 (8.00–217)
MDI >2SD below mean (<70)	4.42 (1.26–15.5)	34.60 (4.68–256)	228.0 (50–1549)

Data are odds ratios (95% confidence intervals).