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Academic Achievement Deficits and their Neuropsychological Correlates in Children Born Extremely Preterm

Natacha Akshoomoff, Ph.D.¹, Robert M. Joseph, Ph.D.², H. Gerry Taylor, Ph.D.³, Elizabeth N. Allred, M.S.^{4,5}, Timothy Heeren, Ph.D.⁶, Thomas M. O'Shea, M.D.⁷, and Karl C. K. Kuban, M.D.⁸

¹Department of Psychiatry and Center for Human Development, University of California, San Diego, La Jolla, CA, USA

²Department of Anatomy and Neurobiology, Boston University School of Medicine, Boston, MA, USA

³Department of Pediatrics, Case Western Reserve University and Rainbow Babies & Children's Hospital, University Hospitals Case Medical Center, Cleveland, OH, USA

⁴Department of Neurology, Harvard Medical School, Boston, MA, USA

⁵Neuroepidemiology Unit, Department of Neurology, Boston Children's Hospital, Boston, MA, USA

⁶Department of Biostatistics, Boston University School of Public Health, Boston, MA, USA

⁷Department of Pediatrics, University of North Carolina, Chapel Hill, NC, USA

⁸Department of Pediatrics, Division of Pediatric Neurology, Boston University Medical Center, Boston, MA, USA

Abstract

Objective—The purpose of this study was to examine the risks associated with learning disabilities (LD) in a large sample of children born extremely preterm. We predicted higher than expected rates of LD, particularly in math, and children with LD in math, reading, or both would have lower IQs and specific patterns of neuropsychological deficits.

Method—We evaluated academic achievement, rates of LD, and their neuropsychological correlates in the Extremely Low Gestational Age Newborn (ELGAN) Study cohort of 10-year-old children born at 23 to 27 weeks gestational age. Primary analyses focused on children without intellectual disability (verbal IQ > 70 and nonverbal IQ > 70; N=668). Low achievement was defined as a standard score < 85 on the reading or math measures.

Results—The risk of low math achievement scores (27%) was 1.5 times higher than the risk of low reading achievement scores (17%). Children were classified as having LD based on low achievement criteria in reading only (RD, 6.4% of sample), math only (MD, 16.2%), both reading and math (RD/MD, 8.3%), or no reading or math disabilities (No LD, 69.1%). Although all three

LD groups had multiple neuropsychological weaknesses compared to the No LD group, the RD and MD groups had different patterns of neuropsychological impairment.

Conclusion—These children from the ELGAN cohort had higher than expected rates of LD, particularly in mathematics, even after taking socioeconomic status into consideration. These results point to specific cognitive weaknesses that differ between extremely preterm children with RD and MD and the utility of neuropsychological assessments in addressing low academic achievement.

Children born very preterm are at high risk for neurocognitive deficits ¹. Several follow-up studies have shown that children born at very low gestational age (or with very low birth weight) perform significantly less well on standardized measures of academic achievement than children born full term ^{2–6}. The impact of preterm birth on education is also reflected in an increased risk of delayed kindergarten entry, lower teacher ratings of progress, greater risk for repeating a grade, and increased likelihood of receiving educational interventions ^{2,5,7–10}.

In a meta-analysis of reading abilities in school-aged children born preterm, Kovachy and colleagues ¹¹ evaluated nine studies of single-word reading and five studies of reading comprehension. The authors concluded that school-aged children born preterm perform significantly more poorly than full term children on both decoding and reading comprehension, even when socioeconomic status (SES) and IQ (i.e., study-level exclusion of children with intellectual disability) are taken into consideration.

Children born very preterm appear to have particularly high rates of difficulties in mathematics ^{7,12}. Deficits in numerical reasoning skills and mathematics among children born very preterm may be evident as early as kindergarten ^{8,13}. Higher than expected rates of math deficits have been reported in children born very preterm, even when limiting samples to those with average IQ (> 80 or 85) or after adjusting for IQ ^{2,3,5,6,9,13,14}. In a meta-analysis of 14 studies, Aarnoudse-Moens and colleagues ¹⁵ reported that very preterm children had a 0.60 standard deviation (SD) deficit in mathematics scores compared with a 0.48 SD deficit in reading. IQ levels among the study participants across the studies were not taken into consideration in this meta-analysis.

After taking general intelligence into consideration, a number of neuropsychological functions appear to be particularly vulnerable to the effects of preterm birth ^{1,4,16}. There is a growing literature on the link between specific neurocognitive functions and academic achievement in children born very preterm. Children born very preterm with learning deficits generally have both lower IQ and selective cognitive impairments. Mathematical performance has been linked to visuospatial skills, processing speed, attention, working memory, and other aspects of executive function ^{6,7,9,14}. Reading performance has been associated with visual processing, language skills, and executive function ^{17–19}.

Here we present outcomes at age 10 from the Extremely Low Gestational Age Newborn (ELGAN) Study cohort of children born at 23 to 27 weeks gestational age ²⁰. As previously reported ¹⁶, this group had lower than expected IQ. Although IQ is not a proxy for learning potential, impairments of cognitive development, including those associated with very

preterm birth, are expected to impede academic achievement^{21,22}. We therefore examined academic achievement in this sample after excluding children with IQ scores 2 standard deviations below the normative mean and thus likely to have intellectual disability. Academic achievement among children born very preterm is also associated with other factors such as low SES^{8,11,15,18,23}. In this study we found that SES was significantly related with the outcome measures and therefore took SES into consideration across all statistical analyses. Previous studies have used age-based achievement scores, which may have contributed to a greater discrepancy between mathematics and reading scores given the potentially larger impact of grade retention on mathematics skills compared with reading skills²⁴. We therefore used both grade-based and age-based academic achievement scores to examine this issue further.

As in previous studies of learning disabilities in children born very preterm^{3,25} or full term²⁶, we examined the rates of “low achievement” learning disabilities (LD) in reading and/or mathematics, defined by standard scores of less than 85 (< 16th percentile), in the ELGAN cohort. We also examined the neuropsychological test correlates of reading and mathematics LD. We hypothesized that children in the ELGAN cohort without generalized intellectual impairment would have higher than expected rates of LD, particularly in mathematics. A second hypothesis was that ELGAN children with a LD would have lower IQs and higher rates of specific cognitive impairments than those without a LD. Finally, based on previous research involving community samples of children with LD^{27,28}, we anticipated that ELGAN children with reading LD only, math LD only, and combined math and reading LD would have multiple cognitive deficits compared to ELGAN children without LD but that profiles of deficits would differ for these three groups. A related expectation was that multiple cognitive deficits would be associated with reading and math skills but that some of these correlates would differ for these two academic domains³.

Method

Participants

The Extremely Low Gestational Age Newborns (ELGAN) study is a multi-center prospective, observational study of the risk of structural and functional neurologic disorders in extremely preterm infants²⁰. During the years 2002–2004, women delivering before 28 weeks gestation in 11 cities in 5 states were asked to enroll in the study. A total of 1506 infants, born to 1249 mothers, were enrolled and 1198 survived to age 10. Of 966 children who were actively recruited for follow-up at age 10 years (because of the availability of blood samples from the first month of life), the families of 889 (92%) returned, and of these families 11 children did not accompany the parent or caregiver and 4 did not cooperate with the child assessment. Of the remaining 874 participants, 17 (1.9%) had severe motor impairment, 7 (0.8%) had functional blindness, and 2 (0.2%) had both severe motor impairment and functional blindness, and were not able to complete a valid testing assessment, resulting in a final sample of 848.

Children were assessed in a single testing session, while the parent or caregiver completed questionnaires regarding the child’s current neurological status and educational history. To avoid attributing reading and math limitations to low intelligence, we restricted our analyses

to the 668 children with both verbal IQ > 70 and nonverbal IQ > 70 and complete academic achievement data.

Maternal and newborn characteristics

Maternal age, education, marital status, receipt of public health insurance (i.e., Medicaid), and racial and ethnic identity were self-reported. These characteristics, as well as gestational age, birth weight, and growth restriction, were defined according to standard procedures described in detail in prior ELGAN publications ²⁰.

Academic Characteristics

Grade placement at the time of testing was compared with what would be expected, based on age (i.e., 4th grade placement at age 9, 5th grade placement at age 10, etc.). A child was classified as "behind grade placement" if (expected grade – actual grade at time of testing) ≥ 1. Parents were also asked if their child had ever repeated a grade and if their child ever had an Individualized Educational Plan (IEP). As shown in Table 1, the likelihood of being behind expected grade placement was high for the ELGAN sample. Information on delayed school entry was not collected during the parent interview, but given the relatively low rates of having repeated a grade, it appears that a sizeable percentage of children were behind in grade placement because of delayed entry to kindergarten. The proportion of children who ever had an IEP was also high.

Assessment of Neurocognitive and Academic Achievement Skills

Verbal and nonverbal IQ were assessed with the Verbal and Nonverbal Reasoning scales, respectively, from the School-Age Level of the Differential Ability Scales–II (DAS-II) ²⁹. Academic Achievement was assessed using selected subtests from the Wechsler Individual Achievement Test–III WIAT-III; ³⁰. We used Word Reading to assess single word reading skills, Numerical Operations to assess the ability to solve paper and pencil calculations using basic math operations, Pseudoword Decoding to assess the ability to apply phonetic decoding skills, and Spelling to assess written spelling of dictated words.

Similar to a previous “low achievement” classification of learning disability ³, we defined LD as a score below the 16th percentile (i.e., a standard score < 85) on a grade-based WIAT-III achievement test. A reading only LD (RD) was identified by low achievement only on WIAT-III Word Reading, a mathematics only LD (MD) by low achievement only on WIAT-III Numerical Operations, a combined mathematics/reading LD (MD/RD) by low achievement on both measures, and No LD by scores > 85 on both measures. Pseudoword Decoding and Spelling were not considered in classifying children into LD groups because of their high correlations with Word Reading ($r = .65$ for both measures).

Neuropsychological correlates were examined using 12 of the measures included in the original follow-up test battery ¹⁶. Five composite measures were created by averaging the standard scores across each pair of test measures to reduce the number of variables included in the analyses. A *Language Composite* score was created by averaging the Listening Comprehension and Oral Expression scores from the Oral and Written Language Scales ³¹. A *Working Memory Composite* score was created from the DAS-II ²⁹ Recall of Digits

Backward and Recall of Sequential Order scores. An *Attention Composite* score was created from the NEPSY-II Auditory Attention and Auditory Response Set subtests³². An *Inhibition Composite* score was created from the NEPSY-II Inhibition Inhibition and Inhibition Switching subtests. A *Visual Perception Composite* score was created from the NEPSY-II Arrows subtest, which measures perception of line orientation, and the NEPSY-II Geometric Puzzles subtest, a measure of mental rotation of complex visual-spatial figures. Correlations between these pairs were evaluated (see Supplementary Table 1) and ranged from .35 to .64 (all p 's < 0.001). The NEPSY-II Inhibition Naming subtest provided a baseline measure of processing speed with no inhibitory component, and was similar to a standard test of rapid naming. NEPSY-II Visuomotor Precision provided a measure of graphomotor speed and accuracy.

Analyses

Maternal education, which we used as a proxy measure of socioeconomic status (SES), was significantly correlated with the academic achievement, IQ, and neuropsychological measures (see below). We therefore used MANCOVA to compare the LD subgroup on the two achievement tests and across all the neuropsychological measures, adjusting for maternal education. Skewness and kurtosis were examined across the WIAT-III Word Reading and Numerical Operations, IQ, and neuropsychological scores, pooled within group. These measures were acceptable for the MANCOVA analyses (Supplementary Table 1). The Hochberg multiple comparison procedure was used to correct for multiple comparisons. Separate ANCOVAs, again controlling for maternal education, were then conducted comparing the study groups on each individual neuropsychological measure. Pairwise comparisons were conducted, using Scheffe's procedure to control for multiple testing. The adjusted p -values are reported in Table 3. Hierarchical linear regression analyses were conducted to identify the neuropsychological measures that accounted for unique variance in Word Reading and Numerical Operations scores. Maternal education was entered in Step 1 followed by the 7 neuropsychological measures. Chi-square tests were used to compare the study groups on maternal demographic and newborn characteristics and on educational variables.

Results

Performance on Tests of IQ and Academic Achievement Relative to Normative Standards

In a normative sample, 2.3% would be expected to have z -scores ≤ -2 (standard score ≤ 70). In the overall ELGAN follow-up sample, children with IQ and age-based WIAT-III z -scores in this range were 6 to 7 times higher than expected¹⁶.

When the sample was limited to children with verbal IQ > 70 and nonverbal IQ > 70 (> 2nd percentile) and who were thus unlikely to have intellectual disability, the mean IQ scores were slightly lower than the normative mean (verbal IQ: $M = 97.7$, $SD = 13.2$; nonverbal IQ: $M = 95.2$, $SD = 12.6$). The distributions of IQ and academic achievement scores for this sample are shown in Table 2. Note that 42% of these children were behind in grade placement compared with children their age at the time of testing (Table 1).

The distributions of grade-based Word Reading and Numerical Operations scores are shown in Figure 1. The risk of low math achievement was higher than the risk of low reading achievement, with 16.8% of the children having a low grade-based Word Reading score compared to 26.9% with a low grade-based Numerical Operations score (McNemar's paired sample chi-square test, $p < .001$).

By comparison, the WIAT-III age-based standard scores were as follows: Reading: $M = 99.5$, $SD = 14.4$; Pseudoword Decoding: $M = 98.1$, $SD = 15.0$; Spelling: $M = 97.4$, $SD = 15.3$; Numerical Operations: $M = 95.5$, $SD = 13.8$. Similar to the grade-based scores, 16.2% of the children had a low age-based Word Reading score while 27.3% had a low age-based Numerical Operations score (McNemar's paired sample chi-square test, $p < .001$).

Rates of Learning Disabilities (LD) and Associated Characteristics

Among children with verbal and nonverbal IQs > 70 , 43 (6.4%) had RD, 109 (16.2%) had MD, 56 (8.3%) had MD/RD, and 460 (69.1%) had No LD. The characteristics of these four groups are shown in Table 3. Chi-square analyses revealed that the four groups were significantly different in maternal education, single marital status, receipt of public health insurance, and racial identity. On all indices of socioeconomic status, the RD/MD group was the most socially disadvantaged and the No LD group the least socially disadvantaged. The children in the four groups differed in gestational age and birth weight, but not in the likelihood of fetal growth restriction (birth weight Z-score). Children in the RD/MD group were most likely to belong to the lowest gestational age stratum of 23–24 weeks. The four groups also differed in academic history, with the children in the LD groups more likely to be behind at least one grade, have repeated a grade, and have a past or current IEP.

Differences Between the LD and No LD groups on Achievement and Neuropsychological Measures

Group results on the IQ, achievement, and neuropsychological tests are shown in Table 4. Maternal education was significantly related to the WIAT-III scores (Wilk's Lambda, $F(4,1192) = 10.43$, $p < 0.001$), as well as the IQ and neuropsychological measures (Wilk's Lambda, $F(18, 1178) = 4.32$, $p < 0.001$). A MANCOVA comparing the groups on verbal and non-verbal IQ and controlling for maternal education revealed a group $\times$ measure interaction ($F(3,597) = 3.51$, $p = 0.015$), documenting significantly larger group differences for non-verbal compared to verbal IQ. ANCOVAs comparing the LD groups on each of the IQ measures indicated group differences in both verbal IQ ($F(3,597) = 20.84$, $p < 0.001$) and non-verbal IQ ($F(3,597) = 25.50$, $p < 0.001$). For both measures, pairwise comparisons revealed a significantly higher score for the No LD group relative to each of the other three groups, which did not differ from each other.

A MANCOVA comparing the groups on Word Reading and Numerical Operations revealed a significant group difference (Wilk's Lambda, $F(6,1192) = 157.83$, $p < 0.001$). The group $\times$ measure interaction was also significant ($F(3,597) = 88.35$, $p < 0.001$), indicating significantly larger group differences for Numerical Operations than for Word Reading. Post-hoc pairwise ANCOVA results indicated significant differences across the four groups on both Word Reading ($F(3,597) = 143.01$, $p < 0.001$) and Numerical Operations ($F(3,597)$

= 231.32, $p < 0.001$). Separate between-groups ANCOVAs for the two achievement measures, with Scheffe corrections of p-values for multiple comparisons, revealed that all three LD groups scored below the No LD group on reading and math (Table 4). Both the RD and RD/MD groups had significantly lower adjusted reading scores than the MD group ($p < 0.001$ for both comparisons) but the RD and RD/MD groups did not have significantly different adjusted scores ($p = 0.88$). Both the MD and the RD/MD groups had significantly lower adjusted math scores than the RD group ($p < 0.001$ for both comparisons) but did not differ from each other (adjusted $p = 0.33$).

As expected, MANCOVAs revealed significant group differences for the 7 neuropsychological measures (Wilk's Lambda, $F(27, 1721) = 5.69$, $p < 0.001$; see Table 4 and Figure 2), though the group $\times$ measure interaction was not significant, $F(18, 3582) = 1.26$, $p = 0.2011$. Results of pairwise MANCOVA comparisons for the neuropsychological tests showed that the RD, MD, and MD/RD groups had significantly lower scores than the No LD group (all adjusted p-values < 0.001). Comparing the LD groups with each other, the RD and MD groups were significantly different from each other overall (adjusted $p < 0.01$) but neither group was significantly different from the MD/RD group. Separate between-groups ANCOVAs with Scheffe corrections for each neuropsychological measure revealed that the MD/RD group had significantly lower scores than the No LD group across all measures. Both the RD and MD groups had significantly lower scores than the No LD group on measures of language, working memory, and inhibition. In comparisons of the RD and MD groups to the No LD group, the RD group was selectively impaired in processing speed, as measured by a rapid naming test, and the MD group was selectively impaired in attention and visual perception. Neither the RD group nor the MD group differed significantly from the No LD group in visuomotor control. Despite these differences between the three LD groups relative to the No LD group, pairwise comparisons between the three LD groups failed to reveal any significant differences in test scores.

Associations of Neuropsychological Measures with Achievement Scores

For Word Reading, maternal education accounted for 9.9% of the variance in scores ($R^2 = 0.099$, $F(2,600) = 33.02$, $p < 0.001$). In Step 2 of the hierarchical linear regression, the total set of 7 neuropsychological measures accounted for an additional 29.9% of the variance ($R^2 = 0.299$, $F(7,593) = 42.10$, $p < 0.001$). The neuropsychological measures that accounted for unique variance in Word Reading, after accounting for maternal education, were the Language Composite ($\beta = 0.32$, $p < 0.001$), the Working Memory Composite ($\beta = 0.18$, $p < 0.001$), the Inhibition Composite ($\beta = 0.13$, $p = 0.003$), and Naming ($\beta = 0.09$, $p = 0.017$) scores.

For Numerical Operations, maternal education accounted for 5.5% of the variance ($R^2 = 0.055$, $F(2,600) = 17.54$, $p < 0.001$), and in Step 2 the 7 neuropsychological measures accounted for an additional 21.8% of the variance ($R^2 = 0.218$, $F(7,593) = 25.42$, $p < 0.001$). The neuropsychological measures that accounted for unique variance in Numerical Operations, after accounting for maternal education, were the Working Memory Composite ($\beta = 0.22$, $p < 0.001$) and Inhibition Composite ($\beta = 0.12$, $p = 0.008$), as well as the Visual Perception Composite ($\beta = 0.14$, $p < 0.001$).

Pairwise comparisons of the magnitude of the associations between each neuropsychological score with Word Reading versus Numerical Operations using tests for correlated r s³³, and controlling for maternal education, revealed that language was significantly more highly and significantly associated with reading than with math (partial r s of .32 and .07, $p < 0.001$). Conversely, Visual Perception was significantly more highly and significantly associated with math than with reading (partial r s of $-.03$ and $.15$, $p < 0.001$).

Discussion

These ELGAN Study results represent the largest U.S. study of school-age performance in children born extremely preterm (before 28 weeks gestation). We found lower than expected performance on standard tests of verbal and non-verbal IQ as well as on reading, phonetic decoding, spelling, and mathematics, and a variety of neuropsychological measures. Consistent with previous research on the consequences of extremely preterm birth, our sample also exhibited greater deficits in non-verbal IQ compared to verbal IQ and in math compared to reading^{6,9,13}. Importantly, these results were found even after controlling for SES.

The rate of low achievement in reading, math, or both was 30.9% among children with verbal and nonverbal IQs > 70 . This is very similar to the rate of 29% in another follow-up study of 11-year-old children with very low birth weight³. Previous studies have suggested that even after controlling for IQ, children born very preterm have specific difficulties with mathematics (for review, see¹²). In conducting similar analyses using age-based achievement scores and limiting our sample to children with IQs > 70 , we replicated these results and found that the rate of MD was double the rate of RD.

These types of analyses, however, ignore the impact of grade placement differences in this population. This is a particular concern when evaluating children who are 10 years old because current grade placement may have a greater impact on the ability to perform the variety of math computation problems included in an achievement test such as the WIAT-III Numerical Operations than on single word reading. Proficiency on math problems is more likely to depend on grade-based learning. We addressed this issue by using grade-based scores and limiting the sample to children with estimated IQs that fell above the significantly impaired range. Weaknesses on all academic achievement measures were found, and the disproportionate weakness in mathematics skills was still apparent. While findings were similar whether based on grade- or age-based scores, assessment of both still seems warranted, whether as part of a clinical assessment or in research studies with children born very preterm, given the higher risk of delayed school entry and/or grade repetition.

Children born extremely preterm who had reading and/or math learning disabilities had multiple neuropsychological deficits relative to the children with no LD. While a number of studies have demonstrated that deficits in phonological processing are the strongest neuropsychological predictors of RD, independent associations between reading proficiency and verbal comprehension, naming speed, processing speed, and working memory, such as we found in this study, are consistent with a multiple-deficit neuropsychological model of RD²⁸. A multiple-deficit model of MD has also gained support from studies of community

and other preterm samples^{3,14,27,28}. In addition to various aspects of numerical competency, deficits in verbal comprehension, working memory, visual spatial and visual perceptual skills, set shifting, and processing speed have also been linked with math LD.

The present findings suggest that RD and MD in preterm children are at least partially distinct forms of LD with different profiles of neuropsychological weaknesses compared to preterm children without deficits in either reading or math. Post-hoc pairwise MANCOVAs revealed a significant difference in the profiles of the RD and MD groups even after SES was taken into consideration. Although both groups had multiple cognitive weaknesses, preterm children with RD had weaknesses in naming speed not evident in the MD group, whereas those with MD had weaknesses in visual perception and attention not evident in the RD group. In parallel with these findings, naming speed was uniquely associated with reading and visual perception was uniquely associated with math in the combined sample. Additionally, the language measure was more strongly associated with reading than math, whereas visual perception was more strongly associated with math than reading. The results are consistent with specific correlates of reading and math in studies of community samples of children with RD, MD, RD/MD, and No LD. For example, Fletcher²⁷ found that attention problems were more closely associated with MD than RD, and Willcutt et al.²⁸ found that slower speed of naming was related, independently of other skills, to lower reading skills but not to math. Studies of preterm cohorts also have observed closer associations of reading with language skills and of math with visual perceptual skills^{3,34}.

Our results further suggest that preterm children with RD/MD have more pervasive neuropsychological weaknesses compared to those with either RD or MD. This finding is consistent with the substantial comorbidity of reading and math problems in community samples^{27,28} and indicates that preterm children with difficulties in both reading and math are likely to be most impaired relative to grade-based expectations. Although neither the RD nor MD group differed significantly from the RD/MD group on pairwise MANCOVAs, the RD/MD group had deficits in several neuropsychological skills that were not evident in the RD or MD, and only the RD/MD group had a deficit relative to the No LD group on Visuomotor Precision. The latter finding provides additional support for the broader range of cognitive deficits associated with comorbid reading and math problems and raises the possibility that weaknesses in visuomotor control may be useful in distinguishing children with comorbid RD/MD from more isolated forms of LD.

The high rates of LD in this preterm sample point to the need for monitoring of academic progress in children born at extremely low gestational ages. Assessments are indicated for both reading and math. Evidence that multiple neuropsychological deficits in preterm children with LD, even those without global intellectual impairment, also suggests a need for comprehensive neuropsychological assessment. Assessments of skills that may help to distinguish RD, MD, and RD/MD are especially important in identifying different types of LD. Identifying the type of LD may also have implications for approaches to intervention. Children with comorbid RD/MD are likely to require the most intensive interventions. Findings from a study of the effectiveness of different types of learning interventions for community (school) samples of children with RD, MD, and RD/MD also raise the possibility that children with different types of LD may have different instructional needs³⁵.

Children with MD were able to benefit from training in number facts embedded in word problems, whereas children with RD/MD required more decontextualized work with math facts, and children with RD responded similarly to the different instructional methods.

One of the limitations of the study is the lack of a demographically matched normal birth weight term-born control group, which would have permitted a more precise estimate of increased rates of learning disabilities relative to expectation. Additionally, although our findings indicate that children in the ELGAN sample at age 10 years are relatively more competent in single word reading skills than in mathematics, they may also be more delayed in other aspects of language arts, such as reading fluency and comprehension skills and more complex measures of written expression. Finally, although a pairwise MANCOVA substantiated differences in the neuropsychological profiles of the RD and MD groups, the nature of the differences would have been clearer had post-hoc pairwise ANCOVAs revealed significant differences between the RD and MD groups on some of the neuropsychological measures. The lack of differences in these comparisons suggests caution in interpreting the profile differences, as patterns evident in comparisons of each group to the No LD group may have reflected differences in statistical power related the small group sizes.

Future follow-up studies should include measures of mathematical competence beyond calculations and, in younger children, early number skills¹² in order to more fully examine the issue of increased prevalence of MD in children born very preterm and the developmental precursors. Recent research suggests that mathematics difficulties in very preterm children are associated with deficits in working memory and visuospatial processing rather than in numerical representations¹⁴. The substantial prevalence of attention deficit hyperactivity disorder (ADHD) in preterm children also suggests the need to consider this disorder as a contributor to their high rates of learning problems³⁶. Very preterm children's mathematics difficulties may therefore be somewhat different in nature from those of children with developmental forms of MD, and early interventions targeting these cognitive problems may have the potential to lessen childhood MD¹⁴.

As in previous studies that have found a link between low socioeconomic status and low academic achievement among children born very preterm^{8,11,15,18,23}, we found significant correlations between achievement scores and maternal education. Thus, higher than expected rates of low achievement compared to normative standards may in part reflect sociodemographic differences between samples, such as the ELGAN cohort, and the broader child population. Controlling for low SES, as we did in this study, is critical for increasing our understanding the longer term impact of very preterm birth on long term outcomes.

Math achievement scores at age 10 may reflect the long-lasting impact of early math difficulties in children born very preterm^{8,13}. These results further illustrate the need for preschool preparation in this population as well as academic support services as children enter formal schooling to lay the foundation for later skills. Early interventions to improve number skills deserve special consideration given evidence for their effectiveness³⁷ and the association of these skills with later mathematics learning³⁸.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Distribution of grade-based standard scores for the WIAT-III Word Reading and Numerical Operations measures for 668 children with verbal and nonverbal IQs > 70. The smooth black line shows the expected normal distribution with a mean of 100 and standard deviation of 15.

Figure 2.
Adjusted mean IQ and neuropsychological scores by LD group.

Demographic characteristics at the time of child's birth and current academic characteristics of the ELGAN study samples.

Table 1

	Total Sample (n=848)		Verbal > 70 & Nonverbal > 70 (n=668)	
	Row N	%	Row N	%
Maternal characteristics				
Age, years	< 21	110	13	85
	21–35	567	67	441
	> 35	171	20	142
Education, years	12	340	41	248
	> 12, < 16	195	24	147
	16	290	35	254
Single marital status	Yes	340	40	243
	No	508	60	425
Public insurance	Yes	295	35	201
	No	541	65	457
Racial identity	White	526	63	450
	Black	222	26	145
	Other	90	11	66
Hispanic	Yes	81	10	60
	No	764	90	605
Newborn characteristics				
Sex	Male	435	51	322
	Female	413	49	346
Gestational age, weeks	23–24	171	20	120
	25–26	286	46	297
	27	291	34	251
Birth weight, grams	750	308	36	213
	751–1000	371	44	307
	> 1000	169	20	148

	Total Sample (n=848)		Verbal > 70 & Nonverbal > 70 (n=668)	
	Row N	%	Row N	%
Birth weight Z-score	< -2	48	35	5
	-2, < -1	112	80	12
	-1	688	553	83
Academic History				
Currently behind expected grade level	Yes	380	281	42
	No	468	387	58
Ever repeated a grade	Yes	159	109	16
	No	689	559	84
Ever had an IEP	Yes	452	288	43
	No	396	380	57

Table 2

Distributions of IQ and grade- and age-based WIAT-III test scores for children with verbal and nonverbal IQ > 70 (N=668; percents listed in Z-score columns).

Z-score	-2	> -2, -1	> -1, 1	> 1
Normal distribution	2.3%	13.7%	68.2%	15.8%
<i>IQ</i>				
Verbal IQ	0	21	70	9
Nonverbal IQ	0	24	69	6
<i>Grade-Based Academic Achievement</i>				
Word Reading	2	15	68	15
Numerical Operations	3	24	67	6
Pseudoword Decoding	4	16	69	11
Spelling	2	12	71	14
<i>Age-Based Academic Achievement</i>				
Word Reading	2	14	68	16
Numerical Operations	3	24	66	7
Pseudoword Decoding	5	17	68	11
Spelling	3	19	65	14

Table 3

Maternal and newborn characteristics and academic history for LD groups for children with verbal and nonverbal IQ > 70 (N = 668, percents listed in group columns).

	n	RD n = 43	MD n = 109	RD/MD n = 56	No LD n = 460	χ^2 p-value
Maternal characteristics						
Age, years	< 21	85	15	20	12	0.105
	21–35	441	70	64	64	
	> 35	142	16	16	24	
Education, years	12	256	50	59	32	0.001
	> 12, < 16	152	23	25	22	
	16	260	28	16	45	
Single marital status	Yes	243	51	54	32	0.001
Public insurance	Yes	205	37	55	25	0.001
Racial identity	White	455	58	55	72	0.008
	Black	145	24	33	18	
	Other	66	11	13	10	
Hispanic	Yes	60	12	16	7	0.074
Newborn characteristics						
Sex	Male	322	51	48	49	0.801
Gestational age, weeks	23–24	120	9	30	17	0.016
	25–26	297	44	50	43	
	27	251	47	23	40	
Birth weight, grams	750	213	28	44	28	0.017
	751–1000	307	49	41	45	
	> 1000	148	23	15	14	
Birth weight Z-score	< -2	35	9	8	5	0.395
	-2, < -1	80	9	15	9	
	-1	553	81	77	86	
Academic history						

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	n	RD n = 43	MD n = 109	RD/MD n = 56	No LD n = 460	χ^2 p-value
Behind grade	Yes	56	27	38	45	0.001
Repeated a grade	Yes	30	19	25	13	0.004
IEP	Yes	56	54	82	35	0.001

Table 4

Comparisons of RD, MD, RD/MD, and No LD groups on IQ, achievement, and neuropsychological measures for children with verbal and nonverbal IQ > 70 with complete data (N = 603).

	RD n = 37	MD n = 100	RD/MD n = 48	No LD n = 418
IQ				
Verbal IQ mean (SD)	88.7 (11.8)	93.2 (11.1)	87.2 (10.6)	100.9 (12.7)
Adjusted mean	90.0	94.2	89.6	100.2
Scheffe p group vs. No LD *	0.001	0.001	0.001	---
Nonverbal IQ mean (SD)	91.4 (10.2)	88.2 (8.9)	86.6 (10.0)	98.3 (12.6)
Adjusted mean	92.3	88.8	88.0	98.2
Scheffe p group vs. No LD	0.030	0.001	0.001	---
WIAT-III				
Word Reading mean (SD)	78.6 (5.7)	97.4 (9.6)	76.2 (6.4)	104.4 (11.5)
Adjusted mean	79.3	98.0	77.5	104.1
Scheffe p group vs. No LD *	0.001	0.001	0.001	---
Numerical Operations mean (SD)	94.1 (8.7)	78.4 (4.7)	75.1 (6.3)	101.3 (10.2)
Adjusted mean	94.5	78.6	75.6	101.1
Scheffe p group vs. No LD	0.030	0.001	0.001	---
Neuropsychological Tests				
Language Composite mean (SD)	85.8 (11.0)	88.4 (11.1)	84.2 (9.8)	95.5 (12.5)
Adjusted mean	85.7	89.7	86.4	95.0
Scheffe p group vs. No LD	0.001	0.001	0.001	---
Working Memory Composite mean (SD)	88.4 (9.3)	89.5 (12.1)	84.5 (11.5)	98.1 (12.3)
Adjusted mean	89.4	89.9	85.7	97.8
Scheffe p group vs. No LD	0.001	0.001	0.001	---
Attention Composite mean (SD)	8.4 (3.0)	8.0 (2.7)	7.4 (2.8)	9.3 (2.5)
Adjusted mean	8.4	8.2	7.4	9.3
Scheffe p group vs. No LD	0.252	0.002	0.001	---
Inhibition Composite mean (SD)	6.6 (2.8)	6.8 (2.7)	5.7 (2.5)	8.3 (2.9)
Adjusted mean	6.7	6.9	5.9	8.3
Scheffe p group vs. No LD	0.016	0.001	0.001	---
Naming mean (SD)	6.4 (3.3)	7.8 (3.7)	6.7 (3.8)	8.7 (3.8)
Adjusted mean	6.6	8.0	6.7	8.8
Scheffe p group vs. No LD	0.009	0.343	0.004	---
Visual Perception Composite mean (SD)	8.0 (2.4)	7.1 (2.3)	7.0 (2.5)	9.1 (2.5)
Adjusted mean	8.2	7.4	7.1	9.1
Scheffe p group vs. No LD	0.170	0.001	0.001	---
Visuomotor Precision mean (SD)	7.5 (3.3)	7.6 (3.1)	6.8 (3.7)	8.5 (3.4)
Adjusted mean	7.4	7.6	6.5	8.5

	RD n = 37	MD n = 100	RD/MD n = 48	No LD n = 418
Scheffe p group vs. No LD	0.343	0.144	0.003	---

* None of the between LD group comparisons were significant with Scheffe adjustment. Adjusted means (ANCOVAs), controlling for maternal education, and adjusted p-values with Scheffe correction for multiple comparisons.