Preterm Birth and Dyscalculia

Julia Jaekel, PhD1,2, and Dieter Wolke, PhD2,3

Objective To evaluate whether the risk for dyscalculia in preterm children increases the lower the gestational age (GA) and whether small-for-gestational age birth is associated with dyscalculia.

Study design A total of 922 children ranging from 23 to 41 weeks’ GA were studied as part of a prospective geographically defined longitudinal investigation of neonatal at-risk children in South Germany. At 8 years of age, children’s cognitive and mathematical abilities were measured with the Kaufman Assessment Battery for Children and with a standardized mathematics test. Dyscalculia diagnoses were evaluated with discrepancy-based residuals of a linear regression predicting children’s math scores by IQ and with fixed cut-off scores. We investigated each GA group’s ORs for general cognitive impairment, general mathematical impairment, and dyscalculia by using binary logistic regressions.

Results The risk for general cognitive and mathematical impairment increased with lower GA. In contrast, preterm children were not at increased risk of dyscalculia after statistically adjusting for child sex, family socioeconomic status, and small-for-gestational age birth.

Conclusion The risk of general cognitive and mathematical impairments increases with lower GA but preterm children are not at increased risk of dyscalculia. (*J Pediatr 2014;164:1327-32*).

Poor mathematical skills impede lifelong achievements such as academic and occupational attainment as well as social functioning.1,2 Mathematical impairments are common in very preterm children3,4 and account for a substantial number of learning disabilities in this population.5-7 Some authors have suggested that very preterm children’s mathematical deficits are specific and not explained by global cognitive function.8-11 However, it is not known whether these specific mathematical impairments that are independent of general cognitive deficits are related to prematurity across the whole spectrum of gestational age (GA). Dose-response effects of GA on early mathematical performance and special educational needs have been reported,12,13 but in these studies authors did not control for general cognitive abilities. Furthermore, only very preterm children may be at significantly increased risk of scoring below −1 SD in mathematic tests.14 In addition, effects of a small-for-gestational age (SGA) birth on mathematic deficits remain unclear: SGA birth is a result of fetal growth retardation, which is a major contributing factor to preterm birth.15 Children with SGA tend to have general cognitive problems;6,16,17 however, recent reviews on mathematic problems in preterm children have neglected possible effects of SGA birth.18

To understand the nature of specific mathematic impairments across the total spectrum of GA, general cognitive, general mathematical, and dyscalculia need to be concurrently investigated while taking possible confounders into account. Children are diagnosed with dyscalculia when there is a clear discrepancy between their mathematic achievement scores and expected performance based on IQ and age.18 However, preterm children often have lower than normal IQ scores;19,20 thus, fixed definitions of dyscalculia (ie, math test scores ≤10th percentile, IQ scores >15th percentile) may miss many children who have low IQ and a very deficient performance in math (*Figure 1*). We propose to use residuals of a regression analysis predicting math by general IQ to obtain specific math scores that are independent of IQ. In this study, we will compare application of the 2 diagnostic alternatives (fixed cut-off scores vs discrepancy-based residual scores) in children born across the whole GA spectrum.

First, we hypothesized that the risk for general cognitive and mathematical impairments increases with lower GA. Second, we tested whether the risk for dyscalculia similarly increases with lower GA after statistically adjusting for child sex, family socioeconomic status (SES), and SGA birth.

**Methods**

Data were collected as part of the prospective Bavarian Longitudinal Study.20,24 Participating parents were approached within 48 hours of the infant’s hospital admission and were included in the study with written consent. At 8 years of age, children’s cognitive and mathematical abilities were measured with the Kaufman Assessment Battery for Children and with a standardized mathematics test. Dyscalculia diagnoses were evaluated with discrepancy-based residuals of a linear regression predicting children’s math scores by IQ and with fixed cut-off scores. We investigated each GA group’s ORs for general cognitive impairment, general mathematical impairment, and dyscalculia by using binary logistic regressions.

Results The risk for general cognitive and mathematical impairment increased with lower GA. In contrast, preterm children were not at increased risk of dyscalculia after statistically adjusting for child sex, family socioeconomic status, and small-for-gestational age birth. Conclusion The risk of general cognitive and mathematical impairments increases with lower GA but preterm children are not at increased risk of dyscalculia. (*J Pediatr 2014;164:1327-32*).

Poor mathematical skills impede lifelong achievements such as academic and occupational attainment as well as social functioning.1,2 Mathematical impairments are common in very preterm children3,4 and account for a substantial number of learning disabilities in this population.5-7 Some authors have suggested that very preterm children’s mathematical deficits are specific and not explained by global cognitive function.8-11 However, it is not known whether these specific mathematical impairments that are independent of general cognitive deficits are related to prematurity across the whole spectrum of gestational age (GA). Dose-response effects of GA on early mathematical performance and special educational needs have been reported,12,13 but in these studies authors did not control for general cognitive abilities. Furthermore, only very preterm children may be at significantly increased risk of scoring below −1 SD in mathematic tests.14 In addition, effects of a small-for-gestational age (SGA) birth on mathematic deficits remain unclear: SGA birth is a result of fetal growth retardation, which is a major contributing factor to preterm birth.15 Children with SGA tend to have general cognitive problems;6,16,17 however, recent reviews on mathematic problems in preterm children have neglected possible effects of SGA birth.18

To understand the nature of specific mathematic impairments across the total spectrum of GA, general cognitive, general mathematical, and dyscalculia need to be concurrently investigated while taking possible confounders into account. Children are diagnosed with dyscalculia when there is a clear discrepancy between their mathematic achievement scores and expected performance based on IQ and age.18 However, preterm children often have lower than normal IQ scores;19,20 thus, fixed definitions of dyscalculia (ie, math test scores ≤10th percentile, IQ scores >15th percentile) may miss many children who have low IQ and a very deficient performance in math (*Figure 1*). We propose to use residuals of a regression analysis predicting math by general IQ to obtain specific math scores that are independent of IQ. In this study, we will compare application of the 2 diagnostic alternatives (fixed cut-off scores vs discrepancy-based residual scores) in children born across the whole GA spectrum.

First, we hypothesized that the risk for general cognitive and mathematical impairments increases with lower GA. Second, we tested whether the risk for dyscalculia similarly increases with lower GA after statistically adjusting for child sex, family socioeconomic status (SES), and SGA birth.

**Methods**

Data were collected as part of the prospective Bavarian Longitudinal Study. Participating parents were approached within 48 hours of the infant’s hospital admission and were included in the study with written consent. At 8 years of age, children’s cognitive and mathematical abilities were measured with the Kaufman Assessment Battery for Children and with a standardized mathematics test. Dyscalculia diagnoses were evaluated with discrepancy-based residuals of a linear regression predicting children’s math scores by IQ and with fixed cut-off scores. We investigated each GA group’s ORs for general cognitive impairment, general mathematical impairment, and dyscalculia by using binary logistic regressions.

Results The risk for general cognitive and mathematical impairment increased with lower GA. In contrast, preterm children were not at increased risk of dyscalculia after statistically adjusting for child sex, family socioeconomic status, and small-for-gestational age birth. Conclusion The risk of general cognitive and mathematical impairments increases with lower GA but preterm children are not at increased risk of dyscalculia. (*J Pediatr 2014;164:1327-32*).
age, children were assessed by an interdisciplinary study team, including neurologic (done by pediatricians) and cognitive assessments (done by psychological assistants). All assessors were blind to group membership. Ethical permission for the study was granted by the Ethics Committee of the University of Munich Children’s Hospital and the Bavarian Health Council (Landesärztekammer).

The Bavarian Longitudinal Study is a whole-population sample of children born between January 1985 and March 1986 within a geographically defined area of Southern Bavaria (Germany) who required admission to a children’s hospital within the first 10 days of life (N = 7505; 10.6% of all live births). In addition, 916 healthy control infants (normal postnatal care) were identified at birth from the same hospital birth records. Infants were classified as SGA if they weighed less than the sex-specific 10th percentile for their respective GA according to the national standard weight charts (1985-1986).26

Information was collected through structured parental interviews within 10 days of child birth. Family SES was computed as a weighted composite score derived from the occupation of the self-identified head of each family together with the highest educational qualification held by either parent and entered into 6 categories (1 = very low, 6 = very high).27

Assessment at 8 Years of Age
Cognitive assessments and tests were performed by trained assistant psychologists who were blind to children’s background characteristics. Target testing age was 8 years and the children were between 7 years, 11 months and 9 years, 6 months old (M = 8.34; 95% CI 8.33-8.35). All test scores were z-standardized according to the scores of the 248 healthy, full-term control children.

General Cognitive Impairment
Children’s cognitive abilities were assessed with the German version of the Kaufman Assessment Battery for Children (K-ABC).28,29 In the K-ABC, IQ is measured as a composite score (mental processing component [MPC]) based on 8 subtests tapping general cognitive functioning. Children were diagnosed with general cognitive impairment if their K-ABC MPC score was below −1 SD.

General Mathematic Impairment
To assess numerical representations and reasoning, children were administered a comprehensive mathematic test.10,24,30,31 Test tasks were presented to children in book form with 79 items assessing numerical estimations, calculation, reasoning, and mental rotation abilities: 12 estimation tasks measured children’s accuracy in estimating numbers and comparing distances between numbers. Retrieval of arithmetic facts and procedural competence were measured with 50 calculation tasks (simple addition), whereas application of these 2 ability dimensions on real-world problems was assessed with 6 reasoning tasks. Finally, children’s visual-spatial problem solving was tested with 11 mental rotation tasks. Item responses were scored for accuracy and subscale scores were then summed into a comprehensive total score. Children were diagnosed with general mathematic impairment if their total score was below −1 SD.

Dyscalculia
Children are diagnosed with dyscalculia when there is a clear discrepancy between their mathematic test scores and expected performance based on general intelligence.18 Preterm children often have lower than normal IQ scores19,20; thus, commonly used fixed definitions of dyscalculia may miss children who nevertheless have very poor math performance. Figure 1 shows a comparison of 2 different dyscalculia
diagnostic criteria applied to children across the full GA range: the box framed by the dotted line in the right bottom corner indicates all children who would be diagnosed with dyscalculia according to a fixed cut-off score definition (ie, math test scores ≤10th percentile, IQ scores >15th percentile). The Table shows relative frequencies for both diagnosis criteria approaches according to GA groups.

### Results

With lower GA, disproportionally more children were affected by both general cognitive and mathematical impairment, as well as dyscalculia (Table). Logistic regressions showed that the risk for general cognitive and mathematic impairment incrementally increased with lower GA, after we statistically adjusted it for child sex, family SES, and SGA status. Figure 2 shows that, compared with healthy, full-term controls, very and moderately preterm children were at increased risk of both general cognitive (OR 3.86 [2.40-6.19] and OR 2.53 [1.38-4.63]) and mathematic impairment (OR 3.22 [2.03-5.11] and OR 2.18 [1.20-3.97], respectively). In contrast, there was no significantly increased risk of dyscalculia according to both the discrepancy-based and fixed cut-off score diagnosis alternatives in either of the preterm groups.

Across the whole gestation spectrum, SGA birth significantly increased the risk for a discrepancy based diagnosis of dyscalculia (OR 1.79 [1.19-2.67]) but not for a fixed cut-off score diagnosis (OR 1.17 [0.54-2.52]). There were no effects of child sex or family SES on dyscalculia.

### Discussion

With earlier GA at birth, children are at increased risk of general cognitive and mathematic impairments, and this risk is independent of SGA birth. In contrast, preterm children are not at increased risk of dyscalculia after we statistically adjusted for child sex, family SES, and SGA birth. SGA children across the whole GA range were at increased risk for a discrepancy-based dyscalculia diagnosis but not for a fixed cut-off score diagnosis.

These findings rebut suggestions that very preterm children may have specific mathematic impairments that are not explained by their general cognitive deficits. Across the whole gestation spectrum, SGA birth significantly increased the risk for a discrepancy based diagnosis of dyscalculia (OR 1.79 [1.19-2.67]) but not for a fixed cut-off score diagnosis (OR 1.17 [0.54-2.52]). There were no effects of child sex or family SES on dyscalculia.
poorly understood. Prematurity is associated with reduced brain volume, white matter microstructure, and alterations in cortical folding. However, these abnormalities in brain structure are associated with both general cognitive and specific mathematic impairments. The study of preterm and/or SGA children who are at increased risk of mathematic impairments may represent a good line of investigation to understand the effects of early aberrant brain development on mathematical abilities. For example, mathematic impairments may be due to disproportional effects of low GA on processing of more complex tasks. The cognitive processes underlying mathematic abilities may rely on fine-tuned activations and intact brain connectivity of distributed fronto-parieto-temporal brain areas. Preterm birth is associated with aberrant brain connectivity, resulting in abnormal activation patterns. Thus, future investigations should consider whether differences in preterm and/or SGA children’s brain connectivity may be associated with dyscalculia.

The data were collected as part of a prospective geographically defined whole-population study of children across the total spectrum of GA. The data set is based upon a cohort recruited in 1985-1986. Neonatal intensive care has changed since then and has resulted above all in increased survival of ever lower gestation infants. Although rates of cognitive problems have remained at similar levels, comparison and cross-validation of our findings in more contemporary cohorts is necessary.

Children are diagnosed with dyscalculia when there is a clear discrepancy between their mathematics achievement scores and expected performance based on general intelligence. In addition, mathematic skills must be well below the average range of test scores and individual difficulties must not be better explained by developmental, neurologic, sensory, or motor disorders. Depending on the operationalization of the dyscalculia definition study results may differ. Our findings compared 2 diagnostic alternatives and found that fixed definitions of dyscalculia may miss many

Figure 2. ORs (95% CI) of A, general cognitive impairment, B, general mathematic impairment, C, dyscalculia according to a discrepancy based definition, and D, dyscalculia according to a fixed cut-off score definition. Models were adjusted for child sex, family SES, and SGA birth. ET, early-term birth; LP, late preterm; MP, moderately preterm; VP, very preterm.
preterm children who do not have severe neurologic impairments or developmental disorders, but math performance well below expectations according to their IQ scores and who may need help with math.

Indeed, although preterm children were not at significantly increased risk of dyscalculia after we adjusted for confounders, relative frequencies of dyscalculia according to a fixed definition were much lower compared with a discrepancy-based definition. This difference in rates was similar in healthy term children as our discrepancy score also included children with normal math abilities if their general IQ was well above average (and their math abilities thus lower than expected). It may be argued that these cases do not qualify for a dyscalculia diagnosis; however, they may be the ones profiting most from interventions. Understanding the high-risk groups for dyscalculia is important for early identification and educational support. Specific and general mathematical deficits may be alleviated with appropriate training as has been found for dyslexia and general reading problems. As long as we are not sure which specific factors predict dyscalculia, screening of preterm as well as SGA children may be recommended during the pre- and primary school years to prevent academic failure of those children with specific needs.

The risk of general cognitive and mathematic impairments increases with lower GA. In contrast, preterm children are not at increased risk of dyscalculia after statistically adjusting for child sex, family SES, and SGA status. Our results, however, suggest that dyscalculia may have its neurodevelopmental origins in prenatal factors such as fetal growth restriction, which is often indicated by both preterm and SGA birth. Preterm and SGA children often have mathematical problems and—whether these are general or specific—they may need special help in school to not be left behind academically.

We would like to thank Wolfgang Schneider, PhD, and Samantha Johnson, PhD, for their feedback on earlier drafts of this manuscript.

Submitted for publication Jul 31, 2013; last revision received Dec 3, 2013; accepted Jan 31, 2014.

Reprint requests: Dieter Wolke, PhD, Department of Psychology and Division of Mental Health and Wellbeing Warwick Medical School, University of Warwick, Coventry CV4 7AL, UK. E-mail: D.Wolke@warwick.ac.uk

References