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ARTICLE

Gestational Age and Birth Weight in Relation to School Performance of 10-Year-Old Children: A Follow-up Study of Children Born After 32 Completed Weeks

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ABSTRACT

BACKGROUND. Children born extremely premature (<28 weeks) or with a very low birth weight (<1500 g) have a poorer school performance than children born at term with a normal birth weight. Much less is known about children of higher gestational ages and birth weights. We studied gestational age after 32 completed weeks and birth weight in relation to the child's school performance at the age of 10 years.

METHODS. We performed a follow-up study of 5319 children born between January 1990 and June 1992. We got the information on birth weight and gestational age from birth registration forms; when the children were between 9 and 11 years of age, we gathered information about their school performance (reading, spelling, and arithmetic) from questionnaires completed by the parents and the children's primary school teachers.

RESULTS. The association between birth weight and reading, as well as spelling and arithmetic disabilities, showed a graded relationship, with children who weighed <2500 g having the highest risks. Even children who weighed between 3000 and 3499 g had an increased risk of all 3 learning disabilities compared with children who weighed between 3500 and 4000 g. This association persisted after adjustment for potential cofounders and when the analyses were restricted to children born at term (39–40 weeks of gestation), suggesting that the association could not be explained by a low gestational age. Compared with children born at term, reading and spelling difficulties were more often found among children born at gestational age 33 to 36 weeks and 37 to 38 weeks, whereas there was no relation between gestational age and arithmetic difficulties.

CONCLUSIONS. Gestational age and birth weight were associated with school performance in the 10-year-old child and the association extended into the reference range of both birth weight and gestational age.

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Key Words
prematurity, low birth weight, learning disabilities

Abbreviations
IQ—intelligence quotient
OR—odds ratio
CI—confidence interval
AOR—adjusted odds ratio

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THE SURVIVAL RATES of extremely premature (<28 weeks) infants and infants with extremely low birth weight (<1000 g) are increasing. This development is expected to result in a greater number of children with brain injuries. Previous follow-up studies have mainly focused on survival rates, short-term mortality and morbidity, and the neurologic development during the first 2 years of life. Follow-up studies of premature children up to school age present higher rates of difficulties with language skills, cognitive function, visuomotor integration, and behavior than their peers delivered at term.[1–5] However, only a few studies have observed these children later on to find out whether their difficulties persisted and whether their academic proficiency was inhibited.[6–11]

Most of our colleagues have focused primarily on children born with a very low birth weight (<1500 g) or children born very premature (<32 weeks of gestation). The number of children born prematurely but closer to term or with a birth weight closer to what is defined as normal is much larger. Only a few studies have followed this group of children, most likely because they are generally considered to be at low risk of neurodevelopmental problems, because they often have an uncomplicated neonatal period and show no signs of abnormal brain function in early infancy. However, more subtle neurodevelopmental problems may not be apparent until school age, where more refined and complex skills, such as reading and writing, are required and assessed accordingly. The few available studies indicate that these children may have an increased risk of a lower school performance than children born at term and within the average birth weight range.[12–16] These studies focused, however, exclusively on the specific cognitive development of the child using cognitive tests. Such tests do not necessarily reflect the child's school performance, and it is uncertain whether the few points difference found on an intelligence quotient (IQ) scale have implications for the child. Furthermore, when birth weight was studied, gestational age was rarely considered. Thus, the effect of intrauterine growth retardation could not be disentangled from that of preterm delivery.

A recent follow-up study with questionnaire data provided by the parents and teachers of 7-year-old children born at 32–35 weeks' gestation showed that nearly one third of the children had some kind of learning difficulty.[17] However, no control group was provided, and the children were examined just after they had started school; some difficulties may have a later debut. A follow-up of the children born after 35 gestational weeks was not conducted. Similarly, a study of 9-year-old children with a birth weight of <2000 g reported that nearly one third of the children required special tutoring. There was a graded relationship between birth weight and the need for special tutoring, but no control group was provided in this study either.[18]

We aimed to evaluate the association among gestational age, birth weight, and learning disabilities in 9- to 11-year-old children, taking potential confounders into account. By including different levels of gestational age and birth weight, we could test for a graded relationship and evaluate the gestational age and birth weight close to average.

METHODS

Population

The study was based on data from the Aarhus Birth Cohort, which includes all of the deliveries at the Department of Obstetrics, Aarhus University Hospital, from 1990 to 2003. All of the singleton children of Danish-speaking women born between January 1990 and June 1992 were included in the study ($N = 7953$).

In April 2001, the parents of these children were invited to participate in a follow-up study. The parents were asked to complete a comprehensive questionnaire covering the general health and development of the child. A total of 5841 (73%) of the eligible parents participated. Permission to contact the children's teachers was given by 4940 parents (62%). In May to June 2002, the children's primary school teachers received a questionnaire concerning child behavior and performance in school. This questionnaire was completed with parental consent for 85% of the children ($N = 4250$). At the same time, the participating parents received another questionnaire about child behavior (the information derived from these questionnaires is not used in the present report).

In the present analyses, only children with complete information on gestational age, birth weight, and school performance reported by the parents were included ($N = 5776$). The adjusted analyses included only those with complete information on the confounders, which were adjusted for ($N = 5319$). Whether this reduction in the number of participants introduced selection bias was checked by applying the bivariate analyses to the entire cohort ($N = 5776$) and then to the cohort with complete information on all of the variables ($N = 5319$).

Gestational Age and Birth Weight

Information on obstetric and medical complications during pregnancy, as well as data concerning the newborn, were obtained from birth registration forms completed by the attending midwife immediately after delivery. The registration forms were manually checked by a research midwife and compared with the medical charts before data entry.

In 81% of the pregnancies, gestational age at delivery was calculated from ultrasonographically determined fetal biparietal diameter before 21 completed weeks of gestation. In women without an early ultrasound scan (10%), gestational age was estimated from a valid last menstrual period, adjusted to a cycle length of 28 days. For the remaining women, the gestational age was the one reported by the attending midwife on the birth registration form, based on an last menstrual period without knowledge of the cycle length or a later ultrasound scan.

Children born before 33 completed weeks of gestation were excluded, because the purpose of our study was to evaluate the children born in the upper range of the premature scale. Gestational age was categorized in 33 to 36, 37 to 38, 39 to 40, and ≥41 completed weeks with a gestational age of 39 to 40 weeks as the reference category.

The weight of the child was measured and registered immediately after delivery. Birth weight was categorized as <2500, 2500 to 2999, 3000 to 3499, 3500 to 3999, 4000 to 4499, and ≥4500 g, with 3500 to 3999 g as the reference category.

Learning Disabilities

The analyses were performed based on the individual information from the parents and the teachers. The parents were asked whether the child had difficulties in acquiring the 3 following skills: reading, spelling (writing words directly from dictation), and arithmetic, assessed on a 4-point scale (none, minor, some, and severe).

Furthermore, they were asked whether the child had had or was presently receiving special tuition. If this was the case, the parents were then asked to provide detailed information on the type of tuition.

A learning disability in any 1 of the 3 areas was defined as a parental report of severe disability combined with the information provided by previous or present tutors. The rest of the children, including those with some or minor difficulties, were defined as reference.

The children's teachers were then asked to compare the child with a typical child of the same age. The teachers classified the child according to whether he/she performed reading, spelling, and arithmetic: (1) some above average, (2) considerably above average, (3) on average, (4) some below average, or (5) considerably below average. They were also asked whether the child had received or was presently being specially tutored and the type of tutoring, if any. Children with serious problems, that is, those who were assessed as being considerably below average at a particular skill and who received or had received special tutoring, were classified as having a learning disability.

Potential confounders were identified from the questionnaires concerning general health and development of the child, which had been completed by the parents when the child was 9 to 11 years of age. The variables considered were parental educational level, separated parents, number of siblings and other sociodemographic factors, and gestational age in the analyses of birth weight. This information was coded as in Table 1. Data on prenatal maternal lifestyle factors (smoking, alcohol, and caffeine intake) were obtained from questionnaires completed by the mothers before the routine antenatal care visits at 16 and 30 weeks of gestation. Maternal characteristics, such as age and parity, were obtained from the birth registration forms.

Statistics

The association among gestational age, birth weight, and school performance are presented as odds ratios (ORs). ORs are presented with 95% confidence intervals (CIs). Logistic regression analyses were used to adjust for potential confounders. Potential confounders remained in the final model if they changed the point estimate of the association by >10%.[19] Potential confounders were entered as a the number of dummy variables equal to the number of categories of the variable minus 1. Similarly, the analyses of birth weight were adjusted for gestational age with the lower gestational ages categorized in 33 to 34 and 35 to 36 weeks (Table 1). We decided a priori to include parental education in all of the analyses. Interactions were evaluated by stratified analyses.

RESULTS

Among the 5319 children in our analyses, the parents reported reading difficulties in 4.6%, spelling difficulties in 4.3%, and arithmetic difficulties in 1.6%. The corresponding percentages reported by the teachers were, respectively, 4.4%, 6.8%, and 2.5%.

Table 1 shows the relation between gestational age, birth weight, and school performance and maternal characteristics, lifestyle, and socioeconomic factors. The child's gender was strongly associated with reading and spelling difficulties, with boys experiencing these problems twice as often as girls. Parental educational level, breastfeeding, and separated parents were associated with all 3 kinds of learning difficulties. Maternal age, smoking, and alcohol and caffeine intake during pregnancy were also strongly associated with school performance.

The crude and adjusted associations among gestational age, birth weight, and school performance are shown in Table 2. Children born between gestational weeks 33 and 36 had a nearly 50% increased risk of having reading difficulties compared with the children born at term (gestational age: 39–40). However, adjustment for parental education level, gender of the child, and breastfeeding reduced the association, and this association was not significant (adjusted OR [AOR]: 1.19; 95% CI: 0.61–2.34). The analyses did not support a dose response-like association, but children born at gestational age 37 to 38 completed weeks had a statistically significantly higher risk of reading difficulties compared with children born at 39 to 40 weeks, even when adjusted for the potential confounders (AOR: 1.46; 95% CI: 1.01–2.10). Children born at ≥41 completed weeks experienced in effect the same frequency of reading difficulties compared with children born after 39 to 40 weeks' gestation.

Children with a birth weight of <2500 g and 2500 to 2999 g had nearly twice the risk of reading difficulties than the children with a birth weight of 3500 to 3999 g (AOR: 1.85; 95% CI: 0.81–4.22, and AOR: 1.76; 95% CI: 1.12–2.76, respectively). The association between birth

TABLE 1 **Preterm Delivery, Low Birth Weight, and School Performance According to Potential Confounders for 5776 Pregnancies and the Children Assessed at Ages 9 to 11 Years in Aarhus, Denmark (Born in 1990–1992)**

Variable	*N*	Preterm Delivery (<37 wk)		Low Birth Weight (<2500 g)		Reading Difficulties		Spelling Difficulties		Arithmetic Difficulties	
		n	%	*n*	%	*n*	%	*n*	%	*n*	%
Gender											
Male	2940	123	4.2	89	3.1	185	6.3	176	6.0	51	1.7
Female	2836	88	3.1	79	2.7	93	3.3	90	3.2	46	1.6
Maternal age											
15–24 y	873	35	4.0	30	3.4	55	6.3	55	6.3	21	2.4
25–29 y	2418	93	3.8	67	2.8	97	4.0	98	4.1	36	1.5
≥30 y	2485	83	3.3	71	2.9	126	5.1	113	4.5	40	1.6
Parity											
Primiparous	2986	127	4.3	93	3.1	123	4.1	128	4.3	45	1.5
1 previous birth	1984	48	2.4	47	2.4	95	4.8	88	4.4	30	1.5
2 previous births	648	29	4.5	23	3.5	51	7.9	43	6.6	18	2.8
≥3 previous births	150	7	4.7	5	3.3	8	5.3	6	4.0	4	2.7
Maternal educational level											
No education	629	38	6.0	20	3.2	49	7.8	44	7.0	26	4.1
1–2 y	1518	64	4.2	53	3.5	94	6.2	87	5.7	34	2.2
≥3 y	3581	109	3.0	94	2.6	129	3.6	129	3.6	35	1.0
Paternal educational level											
No education	723	35	4.8	33	4.6	55	7.6	49	6.8	25	3.5
1–2 y	678	30	4.4	19	2.8	28	4.1	27	4.0	14	2.1
≥3 y	4143	133	3.2	104	2.5	178	4.3	172	4.2	51	1.2
Child living with both parents	4535	154	3.4	111	2.4	194	4.3	192	4.2	64	1.4
Child living with either mother or father	1210	55	4.5	56	4.6	78	6.4	68	5.6	30	2.5
Breastfeeding, mo											
0	324	39	12.0	28	8.6	25	7.7	24	7.4	13	4.0
<4	1598	62	3.9	41	2.6	96	6.0	82	5.1	38	2.4
≥4	3680	106	2.9	91	2.5	144	3.9	148	4.0	44	1.2
Maternal smoking during pregnancy, cigarettes per d											
0	3961	124	3.1	93	2.3	171	4.3	164	4.1	47	1.2
1–9	843.	36.	4.3	30.	3.6	35	4.2	33	3.9	18	2.1
≥10	842	47	5.6	43	5.1	67	8.0	63	7.5	30	3.6
Maternal alcohol intake during pregnancy, units per wk											
<1	3385	130	3.8	90	2.7	173	5.1	168	5.0	66	1.9
1–2	1514.	55.	3.6	51.	3.4	62	4.1	56	3.7	16	1.1
3–4	554	14	2.5	11	2.0	26	4.7	26	4.7	10	1.8
≥5	169	4	2.4	6	3.6	9	5.3	9	7.8	0	0
Maternal caffeine intake during pregnancy, mg/d											
<200	1207	56	4.6	30	2.5	49	4.1	50	4.1	16	1.3
200–399	1702	41	2.4	41	2.4	81	4.8	76	4.5	22	1.3
≥400	2056	77	3.7	69	3.4	111	5.4	104	5.1	43	2.1

weight and reading difficulties seemed to have a U-shaped pattern with a decreasing risk with increasing birth weight ≤3500 g and an increasing risk of having reading difficulties above this weight. Table 2 supports a similar association between gestational age and birth weight and spelling difficulties as for reading difficulties.

The difficulties with arithmetic were generally less frequently reported than reading and spelling difficulties. We found no association between gestational age and arithmetic difficulties. Children with a birth weight of <2500 g had >4 times the risk of arithmetic difficulties compared with children who weighed between 3500 and 3999 g (AOR: 4.46; 95% CI: 1.41–15.00). As was the case with reading and spelling problems, the decreasing frequency of arithmetic difficulties was seen with increasing birth weight ≤3500 g, and >3999 g, the frequency of difficulties with arithmetic increased again.

To test whether the association found between birth weight and the 3 types of learning difficulties could be explained by a low gestational age, the birth weight results, in addition to gender, breastfeeding, and parental educational level, were also adjusted for gestational age. This adjustment resulted in a minor change but could not explain the findings. Moreover, we performed a subanalysis of the association of birth weight and reading, spelling, and arithmetic difficulties for children born at term (gestational age: 39–40 weeks). It showed essentially the same association between birth weight and school performance as the results in Table 2. Thus, the association between birth weight and school perfor-

TABLE 2 **Reading, Spelling, and Arithmetic Difficulties According to Gestational Age and Birth Weight for 5319 Pregnancies and the Children Assessed at Ages 9 to 11 Years in Aarhus, Denmark (Born in 1990–1992)**

Variable	*N*	*n*	%	OR	AOR	95% CI
Reading difficulties						
Gestational age, wk[a]	5319					
33–36	169	10	5.9	1.41	1.19	0.61–2.34
37–38	633	41	6.5	1.55	1.46	1.01–2.10
39–40	3081	132	4.3	1	1	
≥41	1436	59	4.1	0.96	0.99	0.72–1.36
Birth weight, g[b]	5319					
<2500	124	9	7.3	2.03	1.85	0.81–4.22
2500–2999	519	36	6.9	1.94	1.76	1.12–2.76
3000–3499	1739	77	4.4	1.20	1.18	0.85–1.65
3500–3999	1942	72	3.7	1	1	
4000–4499	820	39	4.8	1.30	1.22	0.82–1.83
≥4500	175	9	5.1	1.41	1.27	0.62–2.61
Spelling difficulties						
Gestational age, wk[a]	5319					
33–36	169	12	7.1	1.84	1.61	0.86–3.00
37–38	633	38	6.0	1.54	1.47	1.01–2.14
39–40	3081	123	4.0	1	1	
≥41	1436	57	4.0	0.99	1.02	0.74–1.41
Birth weight, g[b]	5319					
<2500	124	10	8.1	2.49	2.15	0.96–4.79
2500–2999	519	34	6.6	1.99	1.79	1.12–2.76
3000–3499	1739	75	4.3	1.28	1.27	0.92–1.81
3500–3999	1942	66	3.4	1	1	
4000–4499	820	37	4.5	1.34	1.26	0.83–1.91
≥4500	175	8	4.6	1.36	1.22	0.57–2.60
Arithmetic difficulties						
Gestational age, wk[a]	5319					
33–36	169	4	2.4	1.24	0.95	0.34–2.69
37–38	633	10	1.6	0.82	0.71	0.36–1.41
39–40	3081	59	1.9	1	1	
≥41	1436	14	1.0	0.50	0.54	0.30–0.97
Birth weight, g[b]	5319					
<2500	124	5	4.0	4.49	4.46	1.41–15.00
2500–2999	519	13	2.5	2.75	2.46	1.15–5.26
3000–3499	1739	33	1.9	2.07	1.96	1.09–3.51
3500–3999	1942	18	0.9	1	1	
4000–4499	820	14	1.7	1.86	1.93	0.95–3.44
≥4500	175	4	2.3	2.50	2.68	0.88–8.12

[a] Gestational age OR was adjusted for gender, breastfeeding, and parental educational level.
[b] Birth weight OR was adjusted for gender, breastfeeding, parental educational level, and for gestational age.

mance could not be explained by low gestational age (results not shown). When stratified by maternal smoking, no difference in the association was found between the children of mothers who smoked during pregnancy and the children of nonsmokers (results not shown).

The results based on the information provided by the teachers showed the same direction of association as the results based on the parents' information. However, with ~1500 fewer children with information from the teachers, the results did not reach statistical significance (results not shown).

DISCUSSION

The main findings of this prospective follow-up study was that children born at gestational age 37 to 38 weeks may be at increased risk of reading and spelling disabilities compared with children born at 39 to 40 weeks of gestation. The lack of association between lower gestational ages and learning difficulties could be because of the small numbers in our study. Furthermore, birth weight was strongly associated with reading, spelling, and arithmetic difficulties. The results changed slightly after adjusting for gestational age, but the association persisted. The association between birth weight and school performance applied to birth weights <3000 g, as well as high birth weights >4500 g. Thus, the results indicate that not only gestational age but also the intrauterine growth or the pathology or biology related to the size of the child may be important for school performance.

It is possible that early exposure to the extrauterine environment, as well as restricted growth, may lead to impaired brain development, which can have implications for the child in later life. Alternative explanations for the poorer school performance could be perinatal complications after preterm delivery or intrauterine growth retardation, such as infections, or postnatal complications associated with low birth weight or prematurity, such as hypoglycemia, hyperbilirubinemia, infections, poor feeding, and brain growth failure in early childhood.[20–22] The biological basis for the association between a high birth weight and school performance may also include the increased risk of underlying diseases or birth traumas. Another possible explanation is a common cause, perhaps of genetic origin, of prematurity or low birth weight and a poor school performance.

Our results regarding birth weight and school performance are supported by recent reports. In the 1946 British cohort study, cognitive function at ages 8, 11, 15, and 26 years was found to improve with increasing birth weights of ≤3000 g to subsequently deteriorate for birth weights >3500 g. Furthermore, it was found that increasing birth weight was associated with higher educational attainment at age 26 years.[14] Breslau et al found birth weight to be associated with IQ at age 6 years and that the association extended into the range of reference birth weights.[23] Similar results were found in a sibship study of 7-year-old children, where the relation even existed between pairs of siblings of the same gender but with different birth weights. This also supports that the association we found was independent of socioeconomic factors. In a Danish study of 4300 conscripts, increasing cognitive scores were found with increasing birth weight ≤4200 g. Scores decreased slightly above birth weights of 4200 g.[15] These studies have focused on cognitive function and found differences of a few points on an IQ scale. This does not necessarily translate directly into performance in every day life, such as school performance. The studies do, however, support our findings that intellectual performance may improve with increasing birth weight until a certain optimal birth weight, and above that level, the performance may decrease. Within our a priori defined categories, an optimal birth weight is, according to our results, between 3500 and 3999 g. Our study suggests that the association between birth weight and cognitive function found in other studies also extends into impairment of school performance. This is supported by Elgen and Sommerfelt,[24] who reported that children with low birth weight had both a lower IQ and twice as many educational problems reported by their mothers, compared with children with a reference birth weight. Most previous studies failed to separate the potential effect of birth weight from that of gestational age.

To our knowledge, no previous studies have investigated the association between gestational age around term and school performance. Our results indicate that not only extreme prematurity but also children born as late as at 37 to 38 weeks may be at increased risk of learning disabilities compared with children born at 39 to 40 completed gestational weeks.

In the present study, the response rate for the parents' questionnaires was 74%, but complete information was only available for 67%. This loss to follow-up is of concern if nonparticipation is associated with both gestational age and birth weight and school performance.

From the birth registration forms, we have information about gestational age and birth weight in the nonresponding group, and from the questionnaires completed by the mothers of the children during pregnancy, we also have information on parental educational level in the nonresponding group. The nonresponders had a higher rate of preterm deliveries and low birth-weight infants than the responders. Furthermore, nonparticipating parents had a lower educational level. If selection bias is to explain our findings, the nonresponders should be families with preterm deliveries and low birth-weight infants, whose children did well in school, or the families with children born at term at a birth weight within the reference range, who had learning disabilities. We have no reason to believe that the nonresponders were selected this way, and it seems unlikely that selection bias could explain our results.

We believe that the precision and validity of data on birth weight are high. Measurement of gestational age is more difficult and may be less accurate. Because these data are collected prospectively, any misclassification of gestational age tends to be nondifferential, causing bias toward the null hypothesis.

Information bias is likely to be present if the parents' assessment of their child's learning disabilities is influenced by the birth weight or the gestational age. The present study did not focus on preterm or low birth-weight children. Thus, it seems unlikely that parents and teachers took the perinatal history into account when evaluating the child's academic performance. Furthermore, the questionnaires were designed to deal with a variety of issues other than learning disabilities. Focus was, therefore, removed from school performance. Consequently, we expect the misclassification, if present, to be nondifferential and to bias our results toward the null hypothesis.

The prospective collection of information regarding maternal lifestyle factors during pregnancy, postnatal factors, such as breastfeeding, and sociodemographic factors enabled us to adjust for a number of potential confounders. As expected, breastfeeding and parental educational level were associated with learning disabilities, and these variables changed the results a little but could not explain our findings. It is possible that other factors that we could not take into account, like nutrition during childhood or mother's psychosocial stress, could have confounded our results, but these factors often covary with the sociodemographic factors that we have adjusted for. Potential sequelae of prematurity or low birth weight that might contribute to the increased risk of learning disabilities, such as behavioral problems,[25] were not considered as potential confounders but should be seen as possible mediators of the effect of prematurity and low birth weight on learning disabilities and were not adjusted for.

In Denmark, children are not evaluated by standardized tests during the first 9 years of school. We evaluated the children by asking the teachers to compare them with a typical pupil of the same age, which may vary between settings (classes and schools). Special tutoring, however, is established if a child is not able to keep up with the required general level. These levels are, to some extent, regulated by legislations.

The absolute and relative number of surviving children is dramatically increasing with increasing gestational age. Thus, if children born at ~40 completed weeks are at increased risk of developing learning difficulties when they grow up, the impacts on public health may be extensive. From an antenatal care perspective, it also seems important to report whether a slightly reduced gestational age within the range considered to be reference leads to an increased risk of learning disabilities. More than 1 of 8 children are born at 35 to 38 completed gestational weeks. Some of these deliveries are induced and not motivated by infant or maternal safety, including some of the elective cesarian sections. These could have been scheduled at a later gestational age, if risks associated with elective early delivery were well known. However, before these findings are implemented in clinical decision-making, further research is needed to test our findings in independent populations.

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