Ultrasound Obstet Gynecol 2023; **61**: 458–465
Published online 11 March 2023 in Wiley Online Library (wileyonlinelibrary.com). **DOI:** 10.1002/uog.26160.

Birth-weight centile at term and school performance at 12 years of age: linked cohort study

R. J. BURGER[1,2], S. J. GORDIJN[3], B. W. MOL[4,5], W. GANZEVOORT[1,2] and A. C. J. RAVELLI[1,2,6]

[1]*Department of Obstetrics and Gynaecology, Amsterdam UMC location University of Amsterdam, Amsterdam, The Netherlands;* [2]*Amsterdam Reproduction and Development Research Institute, Amsterdam, The Netherlands;* [3]*Department of Obstetrics and Gynaecology, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands;* [4]*Department of Obstetrics and Gynaecology, Monash University, Clayton, Victoria, Australia;* [5]*Aberdeen Centre for Women's Health Research, Institute of Applied Health Sciences, School of Medicine, Medical Sciences and Nutrition, University of Aberdeen, King's College, Aberdeen, UK;* [6]*Department of Medical Informatics, Amsterdam UMC location University of Amsterdam, Amsterdam, The Netherlands*

KEYWORDS: birth weight; cognitive development; educational achievement; fetal growth restriction; gestational age; placental function; placental insufficiency; school performance

CONTRIBUTION

What are the novel findings of this work?
Birth-weight centile is associated positively with school performance at 12 years of age, well beyond the conventional cut-off for small-for-gestational age, with highest school performance achieved at the 81st–85th birth-weight centiles. We hypothesize that reduced placental function and associated fetal growth restriction is the central mechanism underlying this association.

What are the clinical implications of this work?
Improved tools to diagnose (subclinical) fetal growth restriction, other than fetal size, are needed to better identify fetuses and children at increased risk of adverse perinatal and long-term outcomes, and to target pre- and postnatal care more accurately.

ABSTRACT

Objective *Birth weight, fetal growth and placental function influence cognitive development. The gradient of these associations is understudied, especially among those with a birth weight considered appropriate-for-gestational age. The aim of this study was to evaluate the associations between birth-weight centile and intellectual development in term/near-term infants across the entire birth-weight spectrum, in order to provide a basis for better understanding of the long-term implications of fetal growth restriction and reduced placental function.*

Methods *This was a population-based cohort study of 266 440 liveborn singletons from uncomplicated pregnancies, delivered between 36 and 42 weeks of gestation. Perinatal data were obtained from the Dutch Perinatal Registry over the period 2003–2008 and educational data for children aged approximately 12 years were obtained from Statistics Netherlands over the period 2016–2019. Regression analyses were conducted to assess the association of birth-weight centile with school performance. The primary outcomes were mean school performance score, on a scale of 501–550, and proportion of children who reached higher secondary school level.*

Results *Mean school performance score increased gradually with increasing birth-weight centile, from 533.6 in the 1st–5th birth-weight-centile group to 536.8 in the 81st–85th birth-weight-centile group. Likewise, the proportion of children at higher secondary school level increased with birth-weight centile, from 43% to 57%. Compared with the 81st–85th birth-weight-centile group, mean school performance score and proportion of children at higher secondary school level were significantly lower in all birth-weight-centile groups below the 80th centile, after adjusting for confounding factors.*

Conclusions *Birth-weight centile is associated positively with school performance at 12 years of age across the entire birth-weight spectrum, well beyond the conventional and arbitrary cut-offs for suspected fetal growth restriction. This underlines the importance of developing better tools to diagnose fetal growth restriction*

Correspondence to: Dr R. J. Burger, Meibergdreef 9, 1105 AZ Amsterdam, The Netherlands (e-mail: r.j.burger@amsterdamumc.nl)

Accepted: 30 December 2022

and reduced placental function, and to identify those at risk for associated short- and long-term consequences.

INTRODUCTION

Birth weight is correlated strongly with postnatal outcomes, including long-term health and neurodevelopment[1–3]. The negative association between low birth weight and neurocognitive development is best established in those born preterm and small-for-gestational age (SGA) (birth weight < 10th centile)[3–6]. Among those born at term and considered appropriate-for-gestational age (AGA; birth weight between 10th and 90th centiles), however, the associations with long-term development and educational outcome are relatively unexplored, as most studies have focused on the impact of gestational age at delivery instead of birth weight[7–9].

Birth weight is a product of fetal growth and is influenced negatively by reduced placental function. This is most obvious in the case of fetal growth restriction (FGR), which refers to the fetus not reaching it biological growth potential, with reduced placental function as the main underlying mechanism[10,11]. Whilst FGR is more prevalent among SGA fetuses, reduced placental function is also present in a substantial number of term pregnancies that lead to a birth weight considered AGA[12,13]. This is reflected in the absence of a specific centile cut-off above which the effects of FGR are not felt[12,14].

In this paper, we report on the association between birth-weight centile in uncomplicated term/near-term births across the entire birth-weight spectrum and intellectual development as expressed by school performance at the age of 12 years. We hypothesized that this association extends beyond the arbitrary cut-off for SGA, similar to other adverse outcomes of reduced placental function, which would serve as a basis for better understanding of the long-term developmental implications of FGR.

METHODS

This was a population-based cohort study using linked data from The Netherlands Perinatal Registry (Perined) and Statistics Netherlands. Perinatal data were obtained through a validated linkage of three national registries: the midwifery, obstetrics and neonatology registries[15]. Perined covers approximately 96–97% of all deliveries in The Netherlands; variables in the registry are recorded by caregivers. The data are submitted annually to the national registry office, where a number of range and consistency checks are conducted[16]. Statistics Netherlands stores all data collected by the Dutch government and many public bodies. Linkage between Perined data and Statistics Netherlands' Personal Record Database at the individual level was performed by Statistics Netherlands in their secure research environment using data of the mother, date of birth and sex of the child, and the four-digit postal code, providing a unique number for the mother and the child (97% successful linkage). Based on the unique personal number for the child, other databases within the secure environment could be merged. Approval for the use of the data for this study was obtained from Perined (number 19.43) and Statistics Netherlands (project 8617). Under Dutch law, no separate ethical approval was required.

This study included all liveborn singletons delivered between 36 + 0 and 42 + 0 weeks of gestation. Since educational performance is associated strongly with ethnicity and underlying socioeconomic factors, we aimed to create a fairly homogeneous population to study the association. We restricted our analysis to children of the most common ethnic subpopulation in The Netherlands: Dutch and other Western women. We will refer henceforth to this group as white women[17]. We excluded children with congenital abnormalities and those born from a pregnancy complicated by a hypertensive disorder (HDP) or diabetes mellitus (DM), thus creating a relatively uncomplicated population. HDP was defined in compliance with contemporary international literature[18]. DM included Type-1, Type-2 and gestational DM.

The outcome of interest was school performance measured on a standardized test developed by the Central Institute of Test Development (Cito), taken at the end of primary school education[19]. The Dutch education system differs from that of many other countries in that at the end of primary school, at around 12 years of age, children are divided into four different levels of secondary education according to their intellectual ability. All children in regular primary education in The Netherlands are obliged to take a test that is recognized officially by the Dutch government in order to guide their entrance into one of the four levels of secondary education. The Cito school performance test is the most common test, taken by approximately two-thirds of all children[20]. It covers language, arithmetic/mathematics and study skills. The school performance score ranges from 501 to 550, with a mean of 535. A score of 501–536 translates into prevocational secondary school level (referred to in this paper as lower), while a score of 537 or higher translates into senior general or preuniversity secondary school level (referred to in this paper as higher). Schools are obliged to report overall scores to the national education registry; reporting of scores of individual children is voluntary. Approximately 50–60% of schools report individual scores to the national registry[20].

We used the individual education data of children aged around 12 years from the most recently available 4-year period (January 2016–December 2019) to match the cohort born between 2003 and 2008. For children who attend special schooling, a standardized school achievement test was not obligatory until 2020. Therefore, these children were not systematically included in this study.

Birth weight was divided into centiles according to the sex-stratified Hoftiezer birth-weight charts[21,22]. Gestational age was based on the crown–rump length measured during early pregnancy (dating) ultrasound assessment. In the rare case that this measurement was not available, gestational age was estimated based on the first day of the last menstrual period. Parity was categorized as nulliparous (parity 0), primiparous (parity 1) or multiparous (parity ≥ 2). Socioeconomic status (SES) or neighborhood deprivation score was based on household income, education level and unemployment level and was expressed in quintiles, whereby Quintile 1 was the most deprived and Quintile 5 the least deprived.

Statistical analysis

Data were analyzed in the microdata environment of Statistics Netherlands. Analysis was conducted with SPSS version 25 for Windows (IBM Corp., Armonk, NY, USA) and R version 3.6.2 (R Foundation for Statistical Computing Platform, Vienna, Austria). Baseline characteristics, mean school performance score and proportions of children at each level of secondary education were calculated for all birth-weight-centile groups and compared using one-way ANOVA or the chi-square test, as appropriate.

To examine the association between birth-weight centile and school performance, mean school performance score with corresponding 95% CI was calculated for each five-centile-point interval of birth weight on the Hoftiezer scale. The Hoftiezer birth-weight-centile group with the highest mean school performance score in all children was determined. This was considered the birth-weight optimum for school performance and used as reference category. Mean school performance score for each Hoftiezer birth-weight-centile group was compared with the reference group using linear regression analysis, unadjusted and adjusted for maternal age, parity, SES, fetal sex and duration of pregnancy. Similarly, we examined the proportion of children that reached higher secondary school level across the birth-weight-centile groups using logistic regression analysis.

A sensitivity analysis was conducted by excluding children born after iatrogenic start of delivery (either induction of labor or prelabor Cesarean section). A second sensitivity analysis was performed in which children born at 36–37 weeks' gestation and those with a birth weight $< 10^{th}$ centile according to their gestational age and sex were excluded. Results were considered significant when $P < 0.05$.

RESULTS

Population

School performance data were available for 451 717 children between 2016 and 2019. For 374 239 (83%) of these children, perinatal data were available between 2003 and 2008 in Perined. Of these children, 358 891 were born between 36 + 0 and 42 + 6 weeks of gestation, of whom we selected all 349 996 singletons. After exclusion of children with congenital abnormalities ($n = 5464$), those with unknown birth weight or birth-weight centile ($n = 10\,454$), those born from a pregnancy complicated by DM ($n = 2955$) or HDP ($n = 18\,517$) and those with non-white mothers ($n = 46\,116$), 266 440 children born between 36 + 0 and 42 + 0 weeks remained for analysis (Figure S1).

Table S1 compares characteristics of the linked and non-linked groups. Children with school performance data who were not documented in the perinatal registry, likely because they were born before 2003, after 2008 or outside The Netherlands, had a lower mean school performance score compared to children with linked perinatal and educational data (533.8 *vs* 535.4; $P < 0.001$). Perinatal characteristics of children without education data available between 2016 and 2019, largely because they attended schools that used a different performance test, were comparable in absolute terms to those of linked children, even though associated *P*-values were significant, likely because of large sample size.

The characteristics of the linked study population by birth-weight-centile group are summarized in Table 1. Women with an infant $\leq 3^{rd}$ birth-weight centile were slightly younger (mean, 30.5 years) compared to those with an infant $> 90^{th}$ birth-weight centile (mean, 31.8 years). First-born children more often had a birth-weight centile below average compared with second- or later-born children. With increasing birth-weight centile, the proportion of first-borns decreased (64% among those with birth weight $\leq 3^{rd}$ centile *vs* 28% among those with a birth weight $> 90^{th}$ centile). Iatrogenic start of delivery was more frequent among those with a birth weight $\leq 3^{rd}$ centile (25%) or $> 90^{th}$ centile (19%), compared to those with a birth weight between the 4^{th} and 90^{th} centiles (12–14%). The proportion of children born in a more favorable socioeconomic situation increased with increasing birth-weight centile. Mean gestational age at delivery was 39 + 6 weeks and this was similar across all birth-weight-centile groups.

School performance score according to birth weight

On the scale of 501–550, the mean ± SD school performance score for all children in the linked population was 536.0 ± 9.6 (Table 1). Figure 1 shows the distribution of school performance score by birth-weight centile, grouped into five-point intervals. Mean school performance score was lowest for the 1^{st}–5^{th} centile group (533.6) and increased gradually up to the 81^{st}–85^{th} centile group, at which the highest score was recorded (536.8). The 81^{st}–85^{th} centile group was considered the optimal birth weight for school performance and was used as reference category in subsequent analyses. When adjusted for maternal age, parity, SES, fetal sex and duration of pregnancy, mean school performance score was significantly lower in all birth-weight groups between the 1^{st} and 80^{th} centiles ($P < 0.001$–0.02) compared with the optimum birth weight for school performance (Figure 2, Table S2). On adjusted analysis, children in

Table 1 Pregnancy and school performance characteristics of 266 440 cases in linked study population, according to sex-stratified birth-weight centile

	Birth-weight centile								
Characteristic	*1–3* (n = *8494*)	*4–10* (n = *17 164*)	*11–25* (n = *36 789*)	*26–50* (n = *63 387*)	*51–75* (n = *66 188*)	*76–90* (n = *42 421*)	*91–100* (n = *31 997*)	*Total* (n = *266 440*)	P*
Pregnancy characteristics									
Maternal age (years)	30.5 ± 5.1	30.6 ± 4.8	30.7 ± 4.7	30.9 ± 4.6	31.1 ± 4.5	31.4 ± 4.3	31.8 ± 4.3	31.1 ± 4.5	< 0.001
Parity									< 0.001
Nulliparous	5435 (64.0)	10 186 (59.3)	19 966 (54.3)	30 558 (48.2)	27 540 (41.6)	15 124 (35.7)	8875 (27.7)	117 684 (44.2)	
Primiparous	2222 (26.2)	4988 (29.1)	12 256 (33.3)	23 460 (37.0)	27 053 (40.9)	18 527 (43.7)	15 165 (47.4)	103 671 (38.9)	
Multiparous	837 (9.9)	1990 (11.6)	4567 (12.4)	9369 (14.8)	11 595 (17.5)	8770 (20.7)	7957 (24.9)	45 085 (16.9)	
Iatrogenic start of delivery	2080 (24.5)	2418 (14.1)	4636 (12.6)	7736 (12.2)	8581 (13.0)	5963 (14.1)	5949 (18.6)	37 363 (14.0)	< 0.001
Socioeconomic status									< 0.001
Quintile 1 (most deprived)	1460 (17.2)	2620 (15.3)	5011 (13.6)	7945 (12.5)	7703 (11.6)	4736 (11.2)	3528 (11.0)	33 003 (12.4)	
Quintile 2	1722 (20.3)	3374 (19.7)	6955 (18.9)	11 832 (18.7)	12 278 (18.6)	7689 (18.1)	5896 (18.4)	49 746 (18.7)	
Quintile 3	1914 (22.5)	3800 (22.1)	8270 (22.5)	14 258 (22.5)	15 110 (22.8)	9901 (23.3)	7485 (23.4)	60 738 (22.8)	
Quintile 4	1763 (20.8)	3771 (22.0)	8210 (22.3)	14 356 (22.6)	15 110 (22.8)	9876 (23.3)	7427 (23.2)	60 513 (22.7)	
Quintile 5 (most affluent)	1635 (19.2)	3599 (21.0)	8343 (22.7)	14 996 (23.7)	15 987 (24.2)	10 219 (24.1)	7661 (23.9)	62 440 (23.4)	
Male sex	4041 (47.6)	8359 (48.7)	18 008 (48.9)	31 599 (49.9)	33 188 (50.1)	21 287 (50.2)	16 143 (50.5)	132 625 (49.8)	< 0.001
Birth weight (g)	2553 ± 279	2892 ± 215	3124 ± 222	3375 ± 235	3637 ± 249	3903 ± 258	4293 ± 336	3542 ± 495	< 0.001
GA at delivery (weeks)	39 + 5 ± 1 + 3	40 + 0 ± 1 + 2	40 + 0 ± 1 + 2	40 + 0 ± 1 + 2	39 + 6 ± 1 + 2	39 + 6 ± 1 + 2	39 + 6 ± 1 + 2	39 + 6 ± 1 + 2	< 0.001
School performance characteristics									
School performance score	533.2 ± 10.3	534.6 ± 10.1	535.5 ± 9.8	536.0 ± 9.6	536.4 ± 9.4	536.6 ± 9.5	536.7 ± 9.4	536.0 ± 9.6	< 0.001
Secondary school level									< 0.001
Lower	4985 (58.7)	8982 (52.3)	18 162 (49.4)	29 770 (47.0)	29 939 (45.2)	18 700 (44.1)	14 065 (44.0)	124 603 (46.8)	
Higher	3509 (41.3)	8182 (47.7)	18 627 (50.6)	33 617 (53.0)	36 249 (54.8)	23 721 (55.9)	17 932 (56.0)	141 837 (53.2)	
Senior general	2259 (26.6)	5088 (29.6)	11 396 (31.0)	20 210 (31.9)	21 629 (32.7)	14 032 (33.1)	10 504 (32.8)	85 118 (31.9)	
Preuniversity	1250 (14.7)	3094 (18.0)	7231 (19.7)	13 407 (21.2)	14 620 (22.1)	9689 (22.8)	7428 (23.2)	56 719 (21.3)	

Data are given as mean ± SD or *n* (%). *Calculated using one-way ANOVA or chi-square test, as appropriate. GA, gestational age.

the 16th–20th and 26th–30th birth-weight-centile groups scored −1.3 (95% CI, −1.6 to −1.1) and −1.2 (95% CI, −1.4 to −1.0) lower, respectively, on the standardized school performance test compared with those in the 81st–85th birth-weight-centile group. Mean school performance score was not significantly different from the optimum in the birth-weight groups between the 86th and 100th centiles ($P = 0.15–0.95$). Stratification by duration of pregnancy in weeks revealed similar trends, with higher mean school performance scores across the entire birth-weight range for each incremental increase in duration of pregnancy (Figure 3). Children born at 41 weeks had on average the highest mean school performance scores across the birth-weight range. Sensitivity analyses showed very similar results (Table S3).

Secondary school level according to birth weight

In the whole population, 53% reached higher secondary school level (Table 1). The proportion of children reaching higher secondary school level increased with increasing birth-weight centile (Figure 4). Among the children born with a birth weight ≤ 5th centile, 43% qualified for the higher level, compared with 57% of those in the 81st–85th birth-weight-centile group. Logistic regression analysis, both crude and adjusted for maternal age, parity, SES, fetal sex and duration of pregnancy, showed significantly reduced rates of higher secondary school level attainment in all birth-weight groups between the 1st and 80th centiles (adjusted odds ratio, 0.55–0.92; all $P < 0.01$) compared with the 81st–85th birth-weight-centile group (Figure 2, Table S4). Sensitivity analyses showed very similar results (Tables S5 and S6).

DISCUSSION

Principal findings

Birth-weight centile is associated significantly with school performance well beyond the arbitrary cut-off for SGA. The 81st–85th birth-weight-centile group showed the highest school performance, with all lower birth-weight groups scoring significantly lower on the standardized school performance test. Our analysis showed a difference of 25% in the proportion of children reaching higher secondary school level between term births across the birth-weight spectrum.

Strengths and limitations

This study used data from the large, well-maintained, population-based national perinatal registry, combined with national data on school performance. The sample

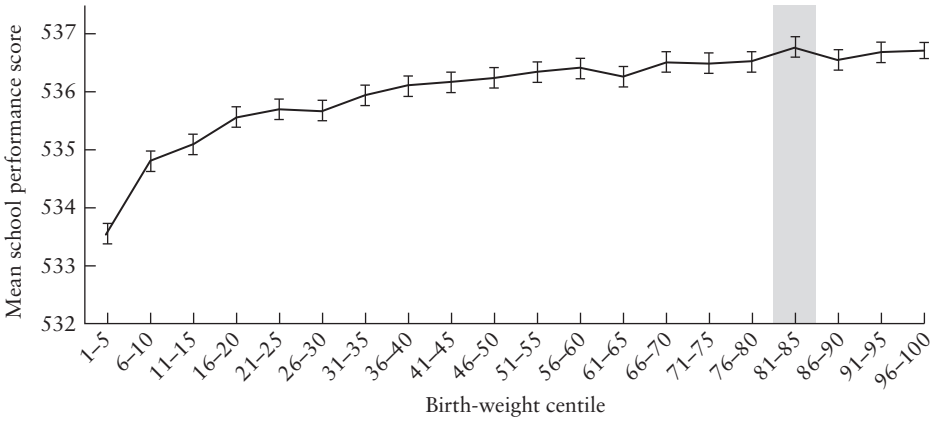

Figure 1 Mean (95% CI) school performance score at 12 years of age according to birth-weight centile in 266 440 liveborn singletons delivered between 36 and 42 weeks of gestation. Shaded region indicates birth-weight-centile group with highest mean score.

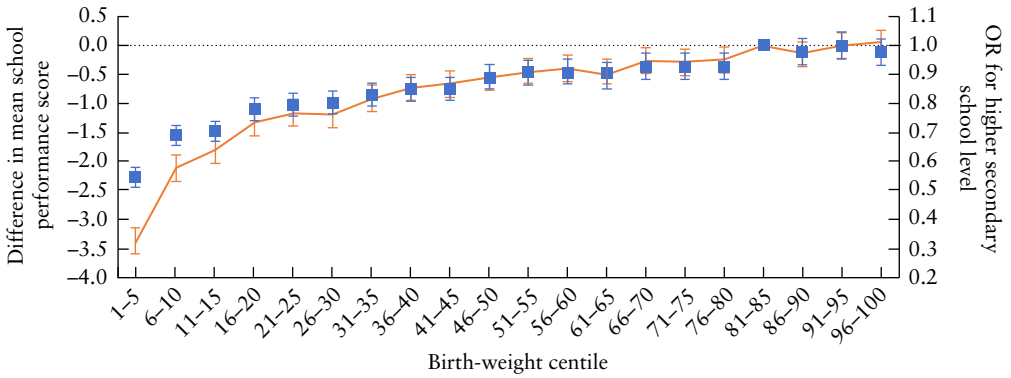

Figure 2 Difference (with 95% CI) in mean school performance score (—) and odds ratio (OR) for proportion of children at higher secondary school level (■) at 12 years of age in each birth-weight-centile group compared with the 81st–85th centile group, adjusted for maternal age, parity, fetal sex, duration of pregnancy and socioeconomic status.

size is large and we selected a fairly homogeneous group of women. This study is unique in its approach, as we examined school performance across the entire spectrum of birth weight and in relation to duration of pregnancy among term/near-term pregnancies. Collection of data on intellectual development was independent of perinatal history. We used robust statistical methods to test the observed differences and to correct for obvious confounders, such as maternal age, parity and SES.

We identified a number of limitations. First, our findings are associations and do not imply necessarily causality. However, we corrected for alternative explanations of educational outcome by adjusting for demographic and familial factors, and excluded maternal ethnicity and disease as sources of variation in birth weight and educational performance from our sample[23]. Second, our analyses depended on the availability of individual school performance scores at the end of primary school. Thus, children that needed special education because they did not meet the cognitive or behavioral requirements for entering or completing routine primary school were not all accounted for in our analysis[24]. It is likely that the exclusion of children who did not meet the requirements for regular primary schooling resulted in more conservative rather than exaggerated estimates of the effect of birth weight on school performance, as low birth weight is associated with increased risk of cognitive or behavioral problems[3]. Also, as schools are not obliged to report individual scores, we cannot rule out a possible selection bias and an underestimation of the true effect size[20]. Third, no data were available regarding placental function, such as Doppler vascular resistance measurements or sequential ultrasound measurements, limiting our ability to support our theory of reduced placental function with physiological evidence. Finally, no information was available in the perinatal registry on maternal smoking, height or body mass index, which are associated with birth weight and gestational age at delivery. This may have left some residual confounding.

Comparison with literature

Our findings are consistent with those of previous studies that showed that a birth weight below the 10th centile

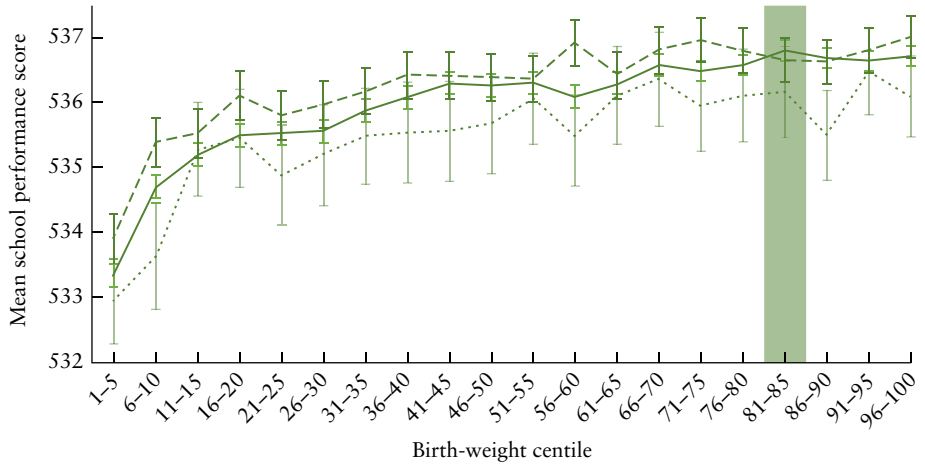

Figure 3 Mean (95% CI) school performance score at 12 years of age according to birth-weight centile in 266 440 liveborn singletons, according to duration of pregnancy in weeks: 37 weeks (·····), 39 weeks (——) or 41 weeks (– – –). Shaded region indicates birth-weight-centile group with highest mean score.

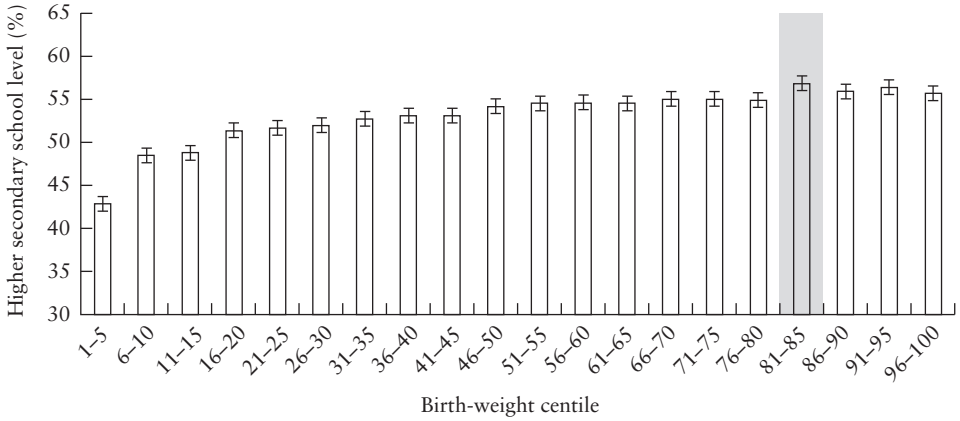

Figure 4 Proportion (with 95% CI) of children at higher secondary school level at 12 years of age according to birth-weight centile in 266 440 liveborn singletons delivered between 36 and 42 weeks of gestation. Shaded region indicates birth-weight-centile group with highest proportion.

is associated with lower school performance[4,6,25,26]. Moreover, they corroborate the study by Murthy *et al.*[4], which found that a birth weight up to the 25th centile is associated significantly with lower school test scores and a higher likelihood of disability classification in school, in those born between 23 and 41 weeks' gestation. A Swedish study reported similar results in a term population and concluded that not only children born with moderate-to-severe SGA, but also those born with mild SGA (corresponding to birth weight between the 2.3rd and 15.9th centiles), are at an increased risk of performing poorly in compulsory school[6]. In contrast with the published literature, we found that the association between birth weight and school performance continues throughout the entire birth-weight spectrum, and that those classified as AGA, with birth weights up to the 76th–80th centiles, are still at increased risk for lower school performance. Our results confirm the finding of a smaller Australian cohort study that a quadratic association exists between birth-weight centile and reading and numeracy scores, with the highest score achieved at the 66th centile[23].

Interpretation

We hypothesize that placental function, in determining the ability of a fetus to reach its growth and developmental potential, is the central mechanism underlying the progressively positive association of birth-weight centile with school performance, up to the 81st–85th centiles[12]. Reduced placental function and subsequent (subclinical) FGR are most prevalent among the lowest birth-weight centiles, but also exist among those with a birth weight considered AGA, with a distribution across birth-weight centiles similar to that reported in the present study for educational performance[12,14]. This is explained by the fact that in late pregnancy, the interval between the development of metabolic insufficiency and respiratory insufficiency is typically short, leading to a fetal size within the normal range when fetal hypoxia occurs[11].

This study shows that those children with a birth weight at the lowest end of the spectrum have considerably poorer educational performance compared to those with an above-average birth weight. Among children with birth weights considered AGA but below the optimum identified in this study, differences in educational performance are relatively small for the individual child and effect size might seem negligible. However, on a population level, the 3–14% difference in the proportion of children at higher secondary school level between those at different birth-weight centiles among children with a birth weight considered AGA is considerable, with potential social and economic impacts. Additionally, following this hypothesis of placental function as the underlying factor, a child with a birth weight considered AGA, but suffering from reduced placental function, might be at a similar level of risk for decreased school performance as a child with a birth weight below the 3rd centile. On a population level, these risks are obscured by the decreasing prevalence of reduced placental function with increasing birth-weight centile. This underlines the importance of not relying solely on birth-weight centile to estimate perinatal and long-term risks and to target pre- and postnatal management[11]. Functional markers of placental performance, including Doppler vascular resistance measurements and biomarkers, or methods that estimate individual growth potential, could be useful in detecting fetuses at risk for short- and long-term consequences, but further evidence, including from intervention studies, is needed[27,28].

In conclusion, in a large cohort of term/near-term infants, we found that birth-weight centile is associated positively with school performance across the entire birth-weight spectrum, with an optimum at the 81st–85th centiles. This highlights the importance of fetal growth and placental function across the birth-weight spectrum and calls for better tools to identify those with reduced placental function at all birth-weight centiles.

DISCLOSURES

B.W.M. is supported by a NHMRC Investigator grant (GNT1176437), reports consultancy for ObsEva and has received research funding from Ferring and Merck. W.G. and S.J.G. report holding government funding (ZonMw 843002825 and ZonMw 852002034, respectively) and free-of-charge test kits from Roche Diagnostics.

REFERENCES

1. Malin GL, Morris RK, Riley R, Teune MJ, Khan KS. When is birthweight at term abnormally low? A systematic review and meta-analysis of the association and predictive ability of current birthweight standards for neonatal outcomes. *BJOG* 2014; **121**: 515–526.
2. McCowan LM, Figueras F, Anderson NH. Evidence-based national guidelines for the management of suspected fetal growth restriction: comparison, consensus, and controversy. *Am J Obstet Gynecol* 2018; **218**: S855–868.
3. Pinto-Martin J, Whitaker A, Feldman J, Cnaan A, Zhao H, Bloch JR, McCulloch D, Paneth N. Special education services and school performance in a regional cohort of low-birthweight infants at age nine. *Paediatr Perinat Epidemiol* 2004; **18**: 120–129.
4. Murthy K, Karbownik K, Garfield CF, Falciglia GH, Roth J, Figlio DN. Small-for-gestational age birth confers similar educational performance through middle school. *J Pediatr* 2019; **212**: 159–165.e7.
5. Abel K, Heuvelman H, Wicks S, Rai D, Emsley R, Gardner R, Dalman C. Gestational age at birth and academic performance: population-based cohort study. *Int J Epidemiol* 2017; **46**: 324–335.
6. Lindström L, Wikström AK, Bergman E, Lundgren M. Born small for gestational age and poor school performance - how small is too small? *Horm Res Paediatr* 2017; **88**: 215–223.
7. Strauss RS. Adult functional outcome of those born small for gestational age: twenty-six-year follow-up of the 1970 British Birth Cohort. *JAMA* 2000; **283**: 625–632.
8. Noble KG, Fifer WP, Rauh VA, Nomura Y, Andrews HF. Academic achievement varies with gestational age among children born at term. *Pediatrics* 2012; **130**: e257–264.
9. Figlio DN, Guryan J, Karbownik K, Roth J. Long-term cognitive and health outcomes of school-aged children who were born late-term vs full-term. *JAMA Pediatr* 2016; **170**: 758–764.
10. Gordijn SJ, Beune IM, Thilaganathan B, Papageorghiou A, Baschat AA, Baker PN, Silver RM, Wynia K, Ganzevoort W. Consensus definition of fetal growth restriction: a Delphi procedure. *Ultrasound Obstet Gynecol* 2016; **48**: 333–339.
11. Thilaganathan B. Ultrasound fetal weight estimation at term may do more harm than good. *Ultrasound Obstet Gynecol* 2018; **52**: 5–8.
12. Damhuis SE, Ganzevoort W, Gordijn SJ. Abnormal fetal growth: small for gestational age, fetal growth restriction, large for gestational age: definitions and epidemiology. *Obstet Gynecol Clin North Am* 2021; **48**: 267–279.
13. Ashoor G, Syngelaki A, Papastefanou I, Nicolaides KH, Akolekar R. Development and validation of model for prediction of placental dysfunction-related stillbirth from maternal factors, fetal weight and uterine artery Doppler at mid-gestation. *Ultrasound Obstet Gynecol* 2022; **59**: 61–68.
14. Ganzevoort W, Thilaganathan B, Baschat A, Gordijn SJ. Point. *Am J Obstet Gynecol* 2019; **220**: 74–82.
15. Méray N, Reitsma JB, Ravelli AC, Bonsel GJ. Probabilistic record linkage is a valid and transparent tool to combine databases without a patient identification number. *J Clin Epidemiol* 2007; **60**: 883–891.

16. Tromp M, Eskes M, Reitsma JB, Erwich JJ, Brouwers HA, Rijninks-van Driel GC, Bonsel GJ, Ravelli AC. Regional perinatal mortality differences in Tthe Netherlands; care is the question. *BMC Public Health* 2009; **9**: 102.
17. Ravelli AC, Tromp M, Eskes M, Droog JC, van der Post JA, Jager KJ, Mol BW, Reitsma JB. Ethnic differences in stillbirth and early neonatal mortality in The Netherlands. *J Epidemiol Community Health* 2011; **65**: 696–701.
18. Brown MA, Magee LA, Kenny LC, Karumanchi SA, McCarthy FP, Saito S, Hall DR, Warren CE, Adoyi G, Ishaku S. Hypertensive disorders of pregnancy: ISSHP classification, diagnosis, and management recommendations for international practice. *Hypertension* 2018; **72**: 24–43.
19. Ruijsbroek A, Wijga AH, Gehring U, Kerkhof M, Droomers M. School performance: a matter of health or socio-economic background? Findings from the PIAMA birth cohort study. *PLoS One* 2015; **10**: e0134780.
20. van der Straaten TFK, Briaire JJ, Dirks E, Soede W, Rieffe C, Frijns JHM. The school career of children with hearing loss in different primary educational settings-a large longitudinal nationwide study. *J Deaf Stud Deaf Educ* 2021; **26**: 405–416.
21. Hoftiezer L, Hukkelhoven CW, Hogeveen M, Straatman HM, van Lingen RA. Defining small-for-gestational-age: prescriptive versus descriptive birthweight standards. *Eur J Pediatr* 2016; **175**: 1047–1057.
22. Hoftiezer L, Hof MHP, Dijs-Elsinga J, Hogeveen M, Hukkelhoven C, van Lingen RA. From population reference to national standard: new and improved birthweight charts. *Am J Obstet Gynecol* 2019; **220**: 383.e1–17.
23. McEwen EC, Guthridge SL, He VY, McKenzie JW, Boulton TJ, Smith R. What birthweight percentile is associated with optimal perinatal mortality and childhood education outcomes? *Am J Obstet Gynecol* 2018; **218**: S712–724.
24. Ministry of Education Culture and Science. Development of the number of children in primary education [in Dutch] 2020 [21-06-2021]. Available from: https://www.onderwijsincijfers.nl/kengetallen/po/leerlingen-po/aantallen-ontwikkeling-aantal-leerlingen.
25. Yu B, Garcy AM. A longitudinal study of cognitive and educational outcomes of those born small for gestational age. *Acta Paediatr* 2018; **107**: 86–94.
26. Larroque B, Bertrais S, Czernichow P, Léger J. School difficulties in 20-year-olds who were born small for gestational age at term in a regional cohort study. *Pediatrics* 2001; **108**: 111–115.
27. Deter RL, Lee W, Yeo L, Erez O, Ramamurthy U, Naik M, Romero R. Individualized growth assessment: conceptual framework and practical implementation for the evaluation of fetal growth and neonatal growth outcome. *Am J Obstet Gynecol* 2018; **218**: S656–678.
28. Melamed N, Baschat A, Yinon Y, Athanasiadis A, Mecacci F, Figueras F, Berghella V, Nazareth A, Tahlak M, McIntyre HD, Da Silva Costa F, Kihara AB, Hadar E, McAuliffe F, Hanson M, Ma RC, Gooden R, Sheiner E, Kapur A, Divakar H, Ayres-de-Campos D, Hiersch L, Poon LC, Kingdom J, Romero R, Hod M. FIGO (international Federation of Gynecology and obstetrics) initiative on fetal growth: best practice advice for screening, diagnosis, and management of fetal growth restriction. *Int J Gynaecol Obstet* 2021; **152** Suppl 1: 3–57.

SUPPORTING INFORMATION ON THE INTERNET

The following supporting information may be found in the online version of this article:

Figure S1 Flowchart summarizing inclusion in the linked study population.

Table S1 Pregnancy and school performance characteristics of children in the perinatal registry in 2003–2008 with a Cito school performance score in 2016–2019 (linked population), children in the perinatal registry in 2003–2008 without a Cito school performance score in 2016–2019 (non-linked Group A) and children with a Cito school performance score in 2016–2019 not documented in the perinatal registry in 2003–2008 (non-linked Group B)

Table S2 Crude and adjusted linear regression analysis of association between birth-weight centile and mean school performance score at 12 years of age, in 266 440 liveborn singletons delivered between 36 and 42 weeks of gestation

Table S3 Crude and adjusted linear regression analysis of association between birth-weight centile and mean school performance score at 12 years of age, excluding children born after iatrogenic start of delivery (sensitivity analysis 1), or excluding children born at 36–37 weeks and those with a birth weight $\leq 10^{th}$ centile (sensitivity analysis 2)

Table S4 Crude and adjusted logistic regression analysis of association between birth-weight centile and proportion of children at higher secondary school level at 12 years of age, in 266 440 liveborn singletons delivered between 36 and 42 weeks of gestation

Table S5 Crude and adjusted logistic regression analysis of association between birth-weight centile and proportion of children at higher secondary school level at 12 years of age, excluding children born after iatrogenic start of delivery (sensitivity analysis 1), or excluding children born at 36–37 weeks and those with a birth weight $\leq 10^{th}$ centile (sensitivity analysis 2)

Table S6 School performance characteristics of the linked study population, excluding children born after iatrogenic start of delivery (sensitivity analysis 1), or excluding children born at 36–37 weeks and those with a birth weight $\leq 10^{th}$ centile (sensitivity analysis 2)