Decline in the negative association between low birth weight and cognitive ability

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Low birth weight predicts compromised cognitive ability. We used data from the 1958 National Child Development Study (NCDS), the 1970 British Cohort Study (BCS), and the 2000–2002 Millennium Cohort Study (MCS) to analyze how this association has changed over time. Birth weight was divided into two categories, <2,500 g (low) and 2,500–4,500 g (normal) and verbal cognitive ability was measured at the age of 10 or 11 y. A range of maternal and family characteristics collected at or soon after the time of birth were considered. Linear regression was used to analyze the association between birth weight and cognitive ability in a baseline model and in a model that adjusted for family characteristics. The standardized difference (SD) in cognitive scores between low-birth-weight and normal-birth-weight children was large in the NCDS [−0.37 SD, 95% confidence interval (CI): −0.46, −0.27] and in the BCS (−0.34, 95% CI: −0.43, −0.25) cohorts, and it was more than halved for children born in the MCS cohort (−0.14, 95% CI: −0.22, −0.06). The adjustment for family characteristics did not explain the cross-cohort differences. The results show that the association between low birth weight and decreased cognitive ability has declined between the 1950s and 1970s birth cohorts and the 2000–2002 birth cohort, despite a higher proportion of the low-birth-weight babies having a very low birth weight (<1,500 g) in the more recent birth cohort. Advancements in obstetric and neonatal care may have attenuated the negative consequences associated with being born small.

low birth weight | cognitive development | children | cross-cohort | United Kingdom

Birth weight is one of the most important birth outcomes because it is strongly associated with infant mortality (1), and it is a predictor of social and health outcomes in childhood and adulthood (2–4). Many studies have shown that children who have a reduced weight at birth, and especially children who are classified as having a low birth weight (less than 2.5 kg), have worse outcomes than children whose birth weight is in the normal range (2.5–4.5 kg).

One of the outcomes that have been linked with low birth weight is cognitive ability (5). Low weight at birth is negatively associated with cognitive ability, even after family characteristics are taken into account (6). Recent studies have shown that childhood cognitive ability scores are associated with various important outcomes in adulthood, such as educational attainment (7, 8), occupational prestige (9), and long-term sickness (10).

A limitation of the existing literature is that some of these studies examined cohorts that were born more than half a century ago (5, 11). Some studies that have analyzed the association between birth weight and cognitive ability in the 1990s–2000s birth cohorts have found significant associations (5, 12), but there are no studies that would have analyzed whether the association between birth weight and cognitive ability has changed over time. Given the advances in neonatology and obstetric practice (13), we hypothesize that the association between low birth weight and cognitive ability has declined over time.

We use three large and representative UK birth cohort studies to analyze changes in the association between low birth weight and cognitive development: the 1958 National Child Development Study (NCDS), the 1970 British Cohort Study (BCS), and the 2000–2002 Millennium Cohort Study (MCS). The negative association between low birth weight and cognitive ability was large in the 1958 and 1970 birth cohorts, but has more than halved for the cohort born around the year 2001. The adjustment for family characteristics did not explain the cross-cohort differences. We comment on how advancements in obstetric and neonatal care may have attenuated the negative consequences associated with being born small.

Results

Table 1 shows the descriptive associations, which indicate that there were striking cohort differences in mean cognitive scores by birth weight categories. In the earlier cohorts, the association between low birth weight and decreased cognitive ability was much stronger than in the most recent birth cohort. In the 1958 cohort study, the cognitive ability of children with a low birth weight was 0.32 SD lower than the cognitive ability of children with a normal birth weight [95% confidence interval (CI): −0.41, −0.22]. In the 1970 birth cohort, the difference was 0.29 SD (95% CI: −0.39, −0.19), and in the 2001 MCS, the difference was 0.12 SD (95% CI: −0.22, −0.03).

Table 2 shows the regression results for birth weight and cognitive ability, and Fig. 1 displays the key results. Tables S1–S3 show the regression results for the other variables included in the models. The baseline model in Table 2 indicates that in all three birth cohort studies, low-birth-weight children had significantly

Significance

Many studies have shown that children with a low birth weight (less than 2.5 kg) have worse cognitive ability than children with a normal birth weight. No existing study has analyzed whether, given the advances in neonatology and obstetric practice that have occurred over the past 50 years in developed contexts, the association between low birth weight and cognitive ability has changed over time. Using data from the 1958 National Child Development Study, the 1970 British Cohort Study, and the 2000–2002 Millennium Cohort Study, we show that the association between low birth weight and decreased cognitive ability has been more than halved between the 1958 and 1970 birth cohorts and the cohort born around the year 2001.

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Table 1. Cohort member (CM) cognitive ability mean z-scores (with 95% CIs) by birth weight categories and birth cohort

	CM birth weight		
Verbal cognitive ability mean z-score, % of observations and no. of obervations, by birth cohort	Below 2,500 g	2,500–4,500 g	Average
NCDS 1958 CM cognitive ability at age of 11 y	−0.32 (−0.41 to −0.22)	0.01 (−0.01 to 0.03)	0.00
Observations, %	4.41	95.59	
Test for difference (*P* value reported)	0.000	Reference	
No. of observations	456	9,885	10,341
BCS 1970 CM cognitive ability at age of 10 y	−0.29 (−0.39 to −0.19)	0.02 (−0.01 to 0.04)	0.00
Observations, %	5.06	94.94	
Test for difference (*P* value reported)	0.000	Reference	
No. of observations	461	8,655	9,116
MCS 2001 CM cognitive ability at age of 11 y			
Observations, %	−0.12(−0.22 to −0.03)	0.01 (−0.04 to 0.06)	0.00
Test for difference (*P* value reported)	0.001	Reference	
No. of observations	663	10,550	11,213

Results for the MCS are weighted to account for its complex survey design.

lower cognitive scores than normal-birth-weight children, after accounting for sex and for whether the cohort member was the first-born child. However, as in the descriptive results, there were marked differences across cohorts, which suggests there was a secular decline in the negative association between low birth weight and cognitive ability. The disparity in the mean cognitive scores between low-birth-weight and normal-birth-weight children was similar and more marked for children born in 1958 (−0.37, 95% CI: −0.46, −0.27) and 1970 (−0.34, 95% CI: −0.43, −0.25), but more than half smaller for children born in 2001 (−0.14, 95% CI: −0.22, −0.06). The CIs of the 1958 and 1970 coefficients were not overlapping with the CIs of the 2001 cohort study.

Adjustments for the mother's and family's characteristics attenuated the association between low birth weight and cognitive scores in all of the cohort studies to a similar extent; however, importantly, the differences across cohorts remained (model 1 in Table 2). The differences were attenuated by 24% in the 1958 cohort study, by 41% in the 1970 cohort study, and by 43% in the 2001 cohort study. Adjustments for additional controls in the 2001 cohort did not change the results (model 2 in Table 2). After these adjustments, the differences between the CIs of the 1958 and 2001 cohort studies' coefficients were still not overlapping.

The pooled results (Table 3) for the baseline model show that the differences in the association between low birth weight and cognitive development were statistically significant at the 1% level between the 2001 and 1958/1970 cohort studies. After the adjustments for the mother's and family's characteristics, the differences between the 2001 and 1958 cohort studies remained significant at the 1% level.

There were similarities across cohorts in the characteristics of families by birth weight categories (Table S4). Across all three cohort studies and compared with normal-birth-weight children, low-birth-weight children were more likely to have come from more disadvantaged families and from families in which the mother had poor health behaviors during pregnancy and did not breastfeed. Low-birth-weight children were more likely to have been a first-born child, and a girl (Table 4).

Table 4 shows that the percentage of very-low-birth-weight children (VLBW; <1,500 g), who have the worst outcomes at birth and later in life (2, 14), increased across cohorts. In Table S5, we replicated the analyses by dividing the low-birth-weight group into VLBW (<1,500 g) and moderately low birth weight (MLBW; 1,500 to <2,500 g). The results show a picture consistent with the main results. Although the results were not statistically significant, the magnitude of the association between being born with a VLBW (vs. normal birth weight) and cognitive ability

Table 2. Ordinary least squares model results (with 95% CIs) of CM cognitive ability on birth weight categories by birth cohort

	NCDS 1958	BCS 1970	MCS 2001
Model specifications	Birth weight: Below 2,500 g	Birth weight: Below 2,500 g	Birth weight: Below 2,500 g
Baseline model*	−0.37 (−0.46 to −0.27)	−0.34 (−0.43 to −0.25)	−0.14 (−0.22 to −0.06)
Model 1: Baseline model + family characteristics†	−0.28 (−0.37 to −0.19)	−0.20 (−0.29 to −0.11)	−0.08 (−0.16 to 0.00)
Model 2: Model 1 + additional family characteristics‡			−0.08 (−0.16 to 0.00)
No. of observations	10,341	9,116	11,213

Reference category: birth weight 2,500–4,500 g.

*Adjustment made for CM sex and first birth.

†Adjustment made for CM sex, first birth, maternal age at CM birth, mother's education, family social class, marital status at the time of birth, whether the mother smoked during pregnancy, mother's height, whether the mother used antenatal care after 12 wk of pregnancy, and whether the mother breastfed the CM.

‡Just for the MCS, in addition to all of the other control variables, we adjusted for household income, whether the mother drank during pregnancy, and the mother's ethnic group. Results for the MCS are weighted to account for its complex survey design.

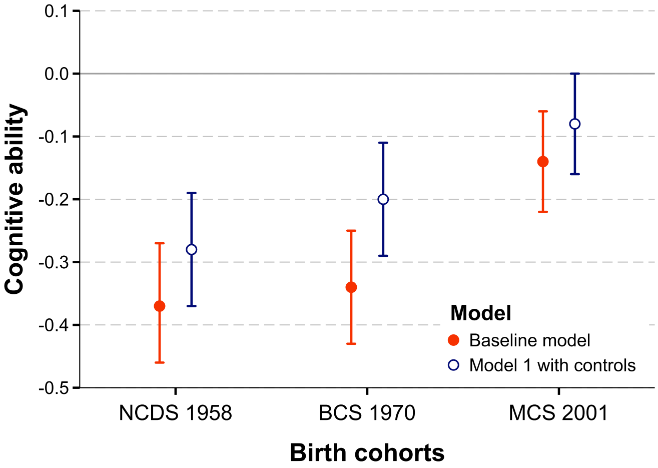

Fig. 1. Linear regression estimates (with 95% CIs) for the association between low birth weight and cognitive ability, by birth cohort. *Y* axis shows the standardized coefficients. Birth weight coefficients are shown in Table 2 and other model controls in Tables S1–S3.

decreased across cohorts. Table S4 shows the characteristics of families with VLBW and MLBW children.

Discussion

In this study, we investigated the question of whether the association between birth weight and cognitive ability in childhood has changed over time. Answering this question complements previous studies showing that the survival and neurological outcomes of VLBW (<1,500 g) children at 2 y of age have improved over time (15, 16). Consistent with existing evidence (6, 11), we show that low-birth-weight children had worse cognitive scores than normal-birth-weight children at the age of 10 or 11 y, but that the disparities have declined dramatically. The gap in the cognitive scores of low-birth-weight and normal-birth-weight children was more than halved for children born in 2001 than for children born in 1958 and 1970. Adjustments for maternal and family characteristics attenuated the differences in the cognitive scores of low-birth-weight and normal-birth-weight children in all three cohort studies, but these adjustments did not explain the striking cross-cohort differences (2, 14, 17).

The results suggest that having a low weight at birth was associated with more negative consequences for a child's cognitive ability in the 1950s and 1970s than it did around the year 2000. One plausible explanation for this shift is that the introduction of and advancements in obstetric and neonatal care have partially attenuated the negative consequences associated with being born with a low birth weight. This hypothesis is supported by evidence that health care for both mothers and babies has gradually improved in the United Kingdom. In particular, neonatal intensive care was introduced in the 1970s, and further technological and pharmacological advancements, such as assisted ventilation, neonatal monitoring, and drugs to treat prematurity, were made during the 1970s and 1980s (5, 13). Therefore, low-birth-weight children born in 2001 would have benefited from a range of medical treatments that were not available to children born in 1958 and 1970. These advancements in medical care helped to prevent brain damage and other negative consequences often associated with low birth weight. This interpretation is consistent with the results showing no significant difference between the older cohorts. These statements are further supported by considering secular changes in the composition of low-birth-weight children; that is, the most healthy and resilient low-birth-weight children survived to the age of 10 or 11 y in the 1958 NCDS/1970 BCS cohorts, whereas there is less selection in the most recent 2001 MCS cohort because of the introduction of prenatal care. This finding is also supported by our results, which revealed that the percentage of VLBW children, who have the worst outcomes at birth and later in life (2, 14), increased across cohorts (5). Differences in the composition of the low-birth-weight analytical samples used in this study should make the secular change less marked or nonexisting (2, 14). The fact that the results suggest that the negative association between low birth weight and cognitive development has declined dramatically over the considered period also for VLBW children makes our results more striking and supports the role of medical developments in explaining the results.

Another potential explanation for the difference could be that the characteristics of families who have low-birth-weight children have changed over time, but the results fail to support this hypothesis.

An implication of the study's findings is that medical developments at least partly explain the secular change in the association between birth weight and cognition. However, the results also suggest that despite substantial improvements in the association between birth weight and cognitive development, low-birth-weight children born in 2001 performed worse than normal-birth-weight children, even after accounting for family characteristics. Hence, despite medical advancements, a disadvantage associated with low birth weight remains that may be both social and biological, and that appears to be difficult to overcome.

This analysis has limitations. First, we were not able to account for gestational age, because in a significant proportion of the 1958 NCDS and 1970 BCS subsamples used in this study, it was either not reported or not reliable. Because additional analyses have shown that the children with a missing or uncertain gestational age tend to have the worst cognitive scores, excluding them from the analyses would have biased the results. Although we would have preferred to distinguish between children based on their gestational age, previous studies have shown that both preterm and full-term children with a reduced birth weight have more problems than children who are born (at term) with a normal birth weight (17). Second, the analyses that distinguished VLBW (<1,500 g) and moderately low birth weight (1,500 to <2,500 g) children need to be interpreted cautiously because of

Table 3. Difference (with 95% CIs) in the association between birth weight and cognitive ability across cohorts

Birth weight: Below 2,500 g	BCS 1970 to NCDS 1958	MCS 2001 to NCDS 1958	MCS 2001 to BCS 1970
Baseline model*	0.05 (−0.08 to 0.17)	0.22 (0.12 to 0.33)	0.18 (0.06 to 0.30)
Baseline model + family characteristics[†,‡]	0.10 (−0.02 to 0.21)	0.19 (0.07 to 0.29)	0.09 (−0.03 to 0.22)

Results were obtained from a pooled model.

*Adjustment made for CM sex and first birth.

[†] Adjustment made for CM sex, first birth, maternal age at CM birth, mother's education, family social class, marital status at the time of birth, whether the mother smoked during pregnancy, mother's height, whether the mother used antenatal care after 12 wk of pregnancy, and whether the mother breastfed the CM.

[‡] Just for the MCS, in addition to all of the other control variables, we adjusted for household income, whether the mother drank during pregnancy, and the mother's ethnic group. Results for the MCS are weighted to account for its complex survey design.

Table 4. CM characteristics by birth weight categories and birth cohort

	VLBW	MLBW	LBW	Normal weight	
CM characteristics, by birth cohort	Below 1,500 g	1,500 g–below 2,500 g	Below 2,500 g	2,500–4,500 g	Average
NCDS 1958					
CM girl	85.7	57.9	58.3	49.0	49.4
CM first birth	57.1	41.9	42.1	37.0	37.2
Percent	0.1	4.3	4.4	95.6	
No. of observations	7	449	456	9,885	10,341
BCS 1970					
CM girl	57.9	50.0	50.3	48.9	48.9
CM first birth	63.2	53.4	53.8	37.6	38.4
Percent	0.2	4.9	5.1	94.94	
No. of observations	19	442	461	8,655	9,116
MCS 2001					
CM girl	45.5	55.0	53.9	48.8	49.1
CM first birth	60.0	48.7	50.0	42.1	42.6
Percent	0.7	5.2	5.9	94.1	
No. of observations	76	587	663	10,550	11,213

Results are shown for the overall low-birth-weight (LBW) group and for the subgroups of very LBW (VLBW; below 1,500 g) and moderate LBW (MLBW; 1,500 to below 2,500 g).

the small number of VLBW children. Third, the results suggest the existence of a secular trend in the association between birth weight and cognitive abilities using three data points; more data could help to confirm the secular trend. Despite these limitations, this study provides important insights into the association between birth weight and cognitive ability. Major strengths of this study are that our data cover a 40-y time period and are representative of the British population, and that the cognitive outcomes analyzed are comparable across cohorts.

Future work should test whether the association between low birth weight and compromised child outcomes are found in other contexts and for other outcomes. It is particularly important to also consider outcomes in adulthood; the current results do not enable us to infer whether, for children born in more recent cohorts, the disadvantage suffered by low-birth-weight children is attenuated throughout the life course, or only in childhood.

Methods

Data. The 1958 NCDS is a longitudinal cohort study that followed the lives of around 17,500 individuals born during a single week of March in 1958 in Britain. We used data from the birth survey (98.8% response rate) and from the age at 11 y survey (response rate around 88%). The 1970 BCS is a longitudinal cohort study that followed the lives of around 17,000 individuals born in Britain during a single week of April in 1970. We used data from the birth survey (95.9% response rate) and the age at 10 y survey (response rate around 87%). The MCS is a longitudinal cohort study that followed the lives of around 19,000 children born in the United Kingdom from September in 2000 to January in 2002. The sample was selected from a random sample of electoral wards using a stratified sampling strategy to ensure the adequate representation of all four of the countries comprising the United Kingdom and of disadvantaged and ethnically diverse areas. In the analyses, we used data from sweep 1 (82% response rate), which were collected when the children were around 9 mo old, and from sweep 5, which were collected when the children were around 11 y old (response rate around 72%). For ease of exposition, we refer to the MCS as the 2001 cohort study, because the majority of the births in the sample occurred in 2001.

When the birth surveys of the 1970 BCS and 1958 NCDS cohort studies were carried out, consent to participate in surveys was gained by respondents agreeing to be interviewed or respondents returning the completed questionnaire to the study team. Parental consent was sought when the data at 11 y (1958 NCDS) and at 10 y (1970 BCS) were collected, but there is no evidence that written consent was obtained. Available records suggest that for the waves of data collection considered in this study, there was only internal ethnical review for the 1958 and 1970 cohort studies because they predated the establishment of the Multicentre Research Ethics Committee in 1997. The 2001 MCS sought written parental consent in each wave of data collection, and Multicentre Research Ethics Committee approval was given for all of the MCS waves of data collection.

Birth Weight. In the NCDS and BCS, birth weight was recorded in the birth survey, which was completed by a midwife who attended the delivery. In the MCS, birth weight was reported by the main respondent in sweep 1 (when the cohort child was around 9 mo old), and evidence suggests that such reports are reliable and in accordance with registration data (18). Birth weight was divided into two categories: low (<2,500 g) and normal (2,500–4,500 g) (19). Heavy-weight (4,500 g and above) children (20) were excluded from the analyses because differences in cognitive outcomes between heavy-weight and normal-weight children in all cohorts were not statistically significant. In supplementary analyses, we divided the low-birth-weight group into two categories: very low birth weight (VLBW; <1,500 g) and moderately low birth weight (MLBW; 1,500 to <2,500 g).

Cognitive Ability. We used a measure of verbal cognitive ability in childhood. One of the strengths of this study is that we relied on measures of cognitive ability that are comparable across the three cohorts because they were collected at around the same age in each cohort (age of 11 y in the 1958 NCDS and 2001 MCS and age of 10 y in the 1970 BCS); they tested the same dimension of cognitive well-being, namely, verbal ability; and they were found to serve as a good proxy for general cognitive ability scores (21–24). In the 1958 NCDS, cognition was assessed based on the verbal score of the General Ability Test (National Foundation for Educational Research), which consisted of 40 items (23). The children were tested individually by teachers, who recorded the answers for the tests. In the 1970 BCS, the cognition of each child was assessed using the 21-item Word Similarity subscale of the British Ability Scales (first edition), which was administered by a teacher (24). The scores were standardized from a normed pool of scores within 3-mo age ranges. In the 2001 MCS, the cognition of each child was assessed using the 37-item Verbal Similarity subscale from the British Ability Scales (second edition), which was administered by the interviewer (25). The scores were standardized from a normed pool of scores within 3-mo age ranges.

Because different tests were administered in each cohort, regression results based on the raw test scores would not be directly comparable across cohorts. We therefore standardized the cognitive scores to a mean of 0 and a SD of 1 within each cohort, which means that children were ranked within their respective cohorts. The standardization procedure ensured that the regression coefficients on the association between low birth weight and cognitive ability, obtained by estimating separate models within each cohort, could be compared across cohorts.

Family Characteristics. We selected the maternal and the family characteristics that were hypothesized to attenuate the association between birth weight and cognition in childhood (19, 26), and that were collected in all three cohort studies. To capture the socioeconomic status of the family, we adjusted for the mother's level of education (in the 1958 NCDS and the 1970

BCS, whether the mother stayed in school beyond the minimum age; in the 2001 MCS, whether the mother had a degree-level education) and for either the father's (1958 NCDS) or the household's (1970 BCS and 2001 MCS) registrar general social class. As sociodemographic variables, we considered the age of the mother at the birth of the cohort child and her marital status at conception or at the time of birth (in the 1958 NCDS and the 1970 BCS, whether she was or was not married; in the 2001 MCS, whether she was married, cohabiting, or single). We considered three markers of the mother's health behavior: whether she smoked during pregnancy, whether she used antenatal care for the first time after 12 wk of pregnancy or did not use it at all, and whether she breastfed the child. Finally, we adjusted for the mother's height, which is a marker of both socioeconomic status and health (27). Because the MCS provides a richer set of variables, we also showed in this cohort study how the results change after we controlled for the mother's heavy drinking during pregnancy, for the quintile of household income, and for the mother's ethnicity.

Inclusion Criteria and Exclusions. We dropped observations with missing values on cognitive scores at the age of 10 or 11 y (1958 NCDS = 1,226, 1970 BCS = 2,267, 2001 MCS = 297). From this subsample, we dropped observations with missing values on birth weight (1958 NCDS = 1,128, 1970 BCS = 965, 2001 MCS = 488) and observations with missing values on any of the covariates measured around the time of the cohort child's birth. We also excluded multiple births from the analytical samples. These exclusions reduced the 1958 NCDS sample to 10,341 observations, the 1970 BCS sample to 9,116 observations, and the 2001 MCS sample to 11,231 observations.

Statistical Analyses. We used linear regression models to estimate, within each cohort, the association between the cohort children's birth weight and verbal cognitive ability at the age of 10 or 11 y. Two sets of models were estimated for each cohort study. The baseline model included an adjustment for the basic characteristics of each child; namely, the child's sex, and whether the child was a first or higher order birth. Model 1 included adjustments for the basic characteristics of the child, of the mother, and of the family. For the 2001 cohort, model 2 was adjusted for additional covariates that were not collected in the 1958 and 1970 cohort studies. To test directly whether the association between birth weight and cognition varied across cohorts, we pooled the three cohort studies and estimated a unique model in which we interacted each regressor by means of a cohort dummy.

All of the analyses were conducted in Stata, version 13. In the analyses of the 2001 MCS, we used weights to account for nonresponse and for the overrepresentation of disadvantaged and ethnically diverse areas and the survey command to account for the clustering of samples within strata. No weighting was used in the analyses of the 1958 NCDS and the 1970 BCS because these surveys were not based on a complex design and weights for nonresponse were not available.

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