LOW BIRTH WEIGHT, SOCIAL FACTORS, AND DEVELOPMENTAL OUTCOMES AMONG CHILDREN IN THE UNITED STATES*

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We used six waves of the National Longitudinal Survey of Youth–Child Data (1986–1996) to assess the relative impact of adverse birth outcomes vis-à-vis social risk factors on children's developmental outcomes. Using the Peabody Individual Achievement Tests of Mathematics and Reading Recognition as our outcome variables, we also evaluated the dynamic nature of biological and social risk factors from ages 6 to 14. We found the following: (1) birth weight is significantly related to developmental outcomes, net of important social and economic controls; (2) the effect associated with adverse birth outcomes is significantly more pronounced at very low birth weights (< 1,500 grams) than at moderately low birth weights (1,500–2,499 grams); (3) whereas the relative effect of very low-birth-weight status is large, the effect of moderately low weight status, when compared with race/ethnicity and mother's education, is small; and (4) the observed differentials between moderately low-birth-weight and normal-birth-weight children are substantially smaller among older children in comparison with younger children.

Social demographers have had a long-standing interest in analyzing the determinants of adverse birth outcomes, including low birth weight and prematurity (e.g., Cramer 1995; Frisbie, Forbes, and Pullum 1996; Kallan 1993; Singh and Yu 1996). For the most part, this interest stems from the close association between adverse birth outcomes and the risk of infant mortality. That is, the infant mortality rate for low-birth-weight infants is over 20 times that of their normal-weight counterparts (MacDorman and Atkinson 1999). Furthermore, birth outcomes are often viewed as the key intervening variables that link social factors, such as race and maternal education, to the risk of infant mortality (Eberstein, Nam, and Hummer 1990). Indeed, controlling for adverse birth outcomes accounts for nearly all the gap in infant mortality between blacks and whites in the United States (Hummer et al. 1999).

In contrast, the contribution of adverse birth outcomes to child health and developmental outcomes—particularly in combination with social risk factors—is much less well established in social demography than in the literature on adverse birth outcomes and infant mortality. This is particularly the case at the national level, where the data requirements for such longitudinal linkages between events that occur at birth and outcomes many years later are especially stringent. Indeed, unlike studies that have relied on large-scale databases to link birth outcomes and social risk factors to the risk of infant mortality, there are relatively few data sets that contain the information that is necessary to link

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adverse birth outcomes with the long-range health and development trajectories of children and adolescents. In our study, we used the National Longitudinal Study of Youth–Child Data (hereafter NLSY–CD), one of the only national-level longitudinal databases of its kind, to answer questions about the relationship of low birth weight and social risk factors to the long-term development of children.

Our purpose is to answer three questions regarding the long-term developmental outcomes of low-birth-weight children. First, are there net negative effects of low birth weight on cognitive outcomes—as measured by scores on standardized reading and math achievement tests—among a national sample of U.S. children? Second, if so, does the effect of birth weight vary across the ages of children? Finally, how do social factors affect the cognitive development scores of children, net of birth weight, and how do the effects of these factors vary across the ages of children?

BACKGROUND

There is a growing body of research on the relationship between adverse birth outcomes and subsequent child development outcomes. Findings from these studies suggest that the negative association between low birth weight and cognitive development begins in early childhood (Hack et al. 1995) and may extend well into and beyond adolescence (Behrman, Rosenzweig, and Taubman 1994). For example, using data from the 1981 National Health Interview Study–Child Health Supplement, McCormick, Gortmaker, and Sobol (1990) found a significantly higher incidence of school difficulty (measured according to whether the child had repeated a grade or was attending special classes) and hyperactivity among children aged 4 to 18 who were born with a very low weight. A greater incidence of developmental problems related to school achievement, in the area of attention deficit, was also found among six-year-old children who were born with low weight compared with normal-weight children (Breslau 1996). Likewise, in a recently well-publicized study, Conley and Bennet (2000) used data from the Panel Study of Income Dynamics and found that the probability of a low-birth-weight infant (< 2,500 grams) completing high school in a timely fashion (i.e., by age 19) is 74% lower than the probability of his or her normal-birth-weight siblings.

The physiological processes underlying the relationship between adverse birth outcomes and children's subsequent development is described in the important works of Barker and colleagues (Barker 1995; Barker et al. 1993), who documented a relationship between low birth weight and the risk of coronary heart disease among adults. These researchers articulated the "fetal programming hypothesis" (i.e., the Barker hypothesis), which states that low birth weight is a risk factor for poor developmental outcomes because the same processes that cause low birth weight also cause poor subsequent development. For example, blood pressure, cholesterol levels, and hormonal levels are believed to be "programmed" at an early stage of fetal development. Programming of the fetus occurs when known risks occur at critical (sensitive) periods in early life, which may have long-lasting impacts on metabolism and physiology. In particular, the nutritional supply to the placenta may not match placental demand at particularly important developmental moments, which may lead to reduced physical growth *and* long-term physiological problems. The bulk of the research on the fetal programming hypothesis has evaluated physical health outcomes (Godfrey and Barker 2001); however, there may be reasons to expect that the processes that affect physiological development may have deleterious effects on other important developmental outcomes as well.

Social risk factors have been found to mediate significantly the effects of birth outcomes on the long-term cognitive development of low-birth-weight children (Hack et al. 1995). Studies have consistently shown that socioeconomic disadvantage has a detrimental effect on cognitive functioning, as well as on a range of outcomes related to school achievement, including absenteeism, the repetition of grades, and the risk of high school dropout (Brooks-Gunn and Duncan 1997; Crooks 1995; McLoyd 1998). A study of white and black children explored whether both the timing and duration of poverty is relevant for cognitive development (Smith, Brooks-Gunn, and Klebanov 1997). On the basis of two separate samples, the authors investigated three cognitive development measures—IQ, verbal ability, and school achievement—for children aged 2 to 8. They found that the longer a child was in poverty, the larger the negative consequences for cognitive development, although the effects of the timing of poverty were not significant for this young age group. In addition, controlling for socioeconomic factors, they found that low birth weight had no significant effect on cognitive outcomes.

Two studies on the relationship between social context and children's developmental outcomes found strong ties between family-level socioeconomic characteristics and the risk of low scores on several achievement tests. First, using the same data set that we used in our analyses, Guo (1998) found that although the between-child variation is significantly larger than the within-child variation, socioeconomic resources are important predictors of both between- and within-child variation in achievement tests (like the scores on the Peabody Individual Achievement Tests, PIATs, used in the present analyses). Moreover, Guo's study found that the disadvantage associated with low socioeconomic status increases over children's lives. Similarly, Guo and Harris (2000), building on this previous research, found that these effects of poverty on children's development are entirely mediated by household characteristics (e.g., parenting style, cognitive stimulation in the home, and physical environment of the home) and appear to be more pronounced in adolescence than in early childhood. Moreover, they indicated that differences in birth weight account for a portion of the difference in developmental outcomes among poor and nonpoor children. However, they did not investigate possible differential birth-weight effects for children of different ages.

A key limitation of current research is that few studies have investigated the effects of birth weight for different age groups of children. One study, which was restricted to the period of early childhood (Klebanov et al. 1998), showed that the effects of very low birth weight on cognitive functioning decreased significantly between the ages 1 and 3. The study was based on a sample of 374 low-birth-weight, preterm children from the Infant Health and Development Program. It contained rich measures of socioeconomic status, including family poverty, family risk factors (e.g., family structure, mother's education and cognitive scores, being a teenage parent at the time of the birth, depression, and social support), and neighborhood poverty. Controlling for socioeconomic characteristics, Klebanov et al. observed a significant negative effect of birth weight when the children were age 1 that was no longer evident at ages 2 and 3. The results, however, should be interpreted cautiously, given that the study was restricted to low-birth-weight infants and contained a limited sample.

Although this research provided useful evidence that helps to clarify these complex relationships, important issues remain unresolved. Specifically, there is convincing evidence that biological (birth weight) and social (socioeconomic) risks are related to developmental outcomes. Whether the relative explanatory power of these characteristics varies with a child's age, however, is not known. A long-term study of British children who were born in 1970 followed up with the respondents at ages 5, 10, 16, and 26 (Strauss 2000). The sample of 14,189 full-term infants included 1,064 infants who were born small for their gestational age (SGA) (their birth weight was less than the fifth percentile for age at term). The study revealed that the children who were born SGA had academic difficulties into adolescence. According to Strauss, "children who were born SGA demonstrated significant deficits in a wide range of standardized testing from the ages of 5 to 16 years" (p. 627). Substantively, however, the differences were fairly small. Measures of academic achievement included teachers' ratings of general knowledge, standardized tests of academic achievement, and enrollment in special education. The analysis did not focus on different levels of cognitive functioning across the three age periods, but rather on comparisons between those who were born SGA and those who were of normal weight for their gestational age. Therefore, no information was provided on how the effects changed across the age span. At age 26, the respondents were compared on educational attainment across birth outcomes. Strauss found that the effects of birth weight on educational attainment disappeared by young adulthood (age 26), although some negative effects were evident in terms of occupational attainment.

Corman and Chaikind (1993) examined the effects of low birth weight on the school performance of children in two age groups, 6 to 10 and 11 to 15. The results of their study were mixed. Using the 1988 Child Health Supplement of the National Health Interview Survey, the authors found that low birth weight was not significantly associated with positive parental reports of school performance in the younger age group. Nevertheless, low birth weight substantially and significantly increased the probability of grade repetition in the older age group. Analyses were conducted for the entire sample of children and for a subsample of children who were not attending special education. However, the study was limited to a cross-sectional analysis and did not follow the children over time.

Perhaps the most similar work to our present study was by Lee and Barratt (1993), who used the first two waves of the NLSY–CD and found a reduction in the effects of birth weight on achievement scores in as little as two years when they compared children aged 5 to 6 with those aged 7 to 8. Similarly, they found tentative evidence that the effects associated with social risk factors, such as low socioeconomic status and risky home environments, on children's developmental outcomes may increase over time. It is not clear, however, that this relationship is consistent across both mathematics and reading achievement assessments. Nor is it clear that this difference is statistically significant, given the parameterization of their models. Our work builds on this complete body of research by using six waves of the NLSY–CD, which allowed us to evaluate the dynamic relationships among birth weight, social risk factors, and child development across a much longer period than has been previously examined.

METHODS

Data

Data for this study came from the NLSY–CD. The NLSY–CD was developed from the original National Longitudinal Survey of Youth (NLSY), a nationally representative sample of 12,686 adolescents aged 14 to 22 as of the 1979 survey date, and contains detailed longitudinal information on health and development outcomes from birth throughout the teenage years for the children of mothers from the original youth cohort (Center for Human Resource Research 1993, 1998). Data were collected every two years from 1986 to 1996 (i.e., six data collection points) regarding the children of the female NLSY respondents. The NLSY–CD contains a number of commonly used measures to assess a range of cognitive, social, and psychological aspects of the children's development. Data on the mothers from the NLSY are linked with corresponding NLSY–CD records on a year-by-year basis.

The NLSY–CD is particularly useful for our analyses because blacks and Hispanics are oversampled, making it possible to conduct meaningful analyses for a more diverse sample of U.S. children. The relatively small size of the Hispanic subsample, however, does not permit detailed analyses of Hispanic subgroups. Given the diversity of the Hispanic population with respect to our key variables of interest, we restricted our analyses to Mexican American, non-Hispanic black, and non-Hispanic white children. Nevertheless, this is a substantial improvement over most studies in this area that have not examined Hispanic children at all. Although the data are based on an oversample of blacks and Hispanics, we did not weight the data because we included children from all six waves of the NLSY–CD (for a discussion, see Center for Human Resource Research 1998:24–26).

We pooled the data for children aged 6 to 14 from the 1986, 1988, 1990, 1992, 1994, and 1996 NLSY–CD. We limited our analyses to children aged 14 and younger because starting in 1994, children aged 15 and older were assessed with different developmental instruments from those used to assess younger children (Center for Human Resource Research 1998:1). This age restriction allowed us to include children for a maximum of five points in time. In total, our analyses included 1,890 non-Hispanic black, 2,411 non-Hispanic white, and 844 Mexican American children, for a total *N* of 5,145. Because children are included anywhere from one to five times in the pooled data set, however, our total number of observations was 12,295. Last, given that the NLSY–CD data were collected from NLSY mothers, a number of children in the data set had the same mothers. Specifically, the 5,145 children in our sample were born to 2,747 women.

Measures

Our dependent variables included two widely used achievement tests: (1) The Peabody Individual Achievement Test of Mathematics (PIAT-M) and (2) the PIAT Reading Recognition (PIAT-RR) Test. The PIAT-M assessment measures children's "attainment in mathematics as taught in mainstream education" (Center for Human Resource Research 1998:60). A multiple-choice test, the PIAT-M starts with basic mathematics skills, such as number recognition, and ultimately progresses to advanced topics like geometry and trigonometry. Age-normalized percentile scores are computed for all children (see Dunn and Markwardt 1970:81–91, 95 for the norm procedures). The PIAT-RR measures two key reading skills: word recognition and pronunciation ability. After reading a word silently, children are asked to repeat the word aloud; they are assessed on matching letters, naming names, and reading single words aloud with 84 items. We used PIAT-RR age-normalized percentile scores. All observations with missing values for the PIAT assessment scores (n = 910; 6.8%) were dropped from our analyses. Ancillary analyses (results not presented) indicated that these cases were not significantly different from the rest of the sample with respect to birth weight, poverty status, or race/ethnicity.

Our primary independent variable, birth weight, was measured with mothers' self-reports. Although maternal reports of birth weight are clearly less accurate than birth certificates, they have been used in several related analyses (e.g., Conley and Bennet 2000; Cramer 1995) and generally are considered to be valid. Similarly, we recognized the heterogeneity within the group of low-birth-weight children (e.g., Frisbie et al. 1996; Solis, Pullum, and Frisbie 2000). Accordingly, we operationalized birth weight with three categories: (1) very low birth weight (VLBW: < 1,500 grams), (2) moderately low birth weight (MLBW: 1,500–2,499 grams), and (3) normal birth weight (NBW: > 2,499 grams).

We also included a number of important sociodemographic characteristics that may affect the relationship between low birth weight and developmental outcomes. We limited our analyses to three racial/ethnic groups: Mexican Americans, non-Hispanic blacks, and non-Hispanic whites. In all models, non-Hispanic white is the reference category. We also included seven other sociodemographic variables in our multivariate models. The first four were *child's age,* measured with a continuous variable in years; *sex,* a dummy variable coded 1 = female and 0 = male; *marital status,* a dummy variable coded 1 = married if the mother was married at the time of the interview and 0 = otherwise; and *age of mother at birth*, a continuous variable tapping maternal age measured in years. The remaining sociodemographic variables were *poverty,* a variable for all the respondents based on family income, household size, and the year of the survey, coded 1 = below poverty and 0 = otherwise; *mother's education*—less than a high school education, high school graduate, some college, and college graduate or higher (reference category); and (7) *HOME,* operationalizing the quality of children's household context with the Home Observation for Measurement of the Environment–Short Form (HOME–SF). Widely used, the characteristics of the home environment covered by this scale (percentile score) measure the extent to which children's home context provides cognitive stimulation and emotional support (Center for Human Resource Research 1998).

The descriptive statistics of all variables used in the analyses by the year of the survey are presented in Table 1. These statistics are illustrative because they clearly show the changing demographic profile of the NLSY–CD sample over the six waves of data from 1986 to 1996. With respect to our primary independent variable, birth weight, children in the earliest wave were significantly more likely to be born at weights less than 2,500 grams compared with those from the most recent survey. This relationship is understandable because the mothers of the children from the earlier waves of data were more likely to have characteristics associated with the increased likelihood of adverse birth outcomes. That is, they were more likely to be black, young, less educated, poor, and unmarried than those from each successive wave of the survey (Center for Human Resource Research 1993). Last, it is important to note the increasing mean age of children in our sample for each successive wave of data. Specifically, the mean age of children from the earliest wave of data is nearly two years less than that of children from the last wave of data, and these mean ages increase monotonically across the waves. Again, this pattern is understandable when we consider that the first waves of data contained few children aged 12 or older. Indeed, in the 1986 sample, only 38 children were 12 to 14 years old.

Statistical Analysis

We evaluated the relationship among low birth weight, social risk factors, and child development with a multilevel statistical method that allows for dependence among observations within children and children within families and provides parameter estimates that enabled us to describe variations in our outcomes measures that were due to this clustering. The model used for these data explicitly takes account of the unique features of the NLSY sample of children in families followed over time and can be expressed in the following framework:

$$y_{ijk} = \beta_0 + \Sigma_h \beta_h x_{hijk} + v_k + u_{jk} + e_{ijk}, \tag{1}$$

where y_{ijk} is the PIAT assessment score for the jth individual in the kth family on the ith measurement occasion (or survey year), x_{hijk} corresponds to the value of the hth covariate ($h = 1, \ldots, H$) for that individual, and β_0 and β_h represent intercept and slope parameters to be estimated. The disturbance terms (v_k, u_{jk}, and e_{ijk}) denote random effects, which are independently normally distributed with means equal to 0 and variances σ_v^2, σ_u^2, and σ_e^2, respectively. The v_k ($k = 1, \ldots, 2{,}747$) term represents unobserved family-level factors affecting y that are shared by all n_k children in the kth family (whereas u_{jk} represents unobserved traits for the jth child ($j = 1, \ldots, n_k$) in the kth family) and that are assumed to be constant over the m_j measurement occasions. The e_{ijk} term denotes unobserved heterogeneity in PIAT assessment scores specific to the jth child measured on the ith occasion ($i = 1, \ldots, m_j$). Therefore, Eq. (1) describes a multilevel model in which measurement occasions (at level 1) are nested within children (at level 2) who are, in turn, nested within families (at level 3) (see, for example, Goldstein 1995). Controlling for these sources of variability, observations are independent. Maximum-likelihood estimation of the model in Eq. (1) yields unbiased parameter estimates and standard errors that are adjusted for the hierarchical nature of the data. We used SAS 8.1 PROC MIXED

Table 1. Descriptive Statistics for All Variables by Year of Survey: 1986–1996 NLSY–CD

	Year of Survey						
Variables	1986	1988	1990	1992	1994	1996	Total
Continuous Variables[a]							
PIAT-M	46.29	44.97	46.33	46.82	48.66	52.14	47.76
	(24.89)	(25.26)	(25.66)	(26.06)	(26.31)	(26.94)	(26.09)
PIAT-RR	55.99	52.57	53.19	54.28	54.09	56.77	54.41
	(25.18)	(26.58)	(27.18)	(27.48)	(28.27)	(27.81)	(27.35)
Child's Age	7.87	8.55	9.03	9.46	9.78	9.81	9.21
	(1.78)	(2.16)	(2.32)	(2.39)	(2.43)	(2.49)	(2.38)
HOME Score	46.16	46.08	47.72	48.65	47.56	47.71	47.47
	(29.22)	(29.14)	(29.13)	(29.48)	(29.06)	(28.35)	(29.06)
Maternal Age	18.15	19.29	20.39	21.56	22.97	24.64	21.56
	(1.98)	(2.33)	(2.66)	(2.95)	(3.10)	(3.21)	(3.49)
Categorical Variables[b]							
Birth Weight							
VLBW (< 1,500 grams)	1.4	1.1	0.7	0.9	0.9	1.1	1.0
MLBW (1,500–2,499 grams)	9.9	8.4	7.3	6.2	6.2	5.1	6.9
NBW (≥ 2,500 grams)	88.7	90.5	92.0	92.9	92.9	93.8	92.1
Race/Ethnicity							
Non-Hispanic black	42.9	37.9	41.4	37.2	34.6	33.6	37.3
Mexican American	12.9	14.6	18.3	18.8	18.5	16.9	17.1
Non-Hispanic white	44.2	47.5	40.3	44.0	46.9	49.5	45.6
Sex of Child							
Female	49.9	49.7	50.1	50.8	49.4	48.9	49.8
Male	50.1	50.3	49.9	49.2	50.6	51.1	50.2
Mother's Education							
Less than high school	46.7	41.1	31.7	27.4	23.1	19.2	29.6
High school graduate	41.1	41.6	44.4	44.6	42.8	39.7	42.5
Some college	10.9	14.4	19.9	20.8	24.0	26.5	20.5
College graduate	1.3	2.9	4.0	7.2	10.1	14.6	7.4
Poverty Status							
Poor	41.3	38.8	31.3	31.0	25.7	21.8	30.4
Not poor	58.7	61.2	68.7	69.0	74.3	78.2	69.6
Marital Status							
Married	52.9	54.2	56.9	58.7	63.7	65.9	59.5
Unmarried	47.1	45.8	43.1	41.3	36.3	34.1	40.5
N	1,070	1,992	2,039	2,453	2,406	2,335	12,295

[a]Cell entries for continuous variables represent means, with standard deviations shown in parentheses.

[b]Cell entries for categorical predictors represent percentages.

(see Littell et al. 1996 for a detailed overview of this application) to estimate these models.[1]

RESULTS

The results of the multilevel regression models are presented in Tables 2 and 3. These tables present three sets of model estimates for our null model (without any covariates), full model (with all covariates), and an interactive model in which we evaluated the extent to which each covariate varies by the child's age. The estimates in the null models provide baseline estimates for the intrachild and intrafamily correlation coefficients. Specifically, 23.4% and 34.4% of the variability in the PIAT-M and PIAT-RR are due to unmeasured child characteristics, and 36% of this variability (for each outcome) is due to unmeasured family characteristics. These estimates are important because they illustrate the dependence among observations nested within children and children nested within families that otherwise would be lost in more traditional single-level approaches.

The second set of parameter estimates addresses one of the key research questions in our study—namely, are there any independent negative effects associated with low-birth-weight status on children's developmental outcomes? According to these values, VLBW is associated with a 9.5- and 11.4-point decrease in children's PIAT-M and PIAT-RR scores, respectively. And although significantly smaller in magnitude ($b = -2.9$, $p < .001$), the estimated net effect of MLBW on each PIAT assessment is, as well, negative and statistically significant. This finding is important because these models control for a range of meaningful social and economic characteristics. In other words, although VLBW and MLBW children are more likely to be from relatively disadvantaged backgrounds (Cramer 1995; Kallan 1993), both VLBW and MLBW statuses are operating independent of these socioeconomic characteristics to have adverse effects on developmental outcomes.

These model estimates also illustrate the significance of several social and economic characteristics on children's development. Here, it is important to note the distributional characteristics of our two dependent variables. Specifically, the standard deviations for PIAT-M ($SD = 27.4$) and PIAT-RR ($SD = 26.1$) scores help contextualize the magnitude associated with the effect of VLBW and MLBW vis-à-vis the social risk factors in the models. First, non-Hispanic black children scored over 13 points lower (nearly half a standard deviation) on the PIAT-M and 9 points lower on the PIAT-RR than did non-Hispanic white children with similar observed social and economic characteristics. And though the race/ethnicity differential is not as large as the black-white differential, the Mexican American children, net of our controls, scored 10 points and 6 points lower on the PIAT-M and PIAT-RR, respectively, than did the non-Hispanic white children. Second, it is clear from these results that maternal socioeconomic status, particularly education, is a significant predictor of children's developmental outcomes. Specifically, children whose mothers did not complete high school scored 16 and 17 points lower (than did

1. The random-effects model assumes that unobserved heterogeneity is a random variable (differing by families) that follows a normal distribution and is uncorrelated with the regressors, whereas a fixed-effects model treats unobserved heterogeneity as a fixed but unknown variable. In either case, the nature of the random effect is the same. However, there are subtle differences between these models in terms of inference. In the fixed-effects model, inference is conditional on the effects that are in the sample. Random-effects models are concerned with marginal inferences with respect to the population of all effects (Hsiao 1986). Our interpretation considers the NLSY families to be a random sample from a larger population of families. Inferences based on the population of all families, rather than on the families actually sampled in the NLSY, are more appropriately handled using a random-effects model. A similar case can be made with regard to the child-level random effect. In addition, to address the assumption of normality of residuals in random-effects models, we obtained empirical Bayes estimates of the family-level and child-level random effects from our complete model and assessed normality assumptions heuristically using standard normal probability plots. We found no evidence of nonnormality of level-2 residuals for either level of analysis (these results are available from the authors on request).

Table 2. Multilevel Regression Coefficients: Low Birth Weight, Social Risk Factors, and PIAT-M Assessment Scores: 1986–1996 NLSY–CD

			Interactive Model	
Fixed Effects	Null Model	Full Model	Main	× Age
Intercept	49.02***	62.94***	79.02***	—
	(0.39)	(2.78)	(6.72)	
Child's Age (Years)		–0.42***	–2.30***	—
		(0.07)	(0.71)	
Birth-Weight Status [≥ 2,500 grams]				
VLBW (< 1,500 grams)		–9.47***	–4.32	–0.55
		(2.63)	(7.17)	(0.74)
MLBW (1,500–2,499 grams)		–2.97***	–8.13**	0.57*
		(1.11)	(2.82)	(0.28)
Race/Ethnicity [Non-Hispanic White]				
Non-Hispanic black		–13.39***	–7.29***	–0.67***
		(0.79)	(1.78)	(0.17)
Mexican American		–9.92***	–8.41***	–0.17
		(0.99)	(2.09)	(0.21)
Female		–0.25	4.49**	–0.53***
		(0.54)	(1.39)	(0.14)
Maternal Age		0.18*	–0.83***	0.12***
		(0.09)	(0.23)	(0.02)
HOME Score		0.08***	0.13***	–0.01**
		(0.00)	(0.03)	(0.00)
Mother's Education [College Graduate]				
Less than high school		–15.95***	–15.95***	–0.03
		(1.32)	(3.29)	(0.34)
High school graduate		–10.93***	–13.19***	0.23
		(1.20)	(3.00)	(0.32)
Some college		–6.56***	–6.38*	–0.04
		(1.22)	(3.17)	(0.33)
Poor		–1.65**	0.69	–0.24
		(0.55)	(1.88)	(0.19)
Unmarried		0.66	–3.33*	0.29
		(0.59)	(1.78)	(0.18)
Residual Variance				
σ_u^2: Child level	158.49	156.15	158.15	
	(8.08)	(7.96)	(7.99)	
σ_v^2: Family level	248.33	138.27	137.99	
	(11.91)	(8.94)	(8.95)	
σ_e^2: Observation level	268.24	268.87	265.74	
	(4.45)	(4.46)	(4.41)	
Chi-Square	—	770.80***	64.40***	

*$p < .05$; **$p < .01$; ***$p < .001$

Table 3. Multilevel Regression Coefficients: Low Birth Weight, Social Risk Factors, and PIAT-RR Assessment Scores: 1986–1996 NLSY–CD

			Interactive Model	
Fixed Effects	Null Model	Full Model	Main	× Age
Intercept	55.55***	75.03***	95.09***	—
	(0.42)	(2.91)	(6.32)	
Child's Age (Years)		–0.73***	–3.05***	—
		(0.07)	(0.65)	
Birth-Weight Status [≥ 2,500 grams]				
VLBW (<1,500 grams)		–11.39***	–5.63	–0.64
		(2.89)	(6.81)	(0.69)
MLBW (1,500–2,499 grams)		–2.85*	–7.69**	0.55*
		(1.24)	(2.64)	(0.25)
Race/Ethnicity [Non-Hispanic White]				
Non-Hispanic black		–9.14***	7.40***	–1.84***
		(0.88)	(1.68)	(0.16)
Mexican American		–5.92***	–4.44*	–0.19
		(1.10)	(1.99)	(0.18)
Female		5.59***	5.16***	0.03
		(0.60)	(0.54)	(0.13)
Maternal Age		–0.19*	–1.47***	0.16***
		(0.09)	(0.21)	(0.02)
HOME Score		0.07***	0.06*	0.00
		(0.01)	(0.03)	(0.00)
Mother's Education [College Graduate]				
Less than high school		–16.99***	–11.48***	–0.63*
		(1.41)	(3.12)	(0.31)
High school graduate		–9.98***	–7.49***	–0.28
		(1.28)	(2.85)	(0.29)
Some college		–5.25***	–6.25*	0.07
		(1.27)	(3.00)	(0.31)
Poor		–0.45	–0.34	–0.01
		(0.52)	(1.72)	(0.17)
Unmarried		–0.07	2.58	–0.26*
		(0.58)	(1.64)	(0.17)
Residual Variance				
σ_u^2: Child level	250.96	242.69	243.80	
	(9.87)	(9.66)	(9.59)	
σ_v^2: Family level	265.21	180.09	180.59	
	(13.45)	(11.30)	(11.28)	
σ_e^2: Observation level	211.90	210.72	202.38	
	(3.53)	(3.52)	(3.38)	
Chi-Square	—	681.50***	300.30***	

*$p < .05$; **$p < .01$; ***$p < .001$

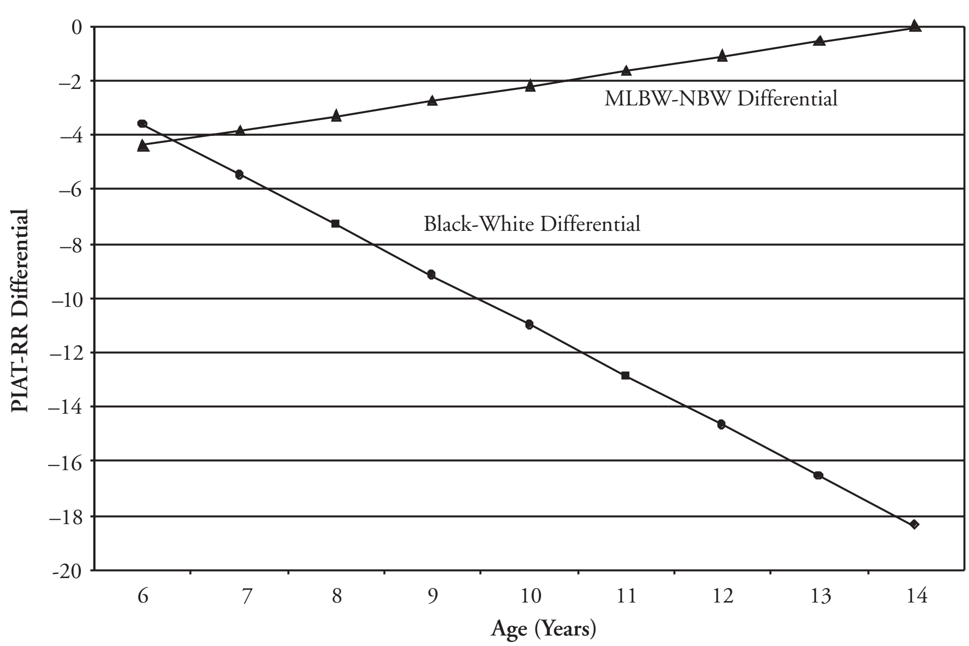
those whose mothers completed college or higher) on the PIAT-M and PIAT-RR, respectively. And although the positive effects associated with increased educational levels are monotonic, children whose mothers completed only high school at the time of the assessment scored 11 (PIAT-M) and 10 (PIAT-RR) points lower than did those whose mothers graduated from college. The effect of maternal education is quite strong and most likely explains the bulk of the relatively modest effects associated with poverty on PIAT-M scores ($b = –1.65$, $p < .01$) and the insignificant effect of poverty on PIAT-RR scores. We also found significant effects associated with the levels of cognitive stimulation (HOME score: $b = 0.08$, $p < .001$; $b = 0.07$, $p < .001$) in children's homes to be positively and significantly related to the children's performance on both tests. Last, similar to recent research in this area (Levine, Pollack, and Comfort 2001), we found that maternal age is positively and significantly related to PIAT-M scores ($b = .18$, $p < .05$). We also found a negative and significant independent effect of maternal age on PIAT-RR scores ($b = –0.19$, $p < .05$). In other words, although children of young mothers are relatively disadvantaged when compared with children of older mothers, once these characteristics are controlled for, children born to younger women actually perform slightly better on the PIAT-RR test.

Overall, the statistical controls in these models explained little of the between-child variation but a large share of the between-family variation. Specifically, our full-model estimates explained roughly 44% (PIAT-M) and 32% (PIAT-RR) of the family-level variation but only 1% of the between-child variation in PIAT-M scores and 3% of the between-child variation in PIAT-RR scores. And because there is little variation among siblings with respect to a number of our predictors (i.e., most of the siblings share similar racial/ethnic and socioeconomic characteristics) except birth-weight status, it is possible that birth-weight differentials among siblings account for this relatively small amount of the variation explained in between-child PIAT-RR scores. In other words, the social context of children's households appears to be significantly more influential on children's development than is their birth outcomes.

Our second research question concerns the ways in which the relationships specified in the full models (Tables 2 and 3) vary significantly with a child's age to affect developmental outcomes. In other words, we know from the previous models that low-birth-weight status is negatively and significantly related to developmental outcomes above and beyond the social and economic context of children's households and that there are powerful associations between several of the social risk factors (e.g., race/ethnicity, maternal education, and HOME score) and our two outcomes. To assess the dynamic relationship between low birth weight, social risk factors, and developmental outcomes with age, we estimated an interactive model with additional parameter estimates for the interaction between each covariate and child's age.

We first focus on the interaction of birth weight by child's age. Tables 2 and 3 show that the deleterious effect of MLBW status on PIAT scores significantly decreases in magnitude by over half a point with each additional year of age (PIAT-M: $b = 0.57$, $p < .05$; PIAT-RR: $b = 0.55$, $p < .05$). The negative effect associated with VLBW status, however, does not vary by age. It is also important to note that non-Hispanic black children fall increasingly behind their non-Hispanic white counterparts on both PIAT assessments from ages 6 to 14. This relationship is most pronounced among reading scores, where the black-white differential increases by roughly 2 points ($b = –1.84$, $p < .001$) with each additional year of age. Among the PIAT-M scores, the rate at which black children fall behind white children is not as severe ($b = –0.67$, $p < .001$), but follows a pattern similar to that of the PIAT-RR scores. To illustrate these findings, we plotted the predicted black-white and low-birth-weight–normal-birth-weight differentials in the PIAT-RR scores by children's ages (see Figure 1). According to these estimates, MLBW children score over 4 points lower than NBW children with similar social and economic characteristics at age 6; but

Figure 1. Race and Birth-Weight Differentials in PIAT-RR, by Age



by age 14, there is no difference between MLBW and NBW children on the PIAT-RR. The disparity between black and white children's scores, however, operates in the opposite direction: at age 6, net of social and economic controls, non-Hispanic black children score, on average, less than 4 points lower than non-Hispanic white children. By age 14, however, this differential is greater than 18 points. The same general pattern holds for PIAT-M scores (this figure is not shown but is available from the authors on request).

We also observed significant interaction terms for child's age with maternal age, gender (math only), HOME score (math only), education (reading only), and marital status (reading only). In particular, although girls score slightly higher on the PIAT-M assessment at age 6, on average, they appear to fall a 0.5 percentile point behind boys every year. Equally important is the increasing difference between the reading scores of children whose mothers have less than a high school education and those whose mothers completed college. At age 6, children with mothers who did not graduate from high school score an estimated 15 points lower on the PIAT-RR than do those whose mothers graduated from college; at age 14, this gap is over 20 points ($b = –0.63$, $p < .05$). Last, on the PIAT-RR, children of unmarried mothers fall an estimated 0.3 point behind children whose mothers are married with every year. At age 6, children whose mothers are unmarried do not significantly differ from children whose parents are married on the PIAT-RR. By age 14, however, children of unmarried mothers score roughly 2 points lower than do those whose parents are married. Taken together, this complete set of interaction effects suggests that whereas the effects of birth outcomes either remain constant (VLBW) or decrease (MLBW) in significance with a child's increasing age, the influence of many of the social risk factors is more pronounced among older children.

CONCLUSION

Demographers have long been interested in studying adverse birth outcomes, largely because of these outcomes' strong influence on the risk of infant mortality and other severe medical problems during early childhood. Few large-scale studies, however, have investigated the effects of adverse birth outcomes on longer-term risks during childhood and adolescence, mainly because of the stringent data requirements necessary to conduct such analyses. Using the NLSY–CD, we found that there are modest-sized negative effects of low birth weight on childhood math and reading scores, although the effects on both are weaker among older children than among younger children. In contrast, we found that the effects of race/ethnicity, maternal education, gender, home environment, unmarried status, and young maternal age on the developmental outcomes exhibit either constant effects across children's ages or are even more pronounced for children at age 14 than at age 6. These results strongly suggest that although the health of children at birth is surely important for their long-term development, children's social experiences are clearly prominent predictors of long-term well-being.

This article makes four important contributions. First, the findings presented here highlight the otherwise masked heterogeneity within the group that is conventionally defined as "low birth weight." Although some have cautioned against the continued use of the 2,500-gram threshold for low birth weight (Kline, Stein, and Susser 1989) and others have effectively demonstrated a nonlinear relationship between birth weight and health risks (Boardman, Finch, and Hummer 2001; Solis et al. 2000), researchers continue to use this binary categorization of birth weight (e.g., Conley and Bennet 2000) as a convenient predictor of a wide range of health and developmental outcomes. We found a strong relationship between birth weight and developmental outcomes such that the VLBW children (< 1,500 grams) in our sample not only scored significantly lower than the NBW children but also scored roughly 6.5 (math) and 8.5 (reading) percentile points lower than the MLBW children (1,500–2,499 grams). And not only did we document an increased risk of poorer developmental outcomes among VLBW than among MLBW children, we also presented evidence that the developmental trajectories of these two subpopulations of children are measurably different. In other words, VLBW children face greater challenges than do MLBW children in terms of positive developmental outcomes, but they also may face different challenges. This finding has important public health implications, given the relative number of VLBW children compared with MLBW children. Specifically, in 1999, whereas 7.6% of all children born in the United States were less than 2,500 grams at the time of delivery, children born weighing less than 1,500 grams made up only 1.2% of the total number of children who were born (Ventura et al. 2001). Of the 3.96 million births that occurred in 1999, this difference represents an at-risk population of over 250,000 for MLBW children, compared with under 50,000 for VLBW children.

Second, the differences in the developmental trajectories of VLBW and MLBW children that we documented are also important because they build on the work of Conley and Bennett (2000). These authors used longitudinal data from the Panel Study of Income Dynamics to show that children who were born with low birth weights are substantially disadvantaged in graduating from high school in a timely fashion. Together with their earlier analysis showing a robust influence of parental birth weight on filial birth weight, these findings suggest a cycle of biological disadvantage such that low birth weight is strongly influenced by parental birth weight and then goes on to have an adverse influence on socioeconomic outcomes. Because of data limitations and a subsequently small number of individuals who were born under 1,500 grams, Conley and Bennett limited their operationalization of low birth weight to a threshold of 2,500 grams. It is possible that the effects that they reported were driven primarily by children with VLBW (i.e., less than 1,500 grams). Indeed, according to our results, the at-risk population that has been conventionally defined as low birth weight, with respect to academic achievement among adolescents, may not necessarily include children who weighed 1,500 to 2,500 grams at birth.

Third, our findings are also important because they suggest that the relative impact of MLBW vis-à-vis the characteristics of children's social contexts is small in magnitude. In particular, the independent net effect of maternal education appears to far outweigh the effect of MLBW as a predictor of children's test scores. Moreover, the deleterious effect of this important characteristic of children's social context on children's academic test scores was more pronounced among older children. These results, which are much more in line with the current thinking of the broader literature on low birth weight (Hack et al. 1995), suggest that children's home environments and the socioeconomic and demographic backgrounds of their parents have a much more powerful influence on children's cognitive development than does the weight at which the children were born.

Finally, it is particularly important to point out that our analyses demonstrate large racial/ethnic disparities in developmental outcomes, such that black and Mexican American children scored below non-Hispanic white children on both the math and reading tests. These racial/ethnic differentials persisted despite a wide range of controls for children's social and economic characteristics. Furthermore, for non-Hispanic black children, the differential with non-Hispanic white children was wider among older children than among younger children, whereas the Mexican American-white gap was constant across ages. Here, it is important to consider school-based disparities in access to educational resources among non-Hispanic white, non-Hispanic black, and Mexican American children as a potentially important mediator between race/ethnicity and performance on standardized tests. For example, according to Ferguson (2001:381) non-Hispanic black children (and to a lesser extent Hispanic children) are more likely than non-Hispanic white children to respond affirmatively to the following statements about their schools: (1) "too many teachers are doing a bad job"; (2) "not enough emphasis on the basics such as reading, writing, and math"; (3) "too many kids get passed to the next grade when they should be held back"; and (4) "classes are too crowded." Likewise, 13% of non-Hispanic black children and 16% of Hispanic children, compared with only 6% of non-Hispanic white children, report being afraid of "being attacked or harmed at school" (Mayer, Mullens, and Moore 2000). Moreover, Roscigno (1998) found evidence that school characteristics (i.e., racial composition; socioeconomic characteristics; teachers' expectations; and, to a lesser extent, student-teacher ratios) are strongly related to students' scores on math and reading achievement tests and that black-white differences in these characteristics accounted for roughly 14% of the observed racial gap in test scores. And although differences in class size along racial/ethnic lines have been reduced since the publication of Coleman et al.'s (1966) influential report, stark differences persist in the average level of school resources and quality of teachers for black, white, and Hispanic children. For example, first-time teachers (Henke, Chen, and Geis 2000), and unqualified teachers (Mayer et al. 2000) are more likely to work in high-minority and high-poverty schools, respectively: whereas 38% of all teachers work in high-poverty schools, 64% of all unqualified teachers work in high-poverty schools (Mayer et al. 2000). Given the overrepresentation of non-Hispanic blacks and Hispanics in high-poverty areas (Jargowsky 1997), the quality of teachers may be an important characteristic that mediates the observed racial/ethnic differentials in both PIAT assessments. It also stands to reason that these differentials would help account for the larger magnitude of the observed black-white differentials among older children. In other words, not only do non-Hispanic black children face a disadvantage compared with non-Hispanic white children in their access to good-quality education, but this disadvantage, with respect to reading and math scores, also appears to be cumulative. Clearly, aggressive steps need to be taken to help end the racial/ethnic disparities in parental, school, and neighborhood resources on which children's well-being depends.

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