Available online at www.sciencedirect.com
SCIENCE DIRECT®
INTELLIGENCE
Intelligence 34 (2006) 351–362

# Low birthweight and social disadvantage: Tracking their relationship with children's IQ during the period of school attendance

Naomi Breslau [a,*], William T. Dickens [b], James R. Flynn [c], Edward L. Peterson [d], Victoria C. Lucia [a]

[a] Department of Epidemiology, Michigan State University, B645 West Fee Hall, College of Human Medicine, East Lansing, MI 48824, United States
[b] Brookings Institution, Washington, DC, United States
[c] Department of Political Studies, University of Otago, Dunedin, New Zealand
[d] Department of Biostatistics, Henry Ford Health System, Detroit, MI, United States

Received 7 December 2004; received in revised form 11 August 2005; accepted 18 October 2005
Available online 20 December 2005

**Abstract**

Generalized estimating equations were used to examine the relation of low birthweight, an indicator of adverse perinatal events, and social disadvantage to IQ changes during the period of school attendance. Data are from a longitudinal study of low birthweight and normal birthweight children in two disparate communities, an inner-city and near-by suburbs in southeast Michigan ($n = 773$). Wechsler intelligence tests were administered at ages 6, 11 and 17. Low birthweight-related deficits (vs. normal birthweight) detected at the start of schooling were about 5 IQ points and these remained constant up to age 17. Initial IQ deficits associated with urban environment (vs. suburban) increased significantly from age 6 to 11, but no further by age 17. These trends were independent of one another: The low birthweight deficit was constant across social environments; the social disadvantage deficit was uniform across birthweight groups. The finding that the urban–suburban gap did not continue to widen after age 11 probably resulted from an atypical IQ decline of suburban children. The causes of this unexpected finding are unclear.


## 1. Introduction

Standardized intelligence tests are strong predictors of important outcomes for members of both majority and minority groups. These outcomes extend beyond academic performance to occupational attainment and other socially valued variables. It is by now widely agreed that genetic factors contribute substantially to individual differences in intelligence, measured by standard IQ tests (Bouchard & McGue, 1981, 2003). There is also little doubt that the environment contributes to these differences (Neisser et al., 1996). Adverse perinatal events, for which low birthweight has served as a proxy, have been implicated (Aylward, 2002a; Bhutta, Cleves, Casey, Cradock, & Anand, 2002; Breslau, 1995; Hack et al., 1992, 2002; McCormick, Brooks-Gunn, Workman-Daniels, Turner, & Peckham, 1992). There is evidence suggesting that growing-up under various conditions of social deprivation, including con-

* Corresponding author. Tel.: +1 517 353 8623; fax: +1 517 432 1130.
*E-mail address:* breslau@epi.msu.edu (N. Breslau).

0160-2896/$ - see front matter © 2005 Elsevier Inc. All rights reserved.
doi:10.1016/j.intell.2005.10.003

ditions that affect the amount and quality of schooling, has an adverse influence on children's IQ (Ceci, 1991, 1996; Douglas, 1964; Lee, 1951).

We have examined the association of low birthweight and social disadvantage with children's IQ after the start of schooling in the inner-city and middle-class suburbs of a major US metropolitan area. The study design, which compares children in two socioeconomically and racially disparate communities, offers a rare advantage for separating the deficits associated with low birthweight from the deficits associated with disadvantaged social environments. The association of social disadvantage with both low birthweight and cognitive development has been a major challenge in evaluating the sequelae of low birthweight per se (Aylward, 2002b; Kramer et al., 2001). Deficits of approximately 5 IQ points in low birthweight children in both the urban and suburban communities, detected at the first assessment, at the start of school, have been previously reported (Breslau et al. 1994). At that assessment, a wide IQ gap (of nearly one standard deviation) was observed between inner-city (urban) and suburban children, independent of low birthweight status (Breslau et al., 1994). Reassessment at age 11 detected the same low birthweight-related IQ deficits as had been observed at age 6, but an increase in the IQ gap between urban and suburban children, low birthweight and normal birthweight alike (Breslau et al., 2001).

In this report, we examine IQ change during the entire period of school attendance, up to age 17, when the sample was about to leave high school. Our focus is on differential IQ change between sub-groups of children, low birthweight vs. normal birthweight, and urban vs. suburban. We address the following questions: 1. What happened to low birthweight children during the period of school attendance, compared to normal birthweight children? 2. What happened to urban children during that period, compared to suburban children? 3. Did changes in IQ gaps vary between the early and later school years?

## 2. Methods

### *2.1. Sample and follow-up design*

Data are from a longitudinal study of low birthweight and normal birthweight children who were assessed at ages 6, 11, and 17. Complete information on the population, sampling, and assessment is presented elsewhere (Breslau, Paneth, & Lucia, 2004) and is summarized briefly here. We identified and assessed random samples of 6-year-old children from two socioeconomically and racially disparate populations. We targeted the 1983–1985 birth year cohorts of newborns who were 6 to 7 years of age in 1990–1992, the scheduled period of the initial fieldwork. Two major hospitals in southeast Michigan, one in the city of Detroit and the other in a middle-class suburb, were selected. In each hospital, for each year from 1983 through 1985, stratified random samples of low birthweight (<2500 g) and normal birthweight newborns were drawn from newborn discharge records. Although the percentage of low birthweight was higher in the urban than the suburban hospital, we sampled equal numbers of low birthweight children from each hospital. Children with severe disabilities, identified at birth or at age 6, were excluded. Of the 1095 in the target sample, 823 (75%) participated. The urban sample was 82.5% black; approximately 25% of the mothers had not completed high school, and more than one-half were single at the time the child was born. In contrast, the suburban sample was 94.5% white; only 7% of the mothers failed to complete high school, and approximately 10% were single. The second assessment was conducted in 1995–1997, with children assessed as they passed their 11th birthday; 717 (87.1%) of the initial sample were re-assessed.

In 2000–2002, when the children passed their 17th birthday, we assessed the sample a third time. A total of 713 children were assessed, 86.6% of the initial cohort, including 56 children who were not assessed at age 11. Of the original 823, 773 (93.9%) participated in one or both follow-up assessments. The Institutional Review Boards of the participating institutions from which the samples were drawn, and Michigan State University, where data analysis was conducted, approved the study.

### *2.2. IQ measurement*

The Wechsler Intelligence Scale for Children-Revised (WISC-R) (Wechsler, 1974) was used to measure children's IQ at ages 6 and 11. The Wechsler Adult Intelligence Scale-third edition (WAIS-III) was used at age 17, as the appropriate test for this age (Wechsler, 1997). The IQ tests are age-standardized and have a mean of 100 and a standard deviation of 15 in the general population. Children were assessed individually under the same standardized laboratory conditions at all ages. Psychometricians were trained to a uniform standard and all tests files were scored by two independent testers. Periodic monitoring for adherence to test administration rules, as specified in the official manuals, was conducted throughout each assessment period.

Tests were conducted blind with respect to low birthweight status and the results of previous assessments. Correlation of full-scale IQ scores between ages 6 and 11 was 0.86 and between ages 11 and 17, 0.90.

### *2.3. Statistical analysis*

Generalized estimating equations (GEE) approach to linear regression (Diggle, Liang, & Zeger, 1994; Liang & Zeger, 1986; Zeger & Liang, 1986) was used to estimate IQ change associated with low birthweight and with growing-up in a disadvantaged urban community. The availability of IQ scores at ages 6, 11 and 17 enabled us to examine whether IQ change associated with these risk factors varied between early and later school years. Toward this end, we incorporated into the models two features. One, we included as a covariate prior IQ, which is IQ at age 6 for the first period and IQ at age 11 for the second. (The implication of including this covariate is given below.) Two, we included an interaction term of age × urban (vs. suburban) to estimate the differential change in urban vs. suburban children between the earlier (6 to 11) and later (11 to 17) school periods. Other two- and three-way interactions involving age, low birthweight and urban vs. suburban were tested but none was detected at alpha = 0.15. The final model includes two interactions, i.e. urban × age and prior IQ × age. The second interaction allows regression to the mean to proceed at different rates between the two school periods.

The model is illustrated in the following equation:

$$Y = \alpha + \beta_1(\text{urban}) + \beta_2(\text{age}) + \beta_3(\text{urban} \times \text{age}) + \beta_4(\text{prior IQ}) + \beta_5(\text{prior IQ} \times \text{age}) + \beta_6(\text{low birthweight}),$$

where standardized IQ scores at ages 11 and 17 are the outcome ($Y$); urban = 1 if child's residence is urban and 0, if suburban; age = 1 for IQ at age 17 and 0 for IQ at 11; prior IQ is WISC-R at age 6 when the outcome is IQ at age 11 and WISC-R at age 11 when IQ is at age 17; low birthweight = 1 if child is low birthweight and 0, if normal birthweight.

The coefficient for urban vs. suburban ($\beta_1$) in this model, which includes an interaction between urban and age ($\beta_3$), is the difference in mean IQ change in urban relative to suburban children from age 6 to age 11, adjusted for IQ at 6. The interaction term, $\beta_3$, is the difference in IQ change between the two periods (6 to 11 vs. 11 to 17) in urban relative to suburban children again adjusted for prior IQ. A significant interaction would indicate that the IQ change in urban relative to suburban children differed significantly between the two periods. The interpretation of the results in relation to the research question concerning what happened to the urban–suburban IQ gap during the period of school attendance, depends on the estimates of $\beta_1$ and $\beta_3$ considered together. For example, a non-significant $\beta_3$ and a significant $\beta_1$ with a negative sign would indicate a widening urban–suburban IQ gap (adjusted for prior IQ), which did not vary overtime but continued at a similar pace. (In fact, as we report below, the urban–age interaction *is* significant.)

A second model in which we added to the equation maternal IQ and maternal education is displayed as well (Model 2, Table 3). It estimates the contributions of these key family characteristics to the trend in the urban–suburban IQ gap during the period of school attendance.

GEE models (an application of Generalized Least Squares) utilize data on all respondents, including those with incomplete data. We include all those with at least one follow-up assessment ($n = 773$). GEE provides regression coefficients and standard errors, taking into account the correlations across multiple IQ tests within individuals. The potential bias in the standard errors due to the correlation across tests taken by the same person is reduced and estimates are asymptotically efficient. We used the exchangeable correlations as the working covariance structure. Statistical inferences are based on the robust variances of the coefficients, which are consistent, even if the covariance structure is misspecified. The coefficients are unstandardized partial regression coefficients, representing IQ points.

To illustrate the main results of this model, we graph in Figs. 1 and 2 the distributions of IQ change scores of urban and suburban children, low birthweight and normal birthweight combined. Fig. 1 depicts the intra-individual changes from age 6 to 11 and Fig. 2, from age 11 to 17. For each period, IQ change was adjusted for prior IQ and LBW. This adjusted difference is defined in the equation: $Y_{\text{adjusted}} = Y - b_1$ (prior $\text{IQ}_{\text{mean}}$ [prior IQ]) $- b_2$ (LBW vs. $\text{NBW}_{\text{mean}}$ [LBW vs. NBW]) (Cohen, 1977).

To dispel doubts that the feature in the GEE approach that allows us to include subjects with incomplete data might have influenced the results, we repeated the analysis on the subset of 657 children who participated in all three assessments. The analysis from this subset confirmed the results from the full sample.

Adjusting for prior IQ in these analyses presupposes the null hypothesis that initial IQ scores vary randomly about an overall sample mean (Fleiss, 1986) (rather than about distinct sub-group means, e.g., urban and suburban), and that re-assessments at 11 and 17 would show regression to a common mean and therefore a closing of the IQ gap. Evidence of a less than expected closing of the gap (expected by virtue of regression to a common mean) would refute the assumption on which the null was based and suggest the need to consider a different null hypothesis as our starting point.

## 3. Results

Results are based on data from 773 children—94% of the original sample—on whom IQ scores were available for at least one follow-up assessment, in addition to the initial assessment at age 6. On sociodemographic characteristics, the urban and suburban groups varied widely. However, within each community, differences between the low birthweight and normal birthweight subsets were not significant (Table 1). Neonatal characteristics were similar in both communities (Table 1). Descriptive data, means and standard deviations for full-scale, performance and verbal IQ scores by age, low birthweight vs. normal birthweight and urban vs. suburban, appear in Table 2.

Table 3 displays the results of the regressions used to estimate the relationship of IQ change with urban vs. suburban and low birthweight vs. normal birthweight status during the early and later school years. Results for Model 1 show that between ages 6 and 11 the urban–suburban IQ gap widened by 8.47 points controlling for previous IQ. In contrast, during the later school period, from age 11 to 17, there was hardly any increment in the urban–suburban IQ gap after controlling for previous IQ. Specifically, the increment was 0.60 points (−8.47+9.07) (SE=0.63) (not significant).

We cannot reject the hypothesis that IQ deficits associated with low birthweight neither increased nor decreased. That is, the initial low birthweight–normal birthweight IQ difference, detected at age 6, appears to have remained unchanged. This interpretation is based on the failure to detect a significant low birthweight by age interaction and a trivial and non-significant coefficient for low birthweight (−0.22) that, in the absence of

Table 1
Sociodemographic and neonatal characteristics of the urban and suburban samples

| | Urban | | | Suburban | | |
|---|---|---|---|---|---|---|
| | Total ($n$=394) | LBW ($n$=241) | NBW ($n$=153) | Total ($n$=379) | LBW ($n$=201) | NBW ($n$=178) |
| | % | % | % | % | % | % |
| Black | 82.5 | 84.6 | 79.1 | 5.5 | 5.0 | 6.2 |
| Male | 44.2 | 42.3 | 47.1 | 52.0 | 50.8 | 53.4 |
| Mother's education | | | | | | |
| <H.S. | 26.1 | 28.6 | 22.2 | 6.9 | 7.0 | 6.7 |
| H.S. | 26.6 | 26.1 | 27.4 | 27.2 | 27.4 | 27.0 |
| Some college | 37.3 | 36.9 | 37.9 | 37.7 | 37.8 | 37.6 |
| College | 9.9 | 8.3 | 12.4 | 28.2 | 27.9 | 28.6 |
| Single mother | 57.4 | 59.2 | 54.6 | 9.3 | 12.0 | 6.2 |
| Birthweight | | | | | | |
| <1000 g | 3.3 | 5.4 | – | 2.9 | 5.5 | – |
| 1001–1500 g | 7.1 | 11.6 | – | 5.3 | 10.0 | – |
| 1501–2000 g | 13.4 | 22.0 | – | 8.7 | 16.4 | – |
| 2001–2500 g | 37.3 | 61.0 | – | 36.2 | 68.2 | – |
| 2501–3000 g | 8.1 | – | 20.9 | 6.9 | – | 14.7 |
| 3001–3500 g | 15.5 | – | 39.9 | 18.8 | – | 40.1 |
| 3501+ g | 15.2 | – | 39.2 | 21.2 | – | 45.2 |
| Apgar Score | | | | | | |
| 1 min≤5 | 13.3 | 17.5 | 6.6 | 12.3 | 20.5 | 2.9 |
| 5 min≤5 | 2.0 | 2.9 | 0.7 | 1.1 | 2.0 | 0.0 |
| SGA (<10th percentile) | 18.6 | 25.3 | 8.0 | 13.6 | 19.0 | 7.4 |
| In NICU | | | | | | |
| 0 days in NICU | 71.6 | 57.3 | 94.1 | 76.1 | 57.0 | 97.7 |
| ≤2 weeks in NICU | 9.0 | 10.9 | 5.9 | 5.8 | 9.5 | 1.7 |
| >2 weeks in NICU | 19.4 | 31.8 | 0.0 | 18.1 | 33.5 | 0.6 |
| Maternal age: mean (SD) | 24.5 (5.8) | 24.6 (6.0) | 24.3 (5.3) | 27.7 (4.8) | 27.7 (5.0) | 27.8 (4.5) |

LBW, low birthweight; NBW, normal birthweight; SGA, small for gestational age; NICU, neonatal intensive care unit.

Table 2
Mean (SD) of IQ scores at 6, 11, and 17 years of age

| | Urban | | | | Suburban | | | |
|---|---|---|---|---|---|---|---|---|
| | LBW | | NBW | | LBW | | NBW | |
| | *n* | Mean (SD) | *n* | Mean (SD) | *n* | Mean (SD) | *n* | Mean (SD) |
| Age 6 | 252 | | 161 | | 221 | | 189 | |
| Full scale IQ | | 93.57 (15.88) | | 99.11 (14.10) | | 106.59 (14.89) | | 112.47 (14.94) |
| Performance IQ | | 93.17 (15.67) | | 98.98 (13.30) | | 105.16 (15.23) | | 110.06 (14.42) |
| Verbal IQ | | 95.03 (16.11) | | 99.46 (15.39) | | 106.75 (15.52) | | 112.60 (15.34) |
| Age 11 | 231 | | 143 | | 180 | | 163 | |
| Full Scale IQ | | 88.13 (14.72) | | 94.11 (13.62) | | 107.77 (14.78) | | 112.80 (14.29) |
| Performance IQ | | 88.52 (15.25) | | 94.09 (13.12) | | 106.47 (15.27) | | 111.14 (14.55) |
| Verbal IQ | | 89.67 (14.44) | | 95.03 (14.23) | | 107.54 (14.25) | | 111.17 (14.20) |
| Age 17 | 222 | | 142 | | 183 | | 166 | |
| Full Scale IQ | | 85.75 (12.27) | | 90.11 (12.87) | | 102.07 (13.56) | | 105.57 (14.66) |
| Performance IQ | | 87.15 (12.42) | | 90.89 (11.69) | | 102.23 (13.69) | | 104.19 (14.19) |
| Verbal IQ | | 86.25 (11.85) | | 90.27 (13.02) | | 102.06 (13.71) | | 105.87 (15.52) |

LBW = Low birthweight; NBW = Normal birthweight.

an interaction with age, applies to both school periods. Further, due to the failure to detect significant interactions between low birthweight and urban (vs. suburban) and 3-way interaction between these two variables and age, we cannot reject the hypothesis that the low birthweight relationship to IQ was stable in both the urban and suburban communities. Results for Model 2 in Table 3 show that the addition of family factors related to children's IQ gains did not alter the estimates in Model 1.

Parallel analyses of verbal and performance IQ showed that, between ages 6 and 11, the urban–suburban gap increased by 7.6 points in both verbal and performance IQ ($p<0.0001$), controlling for previous IQ. Between ages 11 and 17, the urban–suburban verbal IQ gap increased by 2.17 points ($p<0.0001$), whereas the performance IQ gap, increased by 1.08 ($p=0.13$).

To illustrate the results in Table 3, we display in Figs. 1 and 2 the distributions of IQ change, adjusted for prior IQ and low birthweight. From age 6 to 11, changes in IQ scores were pervasive in both urban and suburban children, ranging from decrements of more than 20 points to gain exceeding 20 points (Fig. 1). However, the net effects of the adjusted IQ change differed between the two communities. The urban distribution is shifted to the left of the suburban distribution, indicating that a larger proportion of urban than suburban children declined during the 5-year period.

Table 3
Regression estimates of children's IQ change during the period of school attendance: two successive GEE models adjusted for prior IQ

| | Model 1 | | | Model 2 | | |
|---|---|---|---|---|---|---|
| | *β* | (SE) | *p* value | *β* | (SE) | *p* value |
| Urban (vs. suburban) | −8.47 | (0.71) | <0.0001 | −7.51 | (0.70) | <0.0001 |
| LBW (vs. NBW) | −0.22 | (0.35) | 0.53 | −0.26 | (0.35) | 0.46 |
| Age 17 (vs. 11) | −20.60 | (3.81) | <0.0001 | −18.62 | (3.69) | <0.0001 |
| Urban × age | 9.07 | (1.10) | <0.0001 | 8.60 | (1.06) | <0.0001 |
| Prior IQ[a] | 0.77 | (0.02) | <0.0001 | 0.74 | (0.02) | <0.0001 |
| Prior IQ × age | 0.13 | (0.03) | 0.0002 | 0.11 | (0.03) | 0.002 |
| Mother's IQ[b] | – | | – | 0.07 | (0.02) | <0.0001 |
| Mother's education[c] | | | | | | |
| <High school | – | | – | −1.54 | (0.66) | 0.02 |
| High school | – | | – | −1.39 | (0.57) | 0.01 |
| Part college | – | | – | −1.11 | (0.50) | 0.03 |

*β* = unstandardized partial regression coefficients.
SE = standard error.
LBW = low birthweight (<2500 g); NBW = normal birthweight (>2500 g).
[a] Prior IQ is IQ at 6 for change from 6–17 and IQ at 11 for change from 11–17.
[b] Mother's IQ was measured by the Two-Subset Short Form of the WAIS-R (Silverstein, 1982).
[c] Reference group for education is college.

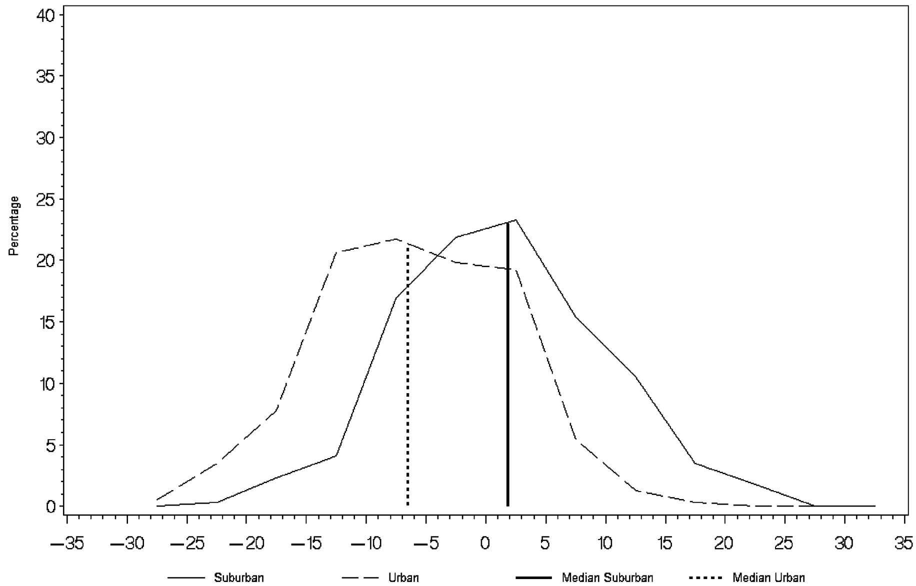


Fig. 1. Adjusted IQ (for prior IQ and LBW) change in urban and suburban children (6–11) ($n = 717$).

The medians of the two distributions are separated by 8.6 IQ points (Fig. 1). From 11 to 17 years of age, the distributions of the adjusted IQ change scores were similar in the two communities; only 2 points separated the medians of the two distributions (Fig. 2).

We examined what happened to the urban–suburban IQ gap, excluding approximately 20% of the sample who migrated out of the urban, inner-city area. The results show that from age 6 to 11, the urban–suburban IQ gap in these residentially stable groups widened by 9.74 points (SE = 0.81) ($p < 0.0001$), controlling for prior IQ. From age 11 to 17, the IQ gap widened by 0.78 points (SE = 0.73) (not significant), again controlling for prior IQ.

### 3.1. Additional analysis: testing divergence from distinct sub-population means over time

The analysis of change, presented above, which included prior IQ as a covariate, tested the null hypoth-

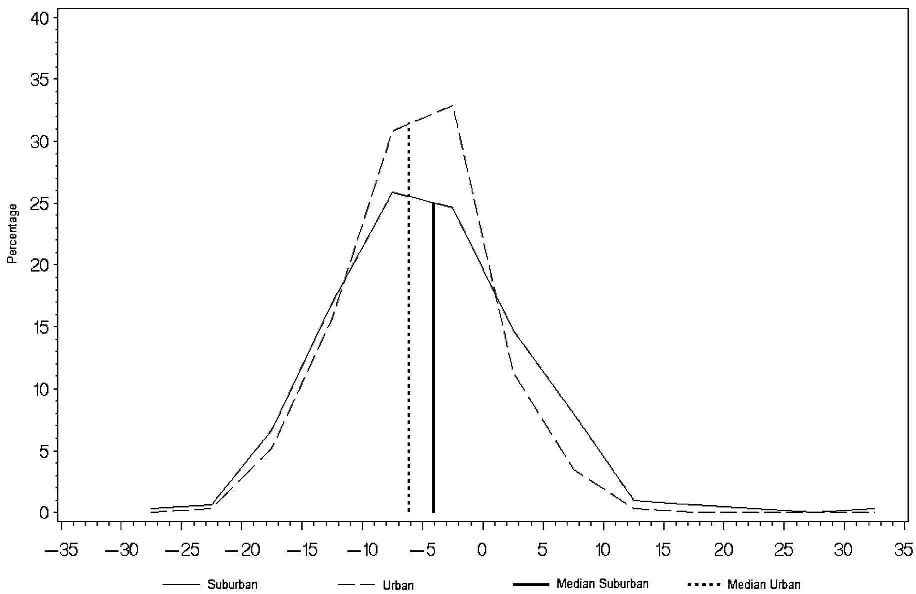


Fig. 2. Adjusted IQ (for prior IQ and LBW) change in urban and suburban children (11–17) ($n = 657$).

esis that IQ scores of sub-groups displayed equal tendencies to regress to the same overall mean. The results refuted this expectation and showed instead an increase in the urban–suburban IQ gap during the early school years. An alternative null hypothesis is that initial and subsequent IQ means of sub-groups of children are different. The null hypothesis in this case would be regression to distinct sub-group means with no change in these means over time. We tested this model, using GEE models that did not include prior IQ as a covariate.

IQ scores at ages 6, 11 and 17 were used as outcomes and were regressed on risk factors of interest. Interaction terms were added in order to estimate IQ change over time associated with risk factors. The model is illustrated in the equation:

$$Y = \alpha + \beta_1(\text{urban}) + \beta_2(\text{age } 11) + \beta_3(\text{age } 17) + \beta_4(\text{urban} \times \text{age } 11) + \beta_5(\text{urban} \times \text{age } 17) + \beta_6(\text{low birthweight}),$$

where IQ score at ages 6, 11 and 17 are the outcomes ($Y$); urban = 1 if residence is urban and 0, if suburban; age 11 = 1 if age is 11 and 0, if 6 or 17; age 17 = 1 if age is 17 and 0, if 6 or 11; low birthweight = 1 if child is low birthweight and 0, if normal birthweight. $\beta_1$ is the mean urban and suburban IQ difference at age 6, adjusted for differences in the number of low birthweight children in each population. $\beta_4$ estimates the IQ change in urban relative to suburban children from age 6 to age 11, and $\beta_5$, from age 6 to age 17. Interaction of low birthweight and age, low birthweight and urban vs. suburban and 3-way interactions involving low birthweight, age and urban were tested but were not detected.

The results for Model 1 in Table 4 show that the coefficients of the two interactions are significant and have a negative sign, indicating decreases in urban relative to suburban children (and therefore increases in the IQ gap) at ages 11 and 17, relative to age 6. At age 11, the increase in the initial gap was by 5.11, but by age 17 it was by 2.25. In other words, the change in the urban–suburban IQ gap during the school years did not show a continuous growth. Instead, the period from 6 to 11 witnessed a widening in the urban–suburban gap, which then closed somewhat from 11 to 17. Specifically, at age 11, urban children lagged behind suburban children by 18.31 IQ points (13.20+5.11), whereas at age 17, they lagged by 15.45 IQ points (13.20+2.25). The change toward a narrower gap from 11 to 17 of 2.86 (SE = 0.67) points was significant ($p < 0.0001$). Low birthweight children scored 5.15 IQ points lower than normal birthweight children, on average, with no evidence of change over time (no significant interactions with age). Model 2 shows that familial variables, which accounted for a considerable part of the initial urban–suburban IQ gap at age 6, altered little the estimate of the changes in the urban–suburban gap as estimated in Model 1. Both models show that mean IQ scores of suburban children did not change from age 6 to age 11 ($\beta$ = 0.16 and 0.17 in the first and second models, respectively) but that

Table 4
Regression estimates of IQ at ages 6, 11 and 17: results from two successive GEE models of children's IQ changes

| | Model 1 | | | Model 2 | | |
|---|---|---|---|---|---|---|
| | $\beta$ | (SE) | $p$ | $\beta$ | (SE) | $p$ |
| Urban (vs. suburban) | −13.20 | (1.05) | <0.0001 | −4.33 | (1.09) | <0.0001 |
| Age 11 (vs. 6) | 0.16 | (0.48) | 0.74 | 0.17 | (0.49) | <0.77 |
| Age 17 (vs. 6) | −6.44 | (0.52) | <0.0001 | −6.48 | (0.52) | <0.0001 |
| LBW (vs. NBW) | −5.15 | (0.95) | <0.0001 | −3.99 | (0.83) | <0.0001 |
| Urban × age 11 (vs. 6) | −5.11 | (0.65) | <0.0001 | −5.13 | (0.66) | <0.0001 |
| Urban × age 17 (vs. 6) | −2.25 | (0.69) | 0.001 | −2.21 | (0.69) | 0.001 |
| Mother's IQ[a] | – | | – | 0.40 | (0.04) | <0.0001 |
| Mother's education[b] | | | | | | |
| <High school | – | | – | −5.68 | (1.74) | 0.001 |
| High school | – | | – | −4.16 | (1.42) | 0.003 |
| Part college | – | | – | −1.88 | (1.25) | 0.13 |
| Single mother | – | | – | −3.62 | (1.03) | 0.0004 |

$\beta$ = unstandardized partial regression coefficients.
SE = standard error.
LBW = low birthweight (≤2500 g); NBW = normal birthweight (>2500 g).
[a] Mother's IQ was measured by the Two-Subset Short Form of the WAIS-R (Silverstein, 1982).
[b] Reference group for education is college.

their mean IQ declined significantly by age 17 ($\beta = -6.44$ and $-6.48$ in the first and second models, respectively).

## 4. Discussion

We examined IQ changes during the period of school attendance in relation to two factors, perinatal risk, as indicated by low birthweight, and social disadvantage. We used two statistical approaches, each posing a different null hypothesis about the nature of IQ differences associated with low birthweight and social disadvantage. The first is that there will be a regression to a common overall sample mean. This approach entails including prior IQ as a covariate in a regression of current IQ on dummy variables (low birthweight vs. normal birthweight, age, and urban vs. suburban) and their interactions. The second null hypothesis is that sub-group differences are fixed and that there would be a regression to distinct sub-group means. This analysis does not adjust for prior IQ. Both approaches converged on the low birthweight question but varied partly on the social disadvantage question.

### 4.1. Low birthweight and IQ

Low birthweight-related IQ deficits, detected at the start of schooling, remained unchanged throughout the school years, according to both statistical approaches. The extent of the deficit and its stability over time did not appear to vary between the urban, disadvantaged community and the suburban, middle-class community. There is no evidence that low birthweight children either fell further behind age-mates in the urban community or caught-up with age-mates in the suburban community. This pattern held across levels of low birthweight, including very low birthweight (less than 1500 g). The stability of low birthweight-related deficits up to age 17 and their uniformity across disparate social environments do not imply that low birthweight children were impervious to the stark disparities between the communities in which they grew-up, and that their social environment had no consequences. To the contrary, low birthweight children in the urban inner-city were worse-off than low birthweight children who grew-up in the suburbs: urban low birthweight children started school with a considerably lower IQ score than suburban low birthweight children, just as their normal birthweight age-mates did, and the initial disparity grew wider during the school years. In other words, apart from low birthweight-related deficits, urban low birthweight children suffered the added adverse effects of social disadvantage (see Discussion of such 'double hazards' in Escalona (1982)). A recent report on very low birthweight children documented independent effects on age 8 IQ of visual recognition memory in the first year of life and SES (Smith, Fagan, & Ulvund, 2002). As we have no control for genetic background, social disadvantage in this case could include a poor genetic endowment.

Our initial assessment at age 6 constrained our ability to trace back the time at which IQ differences first emerged. There is evidence that low birthweight as well as racial- and SES-related differences in cognitive abilities are detectable at 5- and even 3-years of age (Infant Health and Development Program, 1990; Klebanov, Brooks-Gunn, McCarton, & McCormick, 1998).

The observation that IQ varies by birthweight has a long history, as summarized by Matarazzo (1972, pp. 324) more than 30 years ago. Several reviews of the literature on birthweight and IQ dating back to the 1940s are cited in his summary, including a 1968 study that shows a clear gradient between birthweight and IQ in children 8–10 years of age in each of three SES strata (Wiener, Rider, Oppel, & Harper, 1968). A recent meta-analysis confirmed the gradient relationship with birthweight, and, consistent with our finding of the stability of the association of low birthweight with IQ over time, reported no significant correlation between age and low birthweight-related deficits in cognitive scores (Bhutta et al., 2002).

The size of the low birthweight-related IQ deficit—approximately one-third of a SD—means that almost 10% more low birthweight than normal birthweight children of similar backgrounds scored lower than 1 SD below the standardized IQ mean of 100, given that the shapes of the two IQ distributions were similar (Breslau et al., 1994). The implications of the deficit vary across communities. In disadvantaged communities, it amounts to an increment in the proportion of children at the low end of the IQ distribution, whereas in middle-class suburban children, it results in a decrement at the high end of the IQ distribution.

### 4.2. Social disadvantage and IQ

In contrast with the stability of low birthweight-related IQ deficits, deficits related to urban residence increased after children started school. Adjusting for prior IQ, urban children declined by approximately 8.5 IQ points, relative to suburban children. The decline in urban vs. suburban children occurred during the early school years, between ages 6 and 11; little change was detected between ages 11 and 17.

The second analytic approach, in which prior IQ was not adjusted for, yielded results largely consistent with this pattern. It showed a widening of the urban–suburban IQ gap in the early school years (by 5 IQ points), which did not continue in the later school years. The difference between the two analyses concerns what happened between ages 11 and 17. The second approach indicates that the IQ gap at age 17, although significantly larger than the initial gap, was smaller than at age 11, indicating a partial closing of the gap. The first approach, which included prior IQ as a covariate, indicates no deviation from expected change in the gap in either direction after age 11.

Explanations for the increasing urban–suburban IQ gap after the start of schooling and its timing are not entirely clear. The IQ decline in urban relative to suburban children during the early school years is apart from (and additional to) the initial IQ gap observed at the start of schooling. It was previously shown that the initial gap of approximately 1 SD could be accounted for, in a statistical sense, in large part by familial factors, that is, maternal IQ, maternal education and single mother status (Breslau et al., 2001). The results presented here show that, although familial factors were associated with children's IQ development during the school years, they accounted for only a trivial part of the differential IQ change between urban and suburban children. The increase in the IQ gap between urban and suburban children was therefore likely to have resulted from factors other than family environment.

The urban–suburban gap between age 6 and age 11 did not vary between verbal and performance IQ: on both domains, urban children showed the same decline, relative to suburban children. It is therefore not the case that the urban vs. suburban cumulative deficits in skills covered in the school curriculum (which have more weight in verbal IQ) account for the observed IQ change during the early period of school attendance.

### 4.3. Epilogue

Our main findings are based on group contrasts. That is, we found that the IQ deficit associated with low birthweight children (compared to normal birthweight) remained constant over the period of school attendance; that the IQ deficit associated with urban environment (compared to suburban environment) widened significantly from age 6 to age 11 but no further by age 17; that these two trends were independent of one another, that is, the low birthweight deficit was no less pronounced among the socially advantaged children and the urban deficit was no more pronounced among low birthweight children. Comparative analysis at each age—selecting normal birthweight as a reference for low birthweight and suburban as a reference for urban—was sufficient to demonstrate these findings.

However, two objections may be put. First, that one of our findings necessitates going beyond comparative analysis to trace absolute IQ trends for each of our groups from one age to another. Second, that our comparison of low birthweight and normal birthweight children has not taken into account the shorter gestation of the low birth weight children. We will discuss these in reverse order.

In our sample, the difference in gestation between the low birthweight and normal birthweight children was, on average, 4.2 weeks or one month. It can be argued that the average low birthweight child can be expected to take an extra month to catch up with the average normal birthweight child. Therefore, in assessing the IQs of our low birthweight children, should we not focus on age from conception rather than age from birth, thus treating the low birthweight children as one month younger than their chronological age? This would mean using the WISC-R norms to calculate how much an extra month's age would affect their raw scores and raise their IQ scores.

We used the WISC-R tables to approximate the effect of an extra month: over the age distribution in months at the age 6 testing, it added an average of 1.36 IQ points. The effect on our 17-year-olds was negligible at 0.02 IQ points. So it could be argued that about 27.2% of the five-point IQ deficit of low birthweight children at age 6 ($1.36/5.0=0.272$) was due to the one month shorter gestation, and that this faded away to 0.4% by age 17 ($0.02/5=0.004$). That would imply that other perinatal factors inflicted an IQ deficit of 3.64 points at age 6, which increased to 4.98 points at age 17. There is no harm in such an interpretation of our results, but we are skeptical. By age 6, both the low birthweight and normal birthweight children have enjoyed much the same socialization; by the time of testing, both have had the same amount of schooling. In other words, life experience has become the engine of their cognitive development. Expert opinion endorses our view: "correction for degree of prematurity appears to be appropriate in the first few months. After that point, slightly more accurate prediction is achieved by using the uncorrected scores. Early test scores are significantly influenced by the degree of biological maturity, but the impact of environmental influences increases with development" (Siegel, 1983). (See also review by Wilson & Cradock, 2004).

We pass on to the second objection. We found that the urban–suburban IQ gap, which widened between ages 6 and 11, did not continue to widen between ages 11 and 17, indeed, it narrows slightly. Is this because the urban children improved or the suburban children lost ground? Table 2 reveals that the mean IQ of suburban children fell by approximately 6 points between the ages of 11 and 17, a loss greater than that of urban children between the same ages. This suggests that the failure of the IQ gap between urban and suburban children to widen after age 11 was due to an IQ loss in suburban children that is prima facie atypical. Nearly all the suburban children are white, and at every age, cognitive tests are normed on samples dominated by white children. The IQ scores of the suburban children at age 6 and at age 11 are consistent with expectations. But we would not expect them to show losses after age 11.

Comparison of our results with the academic achievement literature adds perspective. Phillips, Crouse, and Ralph (1998) analyzed longitudinal data from national samples and found that while the racial gap increased from the first to the twelfth grade, the rate of the increase was much larger before high-school (before age 14). Others assert that rates of cognitive growth during the early school years are far greater than later on (Entwisle & Alexander, 1994; Jencks, 1985), and that “when growth is rapid, we would expect any contextual effects to be more pronounced” (Entwisle & Alexander, 1994).

However, while all of these imply a reduced rate of increase in the black–white score gap after age 11, it does not imply no increase at all. The Coleman report is a case in point (Coleman et al., 1966). It shows the IQ gap between blacks and whites widening by 6 IQ points between grades 3 and 6 (ages 8 to 11), but it also shows its widening by 2.5 IQ points between grades 6 and 12 (ages 11 to 17). Our results (Table 2) reveal that this is just about the trend we would have found in this study had white (suburban) IQ not declined after age 11. Perhaps most pertinent, our achievement test data confirm the IQ data. At both age 11 and age 17, children took the Woodcock–Johnson Psycho-Educational Battery-R (WJ-R) (Woodcock & Johnson, 1990). The scores of suburban children in mathematics declined by the equivalent of 6.0 IQ points (.40 SD) and their reading scores by 2.3 (.15 SD) points; both of these losses were greater than those suffered by the urban children (Breslau et al., 2004, pp. 1037, Table 2).

We also investigated whether the IQ losses of suburban children could be an artifact of inappropriate test norms. The problems the data pose are two: the IQ scores of our subjects would be affected by the obsolescence of the WISC-III and WAIS-R norms at the time of testing, and their scores would be affected by any other discrepancies between the norms of the two tests.

A word about obsolescence. From the day a test is normed, IQ gains render its norms out-of-date. For example, the standardization sample of the WISC-R was tested in 1972 and its norms, of course, date from that time. When the test was re-normed in 1989, it was discovered that average school pupils were no longer scoring 100 on the WISC-R; rather they were scoring at just above 105 (Flynn, 1998, p. 1232). In other words, IQ scores had become deceptive: subjects who were no better than average for their time appeared as if they were 5 points above average. Clearly, the antidote is to deduct the appropriate number of points to bring the norms up to date.

Children took the WISC-R in 1990 at the age of 6 (18 years after the test was normed) and in 1995 at the age of 11 (23 years after the test was normed). Therefore, their mean IQs should be reduced by 5.4 and 6.9 IQ points respectively, on the assumption that IQ gains were proceeding at a rate of 0.3 points per year. This rate of gain is attested not only by the WISC-R to WISC-III comparison but also by a total of 12 comparisons involving eight Wechsler–Binet tests standardized from 1972 to 2002 (Flynn & Weiss, submitted for publication).

Children took the WAIS-III in 2001 at the age of 17, as the appropriate test for young adults. Its norms were by then obsolete and it poses the additional problem that the norms of the WAIS and the WISC never quite match. The best expedient is to determine what they would have scored on the WISC-III and then allow for the latter’s 12 years of obsolescence (from 1989 to 2001). Fortunately, the Psychological Corporation gave 184 17-year olds both the WISC-III and WAIS-III in counterbalanced order; the results show that the latter gave full scale IQs 0.7 points higher than the former (Flynn, 1998, p. 1237). Moreover, the standard-

Table 5
Mean IQs of urban and suburban samples at various ages adjusted for obsolescence and variant test norms

| Age | Year | Urban (344) | | | Suburban (313) | | |
|---|---|---|---|---|---|---|---|
| | | IQ | SD | Ad IQ | IQ | SD | Ad IQ |
| 6 | 1990 | 96.04 | 14.90 | 90.64 | 110.58 | 15.55 | 105.18 |
| 11 | 1995 | 90.95 | 14.49 | 84.05 | 110.96 | 14.77 | 104.06 |
| 17 | 2001 | 87.07 | 12.28 | 82.27 | 104.42 | 14.07 | 100.12 |

Includes all children who participated in all three assessments ($N$=657).

ization of the WISC-IV in 2002 shows that the WISC-III's norms were becoming obsolescent at the familiar rate of 0.3 points per year (Flynn & Weiss, submitted for publication). Therefore, the WAIS-III scores must be reduced by 4.3 IQ points: 0.7 points to equate them with the WISC-III; and 3.6 points to allow for the WISC-III's obsolescence.

The value for the urban children requires an additional adjustment. The WAIS-R standardization sample included an extra quota of low IQ subjects with the stated intention of making norms in the retardate range more representative. Flynn (1998, Table 2) shows that this would mean an average score rise of 0.554 IQ points. But the rise for low-scoring subjects would be disproportionately large and favor a low-IQ group such as our urban children over an above-average-IQ group such as our suburban children. Therefore, a half point was deducted from the urban mean at age 17.

Table 5 shows the results of the appropriate adjustment for the 657 children who participated in all three assessments. The adjustments are approximate in the sense that one cannot be sure the rate of IQ gain is uniform between standardizations. However, we have had good luck in that our subjects were tested in 1990, 1995, and 2001 and there were Wechsler standardizations in 1989, 1995, and 2002, an almost perfect match.

The results confirm the fact that the failure of the urban–suburban IQ gap to widen between ages 11 and 17 was due to an IQ loss by the suburban children between those ages. The loss has fallen from 6 points on the unadjusted values (Table 2) to 3.94 IQ points on the adjusted values (Table 5).

The fact that we do not know why the suburban teenagers diverged from national norms does not alter our results. Low birthweight-related deficits detected at age 6 remained constant (at 5 points) up to age 17 and were uniform across the social environments represented here. The association between social disadvantage and low IQ was observed across birthweight groups. Our adjusted results show that the growth of the IQ gap between urban and suburban children during their school years was real, indeed, they show it increased by 3.3 points rather than 2.8. The only puzzle is why both groups lost ground in terms of national norms after age 11, rather than the urban group alone. The combination of achievement test data and adjusted IQ scores convinces us that the decline of the suburban children after that age is not an artifact. It was a real occurrence, probably due to unusual environmental circumstances, and deserves further investigation.

## Acknowledgements

This study was supported by grant MH-44586 from the National Institute of Mental Health, Bethesda, Maryland (Dr. Naomi Breslau).

## References

Aylward, G. P. (2002a). Cognitive and neuropsychological outcomes: more than IQ scores. *Mental Retardation and Developmental Disabilities Research Reviews*, *8*(4), 234–240.

Aylward, G. P. (2002b). Methodological issues in outcome studies of at-risk infants. *Journal of Pediatric Psychology*, *27*(1), 37–45.

Bhutta, A. T., Cleves, M. A., Casey, P. H., Cradock, M. M., & Anand, K. J. (2002). Cognitive and behavioral outcomes of school-aged children who were born preterm: A meta-analysis. *JAMA*, *288*(6), 728–737.

Bouchard Jr., T. J., & McGue, M. (1981). Familial studies of intelligence: A review. *Science*, *212*(4498), 1055–1059.

Bouchard Jr., T. J., & McGue, M. (2003). Genetic and environmental influences on human psychological differences. *Journal of Neurobiology*, *54*(1), 4–45.

Breslau, N. (1995). Psychiatric sequelae of low birth weight. *Epidemiological Review*, *17*(1), 96–106.

Breslau, N., DelDotto, J. E., Brown, G. G., Kumar, S., Ezhuthachan, S., Hufnagle, K. G., et al. (1994). A gradient relationship between low birth weight and IQ at age 6 years. *Archives of Pediatrics and Adolescent Medicine*, *148*(4), 377–383.

Breslau, N., Chilcoat, H. D., Susser, E. S., Matte, T., Liang, K. Y., & Peterson, E. L. (2001). Stability and change in children's intelligence quotient scores: A comparison of two socioeconomically disparate communities. *American Journal of Epidemiology*, *154*(8), 711–717.

Breslau, N., Paneth, N. S., & Lucia, V. C. (2004). The lingering academic deficits of low birthweight children. *Pediatrics*, *114*, 1035–1040.

Ceci, S. J. (1991). How much does schooling influence general intelligence and its cognitive components? A reassessment of the evidence. *Developmental Psychology*, *27*, 703–722.

Ceci, S. J. (1996). *On intelligence: A bio-ecological treatise on intellectual development* (Expanded ed.). Cambridge: Harvard University Press.

Cohen, J. (1977). *Statistical power analysis for the behavioral sciences* (revised edition). New York: Academic Press.

Coleman, J. S., Campbell, E. Q., Hobson, C. J., McPartland, J., Mood, A. M., Weinsfeld, F. D., et al. (1966). *Equality of educational opportunity, supplemental index, Sec. 9.10, correlation tables*. Washington D.C.: Office of Education.

Diggle, P. J., Liang, K. Y., & Zeger, S. L. (1994). *Analysis of longitudinal data*. New York: Oxford University Press.

Douglas, J. W. B. (1964). *The home and the school; a study of ability and attainment in the primary school*. London: Macgibbon and Kee.

Entwisle, D. R., & Alexander, K. L. (1994). Winter setback: The racial composition of schools and learning to read. *American Sociological Review*, *59*, 446–460.

Escalona, S. K. (1982). Babies at double hazard: early development of infants at biologic and social risk. *Pediatrics*, *70*(5), 670–676.

Fleiss, J. L. (1986). *The design and analysis of clinical experiments*. New York: John Wiley and Sons, Inc.

Flynn, J. R. (1998). WAIS-III and WISC-III: IQ gains in the United States from 1972 to 1995; how to compensate for obsolete norms. *Perceptual and Motor Skills*, *86*, 1231–1239.

Flynn, J. R., & Weiss, L. G. (submitted for publication). *American IQ gains from 1932 to 2002: The significance of the WISC subtests*.

Hack, M., Breslau, N., Aram, D., Weissman, B., Klein, N., & Borawski-Clark, E. (1992). The effect of very low birth weight and social risk on neurocognitive abilities at school age. *Journal of Developmental and Behavioral Pediatrics*, *13*(6), 412–420.

Hack, M., Flannery, D. J., Schluchter, M., Cartar, L., Borawski, E., & Klein, N. (2002). Outcomes in young adulthood for very-low-birth-weight infants. *New England Journal of Medicine*, *346*(3), 149–157.

Infant Health and Development Program (1990). Enhancing the outcomes of low-birth-weight, premature infants. A multisite, randomized trial. *JAMA*, *263*, 3035–3042.

Jencks, C. (1985). How much do high school students learn? *Sociology of Education*, *58*, 128–135.

Klebanov, P. K., Brooks-Gunn, J., McCarton, C., & McCormick, M. C. (1998). The contribution of neighborhood and family income to developmental test scores over the first three years of life. *Child Development*, *69*(5), 1420–1436.

Kramer, M. S., Goulet, L., Lyndon, J., Seguin, L., McNamara, H., Dassa, C., et al. (2001). Socio-economic disparities in preterm birth: causal pathways and mechanisms. *Paediatric and Perinatal Epidemiology*, *15*(Suppl. 2), 104–123.

Lee, E. S. (1951). Migration: A Philadelphia test of the Klineberg hypothesis. *American Sociological Review*, *16*, 227–232.

Liang, K. Y., & Zeger, S. L. (1986). Longitudinal data analysis using generalized linear models. *Biometrika*, *73*, 13–22.

Matarazzo, J. D. (1972). *Wechsler's measurement and appraisal of adult intelligence* (5th Edition). Baltimore, MD: The Williams and Wilkins Co.

McCormick, M. C., Brooks-Gunn, J., Workman-Daniels, K., Turner, J., & Peckham, G. J. (1992). The health and developmental status of very low-birth-weight children at school age. *JAMA*, *267*(16), 2204–2208.

Neisser, U., Boodoo, G., Bouchard Jr., T. J., Boykin, A. W., Brody, N., Ceci, S. J., et al. (1996). Intelligence: Knowns and unknowns. *American Psychologist*, *51*, 77–101.

Phillips, M., Crouse, J., & Ralph, J. (1998). Does the black–white test score gap widen after children enter school? In C. Jencks, & M. Phillips (Eds.), *The black–white test score gap* (pp. 229–272). Washington, DC: Brookings Institutional Press.

Siegel, L. S. (1983). Correction for prematurity and its consequences for the assessment of the very low birth weight infant. *Child Development*, *54*(5), 1176–1188.

Silverstein, A. B. (1982). Two-and four-subset short forms of the Wechsler Adult Intelligence Scale-Revised. *Journal of Consulting and Clinical Psychology*, *50*, 415–418.

Smith, L., Fagan, J. F., & Ulvund, S. E. (2002). The relation of recognition memory in infancy and parental socioeconomic status to later intellectual competence. *Intelligence*, *30*, 247–259.

Wechsler, D. (1974). *Wechsler intelligence scale for children-revised manual*. New York: The Psychological Corporation.

Wechsler, D. (1997). *Wechsler adult intelligence scale-third edition*. San Antonio: The Psychological Corporation.

Wiener, G., Rider, R. V., Oppel, W. C., & Harper, P. A. (1968). Correlates of low birth weight. Psychological status at eight to ten years of age. *Pediatric Research*, *2*(2), 110–118.

Wilson, S. L., & Cradock, M. M. (2004). Review: Accounting for prematurity in development assessment and the use of age-adjusted scores. *Journal of Pediatric Psychology*, *29*, 641–649.

Woodcock, R. W., & Johnson, M. B. (1990). *Woodcock–Johnson Psycho-Educational Battery-Revised*. IL: Riverside: Itasca.

Zeger, S. L., & Liang, K. Y. (1986). Longitudinal data analysis for discrete and continuous outcomes. *Biometrics*, *42*(1), 121–130.