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Abstract

We used multilevel covariance structure analysis to study the relationship between birth weight, family context, and youth math and reading comprehension growth from approximately age 5 until about age 14. Using data from the National Longitudinal Survey of Youth Child Sample (CNLSY79), we build on previous research examining both the causal relationship between birth weight and subsequent academic achievement disparities, distinguishing between birth weight and other contextual social confounders both within and between families. Taking into account family characteristics, including those that vary between-siblings within-families, we find that lower birth weight is associated with lower math and reading scores at age 5. Although these birth weight gaps do not increase as children age, they do not decrease either. Additional findings indicate that the home environment has important developmental consequences from early childhood and into adolescence. Overall, this pattern of findings paints a complex picture of disadvantage, beginning in the womb and extending through a variety of mechanisms into adolescence.

Introduction

The adverse impact of infant health on development is one of the many mechanisms through which childhood disadvantage is thought to influence later socioeconomic attainment (Conley, Strully, and Bennett 2003). Children by social class and racial/ethnic background are not at equal risk for low birth weight (LBW < 2500g), with the most disadvantaged also more likely to be born prematurely and/or of lower birth weight (Sastry and Hussey 2003; Paneth 1995; Cramer 1995). Although researchers have recently begun using large- scale longitudinal data sets to examine the association between poor birth outcomes, specifically birth weight, and children's developmental outcomes, more research is needed to address the relative influence of birth weight, poverty, and disadvantage on the life chances of America's youth.

The poverty literature has established a strong link between economic disadvantage and hardship, family structure, and child developmental outcomes (Duncan and Brooks-Gunn 1997; Yeung et al. 2002; McLoyd 1998; Link and Phelan 1995), and these characteristics are also thought to be related to the risk of low birth weight (Conley et al. 2003; Cramer 1995). However, although correlational studies suggest that birth weight, along with other risk factors, contributes to developmental heterogeneity in children's cognitive (e.g., Hack et al. 1995), mathematics, and reading skills (e.g., Boardman et al. 2002), questions of causality, effect magnitude and persistence remain because of the correlations between social disadvantage, development, and birth weight (see, for example, Conley et al. 2003; Royer 2006; Behrman and Rosenzweig 2004).

Following Conley and Bennett (2001, 2000; see also Conley et al. 2003; see also Guo and VanWey 1999), who study timely high school completion, we use sibling-comparison growth models to examine the influence of birth weight on children's mathematics and reading skill development from approximately age 5 through 14 amongst the Children of the National Longitudinal Study of Youth (CNLSY79). We use residualized free-loading growth-models conducted using maximum likelihood multilevel covariance structure analysis (e.g., Muthén 1994, 1997) to compare siblings within families in order to estimate the causal influence of birth weight on PIAT mathematics and reading comprehension development, while using the between-family component of the model to understand sources of bias related to family circumstances. The specific aims of this study were to 1) examine the consequences of birth weight for academic development; 2) explore whether initial birth weight disadvantages are due to poverty, the home environment, and/or other family characteristics; 3) investigate whether birth weight disadvantages persist or accumulate over time; and 4) finally, whether the impact of birth weight on math and reading development is exacerbated by disadvantage on developmentally important family characteristics (e.g., Lin et al. 2007; Conley and Bennett 2001).

Review & Motivation

The focus on birth weight and socioeconomic standing has been an issue of importance among social scientists and the medical field because of the strong correlation between health at birth and infant mortality (Cramer 1995). However, improvements in medical technology have led to declining infant mortality rates while U.S. LBW rates, which are amongst the highest in the industrialized world (UNICEF 2004), have been stable or increasing (Hoyert et al. 2006) with nearly 325,000 LBW births annually (Martin et al. 2005). A relatively recent study examining the impact of welfare reform on prenatal care and LBW rates among the poor found that the 50% decline in welfare rolls across the country was associated with declines in first trimester prenatal care and prenatal visits and up to a 10% increase in LBW births (Kaestner and Lee 2003).

Poverty and economic hardship at neighborhood, family, and individual levels of analysis are the most frequently cited contextual predictors of LBW (Morenoff 2003; Sastry and Hussey 2003; Dooley and Prause 2005). There are also notable difference in the likelihood of LBW by race and ethnicity. African Americans have higher incidences of LBW and infant mortality than Caucasians and certain Latino groups (i.e. Mexican American, Cuban Americans) (Shiono and Behrman 1995; Hummer 1993), and marked differences remain even after controlling for background characteristics (Colen et al. 2006; see also Paneth 1995).

Children identified as LBW appear to be susceptible to a number of cognitive and physical developmental challenges that differentiate them from normal birth weight children. Research in the medical literature has consistently found that LBW children, especially those characterized as very low birth weight (VLBW < 1500g), are at increased risk for growth retardation, physical illness, accidents, and mental health problems in childhood and lifetime illness through adulthood (Hack et al. 1993; McCormick 1992; Overpeck et al. 1989). In addition, LBW status is tied to correlates that strongly predict children's life chances, including behavioral and emotional problems in early childhood and into adolescence (Dahl et al. 2006; Klebanov 1994a), increased risk for grade repetition (Klebanov et al. 1994b), lower cognitive and IQ scores (Hack 2002; Ross et al. 1991), and decreased likelihood of timely high school completion (Behrman 2004; Conley et al. 2003; Hack et al. 2002). While these associations have been identified, the role of familial context and disadvantage, also associated with these developmental and educational outcomes, has yet to be fully disentangled.

The biological mechanisms by which birth weight results in decreased achievement and life chances are not entirely clear, particularly for the larger LBW children. Children born premature, predominantly smaller VLBW infants, often have immature lungs which can lead to birth asphyxia[1] and other complications (e.g., severe periventricular hemorrhage) potentially resulting in severe trauma (Hack et al. 1995). The "fetal origins" or "Barker hypothesis," which has been advocated as an explanation for a number of adult-onset chronic diseases, suggests that the factors causing LBW may also increase risk for developmental problems (see Barker 1995; Barker et al. 1993; Godfrey and Barker 2001). The basic mechanism proposed surrounds fetal nutrition, which can vary and may not be sufficiently supplied to the placenta at important developmental stages. This supply-demand mismatch may impact fetal growth negatively and result in long term physiological problems like cardiovascular disease or obesity, but may be manifest early in life as developmental delay or other complications (Boardman et al. 2002; Nathanielsz 1995).

Family Context and Processes as Mediators and Moderators

In examining the mechanisms through which poverty and economic hardship influence child developmental trajectories and potentially exacerbate adverse birth outcomes, the emphasis of previous research has focused on the importance of family context in predicting children's subsequent test scores. The well-established literature examining the deleterious relationship of poverty for children's life chances has repeatedly shown that children in families experiencing poverty, especially in early childhood have lower levels of achievement, more behavioral problems, and increased mental health problems (McLeod and Kaiser 2004; Duncan, Brooks-Gunn 1997; Guo 1998). Guo and Harris (2000), in a careful examination of the mediators between poverty and children's cognitive development using the CNLSY79, reported that the most notable mediators of income and children's intellectual development is cognitive stimulation in the home, parenting behaviors, and a latent variable of child health as measured by indicators including LBW (whose variance was fixed to 1), gestational length, and infant illness. Similar findings were echoed in a study using the Panel Study of Income Dynamics Child supplement examining the association among income and children's achievement and behavioral problems (Yeung et al. 2002). The authors found that income and children's subsequent achievement were mediated by parental investment patterns in children's cognitive development and little contribution of LBW as background control. While both of these studies take into account birth weight as a background control, their primary focus was on the relationship between family economic disadvantage and children's outcomes.

Adverse birth outcomes and children's subsequent cognitive and developmental outcomes have been shown to be mediated by the very social risk factors that potentially predict birth weight (Boardman et al. 2002). Risk factors associated with birth weight status as well as with socio-economic disadvantage may lead to increased risks of adverse outcomes for poor children and persist over time. Although Boardman et al.'s (2002) findings suggest that learning gaps do not grow after childhood, and may in some cases shrink, other researchers have found indications that disadvantage in childhood persist through adolescence and into adulthood (Hack et al. 2002; Dahl et al. 2006). In addition, Conley and Bennett's (2000, 2001) work suggests that even if achievement gaps do not grow between smaller and normal birth weight youth after early childhood, LBW youth are less likely to complete high school on time.

The pattern of results suggests that birth weight influences early childhood development and later educational attainment, although part of the birth weight association with development is apparently produced by unfavorable correlated social conditions. However, it is not entirely clear if LBW children who come from more favorable environments are at increased risk of school failure. Because parents of higher socioeconomic status have the time and resources to invest in their children's development (Lareau 2003; Chin and Phillips 2004) and provide support in instances where their children may require it, otherwise advantaged lower birth weight children may be less negatively affected by the risk of low birth weight relative to their poorer counterparts, which implies that social and birth conditions may interact. Admittedly, the data suggesting that birth weight is moderated by family circumstances is sparse (e.g., Lin et al. 2007; Conley and Bennett 2001; Currie and Hyson 1999; Hack et al. 1995), however research with large samples and sufficient statistical power are relatively rare in birth weight moderation studies.

Our Contribution

Because birth weight is intercorrelated with a variety of family characteristics and circumstances, estimating the causal influence of birth weight on developmental outcomes is difficult. Conley et al. (2003) persuasively argue that sibling comparison models are a useful "natural experiment" that can be used to account for many unobserved characteristics that similarly influence siblings, including much genetic variation (see also Behrman and Rosenzweig 2004; Royer 2006). For example, babies born to mothers who smoke are at risk of being small for gestational age, and those mothers who smoke during pregnancy may have other parenting characteristics that are difficult to measure that also decrease their children's academic performance. Not accounting for these factors may produce what looks like a birth weight gradient, when in fact that effect estimates reflect this unknown and unaccounted for behavior or characteristic. Because sibling comparison studies can account for many of these unobserved characteristics, they may provide one of the most important avenues for the study of the causal role of birth weight on development and life chances. Because experimental manipulations are difficult to envision, in this case, sibling comparisons represent one of the best research designs for understanding the impact of birth weight on development.

Both Conley and Bennett (2000; 2001; Conley, Strully, and Bennett 2003) and Boardman et al. (2002) make use of sibling samples in the PSID and CNLSY79, respectively. Whereas Conley et al. (2003) makes direct sibling comparisons in their studies, Boardman et al. (2002), stopped short of making direct sibling comparisons in their developmental study (it is increasingly acknowledged that random effects do not "control" for those unobserved characteristics. See Allison 2005). Although Conley and colleagues directly compared siblings with respect to high school completion, their approach treated between family processes largely as nuisances and they were unable to account for developmental processes (e.g., reading achievement growth), focusing instead on later attainment outcomes.

We make full use of siblings to compare the mathematics and reading trajectories of children of different birth weights. This design substantially upgrades the causal generalization over much of the previous birth weight literature (see Hack et al. 1995). Because family environments are not constant between children of different ages from the same families, we also include variation in the different environments siblings' experience, accounting for early home and financial characteristics and changes in these environments over time. We also look at the relationship between average family birth weight and average family achievement. Coefficients for these between-family models are difficult to interpret causally because the parameters reflect an unknown degree of omitted variable bias. However, we report these models and look at the decrease in bias due to the addition of other early childhood and time changing covariates. This multilevel between-sibling, between-family approach allows us to explicitly offer a research design-based causal generalization of birth weight (over the range of birth weight captured in the

NLSY), while also exploring the social conditions associated with birth weight and achievement. Finally, we explore the extent to which the impact of birth weight on development is moderated by early childhood social conditions with the CNLSY79, a large nationally representative data source with sufficient power to detect important interactions.

Data & Methods

The following analyses use data from the National Longitudinal Survey of Youth 1979 (NLSY79) adult cohort and their children in the Child and Young Adult Supplement (CNLSY79). The data, collected by The Center for Human Resource Research (CHRR) at Ohio State University, began in 1979 with a sample of approximately 12,600 respondents between the ages of 14 and 21, and includes an oversample of African American and low-income families. Extensive information on employment, education, cognitive skills, training, and family experiences were collected at the early waves, and in 1982, the survey also began including information about pregnancy, postnatal fertility, and childcare experiences of the female respondents. The survey began biennial assessment of all children of the NLSY79 mothers starting in 1986, and included information on child health and background along with responses from children to assessment items and interviewer observations in the child's home environment. The child supplement also included assessments of achievement on the Peabody Individual Achievement Test (PIAT) in math, reading comprehension, and reading recognition. Additional information was gathered from the Home Observation Measurement of the Environment (HOME), items on child's temperament, motor and social development, and behavioral problems using the Behavioral Problems Index (BPI), and information on school and family background, making the CNLSY79 amongst the largest and most thorough developmental data source available to researchers.

For the following analyses we construct a wide, multivariate file where repeat observations are indexed as columns using age as the meaningful, developmental time metric and index. In order to accomplish this, we first created longitudinal files which contained the available information on all child covariates used in the analysis. We used this longitudinal file to create averages which were used to identify the early childhood variables, such as the average early childhood HOME environment (below). Next, we dropped periods missing observations on the reading recognition dependent variables so that the file contained an observation for each child at each observation point. This stage amounted to deleting child-specific observations which would not contribute to the subsequent analysis. From this longitudinal file, we created a series of 2 year age-groups by binning children, in order to reformulate the time metric from "wave" to "age", the more relevant time metric. Properly binning children was important because CNLSY79 measured children at different ages at different waves. We then converted the file to a "wide" format, so that age groups, rather than indexing data rows within children, indexed variable columns within children. This resulted in a base file of 7667 cases, which was further reduced to 5947 for the mathematics analysis and 5924 cases after deletion on missing independent variables, in 2796 families. The sample was about 30% black and 20% Hispanic. Longitudinal and cross-sectional descriptive statistics are presented in Tables 1 and 2, respectively.

Dependent Variables

We analyze two dependent variables in this paper, PIAT mathematics and PIAT reading comprehension. The PIAT was administered to children under the age of fourteen biennially for all children who completed the Peabody Picture Vocabulary Test (PPVT) by age 5 in the CNLSY79. The PIAT Math assessment is based on children's mathematical attainment as it is taught in mainstream education with difficulty increasing from recognizing numerals through trigonometry and geometry. Each child enters the assessment with a basal score and items are administered based on age appropriateness. Once a child answers five out of seven questions incorrectly, a ceiling is reached (CHRR 2000). The PIAT Reading Comprehension subtest measures children's ability to comprehend sentences and read silently. There are 66 items increasing in difficulty. After reading each sentence, the child must choose the picture that best describes the sentence. As with mathematics, this test utilizes an age appropriate basal score and ceiling after 5 out of 7 items are answered incorrectly.

Age-specific descriptive statistics for the total, within-family, and between-family samples appear in Table 1. Both the math and reading skills increase over time approximately average scores of 16 at age 5 category[2] to over 50 for the age 14 group, although the growth for these particular tests is slightly nonlinear with decreasing rates of growth at the older ages.

<u>(Table 1 about here)</u>

Independent Variables

We incorporate both time-invariant and time-variant predictors of reading development that are allowed to vary within- and between-families. The total and within-family birth weight distributions are presented in Figure 1, while the descriptive statistics for birth weight and the other covariates appear in Table 2. Birth weight is transformed for the analysis by subtracting 2500g and dividing by 1000, so that parameter estimates reference children at the low birth weight borderline and so that expected increments are in 1000g (grams) units, which means that +1 references approximately average birth weight children, while a value of -1 for birth weight references children at the very low birth weight cutoff of 1500g. Birth weight-squared is also included to allow the relationships between birth weight, reading development, and math development to be nonlinear. We chose a quadratic formulation both because it mapped relatively well onto nonparametric estimators (e.g., Lowess curves) of the relationship between birth weight, reading comprehension scores and math scores and because cell frequencies using traditional birth weight categorizations using dummy variables for LBW and VLBW children were sparse in the sibling sample for the VLBW categorization. The average child weighted over 3300g, and the birth weight distribution of the CNLSY79 covers a broad range of birth weights, although few VLBW children are included in the survey because birth weights that low are relatively rare. The continuous formulation allows us to make full use of the birth weight heterogeneity in the sample, and, as can be seen in the right hand side of Figure 1, there is considerable birth weight variability between siblings with a coverage about 2000 grams, which is the approximate birth weight difference between average birth weight (e.g., NBW) and the VLBW cutoff.

(Figure 1 about here)

Time-Invariant Covariates

We include early childhood covariates as temporally-invariant predictors of children's reading comprehension growth and math growth that capture important elements of family life and child experiences that may vary between siblings, on the one hand, and that are also known to vary considerably across families and with implications for youth development. Within-families we adjust for whether or not the child is Female (=1), about 40% of the youth in the sample, and between-families whether or not the primary racial designation is black or Hispanic, about 30% and 20% of the youth in the sample, respectively, and 26% and 18% of the families. Between families we also incorporate a standardized measure of maternal Armed Forces Qualifying Test (AFQT) as a measure of maternal cognitive achievement. Both within- and between-families we include a standardized measure of the full Early HOME Score, which is the average HOME score for the child at or before age 5, within-families, and is the family average in the between-family model. The HOME scores is a commonly used measure of the cognitive and supportiveness of the environment for children's development. We take a similar approach to Early Poverty, coded as whether or not the youth experienced a poverty spell prior to or at age 5 (=1), about half of the sample, and which is a proportion of .4 across siblings in the between-family model. Additional early-childhood variables include Early ln(Income), which is the natural logarithm of the average early childhood income, and whether the child was born to a never married single-mother (=1; Early Single Parent), or a divorced mother/parent (=1; Early Divorce), where again the between-family dichotomous variables are proportions. Maternal Age is also included since younger mothers may be less effective parents, and Birth Order since there may be dilution effects in larger families.

(Table 2 about here)

Time-Varying Covariates

Time varying-characteristics, which are shown in Table 1, include a standardized HOME Score, whether the youth experience a Poverty (=1) spell between assessments, the natural logarithm of income, ln(Income), at the current wave of assessment, whether the child lived with a never married Single (=1) parent, or whether the youth lived with a Divorced (=1) mother or parent/guardian. As shown in Table 1, approximately 25% of the sample was in poverty at any given wave, while about 15% of youth lived with single mothers, and about 25% of the sample lived with a divorced parent. Furthermore, there is variation in the time-varying covariates both within- and between-families. Within-family heterogeneity is important because, on the one hand, birth weight associations may be spurious, arising from different family characteristics and experiences if they are correlated with birth weight. On the other hand, the nested design allows us to make stronger inferences about these the relationship between these characteristics and development because they are based upon between-sibling heterogeneity. At the same time, average family levels of these characteristics may also be useful for understanding between-family differences in average achievement.

Analytic Approach

The full structural model we estimate to study the relationships between birth weight, mathematics, and reading achievement growth is presented in Figure 2. Although the model is somewhat complex, the basic idea of the multilevel-growth model where the growth process is modeled between-siblings at level-1 and between-families at level 2 is relatively straightforward. Because of this nesting, the growth model appears in two panels, with the top panel capturing the within-family, between-sibling model comprising the first level of analysis, and the second panel containing the between-family model at level 2. The between-family level-2 model captures average growth with family-specific heterogeneity, while the within-family portion captures child-specific heterogeneity or deviations from average family growth.

<u>(Figure 2 about here)</u>

Conceptually, the two-level approach is based upon the decomposition for multilevel covariance structure analysis put forth by Muthén (1994; see also Muthén 1997), where the total covariance matrix, Σ_T, is decomposed into within- and between-covariance matrices, $\Sigma_W + \Sigma_B$. The important aspect of this decomposition, for our purposes, is the orthogonal construction of the estimator of Σ_W, S_W, which is defined as

$$S_W = (N-G)^{-1} \sum_{g=1}^{G} \sum_{i=1}^{N_g} (y_{gi} - \bar{y}_g)(y_{gi} - \bar{y}_g)', \quad (1)$$

where N is the total sample size, G is the number of groups, g indexes group, and i indexes observations. Given this indexing, y_{gi} is the value of y for child i in family g, and $\bar{y}_g$ is the mean of y for family g. The total covariance matrix used in single-level analysis replaces $\bar{y}_g$ with the sample mean, $\bar{y}$[3] (e.g., Bollen 1989).

This construction of the pooled-within covariance matrix is important because it leads to an intuitive interpretation of focal model parameters based upon sibling differences in the within-family model, and between-family average differences at level-2. Notably, this orthogonal construction, which explicitly accounts for family means in the estimation of within-family parameters, produces results analogous to econometric fixed-effects estimates (i.e., models including a dummy variable for each family) for single-outcome random intercept regression models.[4] In the present example, this means that level-1 parameters represent expected differences between siblings (i.e., sibling fixed-effects), like those of Conley and Bennett (2001; 2000). When group-means are related systematically to processes, such as the achievement processes we study here, and they are not accounted for, regression parameters may be biased because the error terms and the covariates of interest are correlated. This is why fixed-effects and random-intercept estimators often produce different parameter estimates (see Allison 2004; Raudenbush and Bryk 2002). For example, although Boardman et al. (2002) account for family nesting using random intercept models, they do not explicitly account for average differences between families, which may have resulted in biased causal birth weight estimates.

Returning to Figure 2, the picture says that math and reading growth across childhood and into adolescence is captured using a residual free-loading growth model. Development is captured with an intercept and growth factor, where the factor loadings for the intercept are set 1 to define the intercept at time 1, while the first loading between growth and achievement is set to 0 and the final loading is set to 1, with the three intermediate loadings freely estimated. This coding allows growth to be nonlinear and means that the parameters are interpreted as (a) initial status at age 5, and (b) growth by age 14. Because children are assessed at different ages within an age groups, age is included as a time-changing covariate and centered around ages 5, at the first occasion, and 14 at the last occasion (the intermediate centering are around the column values in Table 1), to (a) reduce heterogeneity in the growth parameter estimates which are due to variation in age at assessment within age-groups, and (b) so that the growth parameters have clear interpretations. The growth parameters are modeled as a function of birth weight, birth weight^2, and early childhood characteristics which in many cases vary across siblings within families. In addition, the model in Figure 2 is a residual growth model since the age-specific reading and math measurements are directly regressed upon time-changing or contemporaneous covariates.

There are also small circles and squares depicted in the within-family model.[5] These represent, in the case of the circles, group-means which are allowed to vary across families as latent variables, and which are treated as observed means for the small squares. Together, these circles and squares in the within-family model represent the circles and squares depicted in the between-family model, which defines the growth of average family achievement (and also indicates, per equation 1, that the within-family variables are in group-deviation form). The between-family model is parallel to the within or level-1 model where the growth parameters are regressed on the temporally invariant characteristics (e.g., birth weight) and characteristics that are largely invariant within families (e.g., race/ethnicity and maternal AFQT). In addition to the growth model structure, there are additional paths depicted Figure 2. For example, there are paths between the time-varying characteristics (except for age deviations at assessment), indicating temporal dependencies which allow us to build missing-data into the model. Missingness on time-changing covariates quickly reduces the samples size when information is taken across multiple age groups since a case is dropped from the analysis for any missing values on the independent variables.

The basic structure of the growth model for an aggregate, single-level analysis suggested good fit[6] for both mathematics ($\chi^2[112.6, df = 17, scaling\ correction\ factor = 1.093]$, RMSEA=.031, CFI=.989, TLI=.978, BIC=158,969.4), and the fit was also adequate for the two level formulation ($\chi^2[322.7, df = 38, scaling\ correction\ factor = .980]$, RMSEA=.035, CFI=.969, TLI=.963, BIC=141,846.2). Reading comprehension fit for the aggregate model was sufficient ($\chi^2[271.8, df = 17, scaling\ correction\ factor = 1.068]$, RMSEA=.050, CFI=.980, TLI=.958, BIC=159,842.8) and adequate for the multilevel growth models ($\chi^2[309.0, df = 38, scaling\ correction\ factor = .932]$, RMSEA=.03.5, CFI=.970, TLI=.965, BIC=139,115.8) as well. These results suggest that the basic structure of the free-loading growth model with age adjustments for variation at age of assessment provides an adequate summary of growth with these data.

Results

The results for the multi-level residual free-loading growth models depicted in Figure 2 are presented in two tables for both outcomes. The parameter estimates for the growth model and regressions amongst the growth parameters and early childhood and other temporally invariant characteristics are presented in Table 3, for both math and reading, while the coefficients for the time-changing or temporally proximate effects are shown in Table 4. In addition, in order to provide a sense of bias in the relationship between birth weight and achievement produced descriptively in single-level analyses, results for a simple aggregate growth model including birth weight based upon a single-level analysis are presented in Table 3.

PIAT Mathematics Achievement

As shown in Table 3, children's average scores at age 5 are approximately 9 points, although there is considerable heterogeneity between children (M-1), between children within families, and average achievement levels between families (M-2). Furthermore, achievement levels more than triple by age 14, increasing by over 40 points on average, once again with considerable heterogeneity between children (M-1), between children within families, and average math achievement growth between families (M-2). Descriptively, as shown in M-1, birth weight has a nontrivial association with math achievement at age 5 along with subsequent growth. Children born at the cutoff of LBW (2500g), score about .89 points or.19 standard deviations[7] lower than children born 1000g larger (NBW). Because of nonlinearity in the association between birth weight and initial status, the difference between LBW and VLBW children is even larger, 1.7 points or .36 standard deviations, which translates into a 2.6 point or .5 standard deviation VLBW-NBW gap. There are also important estimated differences in growth. Average birth weight children are expected to grow 1.9 more points than LBW children, which is a difference of .25 standard deviations, while children at the VLBW cutoff are expected to acquire 2.4, about .3 standard deviations, fewer points. The estimate difference between VLBW and NBW children is approximately .56 standard deviations, which suggest nontrivial growth gaps along the birth weight continuum.

By accounting for unobserved family heterogeneity, the estimates in column M-2 capture a better causal generalization than the simple model presented in M-1. The nonlinear birth weight association with children's skills at age 5 is relatively invariant to the inclusion of unobserved family characteristics, as indicated by the fact that birth weight associations change little between models M-1 and M-2. In addition, this nontrivial relationship does not appear to be the result of other early childhood characteristics that vary between siblings including the early HOME environment, poverty experiences, maternal age, or birth order. These findings suggest that birth weight is meaningfully and possibly causally related to children's early math skills. Sibling heterogeneity in HOME scores was also related to youth math skills, however, interpretation of this coefficient is less clear because variation in this covariate may be driven in part by the way the child responds to and determines the environment.

The relationship between family average achievement at age 5 and family average birth weight is similar in magnitude (M-2) to the between-sibling effect. The between-family association, however, is largely accounted for by the less favorable conditions experienced by youth in families with smaller children. In particular, mothers of children born into smaller average birth weight homes have lower cognitive achievement as measured by the AFQT and create less favorable learning environments (HOME). In addition, the average family achievement is lower for larger families, while children from wealthier families have more favorable childhood achievement. The positive association between single parenthood and initial status is driven by maternal AFQT, and suggests that youth born to single mothers would have more favorable outcomes if their mothers possessed otherwise more favorable characteristics.[8]

Differences in math growth by age 14, however, appear to be the product of family characteristics, as indicated by the great reduction and lack of statistical significance of birth weight and the quadratic term in models M-2 and M-3. While birth weight appears to be meaningfully related to children's early math skills, this evidence suggests that the birth weight influence is largely restricted to that time period. Notably, females appear to grow more slowly than their male peers, which might indicate gendered patterns of investment that vary across siblings and are not accounted for by adjusting for omitted family characteristics. Additionally, siblings born to older mothers also grow more by age 14.

There are, however, large average family birth weight differences in average family growth. This large effect (b=3.41, b2=-.88), is greatly reduced from model M-2 when between-family and time-varying covariates are included in equation M-3, although differences remain statistically significant at $p<.05$. The growth gap between a LBW and average family birth weight decreases from 2.3 to 1.1 points, a reduction of over 50%, indicating that much of the average birth weight association with growth is due to factors including race/ethnicity, maternal cognitive scores (AFQT), and the early HOME environment.

Model M-3 also contained contemporaneous or time changing influences, the coefficients for which are presented in Table 4. The HOME environment continues to contribute to mathematics success throughout childhood and into early adolescence, suggesting both that siblings who experience more favorable environments have higher achievement, and that youth from families with more favorable average learning environments have higher average achievement, net of average family and individual growth. In addition, siblings whose parents are married have higher achievement than those siblings who spend more time in single parent families. The other covariates, including divorce, poverty, and income were not systematically related to achievement.

PIAT Reading Comprehension Achievement

The reading comprehension growth results are shown in columns M-4 to M-6 of Table 4. According to model M-4, the aggregate (single-level) descriptive birth weight model, the consequences of birth weight for childhood reading comprehension development are similar to those found for mathematics (above). The expected gap LBW-NBW gap is .7 points or .16 standard deviations, while VLBW-NBW disparity is 2.2 points or .5 standard deviations. The age 5 gap between children at the LBW and VLBW cutoffs is expected to be 1.5 points or .34 standard deviations. Results are similar for growth from age 5 to age 14, although the gaps are slightly larger.

In model M-5, which accounts for family-specific heterogeneity, the age 5 gap is significantly reduced with both the linear and quadratic terms decreasing by approximately 50%. This finding indicates that a substantial proportion of the early-childhood learning differentials apparently due to birth weight are in fact accounted by other aspects of children's family lives. However, as shown by the results for equation M-6, aspects of home life that may vary significantly between siblings do not further account for the age 5 birth weight gap, and in fact increase it somewhat, since the linear term is larger and the negative quadratic term approaches zero. Those youth with more favorable HOME environments than their siblings record better reading comprehension scores at age 5 and those who experience poverty record lower scores, as do later-born children, while females record better skills. The income association, which is negative, deviates from expectations and implies that those siblings who experience higher early-childhood incomes have less favorable scores than their poorer siblings, all else equal.

The positive association between family average birth weight and family average reading comprehension at age 5 (M-5) is indicative of the between-family bias present in the aggregate approach to modeling birth weight. Part of this association is due to the correlations between being black, maternal AFQT, and the early HOME environment to which children are exposed. Maternal AFQT is the strongest predictor of average reading comprehension at age 5 and the black-white gaps flips and becomes positive rather than negative when maternal cognitive scores are included in the model (maternal AFQT, although not shown, also mediates the Hispanic-white gap in these models). Previous studies using the NLSY (e.g., Farkas and Beron 2004; Guo and Harris 2000; Guo 1998) have found that maternal cognitive scores along with HOME scores mediate approximately 35% of black-white gaps, but were unable to fully-account for it. In these models, however, we find that the black-white gap is largely an intergenerational effect that is translated via the mother's own cognitive scores and the early HOME environment. The positive black-white coefficient is largely indicative of the vastly different AFQT and early HOME score distributions between the black and white families in this sample.

While the birth weight gap is greatly reduced but not decreased to nonsignificance when siblings are compared, the birth weight gap in growth from age 5 to 14 is. After accounting for family influences that similarly influence sibling development, the birth weight gap is no longer statistically significant, indicating that the aggregate estimate of the birth weight gap was biased by family factors. Importantly, there are few between-sibling factors that influence growth. Only birth order, which indicates that older siblings grow more slowly, is related to sibling differences in comprehension achievement development.

The estimated aggregate (single-level) birth weight disparity in comprehension growth is due to differences between families, and this is clearly evidenced by the large family mean birth weight gap shown in the between-family model. The gap is greatly reduced when the early-childhood, contemporaneous and time-varying covariates are included. When these additional covariates are added the linear term is reduced by 70% and the magnitude of the quadratic term decreased by over 40%, although the linear term remained significant. The birth weight association reduction resulted from the inclusion of race/ethnicity, maternal cognitive scores, and the average early HOME environment. These covariates indicate that black children grow more slowly than their white counterparts, while, net of the additional control variables, Hispanic children actually grow slightly faster over the study period. Furthermore, children with cognitively advantaged mothers grow significantly faster than other children, with an effect-size of about .43. The early home environment is also important (effect size=.2), as indicated by the positive association. These and race/ethnicity are the two most important characteristics predicting average family achievement, although once again, we find that family size as reported by sibship is negatively related to average family achievement.

The coefficients for the contemporaneous, time changing covariates are reported in Table 4. The only significant association is that between the HOME environment and reading comprehension. Achievement differences related to the HOME score appear in both the within-family and between-family models, indicating that the cognitive environment remains important long after early childhood and continues to differ for families across childhood and into early adolescence. Further research is necessary, however, in order to fully interpret the within-family, between-sibling effect. This relationship may be biased by endogeneity resulting from the ways that youth influence the HOME environment.

Birth Weight Moderation

We test for interactions between birth weight and achievement by race/ethnicity, early childhood HOME score, early childhood poverty, and early childhood income using Wald tests. Models for these results included only the time changing age-variation measures, birth weight, the characteristic main effects, and the interaction terms, interacted with both the linear and quadratic birth weight terms. Results are presented in Table 5. We find little evidence either that disadvantaged youth are more susceptible to the negative impacts of growing up in less favorable environments, or that advantage "buffers" youth from the harmful effects of birth weight. Although we uncover interactions between birth weight, poverty, and average family growth the results are not robust to fuller model specification. These results provide considerable support for the contention that the influence of birth weight is relatively uniform and does not exacerbate, or is not exacerbated by, other forms of social disadvantage (e.g., Hack et al. 1995).

Discussion & Conclusion

We used multilevel covariance structure analysis to study the relationship between birth weight, family context, and youth math and reading comprehension growth from approximately age 5 until about age 14. The multilevel component of this analysis decomposed achievement growth into between-sibling deviations and between-family averages (e.g., Muthén 1994, 1997). This strategy allowed us to eliminate unobserved between-family factors that affect siblings similarly, allowing us to make stronger inferences regarding the influence of birth weight on child development and so that we could identify aspects of family life that differentiate the achievement of siblings, in addition to those characteristics that differentiate average achievement between families.

The results presented here suggest, in accord with a significant literature on birth weight (e.g., Hack et al. 1995), including those employing sibling models (Conley et al. 2003; Boardman et al. 2002; Royer 2006), that birth weight, even when not specifically considering the very smallest children (e.g., Lin et al. 2007; Behrman and Rosensweig 2004; Currie and Hyson 1999), negatively influences development. Siblings, in accord with the arguments put forth by Conley (2003), provide a natural experiment for the study of many processes and effects, including childhood health, since siblings have similar genetic endowments and are exposed to much more similar family environments than randomly selected children, greatly reducing the omitted variables problem, even if not completely obviating it.

The birth weight results need to be contextualized however. First, simple associations between birth weight and math and reading scores are partly driven by family characteristics, some of which are difficult to measure and account for, as evidenced by the residual birth weight disparities reported in our between-family models. We were able to adjust for both the cognitive environment and maternal cognitive skills, two powerful explanatory covariates in the study of development (e.g., Yeung et al. 2002; Farkas and Beron 2004; Guo and Harris 2000), in addition to family structure, race/ethnicity, economic characteristics, maternal age, and sibship size, yet residual average birth weight associations remained. Understanding the birth weight association with youth achievement is more than estimating causal impacts. In a highly intercorrelated social world, elucidating the interconnections between patterns of advantage and disadvantage illustrate the interconnections between social experiences, environments, and circumstances. In this regard, we have only been partially successful since residual between-family birth weight associations remain unexplained and nontrivial.

Second, the impacts of birth weight on children's math and reading comprehension skills appears to be an early-childhood phenomenon, one that is not accounted for by either unmeasured between-family confounders that similarly influence siblings, or by other aspects of children's family lives that vary between siblings. Although we were able to account for differences in the early cognitive environments to which children are exposed, differential economic circumstances, family structure, maternal age, and the child's birth order, birth gaps in children's skills persisted for both children's mathematics and reading comprehension. Gaps in both math and reading comprehension between ages 5 to 14, however, are the result of disparities in family life. More specifically, across the range of birth weights we studied, siblings in the sample do not systematically grow at differential rates, nor do they appear to become more similar. This finding stands in contrast to those of Boardman et al. (2002), who report that gaps either do not grow or shrink (at least when comparing moderately low birth weight children).

In general, the results of this study are consistent with the literature suggesting the importance of mother's own cognitive scores and the home environments within which children develop. Not only did these characteristics predict differences in children's age 5 skills and subsequent growth, variation in the home environment between siblings was also related to sibling variation in achievement. This was true both for the growth parameters, and for the age-specific measures which were regressed on contemporaneous measures. Although there could be some endogeneity in the between-sibling models because youth are not passive participants and because they actively engage and create their environments (e.g., Conger and Donnallen 2007;

Bradley and Corwyn 2002), the results are certainly suggestive that the home environment is not simply an early childhood phenomenon. Rather, it appears to be related to youth achievement for both math and reading across childhood and into adolescence. This was apparent and more clearly interpretable in the between-family model where, as with between-siblings, the home environment predicted both initial status, growth, and the age-specific measurements (net of the smoothed growth process).

Poverty and income did not appear to play terribly strong roles in the developmental outcomes we have studied here, regarding either the growth process itself, or deviations as measured by contemporaneous associations from the time-varying part of the model. This does not mean that these characteristics were unimportant. Instead, it is indicative of a correlated process by which parents with lower cognitive skills have poorer financial characteristics, on the one hand, and where poorer financial characteristics (controlling for cognitive scores) are associated with less favorable HOME scores, which are in turn related to mathematics and reading achievement processes.

These results have shed light on the causal impact of birth weight, suggesting that birth weight influences on mathematics and reading comprehension development are largely restricted to early childhood decrements with little power to differentiate substantive math or reading growth gaps. Substantial numbers of U.S. born children are LBW, and black babies are disproportionately born small (Hoyert et al. 2006; 17.8% for black children relative to 11.3% of white children in 2003). Although we found that birth weight gaps do not grow significantly after age 5, they do not shrink either. Much of the birth weight gap even in early childhood, at least for reading comprehension, appears to be at least partly explained by the racial background of smaller babies, to less favorable home lives, and disadvantaged characteristics of their mothers. This pattern of findings paints the picture of a complex gestalt of disadvantage, one that begins in the womb and persists across childhood and into adolescence.

End Notes

[1] Birth asphyxia can occur for a number of other reasons, including maternal low blood oxygen do to respiratory or heart problems, low blood pressure, poor placental function, and other complications.

[2] As shown in Table 1, the mean of this category is actually closer to 6.

[3] We do not discuss the construction of S_B, the estimator of Σ_B here because it is not relevant to the substantive dimension of our analytic approach. For further details see Muthén (1994: 384).

[4] We note that one does not need an orthogonal variance decomposition. Adjusting for group-means within the regression and including random intercepts will result in approximately the same estimates. At the same time, the level-2 group-means will then be interpreted as contextual rather than between-family effects (e.g., Raudenbush and Bryk 2002).

[5] For comparison purposes, we also include single-level or aggregated analyses with robust standard errors.

[6] All analyses were conducted using M*plus* v4.21 and unless otherwise noted use the MLR estimator.

[7] Dividing by the standard deviation of initial status, model M-1.

[8] The positive coefficient should not be over-interpretted. The average AFQT for single mothers is nearly -.6, while that for married mother is nearly .3.

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Figures

Figure 1: Birth weight distribution

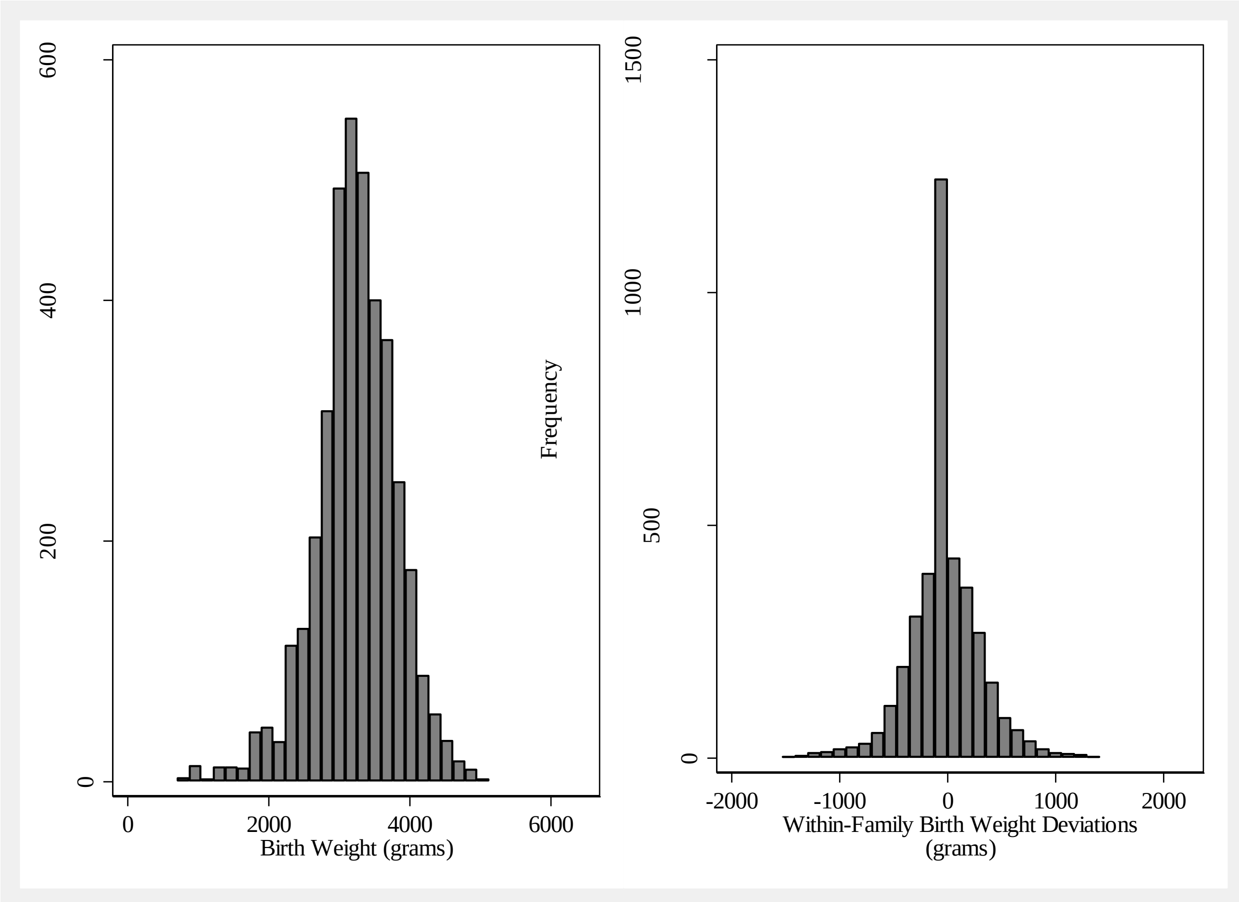
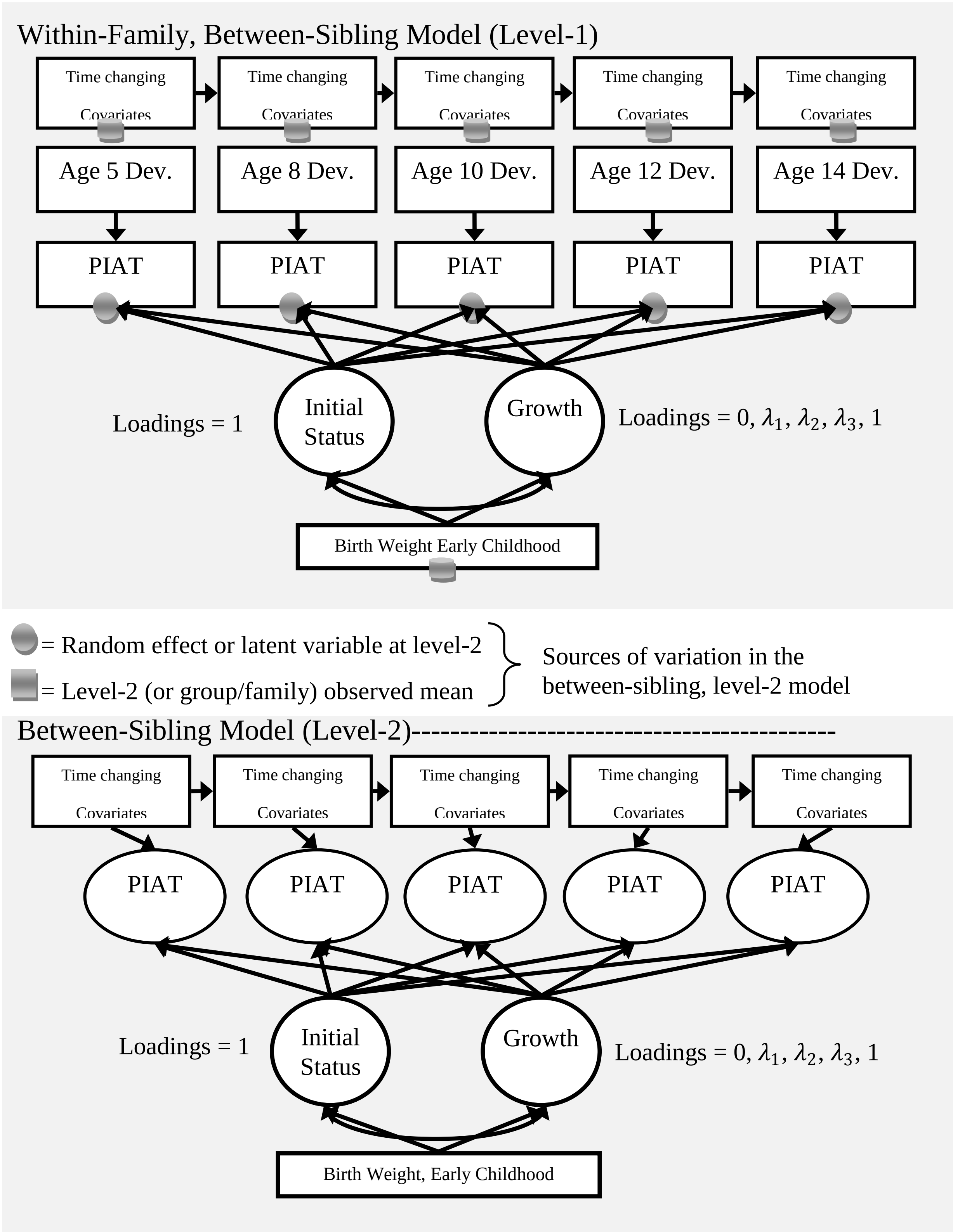


Figure 2: Multilevel path model for PIAT math and reading comprehension growth



Tables

Table 1: Longitudinal descriptive statistics for PIAT mathematics and reading comprehension and the time-varying covariates for the total, within, and between samples

	Age				
Variable	5	8	10	12	14
Total Sample					
Age (Sd)	0.94	-0.09	-0.11	-0.14	-0.25
(Sd)	(0.51)	(0.50)	(0.48)	(0.44)	(0.31)
Math Score	15.45	29.79	42.79	50.04	53.84
(Sd)	(6.45)	(10.14)	(10.38)	(10.20)	(11.21)
Reading Comprehension	16.52	30.60	41.19	48.08	51.99
(Sd)	(5.95)	(9.94)	(10.72)	(11.29)	(12.16)
Home Score	0.01	-0.01	0.01	0.01	0.01
(Sd)	(0.99)	(0.99)	(1.00)	(1.00)	(0.99)
Poverty	0.26	0.26	0.25	0.24	0.23
(Sd)	(0.44)	(0.44)	(0.43)	(0.42)	(0.42)
ln(Income)	10.08	10.15	10.25	10.30	10.34
(Sd)	(1.04)	(1.02)	(1.01)	(0.98)	(0.96)
Single	0.16	0.15	0.14	0.14	0.13
(Sd)	(0.37)	(0.36)	(0.34)	(0.34)	(0.34)
Divorced	0.22	0.24	0.26	0.28	0.30
(Sd)	(0.41)	(0.42)	(0.44)	(0.45)	(0.46)
Within (Level-1)					
Age (Sd)	(0.36)	(0.37)	(0.35)	(0.32)	(0.24)
Math Score	0.04	-0.05	-0.06	-0.02	-0.04
(Sd)	(3.73)	(5.77)	(5.74)	(5.35)	(5.35)
Reading Comprehension	0.06	-0.09	-0.09	-0.08	-0.22
(Sd)	(3.53)	(5.46)	(5.93)	(5.86)	(5.82)
Home Score	0.01	0.00	-0.01	-0.01	-0.01
(Sd)	(0.42)	(0.44)	(0.45)	(0.46)	(0.44)
Poverty	0.00	0.00	0.00	0.00	0.00
(Sd)	(0.19)	(0.20)	(0.20)	(0.20)	(0.18)
ln(Income)	-0.01	0.00	0.01	0.01	0.01
(Sd)	(0.44)	(0.46)	(0.47)	(0.41)	(0.38)
Single	0.00	0.00	0.00	0.00	0.00
(Sd)	(0.09)	(0.09)	(0.08)	(0.07)	(0.06)
Divorced	0.00	0.00	0.00	0.00	0.00
(Sd)	(0.18)	(0.18)	(0.17)	(0.16)	(0.14)
Between (Level-2)					
Math Score	15.85	30.53	43.81	50.85	54.62
(Sd)	(5.61)	(8.88)	(8.95)	(9.11)	(10.47)
Reading Comprehension	16.91	31.37	42.19	49.05	52.96
(Sd)	(5.01)	(8.98)	(9.29)	(10.05)	(11.11)
Home Score	0.11	0.08	0.10	0.08	0.08
(Sd)	(0.86)	(0.88)	(0.88)	(0.89)	(0.89)
Poverty	0.22	0.22	0.20	0.19	0.20
(Sd)	(0.38)	(0.38)	(0.37)	(0.36)	(0.38)
ln(Income)	10.16	10.23	10.33	10.38	10.40
(Sd)	(0.98)	(0.96)	(0.94)	(0.91)	(0.89)
Single	0.15	0.15	0.13	0.13	0.13
(Sd)	(0.35)	(0.35)	(0.33)	(0.34)	(0.33)
Divorced	0.21	0.23	0.25	0.27	0.28
(Sd)	(0.38)	(0.39)	(0.41)	(0.42)	(0.44)
N Within (Level-1)	5064	4853	4513	3817	2694
N Between (Level-2)	2600	2473	2259	1967	1566

Table 2: Cross-sectional descriptive statistics for early childhood characteristics

	Full Sample			Within (L-1)			Between (L-2)		
Variables	Mean/Sd.	Min	Max	Mean/Sd	Min	Max	Mean/Sd	Min	Max
Birth Weight	3313.26	170.10	7597.67	4.04	-1960.84	2891.65	3317.27	907.18	5613.21
	(599.63)			(330.97)			(525.24)		
Birth Weight (-2500 & ÷ 1000g)	0.81	-2.33	5.10	0.00	-1.96	2.89	0.82	-1.59	3.11
	(0.60)			(0.33)			(0.53)		
Birth Weight^2 (-2500 & ÷ 1000g)	1.02	0.00	25.99	0.01	-8.91	16.87	1.02	0.00	9.69
	(1.04)			(0.62)			(0.89)		
Female	0.49	0	1	0.00	-0.88	0.83			
Black	0.30	0	1				0.26	0	1
Hispanic	0.20	0	1				0.18	0	1
Maternal AFQT, Std.	0.03	-1.24	2.38				0.13	-1.24	2.38
	(1.00)						(0.99)		
Early Home Score, Std.	0.00	-5.84	2.37	-0.01	-3.30	2.29	0.12	-3.54	2.22
	(1.02)			(0.49)			(0.87)		
Early Poverty	0.48	0	1	0.01	-0.80	0.83	0.40	0.00	1.00
Early ln(Income)	10.17	0.00	13.87	0.01	-6.81	6.04	10.29	0.00	13.87
	(1.07)			(0.47)			(0.99)		
Early Single Parent	0.24	0	1	0.00	-0.80	0.88	0.24	0	1
Early Divorce	0.10	0	1	0.00	-0.80	0.83	0.08	0	1
Maternal Age	24.36	14	38	0.04	-11.17	12.75	24.86	14	38
	(4.55)			(2.82)			(4.32)		
Birth Order	1.90	1	8	0.01	-4.89	3.50	1.61	1	6
	(1.05)			(0.78)			(0.59)		
Avg. Children Per Mother	2.01	1	9						
	(0.98)								
Number of Mothers	2796								
N	5947								

Table 3: PIAT mathematics and reading comprehension residual growth model estimates (mathematics N=5947, reading N=5924)

	PIAT Math			PIAT Reading Comprehension		
	Agg. (L-1)	Two-Level (Between)		Agg. (L-1)	Two-Level (Between)	
Variables/Parameters	M-1	M-2	M-3	M-4	M-5	M-6
Within-Family Between-Sibling Model						
Initial Status (Age 5)						
Birth Weight	1.30 (0.19) *	1.08 (0.28) *	1.10 (0.27) *	1.11 (0.18) *	0.57 (0.26) *	0.66 (0.25) *
Birth Weight^2	-0.41 (0.11) *	-0.48 (0.16) *	-0.41 (0.15) *	-0.41 (0.09) *	-0.21 (0.14)	-0.06 (0.12)
Female			0.25 (0.18)			0.94 (0.17) *
Early Home Score, Std.			0.39 (0.13) *			0.46 (0.12) *
Early Poverty			-0.24 (0.34)			-0.64 (0.31) *
Early ln(Income)			-0.07 (0.14)			-0.29 (0.13) *
Early Single Parent			-0.48 (0.43)			0.26 (0.40)
Early Divorce			0.83 (0.47)			0.03 (0.44)
Maternal Age			-0.07 (0.05)			0.03 (0.05)
Birth Order			0.08 (0.16)			-0.42 (0.17) *
Growth by Age 14						
Birth Weight	2.10 (0.36) *	0.43 (0.53)	0.35 (0.53)	2.45 (0.42) *	0.52 (0.52)	0.44 (0.50)
Birth Weight^2	-0.24 (0.19)	0.41 (0.24)	0.28 (0.23)	-0.58 (0.22) *	-0.20 (0.30)	-0.05 (0.28)
Female			-1.46 (0.34) *			0.02 (0.35)
Early Home Score, Std.			0.23 (0.26)			0.25 (0.27)
Early Poverty			-0.51 (0.65)			1.08 (0.66)
Early ln(Income)			-0.32 (0.31)			0.31 (0.26)
Early Single Parent			-0.75 (0.80)			-0.74 (0.80)
Early Divorce			0.53 (0.85)			-0.10 (0.82)
Maternal Age			0.29 (0.10) *			0.10 (0.10)
Birth Order			-0.59 (0.32)			-0.96 (0.33) *
Between-Family Model						
Initial Status (Age 5)						
Birth Weight		1.29 (0.32) *	0.35 (0.29)		1.38 (0.25) *	0.79 (0.23) *
Birth Weight^2		-0.33 (0.19)	-0.20 (0.16)		-0.56 (0.15) *	-0.40 (0.13) *
Black			-0.34 (0.22)			1.75 (0.22) *
Hispanic			-0.75 (0.22) *			-0.14 (0.21)
Maternal AFQT, Std.			1.33 (0.11) *			1.20 (0.11) *
Early Home Score, Std.			0.78 (0.12) *			0.34 (0.12) *
Early Poverty			0.39 (0.27)			-0.21 (0.27)
Early ln(Income)			0.33 (0.10) *			0.15 (0.13)
Early Single Parent			0.69 (0.36) *			0.25 (0.32)
Early Divorce			0.43 (0.34)			0.10 (0.32)
Maternal Age			0.05 (0.02)			0.02 (0.02)
Birth Order			-0.60 (0.13) *			-0.69 (0.13) *
Growth by Age 14						
Birth Weight		3.41 (0.55) *	1.82 (0.53) *		3.61 (0.60) *	1.13 (0.56) *
Birth Weight^2		-0.88 (0.32) *	-0.68 (0.30) *		-0.91 (0.34) *	-0.54 (0.31)
Black			-1.27 (0.41) *			-2.34 (0.48) *
Hispanic			-0.34 (0.41)			0.96 (0.44) *
Maternal AFQT, Std.			2.02 (0.20) *			2.58 (0.21) *
Early Home Score, Std.			0.35 (0.22)			1.37 (0.22) *
Early Poverty			-1.34 (0.47) *			-0.64 (0.49)
Early ln(Income)			-0.13 (0.25)			-0.01 (0.24)
Early Single Parent			-0.40 (0.47)			-0.76 (0.52)
Early Divorce			0.45 (0.64)			0.15 (0.69)
Maternal Age			0.20 (0.05) *			0.02 (0.05)
Birth Order			-0.22 (0.24)			-1.13 (0.24) *

* $p < .05$, stand errors are in parentheses.

Table 3 continued: PIAT mathematics and reading comprehension residual growth model estimates (mathematics N=5947, reading N=5924)

	PIAT Math									PIAT Reading Comprehension								
	Agg. (L-1)			Two-Level (Between)						Agg. (L-1)			Two-Level (Between)					
Variables/Parameters	M-1			M-2			M-3			M-4			M-5			M-6		
Growth Parameters																		
Initial Status (Age 5)	9.30	(0.16)	*	9.23	(0.24)	*	10.10	0.209	*	10.84	(0.18)	*	11.12	(0.25)	*	10.75	(0.25)	*
Growth by Age 14	43.41	(0.33)	*	43.32	(0.41)	*	45.70	(0.39)	*	39.94	(0.37)	*	39.38	(0.46)	*	41.32	(0.48)	*
L-1 Variance: Initial Status (Age 5)	22.31	(1.17)	*	10.52	(1.12)	*	10.53	(1.08)	*	19.80	(1.37)	*	11.78	(1.35)	*	10.49	(0.19)	*
L-1 Variance Growth by Age 14	56.14	(2.96)	*	35.29	(3.14)	*	34.96	(3.17)	*	77.10	(3.23)	*	39.47	(3.25)	*	38.11	(0.43)	*
L-2 Variance: Initial Status (Age 5)				11.06	(0.92)	*	4.58	(0.73)	*				7.27	(0.91)	*	4.17	(0.79)	*
L-2 Variance Growth by Age 14				18.84	(2.27)	*	9.97	(2.13)	*				35.21	(2.64)	*	16.22	(2.26)	*
Variance Explained																		
L-1 Initial Status (Age 5)	0.01			0.01			0.02			0.01			0.00			0.03		
L-1 Growth by Age 14	0.02			0.00			0.02			0.02			0.00			0.01		
L-2 Initial Status (Age 5)				0.02			0.48						0.03			0.36		
L-2 Growth by Age 14				0.08			0.53						0.05			0.54		

* p < .05, stand errors are in parentheses.

Table 4: Coefficients for the time-varying effects for the PIAT mathematics and reading comprehension residual growth models (mathematics N=5947, reading N=5924)

	Mathematics M-3			Reading Comp. M-6		
Variable	b	se		b	se	
Within-Family, Between-Sibling Model (Level 1)						
Home Score	0.287	(0.098)	*	0.328	(0.101)	*
Single Mother	-1.31	(0.562)	*	0.227	(0.503)	
Divorced Mother	-0.099	(0.275)		0.019	(0.282)	
Poverty	-0.158	(0.276)		-0.317	(0.261)	
ln(Income)	-0.105	(0.130)		-0.137	(0.127)	
Between-Family Model (Level 2)						
Home Score	0.436	(0.087)	*	0.588	(0.089)	*
Single Mother	-0.478	(0.350)		-0.241	(0.319)	
Divorced Mother	-0.044	(0.198)		0.217	(0.196)	
Poverty	-0.026	(0.215)		0.037	(0.223)	
ln(Income)	0.036	(0.113)		0.082	(0.114)	
Level-1 R^2						
Age 5	0.576			0.681		
Age 8	0.408			0.388		
Age 10	0.49			0.458		
Age 12	0.608			0.542		
Age 14	0.534			0.501		

* $p < .05$. The standard errors are in parentheses.

Note: The between-level R^2 is approximately 1.00

Table 5: Wald tests for birth weight moderation

	PIAT Mathematics			PIAT Reading Comprehension		
Model	Wald	df	p-value	Wald	df	p-value
Race/Ethnic Interactions						
Between						
Initial Status	2.963	4	0.564	4.196	4	0.380
Growth	3.068	4	0.547	1.759	4	0.780
Early Childhood Home Score						
Within						
Initial Status	0.122	2	0.941	2.740	2	0.254
Growth	2.187	2	0.335	1.420	2	0.492
Between						
Initial Status	1.518	2	0.468	2.382	2	0.304
Growth	2.125	2	0.346	0.463	2	0.793
Early Childhood Poverty						
Within						
Initial Status	0.734	2	0.693	3.650	2	0.161
Growth	6.471	2	0.039	4.132	2	0.127
Between						
Initial Status	0.960	2	0.619	1.592	2	0.451
Growth	1.063	2	0.588	0.399	2	0.819
Early Childhood Income						
Within						
Initial Status	0.220	2	0.896	2.552	2	0.279
Growth	0.951	2	0.622	5.753	2	0.056
Between						
Initial Status	0.034	2	0.983	0.163	2	0.922
Growth	0.664	2	0.718	0.461	2	0.794