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Preschools Reduce Early Academic Achievement Gaps: A Longitudinal Twin Approach

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Abstract

Preschools may reduce inequalities in early academic achievement by providing children from disadvantaged families higher quality learning environments than they would otherwise receive. Longitudinal data from a nationally representative sample of over 600 twin pairs was used to estimate the contributions of genes, the shared environment, and the nonshared environment to cognition and achievement scores, in children enrolled versus not enrolled in preschool. Attending preschool at age 4 was associated with reduced shared environmental influences on reading and math skills at age 5, but not with shared environmental influences on cognition at age 2. These prospective effects were mediated by reductions in achievement gaps associated with minority status, socioeconomic status, and ratings of parental stimulation of cognitive development from a videotaped dyadic task. Lower socioeconomic status was associated with lower rates of preschool enrollment, suggesting that the very children who would most benefit from preschools are the least likely to be enrolled in them.

Keywords

Preschool; Socioeconomic Status; Academic Achievement; Cognitive Development; School Readiness; Behavioral Genetics

Children's academic achievement at kindergarten entry predicts their continued academic success throughout the school years (Duncan et al., 2007). Social inequalities in community-level, family-level, and school-level environments have all been implicated as contributing to disparities in early achievement (Duncan, Brooks-Gunn, & Klebanov, 1994; Huston & Bentley, 2010). It is well-established that children from low-income families attend lower quality schools than those attended by higher income families (Huston, 2004; Meyers, 2004). Yet despite the robust associations between socioeconomic privilege and school quality, some researchers have characterized schools as "equalizers" of social disparities in achievement. Supporting this seemingly paradoxical perspective, Downey, Hippel, & Broh (2004) reasoned that "some children may have relatively poor school experiences, but the disadvantages in their non-school environments may be even more severe... In this way schools can favor advantaged students, yet still serve as equalizers" (p. 614).

Based on this same rationale, early organized childcare prior to kindergarten entry (i.e. preschool) may be particularly effective in reducing social disparities in achievement at kindergarten entry, specifically by benefiting children being raised in poorer homes. As Barnett (1995; p. 43) has commented, "the best predictor of the size of [preschool] program effects may be the size of the gap between the program and home as learning environments,

rather than whether a child is a member of a particular group. Thus, effects might be expected to be largest for the most disadvantaged.” Indeed, previous studies indicate that the immediate benefits of center-based care are larger for racial minorities and socioeconomically disadvantaged groups, resulting in reduced racial and socioeconomic disparities in early cognitive functioning and school readiness for those who attend preschool. For example, using data from over 12,000 American children, Magnuson, Meyers, Ruhm, and Waldfogel (2004) reported positive associations between achievement test scores during kindergarten and enrollment in center-based daycare during the previous year, that was stronger for children from impoverished families, and poorly educated mothers (see also Bassok, 2010; Geoffroy et al., 2007, 2010). Previous studies, however, have been limited in a number of respects. First, previous studies have not examined whether the relation between preschool enrollment and the magnitude of achievement gaps emerges prospectively, rather than existing prior to the preschool years, which is a necessary requirement to infer causation rather than selection as the mechanism for gap reduction. Second, because previous studies have used data from only one child per family, they have been unable to estimate the effects of preschool on the total extent of between-family variation. Third, the specific characteristics of families examined have typically been macro-level characteristics such as socioeconomic status and race, but not moreproximal indices of the home environment, such as cognitive stimulation by parents. Based on previous work implicating more proximal learning environments, particularly parenting behaviors, as critical mediators of racial and socioeconomic disparities in achievement (Duncan et al., 1994; Guo & Harris, 2000; Lugo-Gil & Tamis-LeMonda, 2008), one might expect preschools to diminish the influence of minority status and socioeconomic status on child development, in part, by diminishing the influences of more proximal parenting behaviors on child development.

To address these outstanding issues, the current project used longitudinal data from a nationally representative sample of monozygotic and dizygotic twins nested within families. The twin design was used to separate disparities in achievement associated with the family environment from those associated with the unique (within-family) environment and with genes. In addition to estimating the relation between preschool attendance and the total amounts of between-family environmental variation, this project also estimated the association between preschool attendance and the size of achievement gaps associated with minority status, socioeconomic, status and parental stimulation of cognitive development. Thus, this project examined the extent to which total between -family variation in achievement is reduced by preschool attendance, and the extent to which these reductions could be accounted for reductions in the associations between both macro-level characteristics of families and a proximal index of parenting. Moreover, because children were measured at ages 2, 4, and 5, these analyses were able to estimate the extent to which the patterns observed were evident prior to preschool enrollment (which would be consistent with a selection but not causation account) or only after preschool enrollment (which would be consistent with a causal account of preschool enrollment in attenuating achievement gaps).

Method

Participants

Data were drawn from the Early Childhood Longitudinal Study-Birth Cohort (ECLS-B) twin sample (Snow et al., 2009), which was representative of twins born in the United States in 2001. The sample was 61% White, 16% African-American, 16% Hispanic, 3% Asian, 1% Pacific Islander, American Indian, or Alaska Native, 4% multiracial; 51% male; and 25% at or below the poverty line at study entry. The current analyses use three data waves: age 2-years in 2003–2004, 4-years (preschool age) in 2005–2006, and 5-years (kindergarten age)

in 2006. Zygosity diagnoses and preschool information were available for 1,200 twins from 600 families.¹

Measures

Zygosity (2 years)—Zygosity determinations were made from physical similarity ratings by trained investigators, using the procedure described in Tucker-Drob, Rhemtulla, Harden, Turkheimer, & Fask (2011). Zygosity determinations from physical similarity ratings such as these have been consistently shown to be over 90% accurate when cross-validated using twins of known zygosity (Forget-Dubois et al., 2003; Goldsmith, 1991; Price et al., 2000). Same-sex pairs who received a DZ diagnosis were eliminated from analyses if their parents indicated that there was a medical reason for their dissimilarity. Thirty percent of twins in the final sample were diagnosed as MZ, 30% were diagnosed as same-sex DZ, and 40% were opposite-sex DZ.

Preschool enrollment (4 years)—When the twins were 4 -years old, parents were asked whether each of the twins was enrolled in center-based childcare on a regular basis. Parents reported that 15% of twins were enrolled in Head Start, 61% of twins were enrolled in other forms of center-based care, and 26% were not enrolled in any center-based care. A twin was considered enrolled in preschool if he or she was enrolled in any form of center-based care; i.e. if the answer to either of the above questions was yes. Only six pairs were discordant for preschool enrollment and were eliminated from analyses. Eliminating children attending Head Start from analyses produced similar results to those reported here.

Early mental ability (2 years)—At 2-years, ECLS staff individually administered to each twin the Bayley Short Form-Research Edition (BSF-R), a shortened form of the Bayley Scales of Infant Development, Second Edition (Bayley, 1993). Item response theory was used to create a mental ability score, which is based on items tapping the quality of exploration of objects, early problem solving, the production of simple sound and gestures, and receptive and expressive communication with words. The reliability estimate for this score was .88 (Andreassen & Fletcher, 2007).

Early academic achievement (4 years and 5 years)—During the pre-school wave, children's early math (including number sense, counting, operations, patterns, and spatial sense) and reading skills (including letter recognition, letter sounds, phonological awareness, matching words, and receptive vocabulary) were assessed. Separate math and reading scores were derived for each child using Item Response Theory. Reliability estimates for both scores were .92 (Najarian et al., 2010).

Minority status—Minority status was dummy-coded as 1 = White and 0 = Non-White. This decision was made because there were not enough twin pairs from the different minority groups to confidently estimate effects for each race and ethnicity separately.

Socioeconomic status—SES was indexed from parental reports of paternal and maternal education, paternal and maternal occupation, and family income at the four year wave. Each of these five variables was standardized to a mean of 0 and a standard deviation of 1 in the complete ECLS-B sample, and then averaged to create the SES composite.

Parental stimulation of cognitive development (4 years)—At the preschool wave, each twin participated in a separate 10-minute long videotaped semi-structured activity with

¹All sample sizes are rounded to the nearest 50 in accordance with ECLS-B data security regulations.

his/her parent. Trained coders rated the videotaped interactions on a number of different dimensions using 7-point Likert-type scales. This project focuses on *parental stimulation of cognitive development*, a rating of the extent to which the parent demonstrates effortful, developmentally-appropriate teaching of the child to enhance cognitive, language, and perceptual development. Inter-rater reliability of this rating was estimated at over 90% for both waves of data collection (Andreassen & Fletcher, 2007; Najarian et al., 2010). In order to obtain the most reliable index of parental stimulation at the family level, scores for each twin pair were averaged and then centered at the mean (by subtracting 4.276).

Analyses

Mplus (Muthén & Muthén, 2010) was used to fit structural equation models (SEM's) with full information maximum likelihood estimation (FIML).² The basic SEM for twins raised together partitions variation in a given phenotype (Y) into variation attributable to additive genetic influences (A), shared environmental influences (C) that operate at the family level and serve to make twins within a pair more similar to one another, and nonshared environmental influences (E) that operate on each twin individually and serve to make twins within a pair dissimilar from one another.³ Note that aspects of the family environment that are either differentially experienced by twins or have differential effects on twins do not contribute to the shared environment. Based on genetic theory, additive genetic variation is correlated at 1.0 for identical twins and at .50 for fraternal twins. By definition, shared environmental variation is correlated at 1.0 across all twin pairs, and nonshared environmental variation is uncorrelated across all twin pairs. This model was expanded to examine whether the variation attributable to A, C, and E differs for children who attend preschool (*Preschool* = 1) versus children who do not attend preschool (*Preschool* = 0), as follows (cf. Purcell, 2002):

$$Y_{t,p} = \mu + b_{ps} \cdot Preschool_p + (a + a' \cdot Preschool_p) \cdot A_{t,p} + (c + c' \cdot Preschool_p) \cdot C_{t,p} + (e + e' \cdot Preschool_p) \cdot E_{t,p} \quad (1)$$

where μ is the mean of the phenotype, and b_{ps} , a , c and e are the main effects of preschool enrollment, A, C, and E respectively, and a' , c' , and e' represent the interactions of preschool enrollment with A, C, and E, respectively. The subscript t indicates that a term is allowed to vary across twins within a pair, and the subscript p indicates that a term is allowed to vary across twin pairs.

Measured family-level covariates can be added to the model and allowed to interact with preschool enrollment. Such a model that includes a single measured covariate (X), can be written as:

$$Y_{t,p} = \mu + b_{ps} \cdot Preschool_p + (b_F + b'_F \cdot Preschool_p) \cdot X_p + (a + a' \cdot Preschool_p) \cdot A_{t,p} + (c + c' \cdot Preschool_p) \cdot C_{t,p} + (e + e' \cdot Preschool_p) \cdot E_{t,p} \quad (2)$$

where b_F is the main effect of the covariate, and b'_F is the interaction effect of the covariate with preschool enrollment. The addition of measured family-level covariates to the model can potentially be used to account for shared-environment effects, and the addition of measured family-level covariate $\times$ preschool interactions to the model can potentially be used to account for shared environment $\times$ preschool interaction effects. If, in model 2, b'_F is significantly different from 0, and c' is attenuated relative to its value in model 1, the

²FIML assumes that any patterns of missingness in the dependent variables that systematically relate to the missing values can be accounted for by the independent variables in the model. There were only modest proportions of missing data, ranging from 4% to 18%, depending on the variable.

³The shared environment may partially reflect children's genotypes as a result of being the direct or indirect outcome of their biological parents' genotypes (Scarr & McCartney, 1983).

measured covariate $\times$ preschool interaction has mediated some of the shared environment $\times$ preschool interaction effect.

Results

Descriptive Statistics

Study variable means, standard deviations, and intercorrelations are presented in Table 1. It can be seen that (a) the family-level variables were all moderately interrelated, (b) the cognition and achievement variables were strongly interrelated, and (c) the family-level variables were moderately correlated with the cognition and achievement variables.

Likelihood of Preschool Enrollment

Table 2 presents the results of a multiple logistic regression predicting the odds ratio of preschool enrollment at the four year wave. It can be seen that children from higher SES families, and children born earlier in 2001 were more likely to attend preschool.

Shared Environment $\times$ Preschool Interactions

Table 3 presents parameter estimates from the application of Equation 2 to mental ability scores at 2 years, and to reading and math scores at 4 years and 5 years. First, although the logistic regression analyses reported above indicate that there are, in fact, family and child characteristics that systematically predict the likelihood of preschool attendance, the magnitudes of genetic and environmental influences on mental ability at age 2 years do not significantly differ by subsequent preschool enrollment status (i.e., the a' , c' , and e' coefficients are not significantly different from zero). The shared environment accounts for 58% versus 60% of the variance in 2-year old Bayley scores among children who were not enrolled versus enrolled in preschool at age 4. This result is important for establishing that it is not a preexisting selection factor that attenuates family-level influences on subsequent achievement.

Second, at 4 years, shared environmental influences on math and reading scores begin to differ by preschool attendance, although these differences are not statistically significant for reading, and are only marginally significant for math. The shared environment accounts for 74% versus 55% of the variance in math scores among children not attending versus attending preschool at age 4. For reading, these proportions are 82% and 63%.

Finally, by 5 years, shared environmental influences on math and reading scores differ sharply between children who attended preschool at age 4 versus those who did not. The shared environment accounts for 72% versus 47% of the variance in math scores at age 5 among children who were not enrolled versus who were enrolled in preschool the previous year. For reading these proportions are 73% and 43%. To illustrate this pattern, Figure 1 plots the unstandardized variance in math and reading scores accounted for by the shared environment at 4 and 5 years by preschool enrollment. The magnitude of shared environmental influence on these two outcomes begins to differ at age 4, with the difference growing substantially over the 1-year interval. By age 5, family-level influences on achievement are substantially lower for children who had attended preschool during the previous year.

To further illustrate the shared environment $\times$ preschool interaction, Figure 2 plots the relation between the latent shared environment and math and reading scores at age 5 by preschool enrollment. The relation between the latent shared environment and achievement scores is steeper for children who had not attended preschool compared to those who had. For very low scores on the shared environment (1.5 SD's below the mean), children who

had been enrolled in preschool score approximately .8 points better in math and .9 points better in reading than those who had not been enrolled in preschool. For very high scores on the shared environments (1.5 SD's above the mean), there is no appreciable achievement disparity between children who had attended preschool and those who had not. The next set of analyses seeks to clarify these results by examining measured, rather than latent, characteristics of families.

Measured Covariate $\times$ Preschool Interactions

Parameter estimates for measured covariate $\times$ preschool interaction models are presented in Table 4 for math skills at age 5 and in Table 5 for reading skills at age 5. Three parameters from each model are of particular interest: b_F , b'_F and c' . The b_F parameter represents the main effect of the measured covariate for children who had not attended preschool at age 4, and is significantly positive in all cases: For children who had not attended preschool at age 4, being White, being higher SES, and receiving higher parental stimulation predicted higher math and reading scores at age 5. The b'_F parameter (the measured covariate $\times$ preschool interaction) represents the difference in the effect of the measured covariate for children who had been enrolled in preschool at age 4. This parameter is significantly negative in all cases: The association between ethnic minority status, socioeconomic status, and parental stimulation, on the one hand, and math and reading scores at age 5, on the other hand, were substantially reduced for children who had been enrolled in preschool at age 4. Finally, the c' parameter represents the extent to which the remaining shared environmental influences (i.e. unmeasured family-level variation unaccounted for by the measured covariates) are lower for children who had attended preschool at age 4. In all cases, this parameter is attenuated relative to its corresponding estimate in Table 3, suggesting that the measured covariate $\times$ preschool interactions accounted for some of the shared environment $\times$ preschool interactions reported earlier. When measured covariates are not included in the model, the c' coefficient is $-.256$ for age 5 math and $-.278$ for age 5 reading. For models of that included minority status, socioeconomic status, and parental stimulation, these estimates are $-.142$, $-.152$, and $-.203$ for age 5 math, and $-.189$, $-.152$, and $-.224$, for age 5 reading respectively.

All six measured-covariate $\times$ preschool interactions are illustrated in Figure 3. Each panel in the figure plots the model-implied achievement test scores at age 5 for children who had been enrolled in preschool at age 4 and those who had not, stratified by different levels of the measured covariate. For both math and reading, a greater benefit of attending preschool is associated with being nonwhite, lower SES, and raised by a parent rated as less stimulating. In other words, racial differences, socioeconomic differences, and parental stimulation -associated differences in early math and reading are reduced among children who attended preschool.

Stepwise Analyses

The final set of analyses used a stepwise approach to sequentially add minority status, SES, and parental stimulation to the models of reading and math at 5 years. Analyses and results are described in further detail in the online supplement to this article. To summarize, when all three interactions were included in a simultaneous model, none of the interactions was individually significant, indicating that the interaction effects largely represent an overlapping set of family-level influences that are together attenuated by preschool enrollment.

Discussion

The major finding reported in this article is that preschool attendance at age 4 was prospectively associated with substantially reduced family-level influences on early reading and math skills at age 5. Among children who attended preschool, shared environmental influences on early math and reading skills at age 5 years were attenuated, accounting for 47% of the variance in math and 43% of the variance in reading, versus 72% in math and 73% in reading among children who did not attend preschool. The magnitude of shared environmental influences on cognitive functioning at age 2 did not differ by subsequent preschool attendance, suggesting that these interaction effects could not be attributed to pre-existing selection factors. Preschool attendance was prospectively associated with enhanced reading and math skills, particularly for racial and ethnic minorities, children from lower SES families, and children whose parents were rated as less cognitively stimulating. It was primarily the overlapping effect of minority status, SES, and parental stimulation that was attenuated by preschool enrollment. Moreover, SES significantly predicted the likelihood of being enrolled in preschool, suggesting that the very children who would benefit most from preschools are those who are least likely to be enrolled in preschool. Therefore, differences in the rate of preschool attendance across families may actually serve to perpetuate achievement disparities at the population level.

Previous investigations of the role of early childcare in equalizing between-family disparities in academic achievement have used research designs that include only one child per family, and so have been able only to examine whether preschool enrollment attenuates the impact of specific, measured family characteristics. In contrast, by using twin data, the current study was able to estimate the total effect of family-level influences on achievement. The method applied relies on the standard assumptions of the twin approach. Importantly, however, Loehlin, Harden, & Turkeheimer (2009) have demonstrated that interaction effect estimates in twin models are far less affected by violations of standard assumptions than are main effect estimates. Because the current study was primarily concerned with interaction effects (specifically, the shared environment by preschool interaction), the current findings can be considered robust.

Because data were available from multiple waves of longitudinal data, including a wave preceding preschool enrollment, the current study could test whether there were pre-existing differences in the magnitude of shared environmental influences associated with later preschool status. The absence of such pre-existing differences strengthens the inference that the observed interaction effects were indeed caused by preschool attendance. In theory, an even stronger causal inference could be made using a randomized experiment, such as a lottery for preschool vouchers, combined with methods to examine treatment effect heterogeneity (e.g. Tucker-Drob, 2011).

While this study was unique in examining multiple measured family-level covariates as modifiers of preschool effects, a limitation is that specific characteristics of preschools were not examined. One might expect that the greatest preschool boost would occur for the few disadvantaged children who are fortunate enough to attend high quality preschools. Previous work has reported that several indices of childcare quality, including live observer ratings of preschool teachers' sensitivity, responsiveness, and stimulation of cognitive development (Dearing, McCartney, & Taylor, 2009), are specifically associated with reduced achievement gaps. Other factors associated with reduced achievement gaps at school entry include earlier age of enrollment in childcare (O'Brien et al., 1994), being in a full-time rather than part-time program (Geoffroy, 2007), being in a formal center-based program rather than an informal program (Geoffroy et al., 2010), and being exposed to more school transition practices, such as preschoolers spending time in the kindergarten classroom and

teachers visiting the home at the beginning of the kindergarten school year (Schulting, Malone, & Dodge, 2005). Future work should examine these factors in the context of a longitudinal study that charts the achievement gap prior to-and following- preschool enrollment. While empirical research on school and home quality (Dowsett et al., 2008, p. 90) has found that preschools “offer more opportunities for cognitive and intellectual development than do the home-based settings... that are typically used by low-income parents,” it is possible that the preschool-associated gap reductions found here were primarily driven by those preschools meeting a minimum threshold of quality.

Finally, although this study examined (and detected) effects of preschool on achievement gaps in academic achievement in kindergarten, it is unknown whether gap reductions would be maintained into later childhood, adolescence, or adulthood. The vast majority of previous experimental and quasi-experimental studies have reported large immediate benefits of preschools on impoverished children’s achievement, but only a select subset (e.g. Campbell et al., 2002; Schweinhart et al., 2005) have found the effects to persist in the long term, whereas many others have found that the effects fade out over time (e.g. Currie & Thomas, 1995; see Leak et al., 2010 for a meta analysis). Barnett (1995) has speculated that differences in quality and funding across programs may help to account for differences in long term effects. It is also likely that inequalities in children’s post-preschool experiences serve to wash out early gains, and that maintenance of gains among low-income children would generally require amelioration of inequalities that exist during the elementary school, middle school, and high school years. Notwithstanding this latter issue, economic analyses have indicated long term monetary benefits of investment in preschool programs for impoverished children (Barnett, 1995; Duncan, Ludwig, & Magnusson, 2007; Heckman, 2006).

In conclusion, the current results suggest that preschools may help to reduce achievement gaps associated with multiple measured and unmeasured family-level variables. However, because lower-socioeconomic status families are less likely to send their children to preschool, the equalizing effects of preschools at the population level may not be fully realized. It remains unclear, however, what specific aspects of preschools are responsible for these effects, or whether immediate benefits of preschool for reducing achievement gaps would persist in the long term.

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Figure 1.

Left: Amounts of unstandardized variance in math scores accounted for by the shared environment at 4 and 5 years for children enrolled in preschool at 4 years and children not enrolled in preschool at 4 years. Right: Amounts of unstandardized variance in reading scores accounted for by the shared environment at 4 and 5 years for children enrolled in preschool at 4 years and children not enrolled in preschool at 4 years.

Figure 2.

Left: Relation between scores on the latent shared environment (x axis) and average math scores at age 5 (y axis) for children who had, and had not, been enrolled in preschool the previous year. Right: Relation between scores on the latent shared environment (x axis) and average reading scores at age 5 (y axis) for children who had, and had not, been enrolled in preschool the previous year.

Figure 3.

Each panel plots average achievement test scores at age 5 for children who had been enrolled in preschool at age 4 and those who had not, stratified by different levels of the measured covariate. The left column of panels is for math scores, and the right column of panels is for reading scores. The first row of panels stratifies outcomes by minority status. The second row of panels stratifies outcomes by SES. The third row of panels stratifies outcomes by ratings of parental stimulation of cognitive development during a dyadic task between parent and child. Low = 1.5 SD's below mean. Medium = mean. High = 1.5 SD's above mean.

Table 1

Study variable means, standard deviations, and intercorrelations.

Variable	Mean	Standard Deviation	1.	2.	3.	4.	5.	6.	7.	8.
1. Bayley at 2 year wave	122.72	10.74								
2. Reading at 4 year wave	-.56	.72	.41							
3. Reading at 5 year wave	.26	.87	.34	.69						
4. Math at 4 year wave	-.58	.78	.42	.76	.68					
5. Math at 5 year wave	.27	.79	.41	.69	.85	.74				
6. Age (in months) at 4 year wave	52.89	4.10	.02	.28	.31	.33	.27			
7. SES at 4 year wave	.13	.85	.32	.50	.40	.47	.47	.02		
8. Minority Status (Nonwhite = 0, White = 1)	.62	n/a	.24	.36	.27	.29	.33	-.02	.42	
9. Parental Stimulation	.00	.86	.22	.28	.28	.25	.27	-.08	.49	.32

To avoid dependencies in this table, these statistics come from one twin per pair. Parental Stimulation was centered at its mean.

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Table 2
Predictors of log odds preschool enrollment at 4 year wave from a multiple logistic regression.

Predictors	Estimate	SE	p value
Bayley at 2 year wave	−0.003	0.010	.791
Age (in months) at 4 year wave	0.065	0.023	.004
SES at 4 year wave	0.521	0.140	.001
Minority Status (Nonwhite = 0, White = 1)	−0.008	0.210	.969
Parental Stimulation	0.080	0.135	.554

To avoid dependencies in this table, these results come from a model that included only one twin per pair. Values in bold are significant at $p<.05$.

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Parameter estimates from shared-environment $\times$ preschool models of mental ability at 2 years, and academic achievement at 4 years and 5 years.

Table 3

Parameter	Bayley (2 Years)		Math (4 years)		Reading (4 years)		Math (5 years)		Reading (5 years)	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
b_{PS} (main effect of Preschool)	1.877	.863	.481	.068	.440	.063	.401	.084	.481	.091
a	4.122	1.547	.256	.107	.000	.468	.384	.074	.435	.063
a'	.130	1.893	.116	.119	.282	.472	.048	.089	.099	.078
c	7.474	.881	.668	.055	.643	.042	.760	.067	.816	.071
c'	.928	1.033	-.120 ^b	.067	-.085	.054	-.256	.080	-.278	.087
e	4.857	.472	-.307	.033	.303	.018	-.272	.031	-.244	.028
e'	.465	.581	-.014	.039	.014	.028	-.048	.038	-.065 ^a	.035
μ	121.401	.721	-.921	.060	-.868	.055	.005	.077	-.095	.083

Preschool = 0 for no preschool enrollment at 4 year wave and 1 for preschool enrollment at 4 year wave. Values in bold are significant at $p < .05$.

^a $p = .06$.

^b $p = .07$

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Table 4
Parameter estimates for measured covariate $\times$ preschool interaction models of math skills at age 5 years (kindergarten age).

Parameter	Preschool $\times$ Minority Status Model		Preschool $\times$ SES Model		Preschool $\times$ Parental Stimulation	
	Estimate	SE	Estimate	SE	Model Estimate	SE
b_{PS} (main effect of Preschool)	.674	.115	.238	.070	.338	.079
b_F (main effect of family-level covariate)	.886	.133	.570	.068	.430	.082
b'_F (covariate $\times$ Preschool interaction)	-.551	.151	-.216	.079	-.274	.094
a	.382	.074	.379	.074	.381	.074
a'	.049	.089	.057	.089	.050	.089
c	.622	.064	.563	.064	.678	.065
c'	-.142_b	.078	-.152^a	.080	-.203	.079
e	.272	.031	.273	.032	.272	.031
e'	.048	.039	.046	.038	.048	.039
μ	-.489	.100	-.216	.079	.055	.072

Minority Status= 0 for Nonwhite and 1 for White. The ' indicates the interaction with preschool enrollment. Preschool = 0 for no preschool enrollment at 4 year wave and 1 for preschool enrollment at 4 year wave. Values in bold are significant at $p<.05$.

^a $p=.06$,

^b $p=.07$.

Table 5

Parameter estimates for measured covariate $\times$ preschool interaction models of reading skills at age 5 years (kindergarten age).

Parameter	Preschool $\times$ Minority Status Model		Preschool $\times$ SES Model		Preschool $\times$ Parental Stimulation	
	Estimate	SE	Estimate	SE	Model Estimate	SE
b_{PS} (main effect of Preschool)	.750	.130	.325	.078	.415	.086
b_F (main effect of family-level covariate)	.813	.151	.588	.075	.443	.089
b'_F (covariate $\times$ Preschool interaction)	-.533	.170	-.274	.088	-.277	.102
a	.433	.063	.433	.063	.434	.063
a'	.100	.078	.105	.078	.099	.078
c	.711	.068	.622	.067	.733	.069
c'	-.189	.085	-.152 ^c	.087	-.224	.087
e	.244	.028	.244	.028	.244	.028
e'	.065 ^a	.035	.064 ^b	.035	.065 ^a	.035
μ	-.549	.113	-.018	.069	-.043	.077

Minority Status= 0 for Nonwhite and 1 for White. The ' indicates the interaction with preschool enrollment. Preschool = 0 for no preschool enrollment at 4 year wave and 1 for preschool enrollment at 4 year wave. Values in bold are significant at $p < .05$.

^a $p = .06$,

^b $p = .07$,

^c $p = .08$.