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Environmental contributors to the achievement gap[☆]

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ABSTRACT

Extensive research shows that blacks, those of low socioeconomic status, and other disadvantaged groups continue to exhibit poorer school performance compared with middle and upper-class whites in the United States' educational system. Environmental exposures may contribute to the observed achievement gap. In particular, childhood lead exposure has been linked to a number of adverse cognitive outcomes. In previous work, we demonstrated a relationship between early childhood lead exposure and end-of-grade (EOG) test scores on a limited dataset. In this analysis, data from the North Carolina Childhood Lead Poisoning Prevention Program surveillance registry were linked to educational outcomes available through the North Carolina Education Research Data Center for all 100 counties in NC. Our objectives were to confirm the earlier study results in a larger population-level database, determine whether there are differences in the impact of lead across the EOG distribution, and elucidate the impact of cumulative childhood social and environmental stress on educational outcomes. Multivariate and quantile regression techniques were employed. We find that early childhood lead exposure is associated with lower performance on reading EOG test scores in a clear dose-response pattern, with the effects increasingly more pronounced in moving from the high end to the low end of the test score distribution. Parental educational attainment and family poverty status also affect EOG test scores, in a similar dose-response fashion, with the effects again most pronounced at the low end of the EOG test score distribution. The effects of environmental and social stressors (especially as they stretch out the lower tail of the EOG distribution) demonstrate the particular vulnerabilities of socio-economically and environmentally disadvantaged children. Given the higher average lead exposure experienced by African American children in the United States, lead does in fact explain part of the achievement gap.

1. Introduction

Extensive research shows that blacks, those of low socio-economic status, and other disadvantaged groups continue to exhibit poorer school performance compared with middle and upper-class whites in the United States' educational system (Gamoran, 2001; Hallinan, 1988; Hedges and Nowell, 1999; Jencks and Phillips, 2000; Kao and Thompson, 2003; Walters, 2000). Blacks score lower on tests than whites, starting in childhood and continuing throughout their education. Although this gap has narrowed in the last three decades, on most standardized tests, median black scores are below 75 percent of whites (Jencks and Phillips, 2000).

Environmental exposures may contribute to the etiology of the achievement gap. Childhood lead exposure has been linked to a number of adverse cognitive outcomes, including reduced performance on standardized intelligence quotient (IQ) tests (Schnaas et al., 2006; Canfield et al., 2003; Tong et al., 1996; Bellinger et al., 1992; Dietrich et al., 1993; Lanphear et al., 2005; Schwartz, 1993), decreased performance on cognitive functioning tests (Lanphear et al., 2000), adverse neuropsychological outcomes (Ris et al., 2004), neurobehavioral deficits (Chiodo et al., 2004), poorer end-of-grade (EOG) test scores (Miranda et al., 2007), and classroom attention deficit and behavioral problems (Fergusson et al., 1988; Hatzakis et al., 1985; Needleman et al.,

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Abbreviations: EOG, end-of-grade; BLL, blood lead level; NCERDC, North Carolina Education Research Data Center; NCCLPPP, North Carolina Childhood Lead Poisoning Prevention Program.

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1979; Silva et al., 1988; Thomson et al., 1989; Yule et al., 1984; Braun et al., 2006).

Socioeconomic status (measured as occupation, income, education, wealth (Conley, 2001; Orr, 2003; Mayer, 1997; Brooks-Gunn and Duncan, 1997) or home ownership (Mayer, 1997; Green and White, 1997; Aaronson, 2000; Hill and Duncan, 1987)) is positively correlated with many measures of educational attainment, including children's reading levels (Department of Education, 2002), placement in high-achievement curricular tracks (Dougherty, 1996), not dropping out of high school (Alexander et al., 1997), college matriculation directly from high school (Baker and Velez, 1996), elite college attendance (Baker and Velez, 1996), and college graduation (Baker and Velez, 1996).

In previous work (Miranda et al., 2007), we linked lead surveillance data to EOG testing data for seven North Carolina counties. We showed that: (1) African American children in these seven counties are routinely exposed to more lead; and (2) blood lead levels in early childhood are negatively correlated with educational achievement in early elementary school, as measured by performance on EOG testing. This association holds at blood lead levels as low as 2 μg/dL (Miranda et al., 2007).

This paper extends our previous work, and the literature more generally, in three distinct ways. First, we extended the analysis to all 100 counties in NC, which made the constituent school systems and housing stock, as well as the local demographics, much more varied. In addition, this larger study area solved some of the small cell number problems noted in the 2007 paper (Miranda et al., 2007). Second, traditional multivariate regression analysis only examines what is happening at the means of distributions. In contrast, we employ quantile regression analysis to elucidate what is happening across the entire distribution (i.e., the technique shows how the coefficients on the explanatory variables change depending on location along the EOG test score distribution). Thus the technique can answer questions like, "Does lead exposure have a bigger or smaller effect on EOG scores at the bottom tail of the distribution compared to the top tail?" This is especially important when thinking about the tails of EOG scores, which are particularly relevant to educational policy/outcomes. Third, we examined the joint and cumulative effect of social and environmental stressors, again using quantile regression analysis. This analysis allows us to consider how combined effects of social and environmental stress might compound in certain subpopulations.

Insights from this paper provide early signals for identifying children who are particularly at risk for poor performance in school, as well as other longer term adverse developmental outcomes. Early identification of such children allows health care providers and child advocates to play a pivotal role in educating parents and connecting children at risk with relevant resources in a timely manner.

2. Methods

This research was conducted under the auspices of the Children's Environmental Health Initiative at Duke University according to a research protocol approved by the university's Institutional Review Board.

The North Carolina Education Research Data Center (NCERDC) maintains a database with records of all EOG test results for all public school systems in the state for tests from the 1995–1996 school year to present. After establishing a data sharing agreement, researchers can access identifying information such as name, birth date, and test scores, as well as data on parental education, race, ethnicity, participation in the free or reduced lunch program, English proficiency, testing condition modifications, and school district. These data can be linked longitudinally for all years each child has taken EOG tests in NC. The North Carolina EOG reading test is designed to measure students' mastery of the content outlined in the North Carolina English Language Arts Standard Course of Study (NC Department of Public Instruction, 2008). Because states typically develop their own curricula and associated EOG exams, the North Carolina testing data cannot be directly compared to testing outcomes for children residing in other states.

The North Carolina Childhood Lead Poisoning Prevention Program (NCCLPPP) maintains a state registry of blood lead surveillance data. Through a negotiated confidentiality agreement, the Children's Environmental Health Initiative has access to individual blood lead screening data from 1995 to present. The NCCLPPP blood lead surveillance data include child name, birth date, race, ethnicity, test date, blood lead level (BLL), and home address. A description of the laboratory protocols followed by the NC State Laboratory of Public Health can be found in Miranda et al. (2007). For children with duplicate screens, we retained entries with the highest blood lead level, which is consistent with Lanphear et al. (1998) and several studies by Miranda et al. (2002, 2007) and Kim et al. (2008).

To construct our integrated database, children who were screened for lead between the ages of 9–36 months from 1995 through 1999 in the 100 NC counties (318,068 records for 263,403 children) were linked to records in the EOG testing data in age-corresponding years (2001–2005). Our process linked 38.8% of screened children to at least one EOG record. Preliminary analysis was restricted to students who self-reported race as either white or black and who did not report limited English proficiency. We conducted all analyses on 4th-grade reading scores. The final linked dataset for 4th-grade reading results contained 57,678 observations.

We used two methods to analyze the relationship between social factors and blood lead levels and EOG test scores. We employed multivariate linear regression with EOG test scores as the response variable. The explanatory/predictor variables include child's race, child's sex, parental education, whether or not the child is enrolled in the free and reduced lunch program, whether the school is a charter school (in NC, this is typically an indicator of lower socioeconomic status of the enrolled children), and early childhood lead exposure, as well as dummy variables for each school system in the state. Early childhood lead exposure was modeled using dummy variables for each blood lead level. A blood lead level (BLL) of 1 μg/dL served as the referent group, resulting in nine dummy variables ($\text{BLL} = 2\ \mu\text{g/dL}$, $\text{BLL} = 3, \ldots, \text{BLL} = 9$, $\text{BLL} \geq 10\ \mu\text{g/dL}$). Models that use a series of dummy variables for blood lead levels have been shown to fit better than models that use a linear function of lead exposure (Miranda et al., 2007). The child's age at screening for lead was controlled for using two dummy variables (screened between 18 and 27 months, and between 27 and 36 months), with the referent group of being screened between 9 and 18 months.

The linear regression assumes that the distributions of EOG test scores at different social or environmental "exposures" have the same shapes but different means. This may not be the case. For example, poverty or lead exposure may have a greater or lesser impact on those students who tend to be at one end or the other of the EOG test score distribution. Thus, we employed a second method of analysis, quantile regression (Koenker, 2005; Feudtner et al., 2006; Lal et al., 2003), which enabled us to examine distributional differences.

Quantile regressions predict conditional percentiles of an outcome variable from a set of explanatory variables (e.g. what is the 10th percentile of EOG test scores conditioned on early childhood lead exposure levels). It results in an equation for predicting conditional percentiles of interest rather than conditional means. Quantile regression has previously been used in the pediatric literature to assess the risk of chronic lung disease in

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small for gestational age infants (Lal et al., 2003), to assess how distance from home when death occurs is changing for children over time (Feudtner et al., 2006), and to describe the history of somatic growth in HIV-infected children (Carey et al., 1998).

We included the same explanatory variables in the quantile regression as were used in the linear regression. We predicted the conditional percentiles of the EOG test score distributions at every 5th percentile until the 95th percentile (i.e., 5th, 10th, 15th, . . ., 95th). This approximates the entire distribution of EOG scores. This enabled us to examine how entire distributions of EOG test scores change with lead exposure, as well as with parental educational attainment and family poverty status, without assuming only a shift in means.

3. Results

Table 1 provides summary statistics on subgroups within the final linked dataset for 4th-grade reading test scores. Of the total linked children: 43.1% were black (56.9% are white); 52.9% enrolled in the free or reduced lunch program; 8.1% had parents who did not complete high school; 45.3% had parents who completed high school; and 46.6% had parents who had more than high school education (college, graduate school, etc.). Blood lead levels for the linked children ranged from 1 to 16 μg/dL, with the mean and median levels of 4.8 and 4 μg/dL, respectively. The interquartile range was 3, with the 25th and 75th percentiles equal to 3 and 6 μg/dL, respectively. Average EOG test scores were lower for children enrolled in the free or reduced lunch program, children whose parents had lower levels of education, and children who were exposed to more lead. Black children were overrepresented in the "riskier" end of each of these variables.

Table 2 presents the results of the multivariate linear regression for reading EOG test scores, controlling for the covariates in Table 1 and individual school system variability. The referent group is defined as white, female students, enrolled in the Wake County School System, who do not participate in the free or reduced lunch program, whose parents graduated high school, and who have a blood lead level equal to one. The coefficients of all the covariates

Table 1
Summary statistics on subgroups in the final linked 4th-grade reading dataset for 100 counties in NC ($N = 57{,}678$).

Variable	Subcategory	Avg. reading EOG	Proportion (%)		
			Overall	Black	White
Race	White	254.6	56.9		
	Black	248.5	43.1		
Household income	Not enrolled in free/reduced lunch program	255.3	47.1	21.2	66.8
	Enrolled in free/reduced lunch program	249.0	52.9	78.8	33.2
Parental education	Completed graduate school	260.1	3.5	0.9	5.4
	Completed college	257.2	18.5	9.8	25.1
	Some post-high school education	252.7	24.6	23.7	25.2
	Completed high school	249.8	45.3	55.5	37.7
	Some high school education	246.5	8.1	10.1	6.6
Blood lead levels	BLL of 1 μg/dL	254.4	6.7	3.7	8.8
	BLL of 2 μg/dL	253.8	13.4	9.1	16.7
	BLL of 3 μg/dL	253.0	18.5	14.3	21.6
	BLL of 4 μg/dL	252.3	17.8	17.2	18.3
	BLL of 5 μg/dL	251.4	14.1	15.6	13.0
	BLL of 6 μg/dL	250.6	10.1	12.4	8.3
	BLL of 7 μg/dL	250.2	6.7	8.9	5.0
	BLL of 8 μg/dL	249.6	4.1	5.9	2.8
	BLL of 9 μg/dL	249.8	2.5	3.6	1.8
	BLL of 10 μg/dL or higher	248.7	6.1	9.3	3.7

Table 2
Results of multivariate linear regression for 4th-grade reading EOG score data ($N = 57{,}678$)[a].

Response variable: 4th-grade reading EOG score[b]	Coef.	$p > t$	95% confidence interval
Dummy for BLL equal to 2 μg/dL	−0.30	0.04	(−0.58, −0.01)
Dummy for BLL equal to 3 μg/dL	−0.46	0.00	(−0.73, −0.19)
Dummy for BLL equal to 4 μg/dL	−0.52	0.00	(−0.79, −0.24)
Dummy for BLL equal to 5 μg/dL	−0.80	0.00	(−1.08, −0.51)
Dummy for BLL equal to 6 μg/dL	−0.99	0.00	(−1.29, −0.68)
Dummy for BLL equal to 7 μg/dL	−1.07	0.00	(−1.40, −0.74)
Dummy for BLL equal to 8 μg/dL	−1.35	0.00	(−1.73, −0.97)
Dummy for BLL equal to 9 μg/dL	−1.20	0.00	(−1.64, −0.75)
Dummy for BLL equal to 10 μg/dL or higher	−1.75	0.00	(−2.09, −1.41)
Screened for lead between 18 and 27 months of age	0.36	0.61	(−0.10, 0.17)
Screened for lead between 27 and 36 months of age	−0.61	0.00	(−0.78, −0.43)
Black (1 for black; 0 for white)	−3.55	0.00	(−3.71, −3.40)
Male (1 for male; 0 for female)	−1.50	0.00	(−1.62, −1.38)
Enrolled in free or reduced lunch program	−2.09	0.00	(−2.24, −1.94)
Parents with some high school education	−2.78	0.00	(−3.01, −2.55)
Parents with some post-high school education	2.00	0.00	(1.84, 2.15)
Parents completed college	4.94	0.00	(4.75, 5.12)
Parents completed graduate school	7.12	0.00	(6.77, 7.47)
Charter schools	−2.58	0.00	(−3.06, −2.10)
Constant	255.03	0.00	(254.67, 255.39)

[a] The individual school system level dummy variables ($N = 114$) are not presented.

[b] The mean 4th-grade reading EOG score for this sample is 251.9, the median 252, and the standard deviation 8.5. The interquartile range was 12.

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are of the expected signs. We tested for interaction between blood lead levels and parental education or enrollment status in the free and reduced lunch program, but no significant interactions were found. We also tested for interaction between lead exposure and the age indicators, and again, the results were not significant. Therefore, to simplify interpretations, we did not include the interactions in the final model.

The coefficients of the indicator variables for each blood lead level are consistently negative and statistically significant (all $p < .0001$). They generally increase in absolute magnitude as blood lead levels increase. Thus, these results demonstrate a strong and statistically significant dose-response effect between early childhood lead exposure and performance on elementary school achievement tests (i.e., the higher the early childhood lead exposure, the lower the EOG test scores for the child).

Table 2 also demonstrates a strong and statistically significant dose-response effect between parental educational attainment and performance on elementary school achievement tests (i.e., the more education completed by the parent, the higher the EOG test scores for the child). Parental educational attainment may be serving as a proxy for family socioeconomic status or parental IQ (or some combination of the two) (Mueller et al., 2001; Davis-Kean, 2005). The coefficient on participation in the free or reduced lunch program is negative and significant as expected.

While the linear regression results provide interesting and important insights, they focus on study subjects at the mean of the EOG distribution curves. We are interested in both the top and bottom tails of the distribution: location on the top tail determines placement into advanced and intellectually gifted programs, and location on the bottom tail determines grade advancement and class placement. To understand how the environmental and social stressors are affecting subjects/population located on different portions of the EOG curve, we employed quantile regression. Similar to the linear regression model, interaction effects among key explanatory variables were also tested in the quantile regression models, but were not found to be significant. Fig. 1 displays three box and whiskers plots summarizing the results from the quantile regression.

The first panel of Fig. 1 displays the distributions of EOG scores for children at five different blood lead levels. All five boxes are based on children not enrolled in free/reduced lunch and whose parents completed high school. EOG scores generally decrease as blood lead levels increase. For all quantiles, the effects of increasing blood lead level from 1 μg/dL to any blood lead level greater than 3 μg/dL are statistically significant ($p < .05$). The distributions for children with relatively high lead exposure are more spread out than those for children with relatively low lead exposure (e.g., the difference between the 95th and 5th percentiles is 24.6 for children with a blood lead level of 10 μg/dL or higher, and is 23.1 for children with a blood lead level of 1 μg/dL). Most of this additional spread occurs on the low end of the EOG distribution. For example, when going from a blood lead level of 1–10+ μg/dL, the 5th percentile drops about 2.3 points whereas the 95th percentile drops only 0.8 points. Lead exposure stretches out the lower tail of the test score distribution by more than it moves the middle portion or upper tail of the distribution. This differential effect is statistically significant ($p = .04$). Thus, lead effects may be even more potent in populations at the lower performance regions of the EOG curve.

The second panel of Fig. 1 displays the distributions of EOG scores for children with differing parental education. All five boxes are based on children not enrolled in free/reduced lunch and who have a BLL = 1 μg/dL. EOG scores tend to decrease with lower parental educational attainment. For all quantiles, the effects of decreasing education level from any education level more than high school education to the level of less than high school education are statistically significant ($p < .05$). The distributions for parents with comparatively low educational attainment are more spread out than those for parents with higher educational attainment (e.g., the difference between the 95th and 5th percentiles is 23.4 when parents have less than high school education and is 20.7 when parents have graduate education). Akin to the effects of lead exposure, most of this additional spread occurs on the low end of the EOG distribution. There is an 8.0 point gap in the 95th percentile scores between parents who have less than high school education and parents who have graduate education, whereas the gap is 10.7 points in the 5th percentile scores. This differential effect is statistically significant ($p < .00001$).

Fig. 1, in the last panel, displays the distributions of EOG scores for children enrolled or not enrolled in the free and reduced lunch program. Both boxes are based on children whose parents have a high school degree only and who have a BLL = 1 μg/dL. EOG scores tend to be lower for children enrolled in the free and reduced lunch program ($p < .05$). The 95th percentile values for the two groups differ by 1.7 points, whereas the 5th percentile values differ by 2.6 points. This differential effect is statistically significant ($p = .0002$).

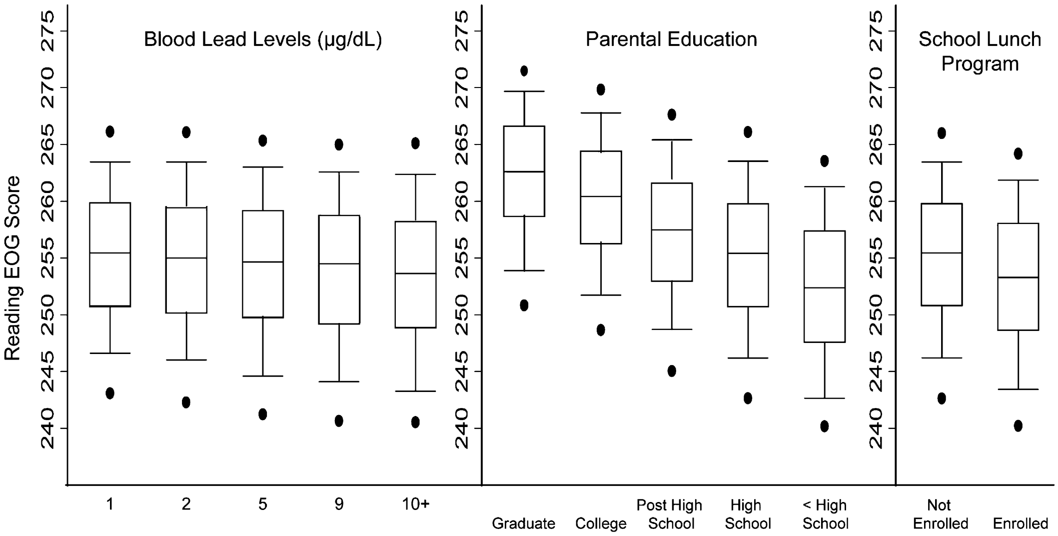

Fig. 1. Box plots of the estimated 4th-grade reading EOG scores from quantile regression models ($N = 57{,}678$).

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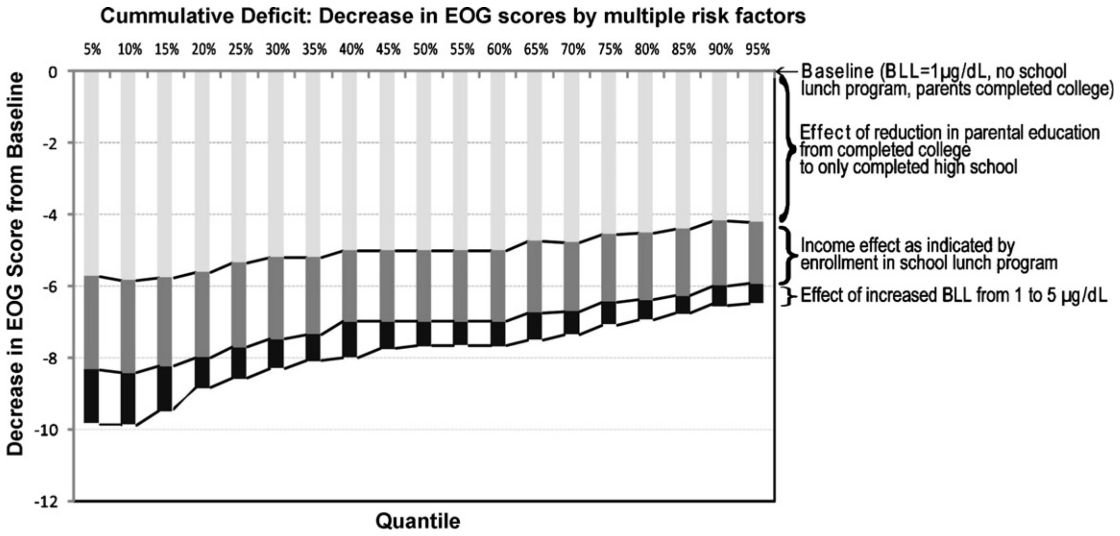

Fig. 2. Cumulative deficit: decrease in EOG scores by multiple risk factors ($N = 57{,}678$).

The negative effects shown in Fig. 1 are for each variable holding the other variables constant. Some children are subject to multiple risk factors that would affect test performance. This is illustrated in Fig. 2, which compares the percentiles of test scores for children who have "lower risk" values on all three variables (parents who have completed college, not enrolled in lunch program, and BLL = 1 μg/dL) with the percentiles of test scores for children who have comparatively "higher risk" values on all three variables (parents who have only completed high school, enrolled in lunch program, and BLL = 5 μg/dL). For example, the 5th percentile of test scores for children in the "higher risk" group is about 10 points lower than the 5th percentile of test scores for children in the "lower risk" group (shown in the first bar in Fig. 2).

Fig. 2 reveals that parental education differences account for the largest part of the test score decrement at any percentile (58–65% of total decrement), and that the lunch program and lead exposure account for 25–28% and 7–16% of the total test score decrement, respectively. Of course, as lead exposure increases, the proportion of the test score drop accounted for by lead exposure increases. Fig. 2 also highlights the trend seen in Fig. 1: deficits in these variables impact low percentiles of the test score distribution more than they impact high percentiles. Again, the combination of risk factors has a greater impact on the population at the lower end of the EOG distribution.

4. Discussion

Exposure to lead does not just shift the EOG score distribution to the left. Rather, it shifts the distribution to the left, pushes it down (i.e., introduces more variability), and stretches out the lower tail. Additional social factors, like low parental educational attainment or family poverty, can also shift the curve further to the left and stretch out the lower tail even more. Thus, children who experience these cumulating deficits are especially disadvantaged when they enter the school system. Given the higher average lead exposure experienced by African American children in the United States, lead does in fact explain part of the achievement gap.

In addition, as important as the lower tail of the distribution is, shifts at the upper tail are of concern as well. The use of EOG scores for placement into advanced and intellectually gifted (AIG) programs is ubiquitous in NC, and across the United States. Thus, at the high end of the distribution, even low level lead exposure can push some children out of the score range that would make them eligible for these special programs. To the extent that low income and minority children are systematically exposed to more lead (U.S. GAO, 1999; Center for Disease Control and Prevention, 2005), then AIG programs become less economically and racially diverse (Gootman and Gebeloff, 2008).

Study limitations include the fact that not all children are screened for lead and, even among those who are screened for lead, not all can be linked to EOG test scores. In addition, we do not have measures of childhood iron deficiency, which tends to increase lead uptake and has been linked to poorer neurodevelopmental outcomes. Measures of the quality of the home environment, including the availability of age-appropriate print materials, would also strengthen the analysis.

In future research, we hope to: include more years of EOG data in order to improve data linkage between the two administrative datasets; link our current data back the NC Vital Statistics detailed birth record data to provide another set of data relevant to child development; follow the same children over time, using subsequent performance on later-grade EOGs, to determine the persistence of the effects found here; and undertake sibling studies to look at differential impacts within the same family. We also hope to include additional environmental exposures.

These results have meaningful implications for policymakers and researchers alike. First, roughly 26% of children aged 1–5 in the United States are estimated to have blood lead levels greater than or equal to 2 μg/dL, but <1% of children aged 1–5 have blood lead levels above the current Centers for Disease Control and Prevention (CDC) blood lead action level of 10 μg/dL (National Center for Health Statistics, 2008). Policymakers and researchers can play a significant role in lobbying the CDC scientific advisory group on lead to lower its current blood lead action level. Second, results from childhood blood lead tests, which are typically provided to the pediatrician of record, serve as a very early signal that certain children would benefit substantially from early reading enrichment programs, including programs that simply engage parents in reading to their children. The efficacy of such enrichment activities is supported by recent animal model research that indicates that enriched environments can ameliorate the neurobehavioral and neurochemical toxicity associated with early lead exposure (Schneider et al., 2001; Guilarte and Toscano, 2003). In addition, Bellinger and Rappaport (2002) outline strategies for evaluation and follow-up of lead-exposed children. Third, policymakers and researchers have an important role to play in helping school systems both define and understand eligibility criteria for access to special educational resources—at both the low and high end of the distribution.

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Conflicts of interest

None to report

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