HEALTH EDUCATION LEAD POISONING (*H.E.L.P.*)

On-Line Professional Development CEU Course Series

Module # 8 - Supplementary Readings

Dr. Marie Lynn Miranda

2006 - 2008 DVD Educational Series

Health Education Lead Poisoning Initiative:

Educational Implications of Childhood Lead Poisoning

CT State Legislative Informational Forum Series

January 31, 2008

<u>The Relationship of Early Lead Exposure and NCLB Testing Results</u>

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Health

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<u>Overview of DVD Presentation:</u>

This **2006 – 2008** Health Education Lead Poisoning (HELP) Initiative DVD provides a medical and educational presentation on the devastating impact of childhood lead poisoning.

<u>Conference sponsors:</u> The Connecticut Health Foundation, Inc., Connecticut Department of Public Health, Connecticut Department of Education, Connecticut Commission on Children, Foundation for Educational Advancement, Inc., State Education Resource Center, and the University of Connecticut Healthy Environments for Children Initiative.

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DVD On-line CEU Course in collaboration with CT DPH and FEA

Health Education Lead Poisoning (H.E.L.P.) On-Line CEU Course Module Supplementary Reading Material

1) **Research Document: <u>The Relationship between Early Childhood Blood Lead Levels and Performance on End-of Grade Tests</u>**

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2) **"Environmental Contributors to the Achievement Gap"**
   <u>Neurotoxicology</u>. (July 2009) **<u>Researchers</u>: M.L. Miranda, D. Kim, J. Reiter, M.A. Overstreet, P. Maxson – <u>Web Link</u>:** http://www.ncbi.nlm.nih.gov/pubmed/19643133

3) **"Early Childhood Lead Exposure and Exceptionality Designations for Students"** **<u>Researchers:</u>** Marie Lynn Miranda, Pamela Maxson and Dohyeong Kim) Forthcoming Article in the **<u>International Journal of Child and Adolescent Health</u>**. (February 2009)
   <u>Web Link:</u> https://www.novapublishers.com/catalog/product_info.php?products_id=10156

4) **Bio and Research: Dr. Marie Lynn Miranda**

The Relationship between Early Childhood Blood Lead Levels and Performance on End-of-Grade Tests

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BACKGROUND: Childhood lead poisoning remains a critical environmental health concern. Low-level lead exposure has been linked to decreased performance on standardized IQ tests for school-aged children.

OBJECTIVE: In this study we sought to determine whether blood lead levels in early childhood are related to educational achievement in early elementary school as measured by performance on endof-grade (EOG) testing.

METHODS: Educational testing data for 4th-grade students from the 2000–2004 North Carolina Education Research Data Center were linked to blood lead surveillance data for seven counties in North Carolina and then analyzed using exploratory and multivariate statistical methods.

RESULTS: The discernible impact of blood lead levels on EOG testing is demonstrated for early childhood blood lead levels as low as 2 μg/dL. A blood lead level of 5 μg/dL is associated with a decline in EOG reading (and mathematics) scores that is roughly equal to 15% (14%) of the interquartile range, and this impact is very significant in comparison with the effects of covariates typically considered profoundly influential on educational outcomes. Early childhood lead exposures appear to have more impact on performance on the reading than on the mathematics portions of the tests.

CONCLUSIONS: Our emphasis on population-level analyses of children who are roughly the same age linked to previous (rather than contemporaneous) blood lead levels using achievement (rather than aptitude) outcome complements the important work in this area by previous researchers. Our results suggest that the relationship between blood lead levels and cognitive outcomes are robust across outcome measures and at low levels of lead exposure.

KEY WORDS: disparities, lead levels, school performance. *Environ Health Perspect* 115:1242–1247 (2007). doi:10.1289/ehp.9994 available via *http://dx.doi.org/* [Online 27 April 2007]

Although much progress has been made, childhood lead poisoning remains a critical environmental health concern. Since the late 1970s, mounting research demonstrates that lead causes irreversible, asymptomatic effects far below levels previously considered safe. Thus, the Centers for Disease Control and Prevention (CDC) lowered incrementally its intervention threshold for lead levels considered dangerous in children by 88% from 60 to 10 μg/dL over the last 40 years (CDC 2006). The 2003–2004 National Health and Nutrition Examination Survey (NHANES) survey data reveal blood lead levels at or above the CDC blood lead action level of 10 μg/dL in 2.3% of 1- to 5-year-olds in the United States, with children tested having an overall geometric mean blood lead level of 2.1 μg/dL (National Center for Health Statistics 2006). These data indicate that > 500,000 children < 6 years of age currently experience blood lead levels at or above the CDC blood lead action level of 10 μg/dL (U.S. Census Bureau 2002).

Low-level lead exposure, including prenatal exposure, has been linked to decreased performance on standardized IQ tests for school-age children (Bellinger et al. 1992; Canfield et al. 2003; Chiodo et al. 2004; Dietrich et al. 1993; Schnaas et al. 2006; Tong et al. 1996). A meta-analysis conducted by Schwartz (1994) estimated that a 10-μg/dL increase in blood lead causes a 2.6-point decrease in IQ level. Dudek and Merecz (1997) observed a statistically significant relationship between blood lead and IQ in a population of 380 children with an average blood lead level of 10.2 μg/dL. The analysis finds that the most severe declines occur in children with blood lead levels between 5 and 10 μg/dL. Not only is there a correlation between blood lead levels and a decrease in IQ, but the slope of the IQ–lead regression is steeper at the lowest levels (Lanphear et al. 2005; Needleman and Landrigan 2004; Schnaas et al. 2006; Schwartz 1993). Needleman and Landrigan (2004) state that this indicates that significant damage occurs at the lowest levels of exposure.

Another study examining repeated blood lead levels in children followed from < 1 to 5 years of age detected steeper declines in cognitive abilities in children whose maximum blood lead level never reached 10 μg/dL (Canfield et al. 2003). Linear modeling incorporating the full range of data indicates a 0.46-point decrease in IQ for every 1-μg/dL rise in blood lead level (Canfield et al. 2003). However, linear modeling restricted to blood lead levels < 10 μg/dL indicates a 1.37-point decrease in IQ for every 1-μg/dL rise in blood lead level (Canfield et al. 2003). Nonlinear modeling indicated a 7.4-point decrease in IQ as lifetime average blood lead levels rise from 1 to 10 μg/dL and a 2.5-point decrease in IQ as lifetime average blood lead levels rise from 10 μg/dL to 30 μg/dL (Canfield et al. 2003). Although the shifts in IQ are relatively small, the shifts are both important on a population scale and could be an indicator for other adverse neurologic effects in the individual (Rogan and Ware 2003).

Thus, research suggests that significant adverse health effects occur at blood lead levels below the current CDC blood lead action level, leading several researchers to call for its lowering. Learning and behavioral deficits may occur at blood lead levels < 5 μg/dL (Canfield et al. 2003; Chiodo et al. 2004; Lanphear et al. 2000; Schnaas et al. 2006). Meta-analysis and reviews suggest that any level of exposure is potentially detrimental (Gatsonis and Needleman 1992; Lanphear et al. 2005; Schwartz 1993, 1994). In a recent review article, Gilbert and Weiss (2006) called for reducing the CDC blood lead action level to 2 μg/dL.

Linking blood lead surveillance data with end-of-grade testing data for several counties in North Carolina, this study explores the potential relationship between early childhood lead exposure and educational achievement in elementary school. The objective of the current study is to determine whether blood lead levels in early childhood are related to educational achievement in early elementary school as measured by performance of end-of-grade testing. In undertaking this study, we linked two large databases generated by two different offices of the State of North Carolina in the same populations but at different time periods.

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.Methods

Study area. Our study focuses on seven counties in the Piedmont region of North Carolina (Figure 1). By assessing adjacent counties jointly, we account in part for migration patterns across counties in North Carolina and thus capture more children in the linking process.

Data. Key data for this study include blood lead surveillance data from the state registry maintained by the North Carolina Childhood Lead Poisoning Prevention Program of the Children's Environmental Health Branch, North Carolina Department of Environment and Natural Resources in Raleigh, North Carolina (2004), and educational testing data from the North Carolina Education Research Data Center (NCERDC) of Duke University, in Durham, North Carolina (2006). Methods for receiving, storing, linking, analyzing, and presenting results related to this study were all governed by a research protocol approved by the Duke University Institutional Review Board.

The blood lead surveillance data include child name, birth date, test date, blood lead level, type of test (venous or capillary), and home address. The North Carolina State Laboratory for Public Health (Raleigh, NC) conducted 90% of the lead analyses of the blood samples. The limit of detection for lead in blood as analyzed by the State Laboratory is 1 µg/dL, but all children whose blood lead levels are below the level of detection are assigned a value of 1 µg/dL in the state database. Blood lead levels are stored in the state database as integer values only. Most of the samples were sent to the State Laboratory from private providers, indicating that the samples were collected by trained health care professionals. Thus we can be confident in the consistency of blood lead sample collection across samples. We used blood lead screening data from 1995–1998. During this period, North Carolina estimates that it screened between 21.9 and 30.4 percent of children 1 and 2 years of age (North Carolina Childhood Lead Poisoning Prevention Program 2004). In theory, all children whose parents responded "yes" or "don't know" to any of the three questions on the CDC Lead Risk Assessment Questionnaire (CDC 1997) should have been screened for lead, but it is difficult to ascertain true practice at the time.

Children in grades 3–8 are tested in reading and mathematics in North Carolina at the end of the school year. These assessments are "curriculum-based multiple-choice achievement tests…specifically aligned to the *North Carolina Standard Course of Study"* (North Carolina Public Schools 2004). The Reading End of Grade (EOG) test consists of multiple choice questions that cover *a)* cognition, *b)* interpretation, *c)* critical stance, and *d)* connections (North Carolina Public Schools Accountability Services Division 2006). The Mathematics EOG consists of multiple choice questions that cover *a)* number sense, numeration, and numerical operations; *b)* spatial sense, measurement, and geometry; *c)* patterns, relationships, and functions; and *d)* data, probability, and statistics (North Carolina Public Schools 2004).

The NCERDC maintains a database with records of all EOG test results statewide for tests from the 1995–1996 school year to the present (North Carolina Education Research Data Center 2006). This database includes identifying information such as name and birth date. Additionally, the database contains data on demographics and socioeconomics, testing conditions such as modifications, computer use, English proficiency, and school

Figure 1. Study counties in North Carolina.

Table 1. Arithmetic mean blood lead levels (BLL; µg/dL) among 4th-grade children whose screening data linked with education data.

	Reading data set		Mathematics data set	
Variable	Mean BLL	Sample size	Mean BLL	Sample
Race				
White	3.71	3,853	3.70	3,861
Black	5.19	4,750	5.19	4,766
Household income				
Not enrolled in free/reduced-price lunch program	3.91	5,194	3.90	5,201
Enrolled in free/reduced-price lunch program	5.47	3,409	5.47	3,426
Parental education				
Completed graduate school	3.57	244	3.57	245
Completed college	3.61	1,309	3.60	1,312
Some post–high school education	4.03	2,779	4.04	2,780
Completed high school	4.99	3,572	4.99	3,584
Some high school education	6.19	699	6.16	706
Overall	4.52	8,603	4.53	8,627

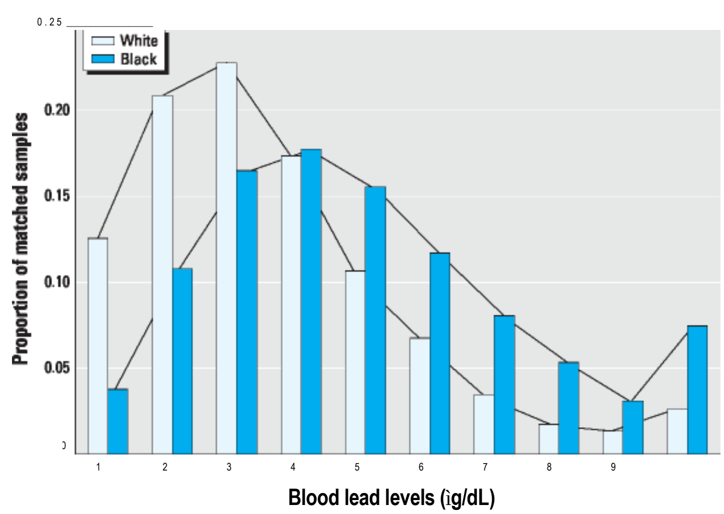

Figure 2. Distribution of blood lead levels among white and black children.

district. These data can also be linked longitudinally for all years each child has taken EOG tests in North Carolina.

Children who were screened for lead between the ages of 0 and 5 years from 1995 through 1998 in seven study counties (36,070 records for 35,815 children) were linked to their records in the 4th-grade EOG testing data in age-corresponding years. The early childhood environmental data (blood lead levels) were linked to elementary school educational outcome data (EOG test results) using 16 different combinations of social security number, date of birth, county federal information processing standards code, and first and last name. The linking schemas were designed to ensure accuracy while trying to achieve the highest number of linked records possible. Records that were linked were given a code for the particular type of linking method used, which enabled each method to be reviewed for the number of accurate matches that it provided. Each of the linking methods used educational data from 2000 to 2004, which allowed individuals to potentially be linked from the blood lead surveillance data to multiple end-of-grade tests from the educational data. Our process linked 42.2% of screened children to at least one EOG record. The percent linked for each county ranges from 24.4% for Orange County to 44.9% for Alamance County.

Assessing educational achievement based on standardized testing data is especially problematic for children for whom English is a second language. Thus we restricted our analysis to students who self-reported race as either white or black and who did not report any limited English proficiency. In so doing, we decreased our linked sample size by roughly 8%. We conducted all analyses on 4th-grade scores, both reading and mathematics. The final linked data set for 4th-grade reading and mathematics results contained 8,603 and 8,627 observations, respectively. Table 1 provides average blood lead levels for subgroups within the final linked data sets. As expected, migration or movement among these counties is significant, and roughly 6.7% of children were tested for blood lead levels in one county but sat for their end-of-grade testing in another county.

We employed both descriptive and multivariate statistical methods in our analysis, including Mantel-Haenzel chi-square tests to check equality of distributions of the black and white subsamples, and three different multivariate models to regress the EOG scores on a series of covariates. All models controlled for the following covariates as listed in the EOG test data: sex and race as standard demographic variables; participation in the free or reduced-price lunch program as a measure of socioeconomic status; parental education as a proxy for parental IQ and as a measure of socioeconomic status; daily computer use as a measure of stimulation in the home environment; and whether the school is a charter school, which in North Carolina is typically a measure of lower socio-economic status of the enrolled children as a group. We included a covariate for age at which the blood lead screen occurred (taken from the blood lead screening data) to control for age-dependent effects of lead exposure. We also incorporated dummy variables for each of the school systems. The three models differed

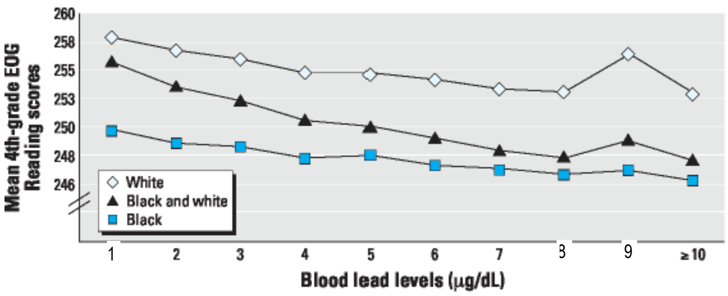

Figure 3. 4th-grade mean Reading EOG test results stratified by blood lead levels.

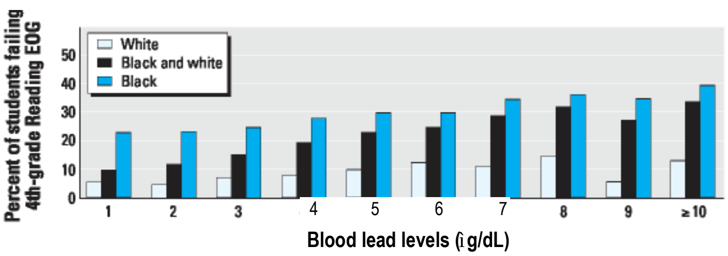

Figure 4. Percent of students failing 4th-grade Reading EOG.

Table 2. Results of multivariate regression models for 4th-grade Reading EOG score data (*n* = 8,603).

	Model 1: linear BLL		Model 2: dummy of BLL5-9 and dummy of BLL ~		Model 3: dummy for each BLL	
Response variable	Coefficient	*p* > *t*	Coefficient	*p* > *t*	Coefficient	*p* > *t*
BLL (continuous, linear term)	–0.20	0.00				
Dummy for BLL 5–9 µg/dL			–1.01	0.00		
Dummy for BLL = 2 µg/dL					–0.70	0.05
Dummy for BLL = 3 µg/dL					–1.16	0.00
Dummy for BLL = 4 µg/dL					–1.77	0.00
Dummy for BLL = 5 µg/dL					–1.75	0.00
Dummy for BLL = 6 µg/dL					–2.33	0.00
Dummy for BLL = 7 µg/dL					–2.68	0.00
Dummy for BLL = 8 µg/dL					–2.66	0.00
Dummy for BLL = 9 µg/dL					–1.49	0.02
Dummy for BLL ~ 10 µg/dL			–1.75	0.00	–2.92	0.00
Male (1 for male; 0 for female)	–1.43	0.00	–1.44	0.00	–1.41	0.00
Black (1 for black; 0 for white)	–4.59	0.00	–4.58	0.00	–4.46	0.00
Uses computer every day at home	–2.26	0.00	–2.24	0.00	–2.20	0.00
Enrolled in free or reduced-price lunch program	–2.03	0.00	–2.04	0.00	–1.97	0.00
Parents with some high school education	–2.18	0.00	–2.21	0.00	–2.17	0.00
Parents with some post–high school education	2.74	0.00	2.75	0.00	2.71	0.00
Parents completed college	4.73	0.00	4.74	0.00	4.67	0.00
Parents completed graduate school	7.49	0.00	7.51	0.00	7.45	0.00
Age when child was screened for lead	–0.81	0.00	–0.81	0.00	–0.83	0.00
Charter school	–3.66	0.00	–3.68	0.00	–3.65	0.00
Alamance–Burlington school system	–1.34	0.00	–1.36	0.00	–1.35	0.00
Chatham County school system	–1.74	0.00	–1.76	0.00	–1.66	0.00
Durham County school system	–1.23	0.00	–1.26	0.00	–1.26	0.00
Granville County school system	–1.69	0.00	–1.74	0.00	–1.66	0.00
Chapel Hill–Carrboro school system	1.26	0.03	1.17	0.04	1.13	0.05
Orange County school system	–0.76	0.07	–0.76	0.07	–0.71	0.09
Person County school system	0.67	0.08	0.63	0.10	0.74	0.05
Constant	258.09	0.00	257.67	0.00	258.74	0.00
Adjusted R^2	0.34		0.34		0.34	
AIC	6.81		6.81		6.81	
Root MSE	7.29		7.29		7.28	

BLL, blood lead level. The mean 4th-grade Reading EOG score for this sample is 251.4, the median 252, and the SD 9.0. The interquartile range was 13.

only by how the blood lead level variables are constructed in the model—as a continuous variable or multiple dummy variables. The models are compared via several test statistics such as adjusted R^2, Akaike Information Criterion (AIC), and root mean squared error (MSE). All analyses were conducted using STATA 9.2 (StataCorp., College Station, TX).

Results

We began our descriptive analysis by examining patterns in the linked data. For space reasons, we present here only the descriptive statistics for 4th-grade reading results. The 4th-grade mathematics results follow strikingly similar patterns. The multivariate analyses presented below include both 4th-grade reading and mathematics.

Figure 2 shows the distribution of children across blood lead levels and race categories. Of the total linked children for 4th-grade reading, 44.8% are white and 55.2% are black. Compared with black children, white children are overrepresented in the lower blood lead level categories (blood lead level, 1 to 3) and underrepresented in the higher blood lead level categories (blood lead level, 4 to ≥ 10). This blood lead level cut point at 3 holds for the 4th-grade mathematics scores as well.

Figure 2 thus demonstrates a distribution for black children that is shifted to the right and is characterized by higher variance compared with white children. These sample distributions are statistically different from each other. Construction of a dissimilarity index indicates that 25% of the members of one group would need to be reassigned blood lead levels for the two groups to show equivalent blood lead level distributions. The Mantel- Haenszel chi-square test for equality of distribution shows the two sample distributions to be statistically significantly different from each other ($p < 0.0001$).

Figure 3 shows the mean reading scores by race and blood lead levels for all linked students in the 4th-grade reading data set, disaggregated by race. This graphic shows a clear negative relationship between test scores and blood lead levels: Higher blood lead levels are associated with lower test scores, with some erratic behavior at blood lead levels of 9 µg/dL, likely due to the small sample size at this higher blood lead level.

At the lower end of the achievement scale, Figure 4 also demonstrates a dose–response effect between blood lead levels and failure on the end-of-grade test. Subgroups of children with lower blood lead levels in early childhood have lower failure rates on both the mathematics and reading end-of-grade tests (data shown only for 4th-grade reading data set); subgroups with higher blood lead levels in early childhood have higher failure rates.

Although this descriptive evidence is consistent with claims of a causal relationship between blood lead levels and test performance, alternative interpretations are plausible and can be addressed using multivariate analysis. For instance, given the higher blood lead level for children of lower socioeconomic status (as measured by free/reduced-price lunch and low parental education), perhaps these factors are responsible for the observed association of blood lead levels and test scores. Thus we used multivariate analysis to control for the covariates noted in "Methods." 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-price lunch program, who do not use a computer daily, and whose parents graduated high school.

To explore the functional form of the association between the lead variable and test scores, we compare three alternative specifications. The 6 analyses (3 models × 2 data sets) are presented in Tables 2 and 3**.** In all models, the coefficients on the covariates are of the expected sign. The coefficient on the age at which the blood screen occurred is negative and highly significant, indicating that a higher blood). lead level at a later age has a stronger depressive effect on test performance. This likely results from the fact that children who have high blood lead levels at 4 or 5 years of age typically would have had even higher blood lead levels at 2 or 3 years of age, given that the latter is typically considered the age of peak exposure (Canfield et al. 2003; CDC 1997; Dietrich et al. 2001).

The first model represents blood lead level as a continuous variable: We constrain the effect of a one-unit increase in blood lead level to be identical over the full range of observed scores. The coefficient on blood lead level is negative and statistically significant for 4th-grade reading and 4th-grade mathematics (both $p < 0.0001$). This effect and others discussed below are net of all control variables shown in the table.

The second model includes two dummy variables: one that is set equal to 1 if the blood lead level is 5–9 µg/dL; and one that is set equal to 1 if the blood lead level is ≥ 10 µg/dL. The coefficient on the dummy variable for a blood lead level of 5–9 µg/dL is negative and significant in both the reading and mathematics models (both $p < 0.0001$). In addition, the coefficient on the dummy variable for a blood lead level of 10 µg/dL is negative and significant in both the reading and mathematics

Table 3. Results of multivariate regression models for 4th-grade Mathematics EOG score data (n = 8,627).

Response variable	Model 1: linear BLL		Model 2: dummy of BLL5-9 and dummy of BLL ~ 10		Model 3: dummy for each BLL	
	Coefficien	$p > t$	Coefficient	$p > t$	Coefficien	$p > t$
BLL (continuous, linear term)	–0.16	0.00				
Dummy for BLL 5–9 µg/dL			–1.05	0.00		
Dummy for BLL = 2 µg/dL					–0.71	0.03
Dummy for BLL = 3 µg/dL					–0.99	0.00
Dummy for BLL = 4 µg/dL					–1.53	0.00
Dummy for BLL = 5 µg/dL					–1.68	0.00
Dummy for BLL = 6 µg/dL					–2.13	0.00
Dummy for BLL = 7 µg/dL					–2.64	0.00
Dummy for BLL = 8 µg/dL					–2.35	0.00
Dummy for BLL = 9 µg/dL					–1.99	0.00
Dummy for BLL ~ 10 µg/dL			–1.03	0.00	–2.07	0.00
Male (1 for male; 0 for female)	0.10	0.46	0.09	0.51	0.12	0.41
Black (1 for black; 0 for white)	–4.53	0.00	–4.50	0.00	–4.40	0.00
Uses computer every day at home	–1.80	0.00	–1.78	0.00	–1.74	0.00
Enrolled in free or reduced-price lunch program	–1.57	0.00	–1.57	0.00	–1.51	0.00
Parents with some high school education	–1.85	0.00	–1.87	0.00	–1.83	0.00
Parents with some post–high school education	2.38	0.00	2.39	0.00	2.35	0.00
Parents completed college	3.93	0.00	3.92	0.00	3.86	0.00
Parents completed graduate school	6.50	0.00	6.52	0.00	6.46	0.00
Age when child was screened for lead	–0.87	0.00	–0.88	0.00	–0.90	0.00
Charter school	–4.35	0.00	–4.37	0.00	–4.33	0.00
Alamance–Burlington school system	–0.49	0.06	–0.51	0.05	–0.51	0.05
Chatham County school system	–2.40	0.00	–2.41	0.00	–2.32	0.00
Durham County school system	–1.10	0.00	–1.14	0.00	–1.15	0.00
Granville County school system	–1.84	0.00	–1.89	0.00	–1.82	0.00
Chapel Hill–Carrboro school system	–1.11	0.04	–1.20	0.03	–1.23	0.02
Orange County school system	–0.65	0.07	–0.65	0.07	–0.61	0.09
Person County school system	0.29	0.40	0.25	0.48	0.34	0.33
Constant	263.70	0.00	263.42	0.00	264.37	0.00
Adjusted R^2	0.35		0.35		0.35	
AIC	6.57		6.57		6.57	
Root MSE	6.47		6.47		6.45	

BLL, blood lead level. The mean 4th-grade Reading EOG score for this sample is 257.8, the median 258, and the SD 8.0. The interquartile range was 11.

models (again, p < 0.000 1). In analysis not shown here, we also estimated a model that used a single dummy variable for blood lead level ~ 5 μg/dL and a separate model with a single dummy variable for blood lead level ~ 10 μg/dL. The results in Tables 2 and 3, in comparison with other models not shown here, indicate that if one is going to conceptualize the association by a threshold value, then ~ 5 μg/dL captures much more of the variation in these data than does the CDC blood lead action level of ~ 10 μg/dL.

The third model enters a dummy variable for each blood lead level (2, 3, 4, … 9, ~ 10 μg/dL). The last dummy variable combines all blood lead levels ~ 10 μg/dL, and the referent group is a blood lead level of 1 μg/dL. This scoring is the most flexible and allows a distinct estimate at each blood lead level score.

For the 4th-grade reading analysis, the coefficient on the dummy variable for a blood lead level of 2 μg/dL is negative and marginally significant at p = 0.05. The coefficients on the dummy variables for blood lead levels of 3–8 and 10 μg/dL are consistently negative and statistically significant, and generally increase in absolute magnitude as the blood lead levels increase (all p < 0.000 1). The coefficient on the dummy variable for a blood lead level of 9 μg/dL is also negative but significant only at the p = 0.02 level, likely due to the small sample size in this grouping. The results for the 4th-grade mathematics analysis follow a very similar pattern to those of the reading analysis, although the coefficient on the dummy variable for a blood lead level of 2 μg/dL is significant at the p = 0.03 level, and the coefficient on the dummy variable for a blood lead level of 9 μg/dL is significant at the p < 0.0001 level.

Model 3 results demonstrate a strong dose–response effect between early childhood lead exposure and performance on elementary school achievement tests. These results indicate clearly that early childhood lead exposure has a statistically significant and negative impact on school performance at levels well below the current CDC blood lead action level. These results are consistent with the observed association between blood lead levels and elementary school achievement scores demonstrated in both the descriptive analysis and regression models 1–2. All three models indicate, net of a set of control variables, that higher blood lead levels are associated with lower test scores. The least constrained model (model 3) reveals a general decline in test scores with rising blood lead levels. Model 1 constrains this decline to be uniform across all blood lead levels. With our data, we cannot reject the latter in favor of the former; any divergence from a linear decline could be attributed to sampling variability. Model 2 can be aligned with the following question: Once we take account of high blood lead levels (i.e., ~ 10 μg/dL) is additional variation in blood lead levels important? Results clearly indicate that blood lead levels of 5–10 μg/dL are consequential for test scores. We conclude from these various representations that early childhood blood lead levels reduce test scores and that this effect is clear even at levels < 10 and even < 5 μg/dL.

Given the statistical measures of model fit provided in Tables 2 and 3 (adjusted R_2, AIC, and root MSE), all three models show adequate and substantially similar model fit. Figures 5 and 6 graphically summarize the results of models 1 and 3 for the 4th-grade reading and mathematics analyses graphically. These figures aptly demonstrate that test scores decline as early childhood blood lead levels increase. Because model 3 allows a distinct estimate at each blood lead level score, it is useful to compare it directly with model 1, which constrains the effect of a one-unit increase in blood lead level to be uniform across observed scores. Figures 5 and 6 show that the decline in both reading and mathematics scores is steeper at lower blood lead levels than at higher blood lead levels.

Conclusions

As perhaps is best seen in Figures 5 and 6, using a variety of modeling approaches, blood lead levels in early childhood are related to educational achievement in early elementary school as measured by performance on end-of-grade testing. According to 2003–2004 NHANES data, 50% of children 1–5 years old nationwide are estimated to have blood lead levels of ~ 3 μg/dL (National Center for Health Statistics 2006). Thus as many as half the children in the United States are experiencing negative effects associated with lead exposure—a significantly higher proportion than the 2.3% estimated using the CDC's current blood lead action level of 10 μg/dL.

In addition, early childhood lead exposures appear to have more impact on performance on the reading than on the mathematics portions of the EOG, although the differences may not be statistically significant. This differential impact on reading versus mathematics is consistent with previous studies (Fulton et al. 1987; Lanphear et al. 2000).

The estimated effects are mean effects—averages of the adverse effects across children. These shifts will affect a substantial number of children at any given test threshold. For

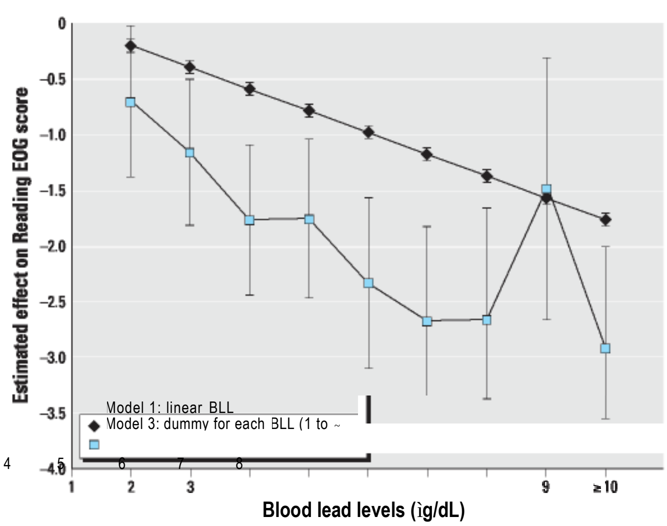

Figure 5. Comparing model results for 4th-grade Reading score. Based on a referent individual who was screened at 2 years of age and is a white female,

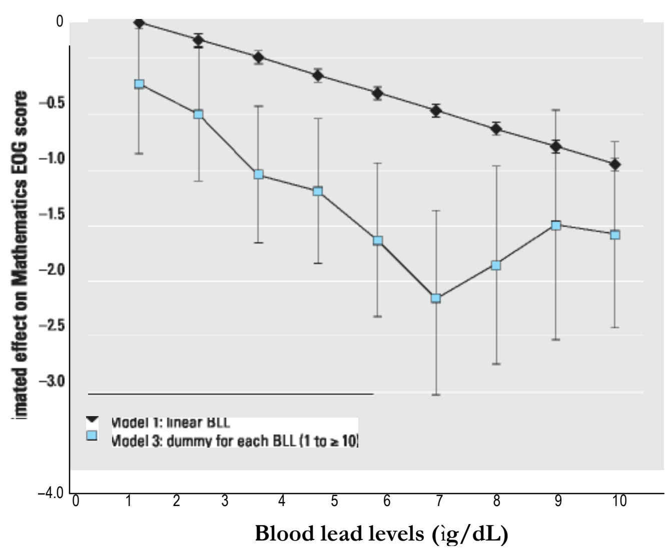

Figure 6. Comparing model results for 4th-grade Mathematics scores. Based on a referent individual who was screened at 2 years of age and is a white female, living in Wake County, parents with a high school education, not enrolled in the school lunch program, and who does not use a computer every day. Baseline score is 262.6.

example, at the low end of the distribution, the impact of lead on EOG test results is sufficient to ensure that some students, who would otherwise have passed the test, will fail. This in turn has implications for retention in grade. In addition, at the high end of the distribution, the impact of lead on EOG test results will essentially block some students from gaining access to the enriched resources provided through advanced and intellectually gifted (AIG) programs. As is true for many states, the use of EOG scores to determine placement into AIG programs is ubiquitous in North Carolina. These two phenomena are especially troubling given that we know that low-income and minority children are systematically exposed to more lead in North Carolina and nationally.

It is also notable that the size of the coefficients on the lead variables is very meaningful compared with other covariates that we typically think of as profoundly influential on educational outcomes. For example, in model 3, in the 4th-grade reading analysis, a blood lead level of 3 μg/dL has an impact roughly equal to 59% of the impact of participating in the free or reduced-price lunch program (the classic poverty indicator in school data). A blood lead level of 4 μg/dL has an impact roughly equal to 90% of the impact of participating in the free or reduced-price lunch program, and a blood lead level of ≥ 6 μg/dL has a greater impact. In addition, the size of the coefficients, which may seem small compared with the constants (~ 250–265), are in fact quite substantial in context. For example, across North Carolina in 2003–2004, the interquartile range for 4th-grade reading EOG test scores spanned 12 points, and the interquartile range for 4th-grade mathematics EOG test scores spanned 10 points. Thus a blood lead level of 5 μg/dL is associated with a decline in EOG reading (mathematics) scores that is roughly equal to 15% (14%) of the interquartile range.

This study has several limitations. First, previous cohort studies have shown that direct measures of parental IQ and quality of the home environment are important explanators of test performance in children (Bacharach and Baumeister 1998). Our study was limited in that we could incorporate only indirect measures of parental IQ via parental education [see Neisser et al. (1996) for a justification of this proxy] and poverty measures (free or reduced-price lunch program and charter school) to substitute for quality of the home environment. To the extent that lead exposure may be correlated with parental IQ or the home environment, by relying on these proxies we may be overestimating the effects of early childhood lead exposure on end-of-grade test performance. Our study does, however, rely on a substantially larger sample size than many previous studies. Second, the children screened for lead are not randomly drawn from the population, raising concerns of selectivity bias. We are in the process of obtaining the data that would allow us to diagnose and directly address any issues of selectivity bias.

Despite its limitations, this study enriches the existing literature on the link between early childhood lead exposure and cognitive outcomes. Our emphasis on a population level analysis of children who are roughly the same age linked to previous (rather than contemporaneous) blood lead levels using achievement (rather than aptitude) outcome complements the important work in this area by previous researchers (Canfield et al. 2003; Fulton et al. 1987; Lanphear et al. 2000, 2005; Schwartz 1994). Our results suggest that the relationship between lead levels and cognitive outcomes are robust across outcome measures and at low levels of lead exposure.

In conducting this analysis, we noted that a higher proportion of black children had higher blood lead levels. Thus, in future analyses we plan to explore whether this differential exposure to lead in early childhood might explain part of the so-called achievement gap. We are also interested in following the same children through their elementary, middle school, and high school years to assess the persistence of the effects we note here.

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Environmental Contributors to the Achievement Gap

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A B S T R A C T

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 socioeconomically 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 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 (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., 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 2mg/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 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 1mg/dL served as the referent group, resulting in nine dummy variables (BLL = 2mg/dL, BLL = 3, ..., BLL = 9, BLL ≥10mg/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). (Carey et al., 1998).

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 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 16mg/dL, with the mean and median levels of 4.8 and 4mg/dL, respectively. The interquartile range was 3, with the 25th and 75th percentiles equal to 3 and 6mg/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 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

Table 1

Summary statistics on subgroups in the final linked 4th-grade reading dataset for 100 counties in N.C. (N=57 ,678)

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

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Table 2
Results of multivariate linear regression for 4th-grade reading EOG score data (N=57,678)

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 1mg/dL to any blood lead level greater than 3 mg/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 10mg/dL or higher, and is 23.1 for children with a blood lead level of 1mg/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+ mg/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 = 1mg/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 = 1mg/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 ($p = .0002$).

Figure 1

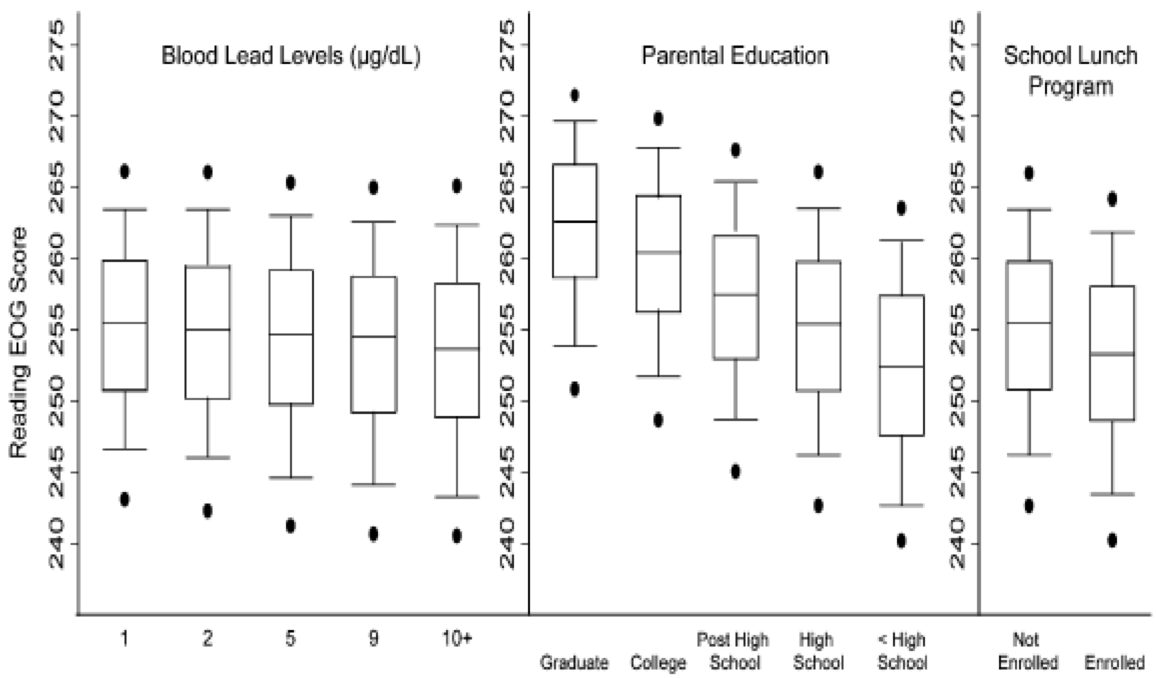

Fig. 1. Box plots of the estimated 4th-grade reading EOG scores from quantile regression models ($N = 57{,}678$).

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 = 1mg/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 = 5mg/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. <u>Discussion</u>

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 2mg/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 10mg/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.

Figure 2

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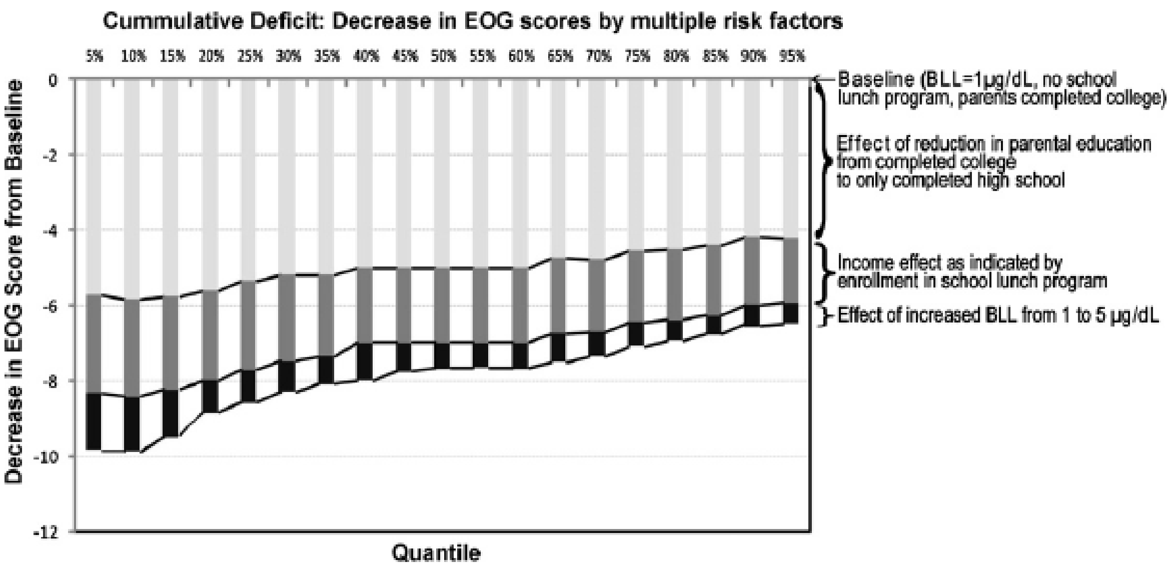

Fig. 2. Cumulative deficit: decrease in EOG scores by multiple risk factors (N = 57,678).

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 = 1mg/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 = 5mg/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).

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Conflicts of interest

None to report

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Early Childhood Lead Exposure and Exceptionality Designations for Students

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Running title: Early childhood lead exposure

Abstract: The achievement gap continues to be an important educational issue, with disadvantaged groups exhibiting poorer school performance. Recently, literature has shown that even very low levels of early lead exposure affect cognitive and academic performance. As individuals at the lower end of the socioeconomic spectrum are more likely to be exposed to lead, this exposure may be an important contributor to the achievement gap. In this paper, we explore whether early childhood blood lead levels are associated with membership in exceptionality designation groups. In addition, we examine the racial and socioeconomic composition of these exceptional groups. Data from the North Carolina Childhood Lead Poisoning Prevention Program surveillance registry were linked at the individual child level to educational outcomes available through the North Carolina Education Research Data Center. Designation into exceptionality groups was obtained from the end-of-grade (EOG) data. Both standard bivariate and multivariate analyses were employed. Bivariate analyses indicate that blood lead levels and reading EOG scores differ by exceptionality, as well as by race and enrollment in free/reduced lunch. Logistic regression confirmed the relationship between blood lead levels and likelihood of exceptionality. Contextual factors – enrollment in the free/reduced lunch program, race, and parental education – are also significant with regard to exceptionality. This study demonstrates that early childhood lead exposure significantly influences the likelihood of being designated exceptional. These results provide additional evidence that early childhood lead exposure is a significant explanator of the achievement gap.

Keywords: Academic achievement, lead levels, exceptional student status, achievement gap

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INTRODUCTION

The achievement gap persists as an important educational issue, in light of and in spite of the "No Child Left Behind Act" from 2001. Disadvantaged groups continue to exhibit poorer school performance compared with middle and upper-class whites in the United States' educational system (1,2). Blacks, on average, score lower on tests than whites, with the trend starting in childhood and continuing throughout the educational process (3). These relationships may be explained by family background effects (4). The influence of parental education on child educational attainment has been shown repeatedly; yet, the disparity remains even after controlling for parental education and income. Children's reading levels (5), placement inhigh-achievement curricular tracks (6), not dropping out of high school (7), college matriculation directly from high school (8), elite college attendance (8), and college graduation (8), are all positively correlated with socioeconomic status as measured by occupation, income, education, wealth (3,9) or home ownership(9). Environmental exposures may represent an important explanator of the achievement gap. For example, childhood lead exposure has been associated with multiple adverse cognitive outcomes, including reduced performance on standardized intelligence quotient (IQ) tests (10), decreased performance on cognitive functioning tests (11), adverse neuropsychological outcomes (12), neurobehavioral deficits (13), and decreased end-of-grade (EOG) test scores (14). In addition, higher lead levels have been associated with students beingmore inattentive, hyperactive, disorganized, and having problems following directions (15). These children later exhibit lower high school graduation rates and greater absenteeism (16). Higher lead levels have also been associated with delinquent behavior and aggression (15).

Those at the lower end of the SES spectrum are more likely to be exposed to lead (17). Further, Singer and colleagues found that lead exposure had additive effects on multiple outcomes, suggesting continued risk to poor exposed children (18). These findings are particularly pertinent to the classification of exceptionality.

In this paper, we explore the relationship between school exceptionality designation and lead exposure. We are specifically interested in whether blood lead levels are associated with membership in exceptional status groups. In addition, we examine the racial and socioeconomic composition of these exceptional groups.

METHODS

This study uses end-of-grade testing data for the State of North Carolina that has been linked to childhood blood lead surveillance data available from a statewide registry. We used the data to evaluate the impact of lead exposure across types of exceptionality, as defined by the North Carolina Department of Public Instruction.

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. In previous work, we used the North Carolina end-of-grade and childhood blood lead surveillance data to determine how EOG distributions as a whole shifted in response to lead exposure (19). That work found that lead exposure shifted the EOG distribution to the left and stretched out the lower tail. Using the same data, this analysis focuses on children who carry an exceptionality designation. We repeat here the description of the data and the data linkage process from the previous study. 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. The North Carolina Education Research Data Center (NCERDC) maintains a database with records of all EOG test results for all public school systems in North Carolina for tests from the 1995-1996 school year to present.

These data include 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. North Carolina EOG testing data also contain information indicating exceptionalities, such as academically and intellectually gifted, learning and behavioral disorders, and physical impairments (hearing, speech-language, vision). All data can be linked longitudinally for all years each child has taken EOG tests in North Carolina.

To construct our integrated database, children who were screened for lead between the ages of 9-36 months from 1995 through 1999 in all 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. Analysis was restricted to students who self-reported race as either non-Hispanic white (NHW) or non-Hispanic black (NHB) and who did not report limited English proficiency. We conducted all analyses on 4th-grade scores, for both reading and mathematics. The final linked dataset for 4th-grade reading and mathematics results contained 57,678 and 57,840 observations, respectively.

Table 1 provides summary statistics on subgroups within the final linked data set for fourth grade reading test scores. Of the total linked children: 45.5% were black (55.5% are white); 52.9% were 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 (some college, college degree, graduate school). Because lead screening is not universal in North Carolina and because we are only able to link children who were screened for lead, the demographics of our sample are different from the population of children in the North Carolina public school system. If data are limited to NHB and NHW students only (as is done in this study), approximately 32% of the statewide sample is NHB, and approximately 68% is NHW. So NHB are overrepresented in the dataset of total linked children.

Summary statistics for math scores are very similar. Exceptional designations are given to provide appropriate education for every child in the public school system. These exceptional designations are intended to best serve the student. There are fifteen exceptional designations in North Carolina. From these, we constructed four distinct groups based on exceptionality status: 1) those students with no exceptional status designated (not designated, ND); 2) students designated exceptional due to their placement in advanced and intellectually gifted programs (AIG); 3) students designated exceptional due to learning or behavioral classifications (Learning and Behavioral Exceptional Designated, LBED); and 4) students designated exceptional for other reasons (i.e., not AIG and not learning or behavioral classifications – Exceptional Designated Other, EDO).

The LBED group contains children designated as behaviorally-emotionally handicapped, educable mentally handicapped (mildly impaired in general intellectually functioning and his/her development reflects a reduced rate of learning) (20), and specific learning disabled. The AIG group contains students who have been classified as having superior intellectual development and are capable of high performance (20). The EDO group contains students identified to have any other exceptional designation, such as: visual, hearing, or speech impairments; physical or health handicaps; autism; or trainable or severe mental handicaps.

Table 2 provides summary statistics on each of the four exceptionality subgroups within the final linked data set for fourth grade reading test scores, as well as separate equivalent statistics for NHW and NHB, as well as children enrolled in the free or reduced lunch program. Results for math scores are very similar. The composition of these groups is noteworthy. NHB students are overrepresented in the LBED group and underrepresented in the EDO group. Students enrolled in the free or reduced lunch program are also overrepresented in the LBED group. In contrast, NHB children and those enrolled in the free/reduced lunch are dramatically underrepresented in the AIG group.

To analyze the relationship between blood lead levels and exceptionality designations, we began by using simple t-tests. These assess whether the average blood lead level differs for those with an exceptionality designation and those without it. We also used logistic regression to predict the presence of exceptionality from blood lead levels.

RESULTS

Figure 1 shows the percentage of children with exceptionality designations (AIG, LBED, EDO) according to blood lead levels. The figure shows a clear negative relationship between percentage of AIG children and blood lead levels; i.e., higher blood lead levels are associated with lower proportion of AIG children, in a clear dose-response fashion. The figure also demonstrates a dose-response effect between blood lead levels and percentage of children designated LBED.

Higher blood lead levels in early childhood are associated with membership in the LBED group. The EDO group shows substantially less variation in blood lead levels. Both the LBED and EDO groups have higher percentages of their members with higher blood lead levels than does the AIG group.

Figures 2 and 3 show that within any of the four exceptionality groups, NHB children and those enrolled in the free/reduced lunch have higher mean BLL. The higher mean blood lead levels for NHB children compared to NHW children is statistically significant ($p<.0001$) for all four exceptionality groups (figure 2). Similarly, children served by the free/reduced lunch program have significantly ($p<.0001$) higher mean BLL than those students not served by the free/reduced lunch program (Figure 3). These students, then, are multiply disadvantaged (by both poverty and environmental exposures) and may be more likely to accumulate further decrements over time, thereby continuing the cycle of disadvantage.

A series of t-tests was performed (see table 3) to compare blood lead levels and EOG scores between the ND groups and the LBED, EDO, and AIG groups. The ND students scored significantly higher ($p<.0001$) on their reading EOG tests and had significantly lower ($p<.0001$) blood lead levels than the LBED and EDO groups. Based on earlier research on the effects of lead exposure in early childhood, this finding is extremely important. It is possible that these students may not have been placed in these exceptionality categories had they not been exposed to lead during early childhood. The AIG students had the lowest blood lead level of all the groups, significantly lower than the ND students ($p<.0001$). Not surprisingly, their reading EOG scores were significantly higher than the ND students ($p<.0001$).

While figures 1-3 and the t-tests provide interesting insights, the complicated question of how lead exposure might affect membership in the exceptionality groups requires multivariate analysis. Using logistic regression, we confirmed the relationship between blood lead levels and likelihood for exceptionality displayed in figure 1. We ran three different logistic regressions that each used ND as the reference group (see table 4). The regressions control for race, sex, enrollment in the free/reduced lunch program, parental education, charter school status, and a separate dummy variable for each of the school systems in the state. In addition, a series of dummy variables are entered for blood lead levels (BLL=2, 3, …9, 10+) with a blood lead level of 1 set as the reference group.

Table 4 provides the odds ratios and 95% confidence intervals for the logistic regressions. When comparing across NC, AIG, LBED, and EDO groups, a clear pattern emerges. At each blood lead level, going as low as a level of 2 ug/dL, blood lead reduces the likelihood that children will be designated as AIG.

In contrast, blood lead levels as low as 4 ug/dL significantly increase the likelihood that a child will be designated LBED. Blood lead levels as low as 8 ug/dL significantly increase the likelihood that a child will be designated EDO. Contextual factors are also significant with regard to exceptionality. Enrollment in the free/reduced lunch program makes it less likely that a child will be designated AIG and more likely that he/she will be designated LBED or EDO. NHB race does not have an impact on the likelihood that a child will be designated LBED. Importantly, when blood lead levels are removed from the model, NHB race becomes highly significant in predicting LBED designation; this represents important evidence regarding how lead exposure contributes to the achievement gap. NHB race decreases the likelihood that a child will be designated EDO or AIG. Parental education significantly influences the likelihood of being designated LBED in a step-wise function. Low parental educational attainment increases the likelihood, and high parental educational attainment decreases the likelihood, of being designated LBED.

The results are very similar for EDO designation. In contrast, low parental educational attainment significantly decreases the likelihood of being designated AIG, and high parental educational attainment significantly increases the likelihood.

DISCUSSION

Earlier research has demonstrated that teachers' expectations and students' self-confidence are important to the achievement process beyond socio-economic status (21). In an environment where children receive special services because of an exceptional classification, the downside is the process of labeling, lowering teacher expectations and decreasing self-confidence. As one of the predictors of exceptional classification is higher blood lead levels, this is a preventable negative cycle.

Our findings demonstrate the importance of recognizing the effect of even very low levels of lead exposure in early childhood and the disparity in that exposure. When mean BLL is examined by race within the exceptionality subgroups, black children have higher mean BLL than white children in all subgroups. Similarly, when examined within subgroups, children enrolled in the free or reduced lunch program have higher mean BLL than those not enrolleed in all exceptionality categories.

This study demonstrates that early childhood lead exposure significantly influences the likelihood of being designated exceptional. In particular, our results suggest that even very low levels of early lead exposure increase the likelihood of having a LBED exceptional designation. This represents another example of how lead may be contributing to the achievement gap.

While we typically think of exceptionality as it pertains to children with disabilities or learning or behavioral disorders, school systems also use the term to designate placement into advanced and intellectually gifted programs. Because EOG score are used ubiquitously in the United States to place students into AIG programs, 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 (22), then AIG programs become less economically and racially diverse (23).

Parts of our student population are in double jeopardy. The LBED exceptional children are predominantly low-income and minority students who may also have higher levels of early childhood lead exposure. Thus, early childhood lead exposure, which we have previously shown is related to performance on EOG tests, also significantly influences the likelihood that students will be designated exceptional. These results provide additional evidence that early childhood lead exposure is a significant explanatory of the achievement gap.

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Table 1. Summary statistics on subgroups in the final linked fourth grade reading dataset

Variable	Subcategory	Avg. Reading EOG	Proportion (%)		
			Overall	Black	White
Race	White	254.6	44.5		
	Black	248.5	55.5		
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

Table 2. Summary statistics on exceptionality subgroups

Exceptionality Category	Avg. Reading EOG	Proportion (%)			
		Overall	Black	White	Free/Reduced Lunch
All students	**250.5**	**100.0**	**44.5**	**55.5**	**54.6**
ND	**250.0**	**73.54**	**47.6**	**52.4**	**56.7**
AIG	**261.5**	**11.00**	**17.3**	**82.7**	**22.3**
LBED	**241.0**	**6.09**	**57.6**	**42.4**	**73.5**
EDO	**244.9**	**9.38**	**43.4**	**56.6**	**63.3**

Table 4. Odds Ratios - Exceptional designations versus not designated (ND)

	Learning and behavioral exceptional designation (LBED)	Exceptional designation other (EDO)	AIG
BLL of 2	NS	NS	.88 .82-.94
BLL of 3	NS	.92 (.86-1.00)	.88 (.83-.94)
BLL of 4	1.16 (1.04-1.30)	NS	.80 (.75-.85)
BLL of 5	1.24 (1.11-1.39)	NS	.78 (.73-.84)
BLL of 6	1.33 (1.18-1.49)	NS	.76 (.69-.83)
BLL of 7	1.51 (1.33-1.71)	NS	.71 (.64-.79)
BLL of 8	1.50 (1.31-1.73)	1.13 (1.01-1.26)	.68 (.60-.78)
BLL of 9	1.49 (1.28-1.74)	1.19 (1.04-1.35)	.65 (.55-.77)
BLL of 10+	1.87 (1.66-2.12)	1.26 (1.14-1.39)	.65 (.58-.74)
Black	NS	.71 (.68-.75)	.34 (.32-.35)
Male	2.37 (2.26-2.48)	2.25 (2.17-2.33)	NS
Free/Reduced lunch	1.35 (1.28-1.42)	1.47 (1.41-1.54)	.58 (.55-.61)
Parental education Some HS	2.37 (2.25-2.51)	1.47 (1.40-1.55)	.35 (.31-.41)
Parental education HS	.56 (.52-.59)	.82 (.78-.85)	2.28 (2.18-2.39)
Parental education Some college	.19 (.17-.23)	.87 (.87-.99)	5.19 (4.93-5.46)
Parental education Post-College	.23 (.16-.35)	NS	9.59 (8.79-10.45)

Figure 1. Percentage of children with exceptionality designations

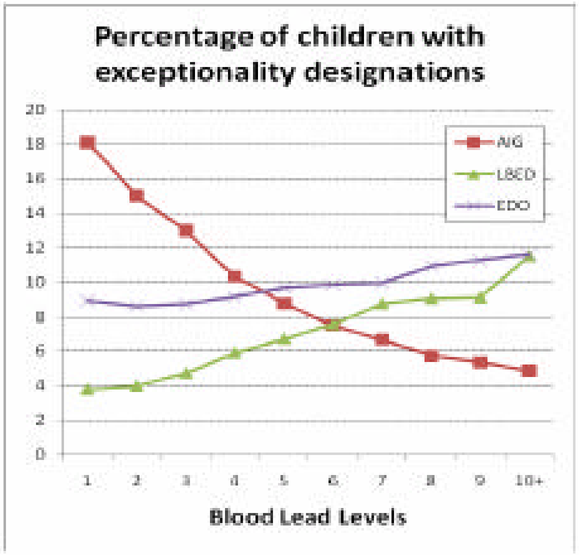
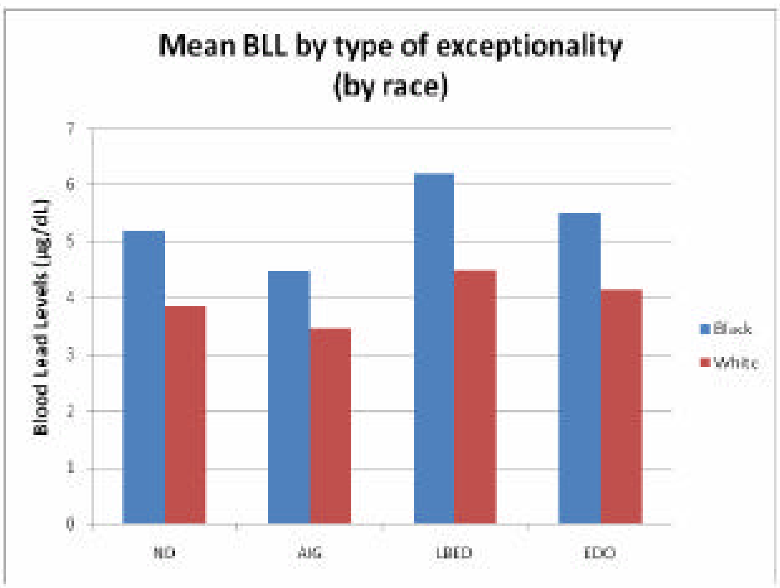


Figure 2. Mean BLL by type of exceptionality designation by race



***Differences in mean blood lead levels significant (p<.0001) for all exceptionality groups.

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Bio and Research:

Dr. Miranda serves as the Director of the Children's Environmental Health Initiative (CEHI) within the Nicholas School of the Environment, and is a faculty member in Duke's Integrated Toxicology Program. With an educational background rooted in economic and mathematical modeling, her professional experiences integrate environmental health sciences with sound social policies. Dr. Miranda has extensive experience managing research projects using geographic information systems (GIS) based analysis focusing on children's environmental health, with an emphasis on reproductive and developmental toxicants and childhood lead exposure. CEHI supports a series of environmental research projects emphasizing the special vulnerabilities of children. Current projects include: 1. A Centers for Disease Control and Prevention-funded grant that uses GIS technology to create household-level predictive models of lead exposure risks and seeks to replicate this predictor model across 27 counties in North Carolina; 2. A National Institute of Environmental Health Sciences-funded grant to replicate the lead exposure risk model in other regions of the United States; 3. A U.S. Department of Housing and Urban Development-funded project to evaluate the importance of crawl spaces as sources of mold contamination in the livable part of the home environment. 4. A Robert Wood Johnson Foundation-funded project with a focus GIS-based applications to support delivery of private and public health care services; 5. A Superfund Center Outreach Core project, part of Duke University's NIEHS-funded Superfund Hazardous Substance Basic Research Center, that uses GIS-based models to compare the spatial distribution of children versus exposures to various contaminants and to provide outreach and education to communities in North Carolina and nationally. 6. PI-Thompson, Co-PI Miranda Howard Hughes Medical Institute Making Meaning of Genomic Information Curriculum development grant to improve Duke's offerings to undergraduates related to genomics. Nicholas School subgrant focuses on gene-environment interactions. 7. PI-Schwartz; Miranda, Deputy Director NIEHS Center for Comparative Biology of Vulnerable Populations This project establishes an EHSRC on Duke University's campus. 8. PI-Miranda NIH/Roadmap Initiative Center for Geospatial Medicine This project brings together seven investigators to develop an interdisciplinary research center that utilizes geospatial (GIS), molecular biological, genomic, epidemiological social and psychological technologies to develop systematic, spatially based methods for analyzing the pathways through which the environment, genetic, and psychosocial domains jointly shape child health and well being. Using neural tube defects as a prototype health endpoint, the researchers are developing a generalized framework for applying methods to a wide variety of endpoints, including autism, obesity, and ADHD. Dr. Miranda currently serves on the Durham County Lead Intervention Team, the North Carolina Ad Hoc Lead Advisory Committee, the North Carolina Lead Elimination Action Plan Strategic Planning Group, the North Carolina State Asthma Coalition, and the Board of Directors for the Alliance for Healthy Homes. * Gabel Chair in Environmental Ethics and Sustainable Environmental Management, (2000-2005) * Fellowships: A.B. Duke Scholar, Marshall, Truman, Eisenhower, the Lilly Foundation, the National Science Foundation, the AAUW American Fellowship Program, and the Harvard University Chiles Program. * Richard K. Lublin Distinguished Award for Teaching Excellence. * U.S. EPA Environmental Justice Achievement Award

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