The Impact of Early Childhood Lead Exposure on Educational Test Performance among Connecticut Schoolchildren, Phase 1 Report

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Motivation for the Project

Researchers at Duke University's Children's Environmental Health Initiative (CEHI) were contacted by state agency representatives from the State of Connecticut about undertaking an analysis of the effects of early childhood lead exposure on test performance among Connecticut schoolchildren. CEHI researchers had previously conducted similar analysis on data from North Carolina (see below). The relevant data were provided to CEHI after all research approvals were obtained (both from the State of Connecticut and the Duke University Institutional Review Board). This report presents the results of the CEHI analysis of Connecticut lead and education data.

Introduction

Although much progress has been made, childhood lead poisoning remains a critical environmental health concern. Since the late 1970s, mounting research has demonstrated that lead causes irreversible, asymptomatic neurocognitive effects in children at levels far below those previously considered safe. Thus, between 1960 and 1991, the CDC incrementally lowered its blood lead action level in children by 88%, from 60 to 10 µg/dL (Centers for Disease Control and Prevention, 2005). According to 2007–2008 National Health and Nutrition Examination Survey (NHANES) survey data, 1.3% of 1 to 5-year-olds in the United States had blood lead levels at or above the current CDC blood lead action level (National Center for Health Statistics, 2010).

Childhood lead exposure has been linked to a number of adverse cognitive outcomes, including reduced performance on standardized IQ tests (7-13), decreased performance on cognitive functioning tests (14), adverse neuropsychological outcomes (15), neurobehavioral deficits (16), decreased end-of-grade (EOG) test scores (17) and classroom attention deficit behavior (18). Moreover, research has linked lead exposure at levels markedly below the blood lead action level of 10 µg/dL to cognitive and socio-behavioral impacts in children (Bellinger, Stiles, & Needleman, 1992; Canfield et al., 2003; Chiodo, Jacobson, & Jacobson, 2004; Dietrich, Berger, Succop, Hammond, & Bornschein, 1993; Schnaas et al., 2006; Tong, Baghurst, McMichael, Sawyer, & Mudge, 1996). For example, in a study of 380 school age children, Dudek and Merecz (1997) found that the steepest declines in standardized IQ test performance occur in children with blood lead levels between 5 and 10 µg/dL. Similar studies have further emphasized the deleterious nature of lead exposure at levels below 10 µg/dL (Lanphear et al., 2005; Needleman & Landrigan, 2004; Schnaas et al., 2006; Schwartz, 1993).

Previous research at CEHI found an association between blood lead levels among children in North Carolina and their educational outcomes, as measured by end of grade (EOG) test scores. The detrimental effect of lead on EOG test scores was observed at levels markedly below 10 µg/dL. For example, in a study based on blood lead surveillance and educational testing data for seven North Carolina counties (2007), lead levels as low as 2 µg/dL showed a discernible impact on test scores. For both reading and mathematics, the magnitude of the average test score decrement associated with a blood lead level of 5 µg/dL was comparable that of a measure of household income (student enrollment status in free or reduced lunch programs) - a risk factor well known to be important to child educational outcomes. CEHI later replicated these findings based on all 100 counties in North Carolina (Miranda, Kim, Reiter, Overstreet Galeano, & Maxson, 2009).

In this report, we use the analytical approach employed in North Carolina as the basis for examining the association between blood lead levels and educational outcomes among Connecticut school children.

Methodology

Data Acquisition and Preparation

Tracy Hung, an epidemiologist with the Lead Poisoning Prevention and Control Program, Connecticut Department of Public Health, provided CEHI with identifier information (including name, date of birth, county, gender, and race) coupled with a child ID code for children born between 1996 and 2002 from the Connecticut Vital Records System. Richard Mooney, with the Department of Education, provided data on third, fourth, and fifth grade test scores in Connecticut during the 2007-2008 and 2008-2009 school years from the Connecticut Mastery Test (CMT) results. We matched records between the two data sets using the child's first name, last name, date of birth, sex, and county of residence together to form a unique identifier. A child's records for the two data sets were matched if they met any of the following criteria:

1. First name, last name, date of birth, sex, and county matched exactly.
2. First name, last name, date of birth, and sex matched exactly, while the county field was inconsistent or not present.
3. First name, date of birth, sex, and county matched exactly, while the last name was either close in spelling (using the SPEDIS function) or a subset (such as "Smith" and "Smith-Jones").
4. Last name, date of birth, sex, and county matched exactly, while the first name was either close in spelling (using the SPEDIS function) or a subset (such as "Mary" and "Mary Lou").
5. First name, last name, date of birth, and county matched exactly, while sex was inconsistent or not present. In this case, race/ethnicity must have been consistent or not present for us to consider the records a match.

We returned the child ID codes for the matched children to Ms. Hung, who then supplied CEHI with the blood lead screening results for any child within this group with at least one blood lead test. Using the maximum recorded lead value for children with multiple tests, the blood lead results were then joined to the CMT scores, yielding 146,175 records with both blood lead and test score information. These 146,175 records corresponded to 98,009 unique children (a child can have a record in both of the school years) with both blood lead and CMT results.

After linking the blood lead and EOG data, we restricted the dataset to non-Hispanic black (NHB) and non-Hispanic white (NHW) children who were in fourth grade during either the 2007-2008 or 2008-2009 school years, had been screened for lead before age seven, and did not have limited English proficiency. These restrictions produced a dataset with 34,935 fourth grade children with reading test results and 35,196 fourth grade children with mathematics test results who had also been screened for lead.

Statistical Analysis

We examined the relationship between blood lead levels and end-of-grade test scores for fourth grade children. Initial exploratory analysis included comparing blood lead levels and test scores graphically and generating tables of summary statistics. We conducted a multivariable ordinary least squares regression in order to determine the importance of blood lead levels to mean test scores, while controlling for individual level characteristics commonly understood to be associated with educational outcomes. Such factors included race, sex, enrollment in free or reduced lunch programs, and enrollment in special education. We also included dummy variables representing the school district for each record in order to account for unmeasured district level factors that may be associated with individual educational outcomes, such as socioeconomic level.

All statistical analyses were conducted using STATA 9.2 (StataCorp., College Station, TX).

Results

Exploratory Analysis

Table 1 shows the distribution of children with mathematics scores across different blood lead levels, disaggregated by race. Of the 35,196 NHW or NHB children with mathematics scores, 21.5% were NHB and 78.5% were NHW. If exposure to lead were evenly distributed across the population, then we would expect to see roughly this same split (21.5%/78.5%) at all blood lead levels. What is apparent from Table 1, however, is that NHB children are under-represented in the low blood lead categories (0-2) and over-represented in the high blood lead categories (3-10+) relative to the total screened children. Conversely, NHW children are over-represented in the low blood lead categories (0-2) and under-represented in the high blood lead categories (3-10+) relative to the total screened children. An important implication of this pattern is that if early childhood lead exposure does affect performance on the CMT (which we will demonstrate below), then the impact of the environmental exposure will accrue more acutely among NHB children because they are more likely to be exposed and exposed at high levels. The distribution for children with reading scores shows a similar trend (data not shown).

Table 1. Blood lead levels for fourth graders with mathematics scores disaggregated by race

Number and Percentage of NHB and NHW Children with Mathematics Scores by Blood Lead Level				
	Number NHB	Percent NHB	Number NHW	Percent NHW
Bll = 0	1749	8.9	17936	91.1
0<Bll≤1	265	14.2	1607	85.8
1<Bll≤2	594	20.1	2358	79.9
2<Bll≤3	920	31.8	1976	68.2
3<Bll≤4	833	44.4	1043	55.6
4<Bll≤5	661	51.8	614	48.2
5<Bll≤6	466	57.9	339	42.1
6<Bll≤7	346	62.6	207	37.4
7<Bll≤8	245	62.5	147	37.5
8<Bll≤9	190	63.8	108	36.2
9<Bll≤10	203	44.2	256	55.8
Bll > 10	1111	52.1	1022	47.9
Total	7583	21.5	27613	78.5

The data from Table 1 are presented in histogram format in **Figure 1**. Compared to the distribution for early childhood lead exposure among NHW children, the distribution for NHB children has a higher variance and is left-skewed. The Mantel-Haenszel Chi-square test for equality of distribution indicates that the sample distributions by race are significantly different from each other ($p<0.0001$). Moreover, by calculating a dissimilarity index, we observed that 45% of members of one racial group would need to move to a different cell in order for NHB and NHW children to be equally distributed by blood lead levels. This racial disparity in early childhood lead exposure replicates previous findings based on North Carolina data. **Tables 2** and **3** present summary statistics on the reading and mathematics datasets.

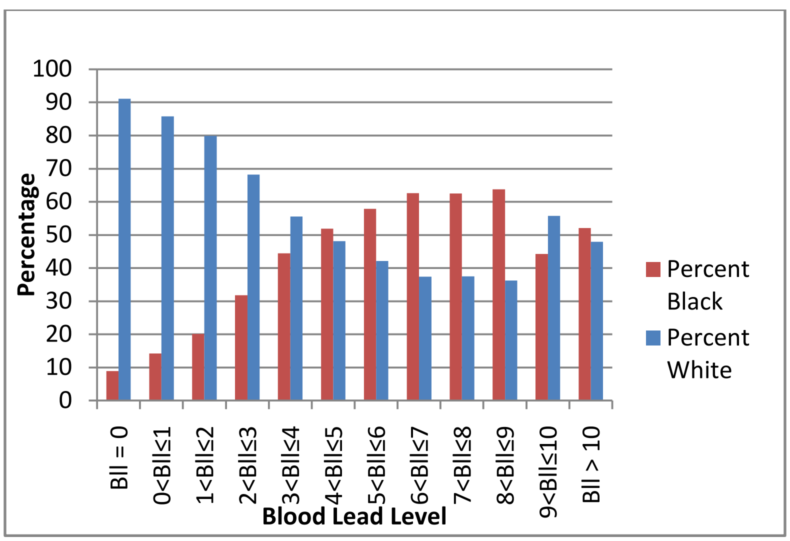

Figure 1. Distribution of blood lead levels among NHW and NHB children

Table 2. Summary statistics for reading test results

Reading Data (N=34,935)	Mean	Stan. Dev	Median	Minimum	Maximum
Reading Score	254.56	43.38	257	100	400
Lead	2.4	4.88	0	0	81
Male (1=male, 0=female)	0.51	0.5	1	0	1
Black (1=black,0=white)	0.22	0.41	0	0	1
Free/reduced lunch (1=enrolled, 0=not enrolled)	0.27	0.45	0	0	1
Age at screen	2.39	1.44	2.02	0	7
Special education (1=received, 0=not received)	0.1	0.29	0	0	1

Table 3. Summary statistics for mathematics test results

Mathematics Data (N=35,196)	Mean	Stan. Dev	Median	Minimum	Maximum
Mathematics Score	262.6	48.79	263	100	400
Lead	2.41	4.88	0	0	81
Male (1=male, 0=female)	0.51	0.5	1	0	1
Black (1=black,0=white)	0.22	0.41	0	0	1
Free/reduced lunch (1=enrolled, 0=not enrolled)	0.28	0.45	0	0	1
Age at screen	2.39	1.45	2.02	0	7
Special education (1=received, 0=not received)	0.1	0.3	0	0	1

Figure 2 graphs reading CMT scores by blood lead levels for all matched students by race. A clear negative relationship between CMT scores and blood lead levels is apparent. Lower blood lead levels are associated with higher test scores, and higher blood lead levels are associated with lower test scores, with some erratic behavior at blood lead levels of 9+, likely due to the small sample sizes in this range (see **Table 1**). **Figure 3** demonstrates a similar trend for mathematics scores.

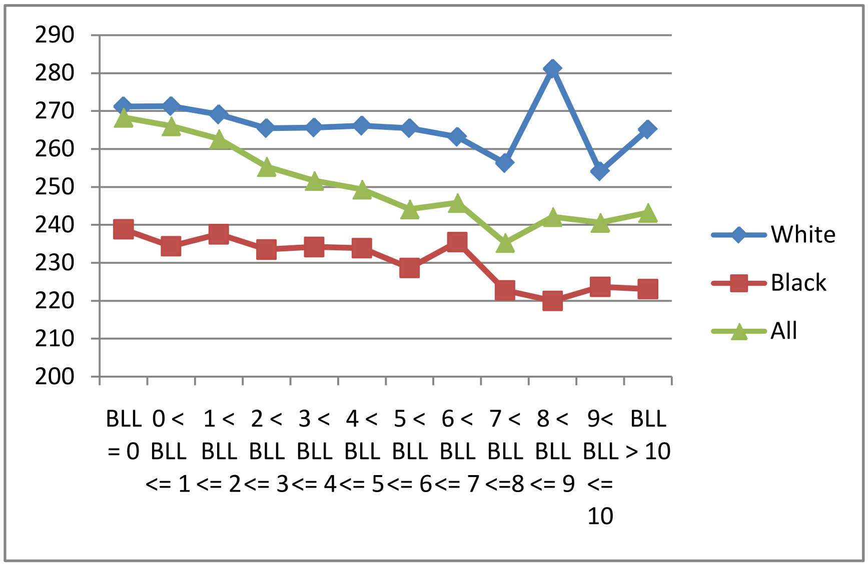

Figure 2. Mean reading score vs. blood lead level by race

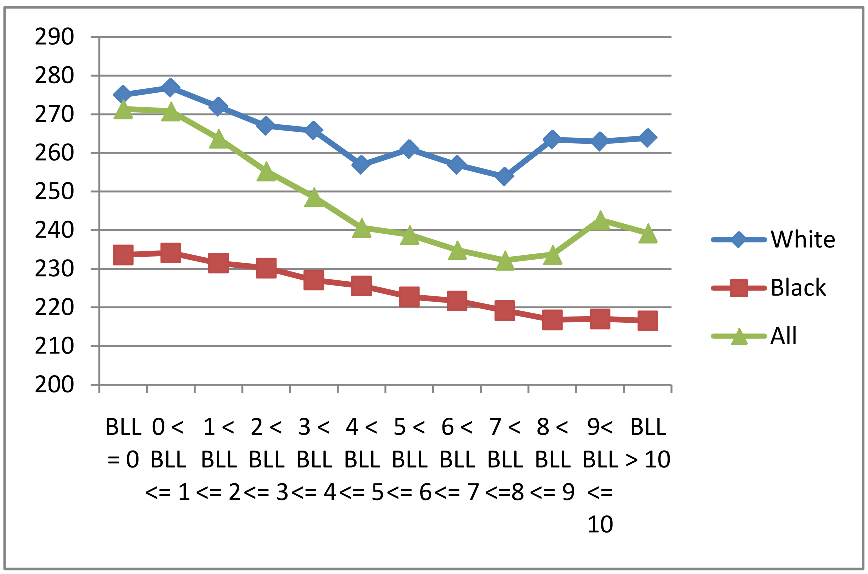

Figure 3. Mean mathematics score vs. blood lead level by race

Figures 4 and **5** examine the low end of the achievement scale: failure rates on the reading and mathematics sections of CMT, respectively. Children with low blood lead levels in early childhood have lower failure rates on both the mathematics and reading CMT than children with high blood levels. Similarly, children with high blood lead levels in early childhood have higher failure rates than those with low blood levels. Moreover, for both NHB and NHW children, a dose-response relationship between blood lead levels and failure on the CMT is evident for blood lead levels between about 1 and 6.

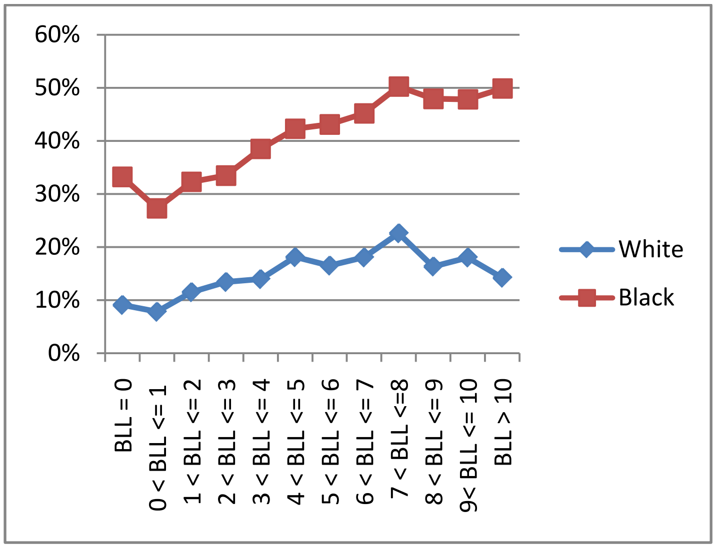

Figure 4. Percentage below basic performance standard for reading test vs. blood lead level by race

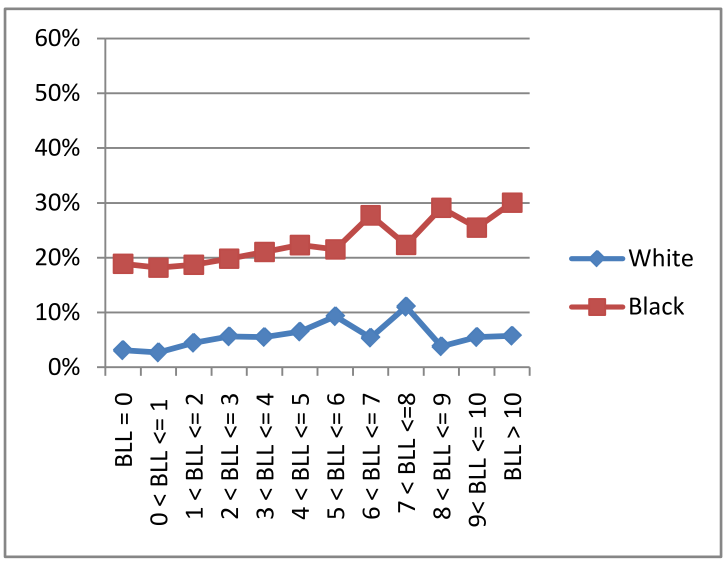

Figure 5. Percentage below basic performance standard for mathematics test vs. blood lead level by race

Multivariable Analysis

While the above exploratory analysis provides insights into how childhood lead exposure relates to reading and mathematics performance, the question of whether early childhood lead exposure is associated with performance on achievement tests is best addressed using multivariable analysis. We employed ordinary least squares regression analysis with robust standard errors to determine the impact of early childhood lead exposure on performance on the CMT, controlling for sex, race, participation in the free or reduced lunch program, age at which the blood lead screen occurred, and special education status. We also incorporated dummy variables for each of the school districts. The referent group is defined as NHW, female students, who do not participate in the free or reduced lunch program, and whose blood lead level was reported as 0. Results are presented in **Tables 4** (reading) and **5** (mathematics). We do not present the coefficients on the 178 district dummy variables, as the tables would become unwieldy.

Table 4. Results of the multiple ordinary least squares regression for reading test scores

Variable	Coefficient	Standard Error	t-stat	P> t	95% confidence interval	
0 < BLL <= 1	2.98	0.89	3.36	0.001	1.24	4.72
1 < BLL <= 2	-0.61	0.75	-0.81	0.415	-2.08	0.86
2 < BLL <= 3	-1.06	0.74	-1.42	0.155	-2.51	0.40
3 < BLL <= 4	-2.39	0.90	-2.66	0.008	-4.15	-0.62
4 < BLL <= 5	-6.28	1.07	-5.87	<.0001	-8.38	-4.18
5 < BLL <= 6	-5.80	1.30	-4.47	<.0001	-8.34	-3.26
6 < BLL <= 7	-2.82	1.56	-1.81	0.07	-5.87	0.23
7 < BLL <=8	-9.74	1.91	-5.11	<.0001	-13.48	-6.00
8 < BLL <= 9	-5.05	2.02	-2.5	0.013	-9.01	-1.09
9< BLL <= 10	-7.79	1.64	-4.76	<.0001	-11.01	-4.58
BLL > 10	-5.55	0.86	-6.45	<.0001	-7.24	-3.86
Male	-3.45	0.38	-9.12	<.0001	-4.19	-2.71
Black	-18.58	0.70	-26.67	<.0001	-19.95	-17.22
Free / reduced lunch	-15.96	0.58	-27.4	<.0001	-17.10	-14.82
Age when screened	-0.71	0.15	-4.84	<.0001	-1.00	-0.42
Special education	-48.96	0.72	-68.31	<.0001	-50.36	-47.55
Number of observations = 34935, F(186, 34759) = 10289.56, Prob > F = 0.0000, Root MSE = 35.16						

As is clear from Tables 4 and 5, blood lead levels as low as 3-4 µg/dL are negatively associated with CMT reading scores, and blood lead levels as low as 4-5 µg/dL are negatively associated with CMT mathematics scores. The magnitude of the coefficients on the lead variables are meaningful in that, though small in absolute value, they are of the same order of magnitude as the coefficient on participation in the free and reduced lunch program. For example, the coefficient in the reading regression analyses of -6.28 for blood lead levels between 4 and 5 µg/dL is roughly 10.5% of the interquartile range for CMT reading scores for the fourth graders included in this analysis. This compares to the coefficient on free and reduced lunch of -15.96 in the same model, which represents 26.6% of the interquartile range. This suggests that even after accounting for the income level (as proxied by the free and reduced lunch variable) of the child, lead has an additional negative and significant impact on CMT test scores in both reading and mathematics.

Table 5. Results of the multiple ordinary least squares regression for mathematics test scores

Variable	Coefficient	Standard Error	t-stat	P> t	95% Confidence Interval	
0 < BLL <= 1	2.60	1.01	2.57	0.01	0.62	4.57
1 < BLL <= 2	-0.27	0.84	-0.32	0.747	-1.92	1.38
2 < BLL <= 3	-1.49	0.84	-1.77	0.077	-3.14	0.16
3 < BLL <= 4	-1.82	1.04	-1.75	0.08	-3.85	0.22
4 < BLL <= 5	-5.25	1.19	-4.43	<.0001	-7.58	-2.93
5 < BLL <= 6	-4.71	1.46	-3.23	0.001	-7.57	-1.85
6 < BLL <= 7	-4.58	1.75	-2.62	0.009	-8.02	-1.15
7 < BLL <=8	-8.63	2.09	-4.13	<.0001	-12.72	-4.53
8 < BLL <= 9	-5.62	2.23	-2.52	0.012	-9.98	-1.25
9< BLL <= 10	-6.16	1.83	-3.37	0.001	-9.75	-2.57
BLL > 10	-6.11	0.98	-6.22	<.0001	-8.04	-4.19
Male	5.65	0.43	13.17	<.0001	4.81	6.49
Black	-24.11	0.79	-30.44	<.0001	-25.66	-22.55
Free / reduced lunch	-15.96	0.66	-24.31	<.0001	-17.24	-14.67
Age when screened	-0.91	0.17	-5.47	<.0001	-1.24	-0.58
Special education	-46.52	0.74	-62.66	<.0001	-47.98	-45.07
Number of observations = 35196, F(186, 35010) = 8512.90, Prob > F = 0.0000, Root MSE = 39.9						

Including lead exposure in analyses of educational achievement is important. We emphasize this point by noting that inclusion of lead exposure in multivariable regression analyses attenuates the effects of race, participation in free or reduced lunch program, and special education status (see **Table 6**).

Table 6. Attenuation of coefficients of key covariates in the ordinary least squares regression

		With lead variables	Without lead variables	Size of attenuation
Reading	Black	-18.58	-19.69	1.11
	Free/reduced lunch	-15.96	-16.75	0.79
	Special education	-48.95	-49.14	0.19
Math	Black	-24.1	-25.17	1.07
	Free Lunch	-15.95	-16.72	0.77
	Special education	-46.52	-46.73	0.21

In addition to ordinary least squares, which examines mean effects of lead exposure on test scores, we implemented quantile regression analysis to determine whether the effect of lead exposure differed across the distribution of CMT scores. Unfortunately, the sample size available for this study was not large enough to adequately support quantile regression.

Conclusions

This report presents the results of the CEHI analysis of Connecticut lead and education data. In summary, early childhood lead exposure negatively affected Connecticut Mastery Test (CMT) scores in both reading and mathematics. Disparate exposures by race suggest that exposure to lead may account for part of the achievement gap among Connecticut schoolchildren. Negative associations were statistically significant at blood lead levels well below the current US Centers for Disease Control and Prevention's (CDC) blood lead action level. These results emphasize the continued importance of protecting children from lead exposure.

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