The Impact of Early Childhood Lead Exposure on Educational Test Performance among Connecticut Schoolchildren

Phase II Report

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Motivation for the Project

Researchers at University of Michigan'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 University of Michigan Institutional Review Board). A previous report was provided to the State of Connecticut as a first phase of this project (see below). This second report expands on the previous results and presents the results of CEHI's Phase II 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 demonstrates that lead causes irreversible, asymptomatic effects far below levels previously considered safe. Thus, the CDC incrementally lowered its blood lead action level in children by 88% from 60 to 10 µg/dL over the last 40 years (1). More recently, the CDC established a new reference level of 5 µg/dL, which is the 97.5th percentile of blood lead levels in children aged 1-5 years based on the National Health and Nutrition Examination survey (NHANES) (2). Almost 500,000 children in the United States aged 1-5 years have a blood lead level above the 5 µg/dL standard (2).

Low-level lead exposure, including prenatal exposure, has been linked to decreased performance on standardized IQ tests for school-age children (3-8). A meta-analysis conducted by Schwartz (9) estimated that a 10-µg/dL increase in blood lead causes a 2.6-point decrease in IQ level. Dudek and Merecz (10) 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 steepest 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 (7;11-13). Needleman and Landrigan (12) state that this indicates that significant damage occurs even at the lowest levels of exposure.

A previous study by Miranda et al. (14) investigated the relationship between lead exposure and performance in North Carolina schools. This study linked blood lead surveillance data for seven counties in North Carolina to educational testing data for fourth grade students, and then analyzed the data using exploratory and multivariable statistical methods. The discernible impact of blood lead levels on end-of-grade (EOG) testing was demonstrated for early childhood blood lead levels as low as 2 µg/dL. A blood lead level of 5 µg/dL was associated with a decline in EOG reading (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. These results suggest that the relationship between blood lead levels and cognitive outcomes are robust across outcome measures and at low levels of lead exposure.

In additional analysis, Miranda et al. extended their lead-EOG analysis to all 100 counties in North Carolina and successfully replicated the earlier results on the larger sample (15). In addition, they employed quantile regression analysis to determine whether the effects of lead on EOG test results varied across the EOG score distribution and examined cumulative deficits by considering the distributional effects of parental educational attainment and family income. Early childhood lead exposure was associated with lower performance on reading and mathematics EOG test scores in a clear dose-response pattern, with the effects most pronounced at 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 paper concluded that the effects of environmental and social stressors – especially as they stretch out the lower tail of the EOG distribution – highlight the special vulnerabilities of particular pediatric subpopulations and point to meaningful opportunities for early intervention. Related research demonstrated that early childhood lead exposure significantly influences the likelihood of being designated exceptional (16).

An initial analysis of linked lead and education data from Connecticut was previously reported in CEHI's Phase I report. This report presented models for mean reading and mathematics scores on EOG test scores for fourth grade children in the 2007-2008 or 2008-2009 school years. The findings from these models indicated that early childhood lead exposure negatively affected Connecticut Mastery Test (CMT) scores in both reading and mathematics. Disparate exposures by race suggested that exposure to lead may account for part of the achievement gap among Connecticut schoolchildren. Negative associations were statistically significant at blood lead levels below the current US Centers for Disease Control and Prevention's blood lead reference level of 5 μg/dL.

The State of Connecticut requested additional analyses to better understand how childhood lead exposure is associated with educational performance among Connecticut schoolchildren. CEHI received additional years of CMT data linked to blood lead screens and undertook analysis exploring whether the effect of lead differed across the distribution of test scores. This report presents the findings from this second phase of analysis.

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 us with data on third, fourth, and fifth grade test scores in Connecticut during the 2007-2008, 2008-2009, and 2009-2010 school years from the CMT results. We matched records between the two datasets, 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 datasets 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 to Tracy Hung the child ID codes for the children matched using the procedure above. Ms. Hung then provided CEHI with the all associated blood lead screening results for any children in this group who had received at least one blood lead test. The blood lead results for these children were then combined with their respective CMT scores. Focusing on fourth grade outcomes, this process yielded 160,495 records with both blood lead screens and fourth grade CMT test score information. Since children may have more than one lead screen and more than one fourth grade CMT record, these 160,495 records corresponded to 74,204 unique children having at least one blood lead screen and a fourth grade CMT results. Of these, 30,114 unique children had at least one venous blood lead screen.

Data restrictions

After linking blood lead data and CMT testing data, we restricted the analysis dataset to children who were in fourth grade during any of the 3 school years. We restricted to non-Hispanic black (NHB) and non-Hispanic white (NHW) children without limited English proficiency who had at least one venous blood lead screen conducted at 7 years of age or younger. For each of these children, we selected the maximum venous blood lead screen result. These restrictions led to a dataset with 17,998 fourth grade children with reading test results and 18,160 fourth grade children with mathematics test results who had also been screened for lead.

Note that despite an additional year of educational outcomes, the number of observations for the analyses presented in this report is significantly lower than the number of observations used in

the Phase I report. This difference is due to the additional restriction, requested by Dr. Vivian Cross and Ms. Tracy Hung (email communication, 01-03-2013), to venous blood lead samples only, which are known to be more reliable than capillary blood lead tests.

Statistical Analysis

With the expanded and newly restricted dataset, we repeated the exploratory analysis and extended the multivariable analysis presented in the Phase I report. We began with exploratory statistics, by comparing blood lead levels and test scores graphically and generating tables of summary statistics. We then used multilevel modeling to determine the effect of blood lead levels on mean reading and mathematics test scores when other factors were considered. These models controlled for enrollment in free or reduced lunch programs, enrollment in special education, race, age at lead screen, and sex. The multilevel models included a random intercept for each school district, accounting for correlation among students within school districts and potential unmeasured confounders at the district level. Models were run for the full dataset, as well as stratified by race.

To further explore the relationship between blood lead and educational performance, we conducted quantile regression analysis. The quantile regression analysis divided test performance into five ordered bins (quantiles) in order to better examine whether lead exposure had differential effects across the distribution of CMT scores. We modeled the 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentile of test scores for both mathematics and reading, controlling for enrollment in free or reduced lunch programs, enrollment in special education, race, and sex. Due to computational restrictions, we present quantile regression models that do not include a random intercept for school district. Again, models were run for the full dataset, as well as stratified by race.

All statistical analyses were conducted using SAS 9.3 (SAS Corporation, Cary, NC).

Results

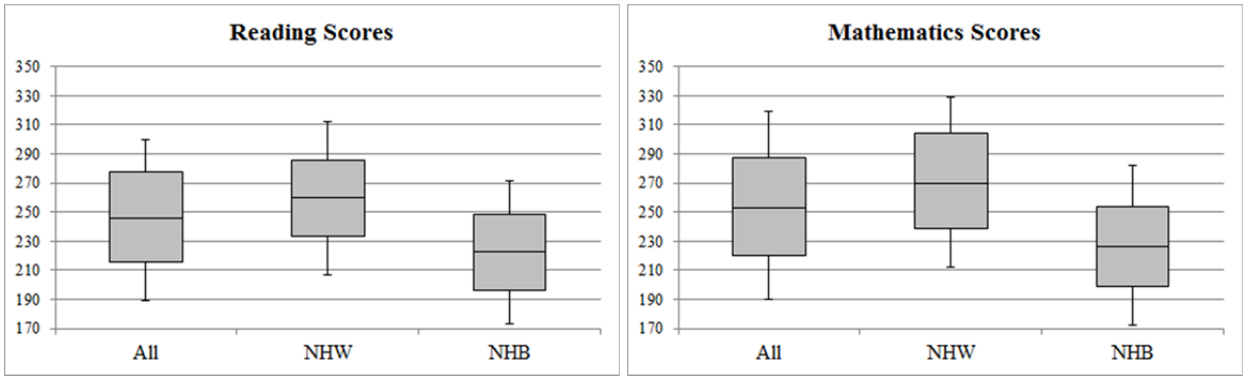
Study population

Table 1 presents the demographic composition of the children meeting all restrictions and having a fourth grade CMT reading score. Most children were NHW (63.3%) and had a mean age of 2.8 years old at the time of their maximum venous blood lead screen. There was no difference in the male to female ratio or the proportion of students enrolled in special education by race; however, NHB children were much more likely than NHW children to be enrolled in the free/reduced lunch program (80.3% for NHB; 22.7% for NHW). The demographic composition of children included in the mathematics analysis was quite similar to that of the children in the reading analysis (data not shown). There were a total of 18,160 children meeting all restrictions

Table 1. Study population with scores on CMT reading test.

	All		NHW		NHB	
	N	%	N	%	N	%
N	17,998		11,397		6,601	
Age in years at lead screen, mean (standard deviation)	2.8 (1.7)		2.7 (1.7)		2.9 (1.5)	
Sex						
Female	8,692	48.3	5,512	48.4	3,180	48.2
Male	9,306	51.7	5,885	51.6	3,421	51.8
Special education						
Yes	1,824	10.1	1,165	10.2	659	10.0
No	16,174	89.9	10,232	89.8	5,942	90.0
Free/reduced lunch program						
Yes	7,888	43.8	2,586	22.7	5,302	80.3
No	10,110	56.2	8,811	77.3	1,299	19.7

Figure 1. Distribution of fourth grade CMT scores in mathematics and reading.



and having a fourth grade CMT mathematics score, with 11,493 of these children being NHW and 6,667 being NHB.

Distribution of test scores

On the mathematics test, the mean score was 254 points with a standard deviation of 50 points. On the reading CMT test, the mean score was 245 points with a standard deviation of 44 points. Boxplots showing the distribution of fourth grade CMT scores in mathematics and reading are displayed in Figure 1. The gray boxes in these plots highlight the 25th through 75th percentile of scores, with the median (50th percentile) score indicated by the horizontal line within the gray box. The 10th and 90th percentile scores are indicated by the lines extending above and below the 25th and 75th percentile, respectively. NHW children performed better on CMT tests than NHB children. In both reading and mathematics, the 75th percentile of scores among NHB children was below the 50th percentile of scores among NHW children.

Distribution of blood lead levels

Figure 2 presents boxplots of the distribution of blood lead levels overall and by race. NHB children experienced significantly higher levels of lead exposure than did NHW children. The 90th percentile of blood lead levels among NHW children was less than the 75th percentile of blood lead levels among NHB children. The stark difference between blood lead levels by race is further highlighted by 44% of NHW children having a blood lead level of < 2 µg/dL, as compared to just 17% of NHB children.

Figure 2. Distribution of blood lead levels by race in both reading and mathematics datasets.

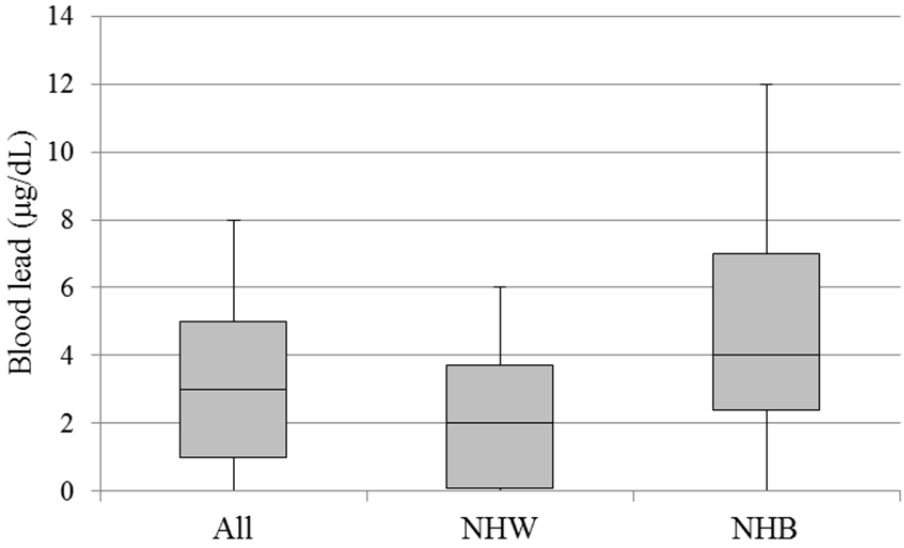
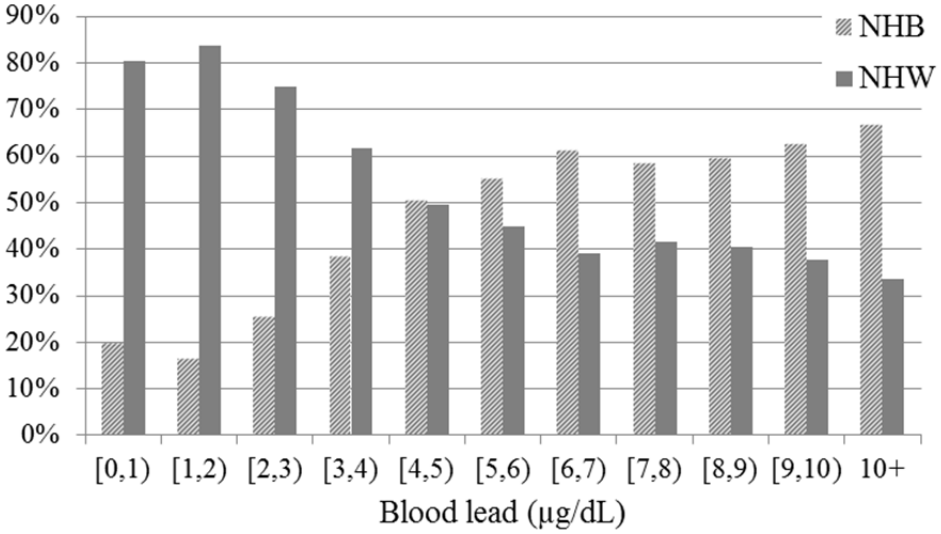


Figure 3 provides additional evidence of differential distributions of blood lead levels by race. Since 63.3% of the study population was NHW, if blood lead levels were similar among NHW and NHB children, then we would expect roughly 63% of the children in each blood lead category to be NHW. As highlighted in the figure, lower blood lead categories were disproportionately comprised of NHW children, while higher blood lead categories were disproportionately comprised of NHB children.

Distribution of test scores across blood lead levels

Figure 4 shows the negative association between mean CMT test scores and blood lead levels. Lower blood lead levels were associated with higher mean test scores, and higher blood lead levels were associated with lower mean test scores. In the highest blood lead level categories, this relationship was slightly less clear, likely due to small numbers of children falling into these ranges.

Figure 3. Percent of children within each blood lead category by race group (reading dataset).



Models for mean test scores

To assess the association between blood lead levels and CMT scores in a multivariable setting, we constructed multilevel models of reading or mathematics test score (depending on the model) with a random intercept for each school district and controlling for enrollment in free or reduced lunch programs, enrollment in special education, race, age at lead screen, and sex. We ran this analysis for the entire dataset, as well as separately by race.

The results of models for mean CMT reading and mathematics test scores are presented in **Tables 2** and **3**, respectively. As expected, enrollment in the free/reduced lunch and special education programs were both associated with decreased reading and mathematics test scores ($p<0.001$). Higher age at the time of a child's maximum venous blood lead screen was associated with a small decrease in CMT scores ($p<0.05$), with the exception of the NHB only model for reading. Male sex was associated with a decrement in reading test scores, but an increase in mathematics scores ($p<0.001$), except in the NHB only model for mathematics.

Blood lead, even at very low levels, was negatively associated with scores on both the reading

Figure 4. Mean fourth grade reading and mathematics test scores by blood lead category.

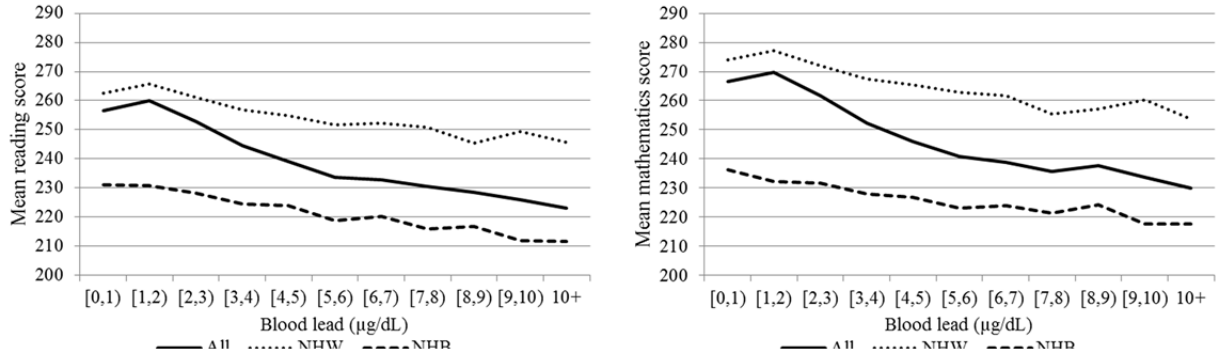


Table 2. Results of multilevel models for mean fourth grade reading CMT score.

	NHW/NHB model		NHW model		NHB model	
Variable	**Coefficient**		**Coefficient**		**Coefficient**	
Intercept	274.11	***	273.97	***	252.20	***
NHB	-18.19	***	*n/a*		*n/a*	
Male	-3.65	***	-2.30	***	-6.04	***
Age at time of screening	-0.88	***	-0.97	***	-0.53	
Enrollment in free/reduced lunch program	-16.73	***	-19.05	***	-12.39	***
Enrollment in special education	-45.00	***	-47.07	***	-41.22	***
Blood lead level (µg/dL)						
[0,1)						
[1,2)	-0.44		-0.55		0.21	
[2,3)	-1.55		-1.66		-1.55	
[3,4)	-3.25	***	-3.13	**	-4.14	*
[4,5)	-3.48	***	-3.84	**	-3.84	*
[5,6)	-7.29	***	-5.08	**	-10.00	***
[6,7)	-4.99	***	-1.51		-7.97	***
[7,8)	-6.52	***	-3.31		-9.73	***
[8,9)	-7.30	***	-7.45	*	-8.53	**
[9,10)	-11.32	***	-5.55		-15.67	***
10+	-10.39	***	-6.18	***	-13.84	***

* p<0.05, ** p<0.01, *** p<0.001

and mathematics CMT tests. Generally, the magnitude of the negative effect of lead on test scores increased with increasing lead level.

In models of reading test scores, lead levels as low as 3 µg/dL were associated with lower mean test scores in the overall and race-stratified models ($p<0.05$). For blood lead levels in the 3 to <4 µg/dL range, the associated decrease in mean reading test scores represented 5.2% of interquartile range (IQR: 25th to 75th percentile) of scores in the full study population, 5.9% of the IQR of scores for NHW children, and 8.0% of the IQR of scores for NHB children. At the highest blood lead category (≥10 µg/dL), the change in reading scores associated with blood lead was 16.8% of the IQR of scores for the full study population, 11.7% of the IQR of scores for NHW children, and 26.6% of the IQR of scores for NHB children. These effect sizes indicate important implications of early childhood lead exposure on reading skills at fourth grade, especially for NHB children.

Table 3. Results of multilevel models for mean fourth grade mathematics CMT score.

	NHW/NHB model		NHW model		NHB model	
Variable	**Coefficient**		**Coefficient**		**Coefficient**	
Intercept	281.16	***	280.75	***	254.04	***
NHB	-23.71	***	*n/a*		*n/a*	
Male	4.30	***	6.65	***	0.16	
Age at time of screening	-1.15	***	-1.29	***	-0.74	*
Enrollment in free/reduced lunch program	-16.05	***	-18.54	***	-11.01	***
Enrollment in special education	-44.01	***	-47.74	***	-37.15	***
Blood lead level (µg/dL)						
[0,1)						
[1,2)	-1.48		-1.35		-2.73	
[2,3)	-2.37	*	-2.62	*	-2.51	
[3,4)	-4.33	***	-4.00	**	-5.62	**
[4,5)	-4.56	***	-4.18	**	-5.75	**
[5,6)	-7.32	***	-4.38	*	-10.90	***
[6,7)	-6.39	***	-3.24		-9.29	***
[7,8)	-8.69	***	-9.57	***	-9.35	***
[8,9)	-6.76	**	-7.84	*	-7.32	*
[9,10)	-10.47	***	-4.89		-14.99	***
10+	-11.22	***	-9.36	***	-13.72	***

* p<0.05, ** p<0.01, *** p<0.001

For mathematics, significant effects on mean test scores were found for lead levels as low as 2 µg/dL in overall and NHW only models, and for lead levels as low as 3 µg/dL in the NHB only model ($p<0.05$). At the lowest blood lead level with a significant effect on mean mathematics test scores, the decrease in scores associated with blood lead represented 3.5% of the IQR of scores for the full study population, 4.0% of the IQR of scores for NHW children, and 10.2% of the IQR of scores for NHB children. At the highest blood lead category (≥10 µg/dL), the change in mathematics scores associated with blood lead was 16.7% of the IQR of scores for the full study population, 14.4% of the IQR of scores for NHW children, and 24.9% of the IQR of scores for NHB children. Similar to the findings for reading test scores, these effect sizes indicate important implications of early childhood lead exposure on mathematics skills at fourth grade.

Models for quantiles of test score distributions

We also implemented quantile regression analysis to determine whether the effect of lead exposure differed across the distribution of CMT test scores. We modeled the 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentile of test scores for both mathematics and reading, controlling for enrollment in free or reduced lunch programs, enrollment in special education, race, and sex. We were unable to include a random intercept for school district due to the computational complexity of such models in the quantile regression framework. We ran this analysis for the entire dataset and by race group.

Covariates generally behaved as expected (data not shown), with enrollment in free/reduced lunch, participation in special education, and age at the time of a child's maximum venous blood lead screen associated with lower CMT test scores ($p<0.05$). In pooled and NHB only models for both reading and mathematics, the effect of sex varied significantly across quantiles ($p<0.05$). For example, in pooled models, at lower quantiles of test scores, male sex had a larger negative effect on reading performance and a smaller positive impact on mathematics performance. The magnitude of the effect of special education on reading scores decreased from the 10^{th} to 90^{th} percentile in pooled and NHW only models ($p<0.05$), with the decrement in NHW models being 16 points larger at the 10^{th} than the 90^{th} percentile. Among NHW children, enrollment in free/reduced lunch also differentially effected reading test scores across quantiles ($p<0.05$), although a clear pattern was not apparent.

Tables 4 and **5** present the estimated coefficients for blood lead levels in pooled and race-specific quantile regression models for reading and mathematics test scores, respectively. Modeled distributions of reading and mathematics test scores across blood lead levels based on the race-specific models are displayed in **Figures 5** (NHW models) and **6** (NHB models). The gray boxes in these plots highlight the modeled 25^{th} and 75^{th} percentile of scores, with the modeled median (50^{th} percentile) score indicated by the horizontal line within the gray box. The modeled 10^{th} and 90^{th} percentile scores are indicated by the lines extending above and below the gray box.

The effect of blood lead levels on CMT test scores varied across quantiles for reading scores in both race-specific models and for mathematics scores among NHW children ($p<0.05$). However, there was no clear pattern to the way blood lead levels differentially affected test score distributions according to quantile. As highlighted in Figures 5 and 6, there was a downward shift in the overall test score distribution as blood lead level increased, but we do not see clear trends in stretching or shrinking of the score distribution as blood lead level changes.

Consistent with the models for mean test scores, blood lead, even at low levels, was negatively associated with score quantiles on both reading and mathematics CMT tests. Significant decrements in reading scores at all modeled quantiles were found for blood lead levels as low as 5 μg/dL in the NHB only model, and for levels as low as 3 μg/dL in pooled and NHW only

models ($p<0.05$). Mathematics test scores were negatively associated with blood lead levels at all modeled quantiles for blood lead levels as low as 3 µg/dL in the pooled model, 4 µg/dL in the NHB only model, and 5 µg/dL in the NHW only model ($p<0.05$). In all models, blood lead levels as low as 2 µg/dL were associated with significant decreases in test scores for at least one of the modeled quantiles ($p<0.05$).

Figure 5. Boxplots of modeled percentiles of fourth grade CMT scores across blood lead levels from NHW only quantile regression model. Modeled percentiles are for a female child of average age at screening (2.8 years), not enrolled in either free/reduced lunch or special education.

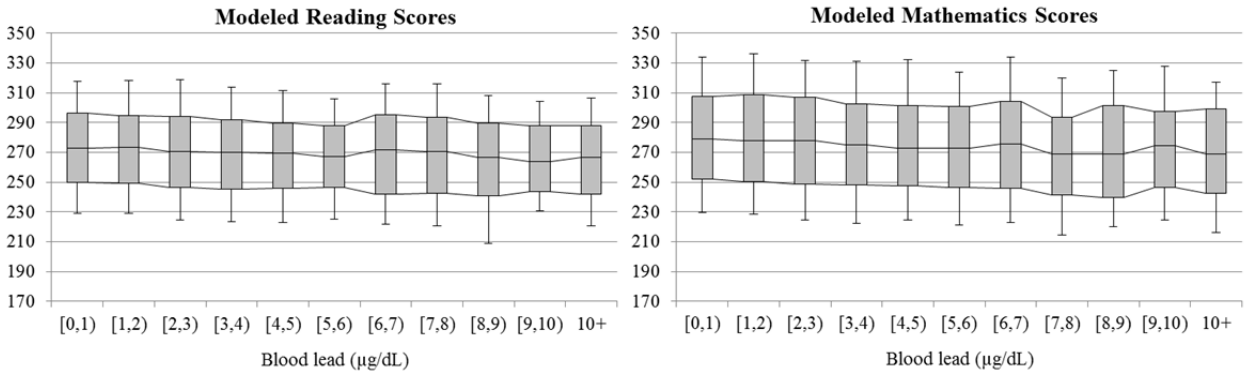
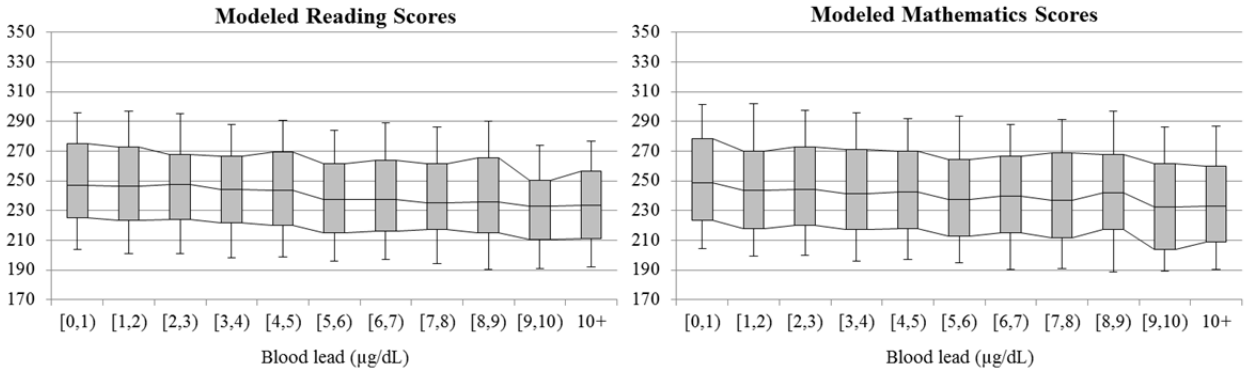


Figure 6. Boxplots of modeled percentiles of fourth grade CMT scores across blood lead levels from NHB only quantile regression model. Modeled percentiles are for a female child of average age at screening (2.8 years), not enrolled in either free/reduced lunch or special education.



Exposure to lead had a larger effect among NHB than NHW children. The decline in both reading and mathematics test scores associated with an increase in blood lead level from the lowest (<1 µg/dL) to the highest (≥10 µg/dL) blood lead level category was larger in magnitude at each quantile for NHB than NHW children. For example, for both reading and mathematics test scores, an increase in blood lead level from <1 µg/dL to ≥10 µg/dL was associated with roughly an 8 point decrease in the 75th percentile score for NHW children, but almost a 19 point decrease in the 75th percentile score for NHB children.

Table 4. Coefficients on blood lead level from quantile regression models of fourth grade CMT reading test scores. Models controlled for sex, age at screening, enrollment in free/reduced lunch, and enrollment in special education. Race was also controlled for in the pooled model.

	Percentile modeled				
Blood lead level (µg/dL)	**10th**	**25th**	**50th**	**75th**	**90th**
NHW/NHB					
[0,1)	—	—	—	—	—
[1,2)	-0.25	-0.79	0.14	-1.06	0.38
[2,3)	-3.72 *	-2.99 *	-1.60	-2.77 *	-0.06
[3,4)	-5.91 ***	-3.98 **	-3.11 **	-5.08 ***	-4.98 **
[4,5)	-5.82 **	-4.61 **	-3.03 *	-5.23 ***	-5.03 **
[5,6)	-7.32 ***	-6.93 ***	-6.89 ***	-9.39 ***	-10.38 ***
[6,7)	-6.82 **	-8.63 ***	-5.76 **	-4.40 *	-4.73
[7,8)	-10.24 ***	-7.51 ***	-7.05 ***	-7.44 **	-8.65 **
[8,9)	-14.45 ***	-8.41 **	-7.55 **	-6.44 *	-9.30 **
[9,10)	-7.14	-9.47 **	-10.47 ***	-16.77 ***	-18.71 ***
10+	-9.51 ***	-11.15 ***	-10.14 ***	-13.11 ***	-15.68 ***
NHW only					
[0,1)	—	—	—	—	—
[1,2)	0.06	-1.06	0.78	-1.27	0.80
[2,3)	-4.17 *	-3.35 *	-1.93	-1.80	0.84
[3,4)	-5.58 **	-4.89 **	-2.52	-4.11 **	-4.09 *
[4,5)	-5.98 **	-4.40 *	-3.07	-6.61 ***	-6.03 *
[5,6)	-4.04	-3.57	-5.30 **	-8.28 ***	-11.84 ***
[6,7)	-7.14 *	-8.22 **	-0.84	-0.98	-1.76
[7,8)	-8.50 *	-7.77 *	-2.14	-2.81	-1.87
[8,9)	-20.11 ***	-9.31 *	-6.03	-6.28	-9.29
[9,10)	1.57	-6.31	-8.60 *	-8.41	-13.75 *
10+	-8.34 **	-7.89 **	-5.66 *	-8.45 ***	-11.28 ***
NHB only					
[0,1)	—	—	—	—	—
[1,2)	-2.94	-1.45	-0.95	-2.30	1.00
[2,3)	-2.91	-0.73	0.32	-7.38 **	-1.00
[3,4)	-5.63 *	-3.07	-3.33	-8.52 ***	-8.00 **
[4,5)	-5.18 *	-5.07 *	-3.72	-5.76 *	-5.00
[5,6)	-7.68 **	-10.22 ***	-9.91 ***	-13.36 ***	-12.00 ***
[6,7)	-6.39 *	-8.73 **	-9.53 ***	-11.43 ***	-7.00
[7,8)	-9.22 **	-7.55 *	-11.88 ***	-13.19 ***	-10.00 *
[8,9)	-13.58 ***	-10.09 **	-11.29 ***	-9.51 *	-6.00
[9,10)	-12.60 **	-14.31 ***	-14.12 ***	-24.55 ***	-22.00 ***
10+	-11.71 ***	-13.85 ***	-13.87 ***	-18.46 ***	-19.00 ***

Table 5. Coefficients on blood lead level from quantile regression models of fourth grade CMT mathematics test scores. Models controlled for sex, age at screening, enrollment in free/reduced lunch, and enrollment in special education. Race was also controlled for in the pooled model.

	Percentile modeled				
Blood lead level (µg/dL)	**10th**	**25th**	**50th**	**75th**	**90th**
NHW/NHB					
[0,1)	—	—	—	—	—
[1,2)	-2.08	-2.40	-2.27	-0.56	1.33
[2,3)	-4.74 **	-3.55 **	-1.98	-2.05	-2.67
[3,4)	-7.11 ***	-4.97 ***	-4.80 ***	-4.38 **	-4.80 *
[4,5)	-6.06 **	-5.35 ***	-4.65 **	-6.20 ***	-6.06 **
[5,6)	-8.21 ***	-8.44 ***	-7.97 ***	-9.36 ***	-9.37 ***
[6,7)	-9.92 ***	-7.58 ***	-5.99 **	-7.03 **	-8.51 **
[7,8)	-11.59 ***	-11.05 ***	-9.56 ***	-9.78 ***	-9.43 **
[8,9)	-12.60 ***	-11.14 ***	-7.59 **	-7.32 *	-5.58
[9,10)	-9.70 *	-15.13 ***	-11.69 ***	-13.49 ***	-12.59 **
10+	-11.94 ***	-11.38 ***	-12.62 ***	-13.15 ***	-15.64 ***
NHW only					
[0,1)	—	—	—	—	—
[1,2)	-1.38	-1.81	-1.29	1.05	2.18
[2,3)	-5.35 **	-3.61 *	-1.28	-0.43	-2.06
[3,4)	-7.19 ***	-3.89 *	-4.00 *	-4.88 **	-2.42
[4,5)	-4.96 *	-4.62 *	-6.11 **	-6.00 **	-1.53
[5,6)	-8.52 **	-5.49 *	-5.96 *	-6.33 *	-9.98 **
[6,7)	-6.80	-6.35 *	-3.61	-3.21	0.32
[7,8)	-15.45 ***	-10.99 **	-9.99 **	-13.82 ***	-13.81 **
[8,9)	-9.81	-12.62 **	-10.28 *	-6.00	-8.70
[9,10)	-5.09	-5.62	-4.80	-10.12	-6.05
10+	-13.59 ***	-9.57 ***	-10.01 ***	-8.12 **	-16.84 ***
NHB only					
[0,1)	—	—	—	—	—
[1,2)	-4.87	-5.60	-4.61	-8.75 *	0.45
[2,3)	-4.41	-3.51	-4.55	-5.71 *	-3.58
[3,4)	-8.51 **	-6.16 *	-6.86 **	-7.73 **	-5.72
[4,5)	-7.56 **	-5.57 *	-5.95 *	-8.64 ***	-9.41 **
[5,6)	-9.67 **	-10.69 ***	-10.90 ***	-14.28 ***	-7.99 *
[6,7)	-13.78 ***	-8.28 **	-8.98 **	-11.87 ***	-13.44 ***
[7,8)	-13.62 ***	-11.52 **	-11.64 ***	-9.84 **	-9.84 *
[8,9)	-15.83 ***	-6.20	-6.63	-10.80 **	-4.54
[9,10)	-15.01 **	-19.81 ***	-16.34 ***	-16.89 ***	-14.73 **
10+	-13.89 ***	-14.40 ***	-15.56 ***	-18.93 ***	-14.40 ***

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 scores in both reading and mathematics. Disparate exposures 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 below the current US Centers for Disease Control and Prevention's blood lead action level of 5 µg/dL. While we did observe some differences in the impact of lead across quantiles of test scores, there was no clear pattern of lead having a larger effect on scores at lower quantiles, a trend which emerged in the analysis conducted in North Carolina. This may be due in part to the smaller sample sizes available in Connecticut compared to North Carolina. The magnitude of decrements in test scores associated with lead indicate important implications of early childhood lead exposure on academic performance at fourth grade, especially for NHB children for whom the effect of lead exceeded the corresponding effect for NHW children. While these results are not without limitations, the findings emphasize the continued importance of protecting children from lead exposure.

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