Association Between Lead Poisoning and Academic Performance of Third-Grade Children in Milwaukee

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ABSTRACT

Introduction: Lead-poisoned children with blood lead levels (BLL) of > 5 µg/dL among those tested in Milwaukee, Wisconsin, increased from 8.6% to 10.4% between 2014 and 2016. We examined the association between lead poisoning and academic performance of third-grade children in Milwaukee.

Methods: Data from Milwaukee Public Schools, birth certificates, and the City of Milwaukee Health Department on third-grade students from 2010 through 2015 were analyzed. The outcome was academic performance measured as standardized math and reading scores. The key independent variable was elevated BLL ≥ 5 µg/dL. Standardized reading and math test scores were modeled using mixed effects linear regression, including a school-specific random intercept and repeated effects for school trimesters using an autoregressive correlation structure of first order. The association of reading scores with lead exposure was explored after adjusting for school year, trimester, child, and maternal characteristics.

Results: Of 18 213 children with available lead testing data, the median maximum BLL was 4.0 µg/dL (interquartile range 34.0-6.1). Nearly 60% (58.3%) had maximum BLLs < 5 µg/dL, 27.7% had maximum BLLs of 5-9 µg/dL, 11.0% had maximum BLLs of 10-19 µg/dL, and 3.0% had maximum BLL ≥20 µg/dL. After controlling for potential confounders, children with BLLs ≥20 µg/dL, 10-19 µg/dL, and 5-9 µg/dL, respectively, had lower standardized math and reading scores when compared to children with BLLs <5 µg/dL at $P < 0.001$.

Conclusions: Even at low levels, childhood lead poisoning persists in Milwaukee and is associated with lower third-grade academic performance in standardized reading and math tests. Parent education, childhood lead testing, and home lead abatement are critical strategies to improve children's educational performance.

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INTRODUCTION

Lead is an environmental neurotoxicant of public health importance that may result in lead poisoning.[1] Lead poisoning remains a public health priority that has harmful effects on the brain development of children and adults.[2] Lead exposure also has demonstrated adverse effects, such as neurobehavioral deficits;[3] cardiovascular, immune, and behavioral development;[4] and adverse birth outcomes.[5] Although the Centers for Disease Control and Prevention (CDC) set a reference blood lead level (BLL) cutoff of ≥ 3.5 µg/dL to indicate lead poisoning, no BLLs are safe.[6] In Wisconsin, children under 6 years of age are considered lead poisoned at a capillary or venous BLL ≥ 5 µg/dL.[7] Studies consistently show an association between low BLL, such as 10 µg/dL or less, and impaired cognitive function in children.[8] The effects of childhood lead exposure can persist throughout a lifetime and result in negative long-term consequences in adulthood, such as cognitive decline, aggressive behavior, sociobehavioral problems,[9] and communication and language difficulties.[10] Lead-based paint is the main source of childhood lead exposure, especially in older houses.[11] Other lead poisoning sources include manufacturing products, such as children's toys containing lead, mining waste, lead dust,[12] and leaded water service lines/pipes,[13] as well as leaded gasoline phased out by the Environmental Protection Agency (EPA).[14]

Reporting blood lead test results to Wisconsin public health officials is mandatory.[15] From 2014 through 2017, 6.9% of children under 6 years of age in Milwaukee had a BLL above

Table 1. Summary of Child/Maternal Variables by Maximum Blood Lead Test Result

	BLL Not Tested N = 2720	Max BLL <5 µg/dL N = 10 618	Max BLL ≥5 µg/dL N = 7595	*P* value
School year, n (%)				< 0.001
2010 – 2011	588 (13.87)	1759 (41.49)	1893 (44.65)	
2011 – 2012	521 (12.78)	1970 (48.31)	1587 (38.92)	
2012 – 2013	553 (13.18)	2163 (51.55)	1480 (35.27)	
2013 – 2014	528 (13.07)	2186 (54.11)	1326 (32.82)	
2014 – 2015	530 (12.10)	2540 (58.00)	1309 (29.89)	
Gender, n (%)				< 0.001
Male	1350 (12.62)	5303 (49.56)	4047 (37.82)	
Female	1370 (13.39)	5315 (51.94)	3548 (34.67)	
Race, n (%)				< 0.001
African American/Black	1425 (11.67)	5707 (46.72)	5083 (41.61)	
White	650 (22.53)	1702 (58.99)	533 (18.47)	
Hispanic	441 (9.25)	2586 (54.23)	1742 (36.53)	
Other	204 (19.17)	623 (58.55)	237 (22.27)	
Area deprivation index				< 0.001
Mean (SD)	124.52 (21.45)	127.62 (21.28)	136.55 (19.40)	
Median (Q1, Q3)	126.82 (107.48, 140.62)	131.06 (111.17, 142.40)	139.39 (126.60, 151.46)	
Minimum, maximum	62.53, 169.26	40.19, 169.26	65.56, 169.26	
Missing	149	845	663	
Food service indicator, n (%)				< 0.001
No	654 (20.38)	1989 (61.98)	566 (17.64)	
Yes	2066 (11.66)	8629 (48.69)	7029 (39.66)	
Special education, n (%)				< 0.001
No	2327 (13.53)	9023 (52.47)	5847 (34.00)	
Yes	393 (10.52)	1595 (42.69)	1748 (46.79)	
English language learner n (%)				< 0.001
No	2557 (13.54)	9576 (50.70)	6753 (35.76)	
Yes	163 (7.96)	1042 (50.90)	842 (41.13)	
Attendance days				< 0.001
Mean (SD)	145.99 (28.06)	148.79 (23.23)	146.48 (26.02)	
Median (Q1, Q3)	155.00 (144.00, 159.00)	155.00 (146.50, 159.00)	154.00 (143.00, 159.00)	
Minimum, maximum	1.00, 187.00	2.00, 204.00	3.00, 195.00	
Missing	1332	5015	4339	
Gestational age (weeks), n (%)				0.002
23 – 25	5 (8.06)	32 (51.61)	25 (40.32)	
26 – 32	56 (11.79)	218 (45.89)	201 (42.32)	
33 – 34	42 (9.50)	205 (46.38)	195 (44.12)	
35 – 37	388 (12.73)	1536 (50.41)	1123 (36.86)	
38 – 43	2229 (13.18)	8627 (51.03)	6050 (35.79)	
Missing	0	0	1	
Small for gestational age, n (%)				0.017
No	2657 (13.03)	10 364 (50.84)	7365 (36.13)	
Yes	63 (11.58)	252 (46.32)	229 (42.10)	
Missing	0	2	1	
1-minute Apgar, n (%)				0.062
0 – 3	50 (12.25)	189 (46.32)	169 (41.42)	
4 – 6	135 (11.96)	555 (49.16)	439 (38.88)	
7 – 10	2519 (13.05)	9834 (50.95)	6947 (35.99)	
Missing	16	40	40	
5-minute Apgar, n (%)				0.598
0 – 3	3 (12.50)	13 (54.17)	8 (33.33)	
4 – 6	10 (9.43)	50 (47.17)	46 (43.40)	
7 – 10	2591 (12.92)	10 158 (50.64)	7312 (36.45)	
Missing	116	397	229	

Abbreviations: BLL, blood lead level; max, maximum; Q, quarter.

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5 µg/dL, decreasing to 6.3% from 2018 through 2021.[15] During 2010 to 2015, the lead poisoning threshold for children under 6 was set at 10 µg/dL by the Wisconsin Department of Health Services (DHS), aligning with CDC guidelines at that time.[16] In 2012, after the CDC lowered this level to 5 µg/dL to improve detection of elevated BLLs, DHS adopted the same threshold.[17]

Average childhood BLLs are disproportionately higher among children in predominantly minority populations who are living in socioeconomically disadvantaged communities[18] in racially segregated neighborhoods.[18] The State of Wisconsin addresses childhood lead poisoning prevention efforts through CDC funding to ensure blood lead testing and reporting, to enhance BLL surveillance, to improve linkage to support services, and to support case management and environmental investigations by local health departments.[20]

Primary prevention of childhood lead exposure is essential to mitigating the negative effects of BLL on children. This includes increasing awareness among parents and caregivers of all children – especially those exposed to lead. Secondary prevention approaches include appropriate provider lead testing, case management, surveillance reporting and referral to and through appropriate service providers,[21] (ie, community outreach[22]) and environmental investigations provided by local health departments. In Wisconsin, children's lead testing typically occurs at pediatricians' offices, Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) clinics, and public health departments – particularly during well-child visits or in high-risk areas.[23] However, data on the percentage of children with a primary care provider or consistent well-child visits for lead testing between ages 1 and 5 years are limited. One-third (35.2%) of Medicaid enrolled children were not tested for lead, suggesting that all children were not receiving appropriate testing for BLL.[24]

This highlights the challenge of childhood BLLs, which may be undetected as this recent evidence suggests.

Studies consistently have demonstrated the association between higher BLLs and poorer academic achievement in standardized reading and math tests among school-aged children.[25,26] However, a need exists to inform childhood lead prevention efforts implemented by the City of Milwaukee Health Department (MHD) and health care centers on the magnitude and significance of lead effects on academic performance. Since academic performance is mostly determined by other (non-lead) factors, the objective of this study was to examine the association between lead exposure and the academic performance of third-grade children in Milwaukee while controlling for the effects of confounding variables.

METHODS

Study Setting and Data Sources

In 2016, Milwaukee County had the highest prevalence of elevated BLLs (≥5 µg/dL) at 10.8% among children under 6 years of age who were tested for lead versus levels statewide of 5.0% and those of 9 other counties with local health department jurisdictions ranging from 5.1% to 8.4%.[27] Similarly, during 2018 to 2021, 6.3% of children under 6 years in Milwaukee County were poisoned with a BLL ≥5 µg/dL when compared to 3.6% in Wisconsin overall.[28] Therefore, we analyzed existing data on 20 933 third-grade students who attended Milwaukee Public Schools (MPS) during 2010 to 2015 and who had individual health-related data collected through the MHD in Milwaukee, Wisconsin.

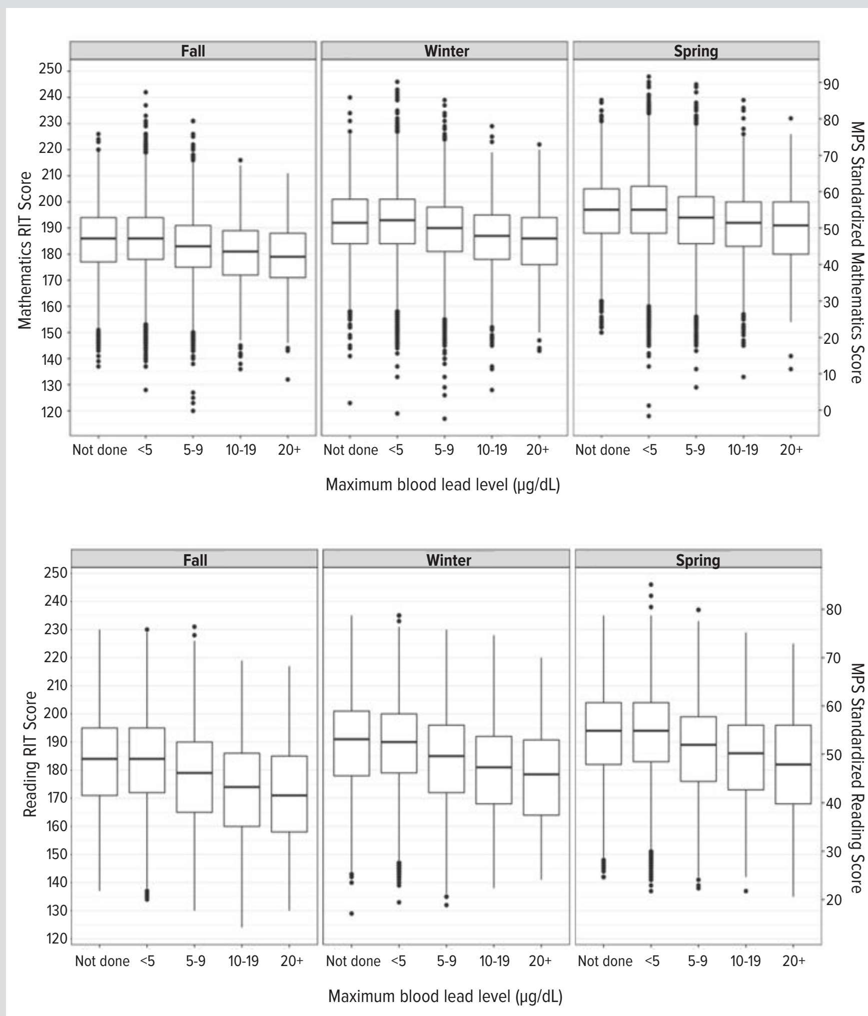
The MHD dataset contains blood lead testing data reported to the Wisconsin Childhood Lead Poisoning Prevention Program of a child's most recent confirmatory (venous) test, which follows an elevated screening (capillary) test. If no confirmatory test for the child is available, the most recent screening test result is reported. We included data that did not have blood lead

Table 1 continued. Summary of Child/Maternal Variables by Maximum Blood Lead Test Result

	BLL Not Tested N = 2720	Max BLL <5 µg/dL N = 10 618	Max BLL ≥5 µg/dL N = 7595	*P* value
Mother's age at birth, n (%)				< 0.001
12 – 18	277 (9.13)	1333 (43.92)	1425 (46.95)	
19 – 34	2176 (13.36)	8416 (51.69)	5690 (34.95)	
35+	267 (16.52)	869 (53.77)	480 (29.70)	
First trimester	2036 (13.06)	8240 (52.86)	5313 (34.08)	
No prenatal care	41 (12.93)	133 (41.96)	143 (45.11)	
Second trimester	523 (12.54)	1897 (45.48)	1751 (41.98)	
Third trimester	109 (14.16)	296 (38.44)	365 (47.4)	
Missing	11	52	23	
Number of prenatal visits				< 0.001
Mean (SD)	10.80 (4.04)	10.88 (3.85)	9.95 (4.07)	
Median [Q1, Q3]	12.00 (9.00, 13.00)	11.00 (9.00, 13.00)	10.00 (7.00, 12.00)	
Min, Max	0.00, 40.00	0.00, 50.00	0.00, 50.00	
Missing		65	29	

Abbreviations: BLL, blood lead level; max, maximum.

Figure. Box Plots of Math and Reading Test Scores by Lead Exposure for Each Season



Abbreviations: RIT, Rasch UnIT scale; MPS, Milwaukee Public Schools.

Table 2. Regression for Math and Reading Standardized Scores

	Standardized Scores			
	Math – Model I		Reading – Model II	
	Coefficient (95% CI)	*P* value	Coefficient (95% CI)	*P* value
Maximum blood lead level (µg/dL)		<0.001		<0.001
<5	Reference		Reference	
Not done	-0.70 (-1.01 to -0.38)		-0.62 (-0.94 to -0.31)	
5–9	-0.65 (-0.91 to -0.40)		-0.94 (-1.19 to -0.68)	
10–19	-0.84 (-1.21 to -0.48)		-1.64 (-2.01 to -1.27)	
20+	-1.29 (-1.93 to -0.64)		-2.26 (-2.91 to -1.62)	
School year	<0.001			<0.001
2010–2011	Reference		Reference	
2011–2012	-0.49 (-0.81 to -0.17)		-0.4 (-0.72 to -0.08)	
2012–2013	-0.36 (-0.68 to -0.04)		-0.11 (-0.43 to 0.21)	
2013–2014	-0.63 (-0.96 to -0.31)		-0.72 (-1.05 to -0.39)	
2014–2015	-0.78 (-1.13 to -0.44)		-0.92 (-1.26 to -0.57)	
Test administration period		<0.001		<0.001
Fall	Reference		Reference	
Winter	4.64 (4.57 to 4.72)		3.59 (3.51 to 3.67)	
Spring	7.88 (7.77 to 7.98)		5.81 (5.70 to 5.91)	
Gender		<0.001		<0.001
Male	Reference		Reference	
Female	-0.72 (-0.93 to -0.52)		1.04 (0.83 to 1.24)	
Race				
Black or African American	Reference	<0.001	Reference	<0.001
White	4.46 (4.06 to 4.85)		3.29 (2.89 to 3.69)	
Hispanic	2.71 (2.31 to 3.10)		1.83 (1.44 to 2.22)	
Other	3.66 (3.10 to 4.22)		2.75 (2.19 to 3.32)	
Gestational age in weeks		<0.001		<0.001
38+	Reference		Reference	
23 to 25	-2.65 (-4.61 to -0.68)		-0.63 (-2.58 to 1.33)	
26–32	-2.16 (-2.84 to -1.47)		-1.43 (-2.12 to -0.74)	
33–34	-0.66 (-1.35 to 0.04)		-0.31 (-1.01 to 0.39)	
35–37	-0.33 (-0.61 to -0.05)		-0.32 (-0.6 to -0.03)	
1-minute Apgar		0.941		0.468
7–10	Reference		Reference	
0–3	-0.12 (-0.85 to 0.61)		0.37 (-0.36 to 1.09)	
4–6	-0.03 (-0.48 to 0.42)		0.19 (-0.27 to 0.64)	
Mother's age at birth		<0.001		<0.001
19–34	Reference		Reference	
12–18	-0.66 (-0.95 to -0.37)		-0.66 (-0.96 to -0.37)	
35+	0.27 (-0.12 to 0.66)		0.69 (0.30 to 1.07)	
Mother's number of prenatal visits (continuous)	0.06 (0.03 to 0.08)	<0.001	0.06 (0.03 to 0.08)	<0.001
Mother cigarette use during pregnancy		<0.001		<0.001
No	Reference		Reference	
Yes	-0.52 (-0.81 to -0.22)		-0.91 (-1.21 to -0.62)	
Food service indicator		<0.001		<0.001
No	Reference		Reference	
Yes	-2.64 (-2.98 to -2.31)		-2.62 (-2.96 to -2.29)	
Special education indicator		<0.001		<0.001
No	Reference		Reference	
Yes	-6.34 (-6.61 to -6.07)		-8.91 (-9.19 to -8.64)	
English language learner		0.998		<0.001
No	Reference		Reference	
Yes	0.001 (-0.44 to 0.44)		-2.92 (-3.36 to -2.48)	
Attendance days (continuous) among available	0.03 (0.03 to 0.04)	<0.001	0.03 (0.02 to 0.03)	<0.001

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results in our analyses.[29] We first merged data from the MHD birth certificate files and lead exposure files, then merged these data with MPS standardized math and reading scores. Math and reading scores for each third-grade student were linked to their corresponding BLL and birth certificate data. Measures of Academic Progress (MAP) tests are purposely designed to be comparable from year to year in order to track children's academic performance over time.[29]

This research obtained ethical approval from the Medical College of Wisconsin Human Research Review Board. Both MPS and MHD data were obtained from DataShare, a secure, integrated data system that links and deidentifies data across multiple sectors to support research and analysis in public health, public safety, education, and related areas.[30] DataShare was established as a collaboration across multiple partner agencies to enhance the use of data to inform decisions to improve the health and safety of individuals and the community.

Study Measures

Student characteristics included in our analyses were as follows: gender (female or male), race (African American, White, Hispanic, Other), gestational age categorized into week groups (23–25, 26–32, 33–34, 35–37, 38–43), birth weight, small for gestational age designation (no, yes), 1-minute and 5-minute Apgar scores (score categories 0–3, 4–6, and 7–10), food service indicator measured as yes/no to receipt of free/reduced lunch, special education status (no, yes), and English language learner status (no, yes). Our continuous variables were the number of third-grade attendance days and the number of prenatal visits attended by the mother during pregnancy. Other parental characteristics included mother's age at birth (12–18, 19–34, or 35+ years). To account for the neighborhood effect, area deprivation indices were calculated for the census tracts at each student address whose computation is described in prior literature.[31]

Lead testing data were obtained from the MHD, including dates and results for all tests on record from birth to third grade. Students were grouped into lead exposure categories based on the highest observed BLL: <5, 5–9, 10–19, and ≥20 μg/dL; students without any blood lead testing information on record were grouped into a separate category.

Table 2 continued. Regression for Math and Reading Standardized Scores

	Standardized Scores			
	Math – Model I		Reading – Model II	
	Coefficient (95% CI)	*P* value	Coefficient (95% CI)	*P* value
Attendance data availability		< 0.001	< 0.001	
Available	Reference		Reference	
Unavailable	3.74 (2.76 to 4.73)		2.79 (1.81 to 3.78)	
ADI (continuous) among available	-0.02 (-0.02 to -0.01)	< 0.001	-0.02 (-0.03 to -0.02)	< 0.001
ADI availability	< 0.001	< 0.001		
Available	Ref		Ref	
Unavailable	-2.75 (-3.64 to -1.85)		-3.03 (-3.93 to -2.13)	

Abbreviations: ADI, area deprivation index.
Models I and II are adjusted linear regression models that controlled for potential confounders in Table 2.

Statistical Analysis

Student academic performance outcomes included reading and math Rasch UnIT scale (RIT) test scores taken during the fall, winter, and spring trimesters of third grade. All test scores were standardized to a mean of 50 and standard deviation (SD) of 10 prior to analysis. All study variables were described using the mean, SD, median, and range for continuous variables and frequency and percentage for categorical variables. The frequency of missing values was reported for each variable. Variables were summarized both overall and stratified by lead exposure groups. Child and parental characteristics were compared between lead exposure categories using ANOVA for continuous variables and chi-square tests for categorical variables. Standardized reading and math test scores were modeled using mixed effects linear regression including a school-specific random intercept and a repeated effect for school trimester (fall, winter, spring) within student using an autoregressive correlation structure of first order. Model covariates were selected a priori based on clinical expertise and data availability. The global models were presented without subsequent model selection procedures. The regression models were fitted for each reading outcome separately and included multiple predictors: lead exposure group, school year, trimester, and all child and maternal characteristics. All statistical analyses were performed using R software version 3.6.0 (R Core Team, R Foundation for Statistical Computing, Vienna, Austria). All *P* values were two-sided, and those < 0.05 were considered statistically significant. No adjustments were made for multiple testing.

RESULTS

Table 1 describes the characteristics of children and their mothers stratified by BLL. A slightly higher proportion of males (37.8%) show elevated BLL (≥ 5 μg/dL) compared to females (34.7%). Conversely, more females (51.5%) had BLLs below 5 μg/dL compared to males (49.6%). In terms of availability of BLL test results, a higher percentage of females (13.4%) had no BLL test results, compared to 12.6% of males. Mothers' mean number of prenatal care visits were higher when children's BLL was < 5 μg/dL (mean 10.8, SD ± 3.9) and BLL was not tested (mean 10.7, SD ± 4.1) versus children with BLL ≥5 μg/dL (mean 9.9, SD ± 4.1) at *P* < 0.001

From 2010 to 2015, the proportion of children with BLLs below 5 μg/dL increased from 41.5% to 58.0%, while the proportion of children with BLLs of 5 μg/dL or higher decreased from 44.7% to 29.9% over the same period. In addition, from 2010 to 2015, the percentage of children with no BLL test results declined slightly from 13.9% in 2010-2011 to 12.1% in 2014-2015.

As shown in the Figure, the children's math test scores changed by different lead exposure levels and over the 3 school-year seasons. On average, third-grade math scores increased over the course of the school year from the fall to winter and winter to spring trimesters. In all 3 seasons, the highest median math RIT scores were observed consistently in children with the lowest lead levels (<5 μg/dL) and children whose BLLs were not tested. This was followed by lower median math RIT scores at 5-9 μg/dL and 10-19 μg/dL BLLs, respectively. The lowest median math RIT scores were seen in children with the highest (≥ 20 μg/dL) lead levels in the fall, winter, and spring seasons. Similar trends were observed for reading scores in the Figure.

Results of the adjusted linear regression model for the independent association between math standardized score and maximum BLL while controlling for potential confounding factors are shown in Table 2. Among children with a maximum BLL ≥ 20 μg/dL, each unit increase in BLL is associated with a 1.29 decrease in standardized math scores. This association was statistically significant (*P* < 0.001) when compared to the decrease in standardized math scores among children with a maximum BLL < 5 μg/dL. Similarly, among children with a maximum BLL of 10-19 μg/dL, each unit increase in BLL is associated with a 0.84 decrease in standardized math scores, and among those with a BLL of 5-9 μg/dL, each unit increase is associated with a 0.65 decrease in standardized math scores—all with statistical significance (*P* < 0.001) when compared to the decrease in standardized math scores among children with a maximum BLL < 5 μg/dL after adjusting for potential confounders.

Table 2 also shows the adjusted linear regression model for the independent association between standardized reading scores and maximum BLL while controlling potential confounders. Among children with a maximum BLL ≥ 20 μg/dL, each unit increase in BLL is associated with a 2.26 decrease in standardized reading scores. This association was statistically significant ($P < 0.001$) when compared to the decrease in standardized reading scores among children with a maximum BLL < 5 µg/dL. Similarly, among children with a maximum BLL level of 10-19 µg/dL, each unit increase in BLL is associated with a 1.64 decrease in standardized reading scores, and among those with BLLs of 5-9 µg/dL, each unit increase is associated with a 0.94 decrease in standardized reading scores—all with statistical significance ($P < 0.001$) when compared to the decrease in standardized reading scores among children with a maximum BLL < 5 µg/dL after adjusting for potential confounders.

DISCUSSION

This study revealed 2 main findings. First, most children (58.3%) in third grade had a maximum BLL < 5 µg/dL, while 3.0% had a maximum BLL of 20 µg/dL or higher. Second, our results suggest that having a BLL ≥ 20 µg/dL was a significant independent risk factor for lower math and reading scores compared to children with a BLL < 5 µg/dL after controlling for potential confounding factors.

Although most children in Milwaukee had a recorded BLL < 5 µg/dL, there are still children who are exposed to very high BLLs (> 20 µg/dL). These finding align with a prior Wisconsin CDC report showing that 5% of children tested had lead poisoning at the CDC cutoff of ≥ 5 µg/dL.[27] DHS surveillance reports showed an increase in children tested for lead, with lead poisoning rates rising slightly from 4.4% to 5.0% between 2014 and 2016.[27] The ongoing childhood lead poisoning crisis disproportionately affects communities in Milwaukee due to socioeconomic and racial inequities.[32,33] For example, a previous study found that Milwaukee students had equal proportions of lead-exposed and nonexposed individuals, whereas in Racine, three quarters of students had no lead exposure.[26]

Lead poisoning remains an environmental justice issue that perpetuates disparities in health outcomes, even at low BLLs.[34] Communities most affected by lead exposure usually consist of minority populations, with children in low-income households and often residing in rental properties within economically disadvantaged ZIP codes.[35,36] For example, in our study, the majority of children (66.9%) with BLLs above 5 µg/dL were African American, food insecure, and their mothers were in their late third trimester (38-40 weeks) at birth. Multiple factors are implicated in lead poisoning in Milwaukee; however, age of housing is one of the most important factors linked to the risk of elevated BLL. Before 2006, nearly all incident cases of lead poisoning in Milwaukee were among children who lived in houses constructed prior to 1950. Older houses are associated with the use of lead-based paints, dust, and old water lateral supplies, which increases predisposition of children to lead and their harmful effects. Children living in socioeconomically disadvantaged neighborhoods are more likely to have greater exposure to lead, hence lead poisoning.[37] This finding highlights the importance and need to strengthen community-based lead prevention strategies targeting older homes with children at-risk for childhood lead exposure in Milwaukee.

The second key finding showed a significant association between BLL and both math and reading scores in third-grade students in Milwaukee. These findings are in line with prior literature that demonstrated an inverse relationship in between BLL and end-of-grade examination and standardized intelligence scores of school-going children.[26,38] A recent study showed that although BLL had a detrimental effect on both fourth-grade reading and math scores, racial residential segregation specifically augmented the negative effect of elevated BLLs on reading test scores among non-Hispanic Black children compared to non-Hispanic White children.[39] This implies that environmental lead exposure may result in high BLLs, which has detrimental cognitive effects on children. It is worth noting that the timing (early childhood) and dosage of lead exposure may be related to long-term mental health effects, such as cognition and intellectual impairment in adulthood.[40] This suggests a potential longer susceptibility period to environmental lead exposure.

Study Implications

No lead levels are safe; therefore, building a lead-safe environment for all children requires deliberate and decisive policy action that addresses the sources of lead exposure. In Milwaukee, paint and dust remain the primary sources of lead exposure, followed by lead in drinking water. Recently, the Wisconsin Department of Natural Resources estimated that replacing the current 229 000 private laterals containing or galvanized with lead would cost from $620 million to $966 million.[41] A new proposed rule by EPA, the Lead and Copper Rule Improvements (LCRI), would accelerate the rate at which existing lead pipes will be replaced to 2037.[42] Policy efforts to address this challenge included $30 million in funding through the federal bipartisan infrastructure law to replace lead service lines and eliminate lead pipe replacement costs to residential property owners.[43]

From a clinical perspective, DHS recommendations in 2000 of universal childhood lead testing[44] for all children in Milwaukee and Racine and universal testing for all children in Wisconsin in 2024 could address the missingness of BLL in our data, which may allow for better estimation of lead exposure and its impact on school-going children in the MPS system. More complete data containing BLLs for MPS, Medicaid, and non-Medicaid students may better inform state strategies to educate affected populations, which is key to lowering lead poisoning's burden. These findings guide community-based interventions like educating individuals and highlight the importance of ongoing lead surveillance and reducing primary sources of lead exposure.

Lead prevention interventions that need strengthening, such as the lead outreach program in primary care health centers, can be a potential source of referrals and education while the state-funded Lead Safe Homes program[45] may increase environmental investigations and abatement to partner organizations. It is worth noting that ongoing lead prevention programs in Wisconsin are implementing door-to-door home visits to conduct educational sessions on lead exposure reduction, such as distributing water filters, faucet replacement, home-based lead testing, and follow-up of lead poisoned children.

The CDC currently recommends routine BLL testing for all young children – particularly those at higher risk – to prevent and mitigate the effects of lead exposure.[46] Public health agencies, such as the WDHS, advocate for universal lead testing in high-risk areas like Milwaukee to identify elevated BLLs early.[44] Research increasingly shows that even low BLLs negatively affect cognitive development and academic performance, especially in reading and math.[26,39] To further address lead exposure risks, the EPA's recent LCRI proposal[47] mandates replacement of all lead service lines within 10 years, lowering the lead action level from 15 μg/dL to 10 μg/dL, enhancing tap water sampling protocols, and requiring public transparency on lead service line locations. These initiatives align with our research findings and underscore the urgent need for lead-safe environments to support children's academic success and overall well-being.[34]

For research, leveraging multi-institutional datasets to inform childhood lead prevention activities has been underscored. Our findings have highlighted the potential to prospectively examine long-term effects of childhood lead exposure to inform prevention efforts in Milwaukee and other communities. Our key study strength was the robustness of our analysis, using longitudinal data merged from MPS and MHD datasets and analyzing data on over 20 000 third-grade students. Additionally, our findings are generalizable to urban communities; however, it is likely for lead poisoning to be a public and environmental issue in rural settings too.

Standardized testing as a measure of academic performance has faced criticism for its inherent limitations and potential biases, especially in diverse and underresourced districts like MPS. Studies indicate that standardized tests may disadvantage English language learners, students with individualized education plans or Section 504 protections for persons with learning disabilities, and students from various socioeconomic backgrounds due to cultural bias and language barriers.[48] Additionally, standardized tests may not fully capture a student's academic progress or abilities, overlooking essential factors such as progression through grades, high school matriculation rates, or support needs, which are often more indicative of long-term success. These limitations are particularly pronounced in Milwaukee, where schools face funding shortages and high needs across certain ZIP codes, amplifying disparities in test preparation and performance.[49]

Our study findings should be interpreted in light of some limitations. First, it is possible that unavailable variables in our dataset could be correlated with both lead exposure levels and academic performance, such as prenatal cocaine or other drug exposures, neighborhood violence exposure, parental IQ, and secondhand smoke exposure during childhood. This study also identifies covariates as intervention targets that pediatricians or primary care providers should be more alert about as potential risk factors for high BLL. Such factors to target include late prenatal care, young maternal age, children in special education, and food insecurity. Parental health education is needed to improve prevention and early abatement efforts prior to lead testing.

Second, selection bias may have occurred. Our data may not be representative of third graders in the MPS system during 2010-2015 due to the following: (a) the data being a convenience sample, (b) the population being limited to individuals with health-related data with the MHD, (c) pediatric BLL testing among the Medicaid population may be low in Wisconsin[24] despite CDC mandatory universal lead testing requirements, (d) no recommendations during 2010-2015 for pediatric universal lead testing for the non-Medicaid children in Milwaukee, and (e) approximately 20% of our final study population did not have test results. Additionally, measurement error may have occurred, although standardized tests taken during 2010- 2015 are intended to be comparable. Finally, this study did not examine the impact of high- versus low-performing schools on standardized testing as a potential modifying or interacting factor.

The missing test results for 20% of our study population likely arise from health care access barriers, affecting data completeness and possibly underestimating lead exposure's effects. This gap adds some uncertainty to our findings, so conclusions require cautious interpretation. This untested group may face a uniquely high risk of elevated lead levels due to socioeconomic and environmental factors and are more likely to lack health care access, as shown by their higher deprivation and food insecurity levels (Table 1). Wisconsin's universal testing policies in Milwaukee and now statewide aim to close this gap, enhancing data accuracy and the assessment of the impact of lead exposure on Milwaukee children.

CONCLUSIONS

Although most children had BLLs below 5μg/dL, some had very high BLLs. Higher BLLs were associated with lower math and reading scores among children in Milwaukee. The implications of surveillance to detect blood lead in children are significant and timely for policy action to strengthen childhood lead prevention strategies in Milwaukee amd other urban and rural settings

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