The Relationship of Neighborhood Socioeconomic Differences and Racial Residential Segregation to Childhood Blood Lead Levels in Metropolitan Detroit

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ABSTRACT *This study uses a new approach to assess the impact of different neighborhood characteristics on blood lead levels (BLLs) of black versus white children in metropolitan Detroit. Data were obtained from the Michigan Department of Community Health and the US Bureau of the Census American Community Survey. The Modified Darden-Kamel Composite Socioeconomic Index, bivariate regression, and the index of dissimilarity were used to compute neighborhood BLL unevenness by neighborhood characteristics. Neighborhoods with lower socioeconomic characteristics and high racial residential segregation predicted higher average childhood BLLs. This reveals a social spatial structure that will aid researchers/policymakers in better understanding disparities in childhood BLLs.*

KEYWORDS *Lead poisoning, Detroit, Race, Socioeconomic position, Neighborhood segregation*

INTRODUCTION

Despite regulations eliminating paint, leaded gasoline, and other lead-based products in the USA, childhood lead poisoning remains one of the most important preventable childhood diseases. This was evidenced most recently by the Flint water crises in which thousands of children became lead poisoned due to lead-tainted water.¹ Primary exposure routes for children are through ingestion of lead incorporated into dust/soils, primarily from old lead-based paints. Secondary exposure routes are through inhalation of industrially emitted airborne lead/lead-laden dusts or ingestion of water that has traveled through lead-based and/or soldered pipes.² Children are more susceptible to exposure because they exhibit hand-to-mouth behavior and play on floors, breathing and eating more lead dust than adults or older children do. Their developing bodies are more susceptible because they absorb lead more readily, and their developing nervous system puts them at increased risk for permanent damage.² Once in their bodies, lead travels to the nervous system, then to soft tissues, and resides in the bone and teeth for long-term storage. Some of that lead is excreted over time through urine or feces.²

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Historical and recent research show that there is no safe exposure to lead in children without doing permanent and irreparable neurological, neurobehavioral, and physiological damage.^{2–13} This damage may include a wide range of problems in children with the most common effect being permanent behavioral and learning deficits such as reduced IQ, ADHD, memory loss, etc.²

Evidence of this irreparable damage led the Centers for Disease Control and Prevention (CDC) to lower the *reference level* (previously called the *level of concern*) for lead poisoning from ≥ 10 to ≥ 5 $\mu\text{g}/\text{dL}$ in 2012. This new reference level is termed the “elevated blood lead level” because negative and irreversible health effects have been well established below this level. The CDC recommends that the new elevated level be used in recommendations that involve follow-up evaluations and services covered by Medicaid and all other primary healthcare providers (clinics/hospitals, private providers, etc.). The CDC is expected to lower the current ≥ 5 $\mu\text{g}/\text{dL}$ level and has agreed to seek additional research directed toward developing intervention capable of maintaining children’s blood lead levels (BLLs) at lower levels.^{12–14}

PAST HEALTH GEOGRAPHIC RESEARCH

Over the last several decades, health geographic research has concluded that minorities, especially blacks, tend to live disproportionately in impoverished, poor-quality urban neighborhoods compared to whites. Very low and low socioeconomic status neighborhoods are significant pathways to declines in health. Thus, health disparities and declines in health are racial and spatial issues occurring most significantly in black neighborhoods of very low socioeconomic status.^{15–22}

Past geographic research has also revealed that childhood lead poisoning too has been shown to be influenced by neighborhood socioeconomic characteristics and race because the major sources of lead are historically and today located in impoverished urban neighborhoods. These neighborhoods typically contain older homes with lead-based paint and pipes and are in geographic proximity to industrial emissions and roads laden with historic leaded gasoline deposits. Lead-based paint in and on older homes is the major source of lead exposure for children in the USA.^{2,23} Consequently, childhood lead exposure has been found to be greatest among black children compared to other racial or ethnic groups.^{20,24–27} It is also associated with poverty.^{22,26–30} Neighborhoods with higher median household incomes and/or newer housing significantly protect children from elevated BLLs.^{24,25,27–31} Most recently, Moody et al.²² found that even in neighborhoods of the highest household incomes, black children were still significantly more at risk for lead poisoning than white children were in the Detroit Metropolitan Area (DMA).

Nationally, Michigan ranks fifth highest for childhood lead poisoning along with other rustbelt states (Pennsylvania, Illinois, Ohio, New Jersey) with older urban centers.³² The Michigan Department of Community Health (MDCH) reports that in 2014, of the 34.6 % of the children tested in the city of Detroit under the age of six (approximately 14,500 children), 10.6 % of those (1,540 children) had BLLs at the reference level of ≥ 5 $\mu\text{g}/\text{dL}$.³³ These levels eclipse the increased BLLs of children drinking newly tainted Flint water; 3.21 % ($n = 3,831$) of children under the age of 16 had a blood reference level of ≥ 5 $\mu\text{g}/\text{dL}$ after the water supply switch of April 2014.³⁴

Organ damage and severe cognition and behavioral or neuropsychological damage may occur in children whose blood lead concentration reaches 45 $\mu\text{g}/\text{dL}$ or more.² At much lower levels, grade level performance may become impaired.

Zhang et al.³⁵ evaluated the relationship between early childhood lead exposure and declines in academic achievement of Detroit Public School children from 2008 to 2010. Significantly, they found that children who had a BLL report of >10 $\mu\text{g/dL}$ before they turned six were greater than twice as likely to score “less than proficient” on academic achievement tests in reading, math, and science compared to those children who had a BLL report of <1 $\mu\text{g/dL}$.

Although many studies have focused on the combined association race and poverty have on childhood lead exposure, very few, if any, have related lead exposure to racial residential segregation or a composite index of neighborhood socioeconomic position.

OBJECTIVES

The first objective of this research was to determine if average BLLs in children in the Detroit Metropolitan Area (DMA) were related to composite socioeconomic neighborhood characteristics where they lived in 2010. The second objective was to determine the extent of racial disparities in BLLs by neighborhood characteristics and residential segregation. Further examination of residual BLLs was used to reveal a pattern of spatial-autocorrelation in the context of class and race. This study is the first to examine race, quality of place of residence, and BLL residential segregation in relation to childhood BLLs.

STUDY AREA—METROPOLITAN DETROIT

In terms of academic research, the Detroit Metropolitan Area historically and most recently includes three counties: Macomb, Oakland, and Wayne (see Fig. 1). This metropolitan area houses a disproportionate percentage of blacks residing in neighborhoods of very low socioeconomic characteristics located in the city of Detroit compared to a disproportionate percentage of whites living in neighborhoods of very high socioeconomic characteristics located in the suburbs of Detroit.^{36,37} The distinct pattern of both race- and class-differential place of residence in metropolitan Detroit provides an ideal testing ground for racial and socioeconomic disparities in health and in particular childhood lead poisoning.

DATA AND METHODS

Pediatric BLL Data

Individual pediatric BLLs, reported in $\mu\text{g/dL}$, were obtained with Institutional Review Board (IRB) approval from the MDCH Childhood Lead Poisoning Prevention Program’s statewide database. Michigan children enrolled in Medicaid are required to be blood lead tested at 12 and 24 months of age or between 36 and 72 months of age if not previously tested over the prior age span. As required by law, all blood lead test results (Medicaid and non-Medicaid) are sent to the MDCH.^{38–40}

There were 277,676 children, less than 1 month to 16 years of age, BLL tested in the DMA from 2006 through 2010. These BLL reports were made available for this research after they were submitted to the MDCH from the testing laboratories. A total of 8391 records were missing census tract identifiers (out of the 277,676 case reports) leaving 269,285 records for subsequent analyses. Another 53,184 records

FIG. 1 Detroit Metropolitan Area with census tract boundaries. Source: US Census Bureau (2010).

were eliminated from the dataset because they did not meet the criteria to be included in the census composite socioeconomic index (CSI). A total of 216,101 BLL records remained of all race/ethnicity for the study.

Laboratories across the USA use a variety of BLL testing/measuring devices. Most were capable of detecting BLLs of less than 1.0 $\mu\text{g/dL}$, but a small number of these laboratories produce higher detection limits. Consequently, the CDC requires testing sites to code all non-detect values and any value 1.4 $\mu\text{g/dL}$ or less, as 1 $\mu\text{g/dL}$. Otherwise, higher value test results are required to be rounded to the nearest whole number. Additionally, a small portion of the portable blood lead analyzers had a 3.3 $\mu\text{g/dL}$ detection limit. This means that they either detected no lead (recorded as 1 $\mu\text{g/dL}$ as dictated by the CDC), 3.3 $\mu\text{g/dL}$ of lead (recorded as 3.0 $\mu\text{g/dL}$), or greater values. As the BLL data is recorded, the CDC does not require information about detection limits or even portable unit designations before the test results are reported back to state community health departments; in this case, the MDCH. For the entire data collection period, the CDC reference level was $\geq 10 \mu\text{g/dL}$.

The MDCH receives all Medicaid and non-Medicaid BLL tests from the laboratories identifying each case child by name, gender, address, birth date, Medicaid or non-Medicaid recipient status, and parental self-reported race/ethnicity. By the time Detroit Metropolitan Area children are age 6, approximately 90 % have been tested at least once and entered into the database (per communication with Dr. Robert Scott, MDCH

BLL testing program database manager). These factors ensure large numbers of both Medicaid and non-Medicaid BLL reports. Regardless, the screening rate of the data provided to this study by the MDCH was calculated as the proportion of children blood lead tested divided by the census 2010 5-year estimate childhood population as a whole per census tract. The “In Households 0 to Less Than 3 Years Old” category⁴¹ (Table BO9001) was used to calculate this prevalence rate for the three counties from 2006 to 2010.

The MDCH assigns each case child a unique de-identified ID and all addresses (100 %) were geocoded by the MDCH to the corresponding census year 2010 census tract. There were children who were BLL tested using the capillary and venous methods. If an elevated BLL presented in the first capillary or venous test (≥ 10 $\mu\text{g/dL}$), the child was administered a second venous test and only this new venous BLL was entered.

Birth dates (100 % report rate) were converted to age in months as a continuous variable. The large majority of cases were less than 6 years-old. Blood lead test results reflect relatively current exposures because blood lead travels to the soft tissues/organs where it is stored only for a period of weeks.²

The MDCH racial and ethnic group designations included non-Hispanic black or African American, non-Hispanic white, Hispanic, Native Hawaiian or other Pacific Islander, Asian, Arab, American Indian or Native Alaskan, and mixed race. Tested children’s parents report race approximately 50 % of the time⁴⁰ and otherwise a “no report” designation is entered. If Hispanic and another race/ethnicity were both reported, the child was coded as Hispanic. Significantly, the MDCH linked the BLL reports of children on Medicaid to their Medicaid case records. This yielded an 80 to 90 % complete report on race in the dataset. In total, there were 34,984 cases (16.19%) entered as no report on race. These no reports were included in the first bivariate regression portion of this study but were removed for subsequent analysis that focused on black-white racial segregation only. The number of non-Hispanic black and non-Hispanic white children used in this analysis was 165,859.

Neighborhood Data

Census tracts were the geographic level of analysis used in this study because they are smaller than ZIP codes and serve as surrogates for neighborhoods, best capturing their socioeconomic and demographic characteristics^{28,37,42} while also capturing socioeconomic gradients in health.^{22,43} Furthermore, due to a prior breach in patient confidentiality of children’s BLLs at the address level, the State of Michigan’s IRB policy prohibits a finer level of geography provided by the MDCH in order to maintain confidentiality of each case.

The pediatric blood lead medical records provided by the MDCH do not include socioeconomic data of the tested children’s’ parents. Using census socioeconomic data at the tract level provided a quantitative proxy, representing these characteristics and their relationship to disparities in health. As such, census tracts were most useful to this research because of the wealth of socioeconomic data available and the large number of cases available per unit area, revealing the spatial distribution of these characteristics.

There were a total of 1046 DMA census tracts used in the analyses of this study. The US Bureau of the Census, American Community Survey provided data by census tract on a variety of socioeconomic variables such as percent below poverty, unemployment rate, etc. (see the nine socioeconomic position variables used below) within the DMA for the years 2006 through 2010.⁴¹ The 5-year BLL data (2006–

2010) corresponded with the 5-year census estimate data for the variables used in all analyses.

Statistical Analyses

The MDCH census tract boundaries were derived from the 2010 census and all (100 %) BLL reports with census tract identifiers were coded to those 2010 census boundaries ($n = 1,162$) yielding a zero margin of error. There were 213 census tracts within Macomb County, 337 in Oakland County, and 612 in Wayne County. Analyses were performed using SYSTAT 13.1.⁴⁴

Blood lead data The CDC's policy of recording non-detected BLL values as 1 $\mu\text{g}/\text{dL}$ (problematic for statistical analyses) has resulted in methodological guidance issued by the Department of Health and Human Services, Centers for Disease Control and Prevention to deal with these values.⁴⁵ Blood lead level concentrations less than the detection limit should be divided by the square root of two before calculation of geometric means. As such, BLLs recorded as 1.0 $\mu\text{g}/\text{dL}$ (meaning the original values of non-detect could have been 0.0 $\mu\text{g}/\text{dL}$ or up to 1.4 $\mu\text{g}/\text{dL}$ and as high as <3.3 $\mu\text{g}/\text{dL}$ for portable units) were first divided by the square root of two for eventual calculation of geometric means. All analyses required aggregation of BLLs at the census tract level and accordingly, all values were first log-transformed facilitating the computation of geometric means per census tract.⁴⁵

The Modified Darden-Kamel Composite Socioeconomic Index to Measure Socioeconomic Position Area-based indicators of socioeconomic position were applied as proxy for individual level measures of socioeconomic position by using the modified Darden-Kamel Composite Socioeconomic Index (CSI). Researchers³⁴ have successfully used this index which assigns a higher score to census tracts with high socioeconomic position (SEP). A high score reflects better socioeconomic quality of neighborhood characteristics and a low score reflects poor-quality neighborhood characteristics. The index incorporates nine variables as follows:

1. Percent below poverty—the percent of all occupied households whose income in the past 12 months is below the US poverty level. The poverty thresholds vary depending on size of family, number of related children, and, for one- and two-person families, age of householder by the Bureau of the Census.
2. Unemployment rate—the percent of civilians 16 years and older who were neither at work nor with a job but not at work during the reference week and who were actively seeking work during the last 4 weeks and available to start a job.
3. Median household income—the median income of all family members 16 years and older including those without income.
4. Percent of households with vehicle—percent of occupied housing units with a vehicle available were calculated.
5. Percent of residents with management, business, science, and arts occupations—percent of workers 16 years and older that hold 1 of 194 positions codified by the US Bureau of the Census for the 2006–2010 5-year estimates.

6. Percent of residents with bachelor degrees or higher—percent of the total population 25 years and older that holds at least a bachelor's degree (for example four or more years of schooling beyond a high school education).
7. Median value of dwelling in dollars—the median value of owner-occupied housing which is the respondent's estimate of how much the property would sell for if it were for sale.
8. Median gross rent of dwelling in dollars—the contract rent value plus the estimated average monthly cost of utilities.
9. Percent homeownership—percent of owner-occupied housing units regardless of mortgage status.

A Z-score was created for each of the nine census tract variables to standardize the contribution each contributes to the index. The Z-scores for two depreciating variables, percent unemployment and percent of the population below poverty, were multiplied by -1 before they were added to the remainder variables so that they contributed appropriately to the index.³⁴ The formula for the index follows:

$$CSI_i = \sum_{j=1}^k \frac{V_{ij} - V_{jDMA}}{S(V_{jDMA})}$$

CSI_i = the composite socioeconomic Z-score index for census tract i , is the sum of Z-scores for the socioeconomic status variables j , relative to the DMA's socioeconomic status.

DMA = three counties Wayne, Oakland, and Macomb.

k = the number of variables in the index

V_{ij} = the j th socioeconomic position variable (Z-score) for a given census tract i

V_{jDMA} = mean of the j th variable in the three-county DMA

$S(V_{jDMA})$ = standard deviation of the j th variable in the three-county DMA

The DMA was divided into five levels (i.e., ranges of SEP) with cutoffs at the 20th, 40th, 60th, and 80th percentiles (quintiles) of the CSI frequency distribution.³⁵ These levels permitted division of DMA census tracts of residence into five approximately equal proportions of the population in each group of socioeconomic status, i.e., very high socioeconomic position (VHSEP), high socioeconomic position (HSEP), middle socioeconomic position (MSEP), low socioeconomic position (LSEP), or very low socioeconomic position (VLSEP).

Using the CSIs (summed Z-scores of each of the 9 above variables) and/or their subsequent SEP quintiles required removal of 116 census tracts from the population above, providing 1046 (originally 1162) census tracts. These tracts were excluded from the index if the Census Bureau's 5-year estimates yielded fewer than 100 people, housed only juvenile institutions, or lacked census data. Subsequent black-white segregation analysis required removal of all children of a race/ethnicity other than non-Hispanic white or non-Hispanic black consistent with the Darden et al.³⁷ application of this composite index in the three-county metro area of Detroit. Thus, census tracts reporting more than 10 % of the population as Arab or Hispanic ethnicity were removed because this portion of the study mainly compared non-Hispanic black and non-Hispanic white populations. This still ensured a large sample size of black and white populations providing an individual sample size of 216,101 children, their census tracts, and BLLs.

Bivariate Regression Analyses Bivariate regression analysis was used to test the association between neighborhood socioeconomic position (CSI values) and geometric mean pediatric BLLs of all race/ethnicity children of the DMA for the years 2006 through 2010. Using ArcGIS 10.1,⁴⁶ resulting residual BLL patterns were located by census tract and further investigated.

The Index of Dissimilarity The index of dissimilarity was used to compute the level of racial unevenness by neighborhood SEP between BLL tests of non-Hispanic black and non-Hispanic white children. The five quintiles of SEP clustered census tracts and their children and are depicted in the following equation:

$$D = \left(1/2 \sum_{i=1}^k [x_i - y_i] \right)$$

k = 1 of 5 quintiles of SEP as clustered census tracts within the DMA

x_i = percent of DMA's total reported non-Hispanic black children in the i th SEP

y_i = percent of the DMA's total reported non-Hispanic white children in the same SEP

D = half of the sum of the absolute differences between the proportional distribution of the black and white children within the DMA.

The resultant values represent the minimum percentage of children from either non-Hispanic black or non-Hispanic white race/ethnicity that would have to move from one SEP cluster to another to achieve an even spatial distribution across the DMA.⁴⁷

RESULTS

Screening Rate

The BLL screening rate of only those children 0 to just under 3 years of age in Oakland County was 0–7.67 children, Macomb 0–2.17 children, and Wayne 0.02–10.88 children.

Sex There were 110,788 (51.54%) male and 104,181 (48.46%) female case BLL reports (no reports = 1132).

Age At the time of BLL testing, the children's birth dates were recorded and also rounded to age in months by the testing sites. Additional data management transferred these ages into years and age categories. The number of children aged less than 1 month to 2 years (24 months) equaled 101,617 (47.02 %). Those aged over two (25 months) and up to 6 years (72 months) encompassed 88,260 (40.84 %) children, and those greater than 6 (73 months) and up to 16 years (192 months) consisted of 26,224 (12.14 %) children. The MDCH's emphasis is to test children once and before they reach the age of two.

Race/Ethnicity The following lists the coded self-reported race/ethnicity for the children tested and provides the racial/ethnic composition of the test population: non-Hispanic black or African American 97,344 (53.75%) children; non-Hispanic white 68,515 (37.83%) children; Hispanic 5408 (2.99%) children; Native Hawaiian or other Pacific Islander 99 (0.05%) children; Asian 4701 (2.60%) children; Arab

3887 (2.15%) children; American Indian or Native Alaskan 569 (0.31%) children; and mixed race 594 (0.33%) children.

BLL Collection Method There were 45,202 (21.07 %) and 169,365 (78.93 %) children who were BLL tested using the capillary and venous methods respectively (no data available = 1534).

Insurance Coverage Children who were tested and on Medicaid equaled 153,890 (71.21 %) and those on non-Medicaid 62,211 (28.79 %). All cases (100 %) were coded as either having Medicaid or some other non-Medicaid insurance type. The larger number of Medicaid children introduced into the analyses created potential bias, but this was ameliorated to some extent by the large number of children in the database and the diversity of racial/ethnic designations.

BLL Test Dates During the 5-year period from 2006 to 2010, the greatest frequency of tests occurred during the month of August ($n = 26,699$; 12.35 %) and least during the month of December ($n = 12,578$; 5.82 %). Tests were administered throughout all four seasons (Table 1).

Black-White Analysis Frequencies Frequencies generated of the non-Hispanic black and non-Hispanic white children used in the subsequent analysis and tested across the five quintiles of SEP are depicted in Table 2 below. Childhood BLL data per census tract was grouped into one of these five quintiles for analysis. Of the total 1046 census tracts, 209 to 210 were grouped into each of one of the five SEP quintiles for analysis.

Bivariate Regression

Bivariate regression analysis was used to test if geometric mean BLLs were greater in neighborhoods of lower socioeconomic position (CSI values) of all race/ethnicity children. The standardized slope coefficient estimate for the regression was -0.05^{****} (S.E. = 0.002) as displayed on Fig. 2, validating the hypothesis; CSI explains a statistically significant amount of variation in BLLs of all race/ethnicity children in neighborhoods across the DMA.¹

The y-intercept estimate from the analysis was 2.06, and the R-square value was 0.47. Residual frequency values indicated a skewed pattern of errors, and upon mapping the positive and negative extreme residuals, their spatial patterns appear to be associated with average housing age by census tract. The MDCH privacy policies prevent researchers from obtaining age of housing associated with children's BLL reports. This phenomenon is explored in more detail below. Multiple regression and hierarchical linear modeling analyses of a variety of variants at both the individual level and census tract level resulted in colinearities and unacceptable residual patterns as described in more detail in Moody et al.²² No doubt, the CDC's policy of recording non-detectable values as a 1.0 $\mu\text{g/dL}$ and the influence of a variety of variables at a larger census tract scale of geography are contributors.

¹* $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$; **** $P \leq 0.0001$

TABLE 1 Demographic characteristics of all race of BLL-tested children and the characteristics of their BLL reports across CSIs

Variables	Number	% of reported
Sex		
Male (0)	110,788	51.54
Female (1)	104,181	48.46
No report	1132	
Total	216,101	
Age in months ^a		
0–24 (0–2 years)	101,617	47.02
25–72 (2.1–6 years)	88,260	40.84
>72 (>6 years)	26,224	12.14
Total	216,101	
Race/ethnicity		
Non-Hispanic black	97,344	53.75
Non-Hispanic white	68,515	37.83
Hispanic	5408	2.99
Native Hawaiian or other Pacific Islander	99	0.05
Asian	4701	2.60
Arab	3887	2.15
American Indian or Native Alaskan	569	0.31
Mixed race	594	0.33
No report	34,984	
Total	216,101	
Blood collection method		
Capillary (0)	45,202	21.07
Intravenous (1)	169,365	78.93
No report	1534	
Total	216,101	
1.0 µg/dL reports	91,104	42.16
Reports >1.0 to <5.0 µg/dL	103,513	47.90
Reports ≥5.0 µg/dL	21,484	9.94
Total	216,101	
Insurance coverage		
Non-Medicaid	62,211	28.79
Medicaid	153,890	71.21
Total	216,101	

^aRange = 191 months

Source: MDCH (2006–2010)

Index of Dissimilarity

The mean socioeconomic characteristics within SEP quintiles are presented in Table 3. Frequencies were generated of the nine CSI characteristics per census tract. Neighborhoods of very low SEP had the highest unemployment rates and those living below poverty. Median household income was only \$23,999; average dwelling value was \$79,621; and median gross rent was \$730. Homeownership, vehicle ownership, professional/managerial occupations, and education levels were the lowest values. Conversely, neighborhoods of very high SEP had the lowest unemployment rates and those living below poverty. Median household income was \$98,228, average dwelling value was \$290,870, and median gross rent was \$1,294.

TABLE 2 Demographic characteristics of non-Hispanic black and non-Hispanic white DMA children tested and the characteristics of their BLL^a reports across SEP quintiles

Variables\quintile	1	2	3	4	5
Sex					
Male	30,656 (50.76)	21,676 (51.32)	14,287 (51.67)	10,870 (52.20)	7277 (52.18)
Female	29,740 (49.24)	20,561 (48.68)	13,366 (48.33)	9953 (47.80)	6668 (47.82)
Total	60,396	42,237	27,653	20,823	13,945
Age					
0–2	24,411 (40.14)	19,401 (45.69)	14,251 (51.49)	11,217 (53.73)	7598 (54.34)
2.1–6	27,531 (45.27)	18,019 (42.44)	10,723 (38.68)	7690 (36.83)	4928 (35.25)
>6	8872 (14.59)	5041 (11.87)	2751 (9.92)	1970 (9.44)	1456 (10.41)
Total	60,814	42,461	27,725	20,877	13,982
Race/ethnicity					
Non-Hispanic black	56,863 (93.50)	26,397 (62.17)	7670 (27.66)	4167 (19.96)	2247 (16.07)
Non-Hispanic white	3951 (6.50)	16,064 (37.83)	20,056 (72.34)	16,710 (80.04)	11,735 (83.93)
Total	60,814	42,461	27,725	20,877	13,982
Blood collection method					
Capillary	7758 (12.79)	8241 (19.54)	7175 (26.12)	5779 (28.02)	4053 (29.27)
Intravenous	52,913 (87.21)	33,935 (80.46)	20,290 (73.88)	14,844 (71.98)	9793 (70.73)
Total	60,671	42,176	27,465	20,623	13,846
1.0 µg/dL reports	13,620 (20.13)	17,781 (26.28)	15,372 (22.72)	12,371 (18.28)	8514 (12.59)
Reports >1.0 to <5.0 µg/dL	33,900 (42.30)	21,669 (27.04)	11,433 (14.27)	7975 (9.95)	5158 (6.44)
Reports ≥5.0 µg/dL	13,294 (73.59)	3011 (16.67)	920 (5.09)	531 (2.94)	310 (1.71)
Insurance coverage					
Non-Medicaid	2222 (3.65)	4416 (10.40)	6101 (22.01)	6696 (32.07)	6604 (47.23)
Medicaid	58,592 (96.35)	38,045 (89.60)	21,624 (78.00)	14,181 (67.93)	7378 (52.77)
Total	60,814	42,461	27,725	20,877	13,982

Source: MDCH (2006–2010); *n* = 165,859^aGeometric mean BLL

Homeownership, vehicle ownership, professional/managerial occupations, and education levels were the highest values.

The Significance of Neighborhood Characteristics

To provide perspective on the disparity between black and white children's BLLs, Table 4 displays their respective geometric mean BLLs, standard deviations, and

FIG. 2 CSI and geometric mean blood lead levels (BLLs) All race, 2006 to 2010. Source: US Census Bureau (2010) and Michigan Department of Community Health, 2006 to 2010.

percent populations at each level of SEP (neighborhood characteristics). In all levels of socioeconomic position, black children had higher average BLLs than white children. Black children were overrepresented in the very low and low SEP neighborhoods and white children overrepresented in the middle, high, and very high SEP neighborhoods. Importantly, children of black race had higher predicted geometric mean BLLs across all neighborhood SEP levels. Considering the DMA as a whole, $D = 56.32$ demonstrating that 56.32 % of either black or white children with reported BLLs would have to move from one SEP cluster to another to achieve an even spatial distribution across census tracts in the DMA. The higher BLLs presented in children was related to the neighborhoods in which they lived. If black children lived in higher SEP neighborhoods, their collective BLLs were lower. Black children residing in very high SEP neighborhoods had lower geometric mean BLLs than did white children residing in very low SEP neighborhoods. Regardless of the socioeconomic position quintile employed, black and white children were extremely segregated, i.e., unevenly distributed across neighborhood SEP levels in the DMA.

Examination of Residuals of the Bivariate Regression

Although the highest mean BLLs exist in the central city, two of the highest-ranking positive BLL residuals presented in the bivariate regression are located outside or on the inner edge of the city of Detroit. Both residuals can be explained by geographic location in very low SEP neighborhoods of Pontiac City (mean BLL of 2.26 $\mu\text{g/dL}$) and the city of Detroit (mean BLL of 2.27 $\mu\text{g/dL}$). Lead-based paint was banned for sale in 1978. Table 5 depicts the percent-occupied housing built before 1939 or earlier (the oldest designation available at the Census Bureau, 2010), built in 1979 or before (chosen to encompass the ban of lead-based paint in 1978) and built in 2005 or later (the most recent categorical designation available at the Census Bureau,⁴¹). Both census tracts had 0 % housing built during the year 2005 or later, 18.4 % built in 1939 or before, and 98.7 % built before 1979. Although captured in part by measures embedded within the Modified Darden-Kamel Composite Socioeconomic Index (i.e., housing value and rent), most of the housing age stock in these two census tracts was built before lead paint was banned.

TABLE 3 The mean social structure of DMA's census tracts from 2006 to 2010 based on the modified Darden-Kamel Composite Socioeconomic Index

Neighborhood SEP quintile	% below poverty	% unemployment rate	Median Household income (\$)	% households with a vehicle	% residents with Mgmt., business, science, arts, occupations	% residents with Bachelor degrees or higher	Median dwelling value (\$)	Median gross rent (\$)	% homeownership
Very low SEP (quintile 1)	37.06	29.01	23,999	72.58	17.59	8.75	79,621	730	46.23
Low SEP (quintile 2)	14.63	16.42	40,013	89.46	25.51	15.10	108,309	782	64.36
Middle SEP (quintile 3)	7.00	11.45	52,244	94.40	31.56	22.15	146,355	838	76.63
High SEP (quintile 4)	4.18	8.97	65,582	95.93	41.52	32.86	182,102	748	81.69
Very high SEP (quintile 5)	2.33	7.05	98,228	97.86	54.80	53.77	290,870	1,294	89.26
All tracts	13.03	14.57	56,054	90.05	34.22	26.55	160,927	914	71.65

Count = 1046 census tracts (209 to 210 each for each level of SEP). Source: computed by the authors from data obtained from the US Bureau of the Census, 2010

TABLE 4 Descriptive characteristics of children by geometric mean BLLs and total population and the modified Darden-Kamel Composite Socioeconomic Index of SEP in Metropolitan Detroit, 2006–2010

SEP quintiles	Non-Hispanic white and non-Hispanic black children's geometric mean BLLs (µg/dL) and standard deviation per SEP quintile				Percent of tested population	Difference in percent of total black and white children $x_i - y_i$
Very low SEP (quintile 1)	White	n (%) 3,951 (6.50)	Mean 2.74	S.D. 1.32	5.77 (y_i)	52.65 [52.65]
	Black	56,863 (93.50)	2.95	0.69	58.41 (x_i)	
Low SEP (quintile 2)	White	n (%) 16,064 (37.83)	Mean 1.95	S.D. 0.35	23.45 (y_i)	3.67 [3.67]
	Black	26,397 (62.17)	2.10	0.31	27.11 (x_i)	
Middle SEP (quintile 3)	White	n (%) 20,055 (72.34)	Mean 1.80	S.D. 0.25	29.27 (y_i)	−21.39 [21.39]
	Black	7,670 (27.66)	2.00	0.69	7.88 (x_i)	
High SEP (quintile 4)	White	n (%) 16,710 (80.04)	Mean 1.78	S.D. 0.26	24.39 (y_i)	−20.11[20.11]
	Black	4,167 (19.96)	1.92	0.41	4.28 (x_i)	
Very high SEP (quintile 5)	White	n (%) 11,735 (83.93)	Mean 1.73	S.D. 0.15	17.13 (y_i)	−14.82 [14.82]
	Black	2,247 (16.07)	1.94	0.49	2.31 (x_i)	
All SEP	White	n (%) 68,515 (41.31)	Mean 1.94	S.D. 0.58	41.31 (y_i)	Index of dissimilarity
	Black	97,344 (58.69)	2.11	0.53	58.69 (x_i)	56.32

$n = 165,859$; children count = 1046 census tracts (209 to 210 each for each SEP). Source: computed by the authors from data obtained from the U.S. Bureau of the Census, 2010 and MDCH, 2006–2010

Conversely, there are two census tracts with lower than average mean BLLs that also rank as the first and second most negative residuals from the bivariate regression results above. These residuals may be attributed to the younger than average housing age atypical of these very low SEP neighborhoods (Table 5) located in the city of Detroit (mean BLLs of 2.11 µg/dL) and the city of Taylor (mean BLL of 1.91 µg/dL). The city of Detroit census tract had over 1 % of its housing built during the year 2005 or later, only 3.9 % built in 1939 or before, 18.6 % built before 1979, and most of it built from 1990 to 1999. The city of Taylor census tract had over 5 % of its housing built during the year 2005 or later, only 1.4 % built in 1939 or before, and 42.6 % before 1979.

TABLE 5 Average percent occupied housing stock of DMA's census tracts by the modified Darden-Kamel Composite Socioeconomic Index

Neighbor- hood SEP quintile	% year structures built 1939 or earlier	% year structures built before 1979	% year structures built 2005 or later
Very low SEP (quintile 1)	36.34	85.54	1.02
Low SEP (quintile 2)	12.57	71.73	1.02
Middle SEP (quintile 3)	7.87	61.24	1.62
High SEP (quintile 4)	7.35	53.30	2.25
Very high SEP (quintile 5)	7.69	39.61	3.02

Count = 1046 census tracts (209 to 210 each for each level of SEP). Source: computed by the authors from data obtained from the US Bureau of the Census, 2010

There are other census tracts of high mean BLLs in the high and very high SEP neighborhoods that cannot be explained by lower SEP but partially explained by housing stock age. Exterior environmental sources are likely contributing to these residual values as well. Again, these higher than average mean BLL outliers were top ranked among the positive residuals resulting from bivariate regression. A census tract located in Grosse Pointe Park (mean BLLs of 2.27 $\mu\text{g/dL}$) had 0 % housing built during the year 2005 or later, 71.8 % built in 1939 or before, and 91.2 % built before 1979. This community had older housing stock than the communities in the very low SEP neighborhoods of Pontiac and Detroit above, possibly historic homes that had not undergone lead paint removal. Another high mean BLL tract located in the city of Detroit (mean BLLs of 3.55 $\mu\text{g/dL}$) had 0 % housing built during the year 2005 or later, 77.1 % built in 1939 or before, and 100 % built before 1979.

Two other examples can be found in very high SEP neighborhoods. First, another community in Grosse Pointe Park (mean BLLs of 2.32 $\mu\text{g/dL}$) had housing stock ages comparable with the high SEP Grosse Pointe Park tract (0 % built 2005 or later, 49.3 % built in 1939 or earlier, and 93.8 % built before 1979). Second, a very high SEP neighborhood in the city of Detroit named Palmer Woods Historic District (mean BLLs of 2.20 $\mu\text{g/dL}$) had 0 % of the housing stock built in 2005 or later, 53.8 % built in 1939 or earlier, and 98.4 % built before 1979. These few neighborhood BLL anomalies may be better explained by the older housing stock rather than SEP of the neighborhoods.²

²Additional bivariate regression analyses were performed to test if geometric mean BLLs were greater in neighborhoods of older occupied housing stock and less in neighborhoods of younger occupied housing stock for all race/ethnicity children in attempt to explain the residuals discussed above. The regression slope coefficient estimates for the percent year structure built in 1939 or before was 0.020**** (S.E. = 0.001), percent year structure built in 1979 or before 0.008**** (S.E. = 0.000), and percent year structure built in 2005 or later -0.027**** (S.E. = 0.005), validating that as housing stock increases in age, small but significant amounts of variation in BLLs increase across neighborhoods in the DMA. The y-intercept estimates from the analyses were 1.75, 1.57, and 2.12 with R-square values of 0.58, 0.21, and 0.03, respectively. These weak but interpretable patterns help in part to explain the imperfect associations of BLLs and SEP. Source: housing age stock was computed by the authors using the US Bureau of the Census, 2010 data.⁴¹

The most significant exposure to childhood lead is from lead-based paint, and older homes are typically located in inner cities²⁶ that are also more racially segregated, poor, and minority. Housing age is captured in part by measures of median value of dwelling, median gross rent, and percent homeownership embedded within the modified Darden-Kamel Composite Socioeconomic Index, but more thorough examination of this variable was investigated as a possible contributing factor to unexplained variation and residual BLL results. Generally, housing age is related to SEP of neighborhoods with the oldest housing stock concentrated in the poorest (very low SEP) neighborhoods of the central city. Historically and today, a dichotomous model of development exists within the DMA between the central city and the suburbs. Increasing population, tax base, economic development, jobs, and housing investment dollars and loans have been made available to the inner and outer suburban ring. At the same time, disinvestment in the central city since the 50s has resulted in a decline in population, tax base, economic development, and jobs.⁴⁸

DISCUSSION

Well-defined racial and socioeconomic inequality in metropolitan Detroit exists. The level of neighborhood SEP in which children lived was a factor in predicting mean BLLs. Using bivariate regression, we determined that there was a significant increase in mean BLLs as neighborhood socioeconomic status declined for all races. Race too was a factor as evidenced by the greater mean BLLs of black children as opposed to white children residing in the same SEP neighborhoods. An uneven distribution (segregation) of black and white children across the DMA and their mean BLLs was confirmed using the index of dissimilarity. Being a black child predicted higher mean BLLs across all neighborhood SEPs. However, neighborhood characteristics where black children reside also matters. The research revealed that black children residing in neighborhoods of very high socioeconomic characteristics had mean BLLs (1.94) lower than white children residing in neighborhoods of very low socioeconomic characteristics (2.74). High black-white segregation and very low SEP neighborhoods predicted the greatest geometric mean BLLs for both races.

This research built upon neighborhood effects health literature by capturing a variety of neighborhood effect variables within a composite socioeconomic index to study a unique health outcome and mean pediatric BLLs of neighborhoods in the DMA. Building upon the social science lead literature, the Darden-Kamel Composite Socioeconomic Index incorporated established predictors of higher BLLs (poverty, income, home value, etc.), providing results that were more predictive than any one variable alone.

Limitations of this Study

The lead surveillance testing protocol is limited in that it is biased toward minorities who are Medicaid enrolled and tend to live in lower SES neighborhoods. Also, lead screening rates vary from county to county. Oakland County, being the wealthiest county, possesses the highest rate. Conversely, Wayne County has the lowest rate likely corresponding to a lack of access to healthcare. These weaknesses contribute potential bias to the results but were addressed to some extent by gathering 5 years of BLL surveillance data and thus capturing more non-Medicaid children as well. Also, the large sampling sets increased precision and margins of errors.

AREAS FOR FURTHER STUDY

Future studies can determine whether a finer geographic level of analyses, ideally at the address level, can uncover explanation of the highest and lowest BLL outliers atypical of the SEP neighborhoods in which children reside. At the time of this writing, the MDCH is seeking approval from its IRB board to allow researchers information on housing age characteristics at the individual level. Additionally, investigation of renovation status, external environmental contributors, etc. may capture some of the imperfect associations between pediatric BLLs and neighborhood socioeconomic position.

IMPLICATIONS FOR PUBLIC POLICY

We assert that the effects of black residential segregation in very low SEP neighborhoods has contributed significantly to the high level of childhood lead poisoning of black children in metropolitan Detroit. Even though lead poisoning is a preventable environmental threat that has long-term effects, national policy has failed to ameliorate the problem. Future research should be translated into national health policies, mandating the abatement of lead-contaminated paints/pipes in housing, before children become poisoned, especially in disparate low-income and segregated communities.

Such a national public health threat and educational crisis would normally be treated as an epidemic. However, because the epidemic is non-contagious and the children most affected are black and live in segregated and poor socioeconomic neighborhoods, little has been done on a national scale. As lead exposure is related to race through place of residence and neighborhood characteristics, it has become a critical spatial justice and environmental inequality issue.

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