Downstream Consequences of Childhood Lead Poisoning:

A Longitudinal Study of Cleveland Children from Birth to Early Adulthood

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Summary: *Lead poisoning typically occurs in early childhood, but it can have long-term effects on exposed individuals. It is important to document some of the downstream consequences of lead poisoning in order to appreciate the costs of inaction and to target prevention resources where most needed. In this brief, we report on a longitudinal study of two cohorts of Cleveland youth that had elevated blood lead levels (≥ 5 µg/dl) before age 3 and matched comparison groups whose lead tests were not as elevated. We track markers of their educational success throughout elementary and high school, and also look at adverse events, such as juvenile delinquency, adult incarceration, homelessness, and having to rely on public assistance. We find that children with elevated lead levels in early childhood have significantly worse outcomes on markers of school success, and higher rates of adverse events in adolescence and early adulthood, compared to their non-exposed peers. The size of these disparities is generally in the 20-30% range across both cohorts, and represents a sizable societal cost due to the loss of human capital, the burden on local systems, and persistence of inequality.*

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Note: Lead data used in this report come from the Ohio Department of Health. This should not be considered an endorsement of this study or these conclusions by the Ohio Department of Health.

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INTRODUCTION

Acting on lead poisoning prevention promises to have benefits that well exceed the costs. Much of this return-on-investment is anticipated to come from avoidance of negative consequences of lead poisoning over the course of child and adolescent development. Numerous studies show that there are long term costs of lead poisoning to society in the form of lower lifetime earnings, neuropsychiatric disorders, special educational needs, lower tax contributions, and criminal involvement.[1,2] However, there is little research that traces the impact of childhood lead exposure on public systems in regions where lead poisoning rates have been persistently high and many children have been affected. In this report, we examine some of the downstream consequences of lead poisoning in Cleveland from the perspective of the systems that serve children and youth. The focus is on estimating the net increase in the risk of selected, and potentially costly, events in these systems that can be attributed to lead poisoning.

BACKGROUND

Lead poisoning in young children has been recognized as a public health problem for many years. A number of studies have shown that lead exposure in early stages of life has adverse effects on child development, such as cognitive impairment manifested by scores on intelligence tests,[3–5] poor academic achievement,[6,7] and behavioral problems.[8,9] A meta-analysis of 24 quantitative studies published in 1990 documented that early childhood lead exposure impairs children's IQ even at levels that had previously been considered safe.[10] A recent study in Cleveland also demonstrated that young children with blood lead levels at or exceeding the threshold of 5 µg/dl displayed lower scores on kindergarten readiness compared to their unexposed peers.[11,12] Further-more, studies suggest that early childhood lead exposure may have persistent effects over a longer period, as seen in diminished cognitive abilities, delinquency, or criminal behaviors in later adolescence and even adult-hood.[13,14]

However, few studies have been able to fully evaluate the long-term consequences of early childhood lead poisoning, due to the lack of available datasets to track its impacts on later outcomes, and the difficulties of estimating the causal impact of lead in the presence of other factors that increase both the chances of lead exposure and of poor outcomes.[15] Only a few studies that attempt to examine downstream consequences of early childhood lead poisoning have used research designs that enable causal inference. One such study in Rhode Island used linked administrative data to estimate the effects of lead on school suspensions and juvenile delinquency for children born between 1990 and 2004.[16] To isolate the causal effects of lead, this research used sibling fixed effects models and instrumental variable (IV) models that exploit lead variation due to traffic exposure. The Rhode Island study found that increased lead exposure resulted in increased school suspensions and juvenile detention for adolescent boys, but not for girls. Another study in Chicago, also sought to evaluate the causal effects of early childhood lead exposure on youth development. To reduce confounding bias, these researchers used coarsened exact matching (CEM) of children with and without elevated blood lead levels, and instrumental variables models that leveraged lead variation from distance to a smelting plant for children born in in the 1990's. They found a causal effect of early childhood lead exposure and later records of adolescent delinquency, but not official arrests.[17]

Building on these examples, the current study examines the impact of early childhood lead poisoning throughout childhood and the transition to adulthood, using administrative records for two cohorts of children attending school in Cleveland, Ohio. It estimates the effect of lead poisoning by comparing outcomes among children that had lead levels at or above the public health threshold of 5 µg/dl and a matched comparison group of children whose lead values did not exceed the threshold. The differences in the two groups illustrate the impact that lead poisoning has had on local institutions and in prolonging racial inequities. The findings are suggestive of the societal benefits and reduction in local burden that can be anticipated as lead safety in housing is achieved.

STUDY METHODS

We conduct a longitudinal study of two cohorts of Cleveland youth that had elevated blood lead levels (≥ 5 µg/dl) before age 3 and matched comparison groups whose lead tests did not exceed this public health threshold. We track markers of their educational success throughout elementary and high school, and also look at adverse events such as juvenile delinquency, adult incarceration, unemployment, homelessness and having to rely on public assistance in early adulthood. The study sample (N=10,470) includes students that attended 9th grade in the Cleveland metropolitan School District (CMSD) in 2007-2008 (Early cohort) or 2016-2017 (Recent cohort). For each student, we build a longitudinal record from birth through early adulthood, drawing on administrative records from multiple systems. We use coarsened exact matching to compare the outcomes of children with and without elevated lead levels who are similar on numerous background and early childhood characteristics. This process allows us to statistically estimate the impact of lead on subsequent outcomes adjusting for potential confounders. The advantage of having two cohorts is that we can the estimate effects of lead exposure for a contemporaneous group of children and young adults, and evaluate how these effects have persisted over time.

DATA AND MEASURES

Figure 1 illustrates the general approach to building the longitudinal data for the study cohorts. Records from all of these systems are linked together for each child in the study, using tools within the Child-Household Integrated Longitudinal Data system maintained by the Center (See Appendix A for a detailed description of

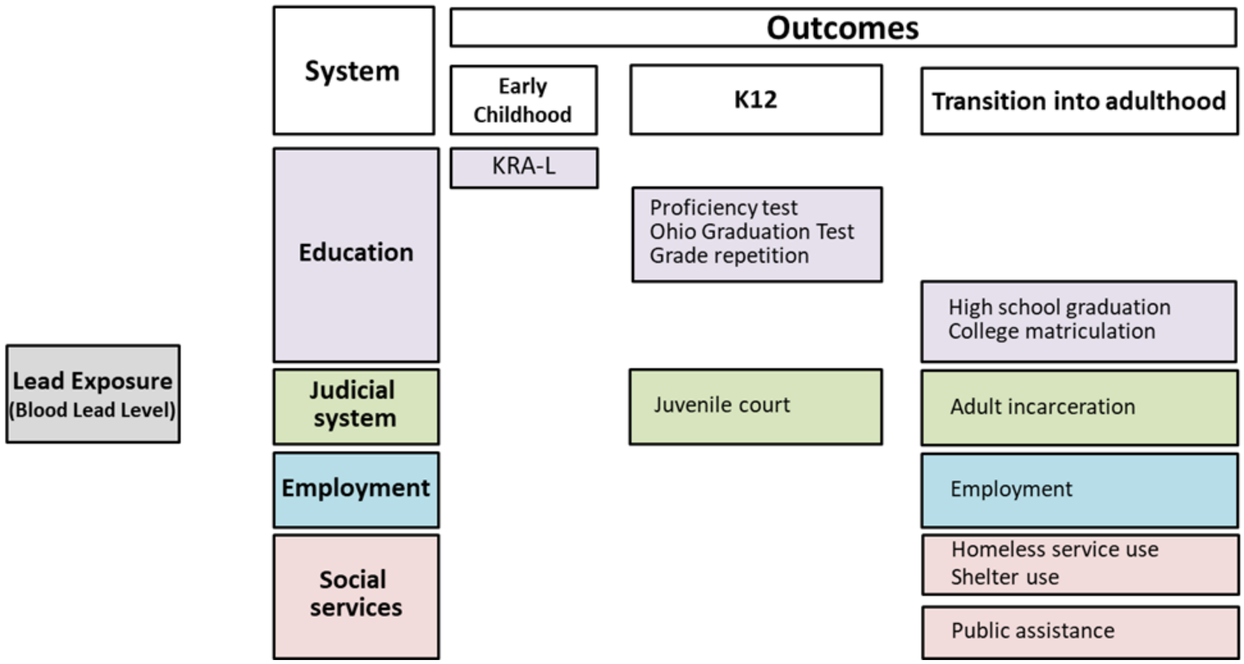

Figure 1. Diagram of lead exposure outcomes by system and chronology

study variables and data sources). The main predictor in the study is whether the child was found to have an elevated blood lead level in early childhood. Lead exposure is a dichotomous variable, with elevated blood lead level (EBLL) set at the public health threshold of equal or greater than 5 µg/dl. We determine the EBLL status for each child by taking the geometric mean of all venous and capillary tests that occurred before age five. This summary measure is less influenced by outliers than the arithmetic mean, and has been used in similar studies looking at the developmental consequences of lead poisoning.

The outcomes for the study reflect the child's experiences over time in the educational, judicial, employment and social services systems. The educational outcomes for the study include measures of kindergarten readiness, proficiency test and graduation test passage, grade repetition in selected grades, and high school graduation. All of these measures are dichotomous, and are determined based on the last score if the tests are taken multiple times. Justice system involvement is measured based on whether or not the child was the subject of a delinquency filing in Juvenile Court, and whether they had a record of incarceration in county jail between the age of 18 and 23. Whether the individual is employed at age 23 is ascertained through the Ohio Wage Record System that has records of *covered* quarterly employment (not including self-employed, independent contractors and federal government employees). In the area of social services, we determine whether the individual has a record of utilization of homelessness services or public assistance programs between 18 and 23 years old. It is important to note that relying on state and local administrative data to track outcomes imposes some limitations. In particular, we assume that individuals who do not have a record of an event (e.g. high school graduation, employment, homelessness) did not experience these outcomes. Although it is possible that some individuals are missing because they experienced the event outside of Ohio, we assume that these measurement errors are 'randomly' distributed across our EBLL and non-EBLL groups, not affecting the validity of our estimates of lead poisoning impact.

STUDY POPULATION

Due to data availability, we restrict the study population to children born in Ohio that had at least one lead test by their 5th birthday. These restrictions result in a sample comprising approximately 62% of the students that were in the two 9th grade cohorts. Students in our early cohort were born between 1991 and 1993, and those in the more recent cohort were born between the years 1999 and 2002.

As can be seen in the top portion of Table 1 (Section A), lead poisoning rates were considerably higher in the earlier cohort. The geometric mean of test results averaged across children in the early cohort was 10.6 µg/dl, almost twice that for the recent cohort. Further, 85 percent of the children who were tested in the early cohort met the public health threshold of ≥ 5 µg/dl, compared to 48% of children in the recent cohort. With respect to demographic characteristics, there were no differences in the two cohorts on sex or on their mean age in 9th grade. However, we see differences in the racial and ethnic makeup of the students between cohorts, as the share of African American students

	Early Cohort 2007-2008 (n = 6,063)	Late Cohort 2016-2017 (n = 4,414)
A: All Students		
Lead Levels		
EBLL (BLL ≥ 5µg/dl)	85%	48%
BLL (Geometric mean)	10.6	5.9
Age (mean at 9th grade)	15.6	15.6
Sex		
Female	50%	50%
Race/Ethnicity		
Black/African American	82%	73%
Hispanic/Latino	6%	10%
White	10%	14%
Other	2%	2%
B: Percent students with EBLL by sex and race		
Sex		
Male	85%	51%
Female	84%	45%
Race/Ethnicity		
Black/African American	87%	51%
Hispanic/Latino	72%	35%
White	80%	47%
Other	78%	42%

Table 1: Lead poisoning rates and selected characteristics of 9th grade student cohorts

decreased and the shares of white and Hispanic/Latino students increased over time. In section B of Table 1, rates of EBLL are displayed by sex and race/ethnicity. Notably, black or African American children are the most impacted, as the rate of EBLL is highest for this group in both cohorts. Boys have higher rates of EBLL than girls only in the recent cohort.

MATCHED COMPARISON GROUP ANALYSIS

From the above population, we create two matched groups for comparison. Following previous research, we dichotomize lead levels at the public health standard of ≥ 5 µg/dl of blood to define the groups. We apply coarsened exact matching (CEM) to achieve comparability between the groups. CEM is a non-parametric technique that temporarily coarsens values on the matching variables, finds exact matches for each case using the coarsened data, and estimates the model on the matched, un-coarsened data.[18] We match our EBLL sample children to others that do not exceed the threshold for EBLL on numerous variables (i.e., potential confounders) that could simultaneously be related to the chances of lead exposure and to the outcomes of interest. The matching variables include year of birth, race/ethnicity, and dichotomous variables to account for low-birth weight status, having a teenage mother, mother without a high school diploma, mother who smoked during pregnancy, mother who did not have pre-natal care, and mother who spoke a native language other than English. Additional matching variables that are dichotomized by the CEM algorithm are months the child lived in public housing between 12 and 18 months of age, months the household received Supplemental Nutrition Assistance Program (SNAP) benefits between 12 and 18 months of age, and the Opportunity Index[19] rank score for the neighborhood of birth. We are careful to match only on characteristics that occur early in life (by 18 months of age) and that could not result from lead exposure. CEM is able to match 85% of students that have EBLLS in the recent cohort and 82% in the early cohort with students in their own cohort with BLLs that are underneath the threshold.

Using these matched groups produced through CEM, we then estimate a weighted linear regression model for each outcome of interest with the dichotomous measure of having EBLL or not as the sole regressor. The coefficients derived from these models are used to evaluate whether there is a statistically significant impact of lead poisoning on the outcomes and to estimate the percentage differences in the rates between the groups that can be attributed to lead.

FINDINGS

The study shows that there is a large impact of lead poisoning on children, and that the disparities between the students with and without elevated lead levels first seen in early childhood persist through early adulthood. The results of the regression models confirm that the children with EBLL compared to the matched comparison children without EBLL have significantly worse outcomes across multiple systems. Table 2 displays the estimated parameters derived from OLS regression models applied to coarsened-exact-matched groups, where 'outcome' is the dependent variable and EBLL is the binary independent variable. These parameters represent the estimated percentage of children having each outcome in the group without EBLL (base rate) and the percentage point difference from this base rate in the EBLL group. We also provide the effect size due to lead expressed as a percent difference (% Δ). For example, in the first row of the table we see that the rate of being on track according to the KRA-L test is estimated at 33 percent for the group without EBLL in the recent cohort. For the group with EBLL, the KRA-L on-track rate is 9% lower. The estimated impact of lead (% Δ) is -27%, which means that children with EBLL have a 27% lower chance of being on-track for kindergarten than children without *EBLL.*

Table 2. Impact of EBLL on selected outcomes (Model based estimates)*

Outcomes	2007-2008 9th grade students			2016-2017 9th grade students		
	Estimated percent in group without EBLL **	Estimated percent point difference in EBLL group***	Impact of lead- effect size (% Δ)	Estimated percent in group without EBLL	Estimated percent point difference in EBLL group	Impact of lead - effect size (% Δ)
Education						
KRA_L (on-track)				32.9	-8.8	-27%
3rd GR reading (Pass)				34.8	-11.0	-32%
3rd GR math (Pass)				55.5	-6.2	-11%
6th GR reading (Pass)				60.7	-9.6	-16%
6th GR math (Pass)				42.1	-5.9	-14%
8th GR reading (Pass)	59.4	-11.4	-19%	31.6	-6.8	-21%
8th GR math (Pass)	39.1	-7.5	-19%	25.6	-6.5	-25%
OGT Reading (Pass)	73.3	-11.7	-16%	36.1	-8.3	-23%
OGT Math (Pass)	62.7	-12.1	-19%	22.2	-4.7	-21%
Grade repetition in 3rd	1.7	0.7(NS)	(NS)	2.7	0.6 (NS)	(NS)
Grade repetition at 9th	23.2	7.1	31%	12.8	3.5	27%
High school grad on-time	51.8	-9.2	-18%			
High school grad (ever)	59.1	-7.5	-13%			
College matriculation	55.2	-9.8	-18%			
Judicial system						
Delinquency filing (any)	21.7	3.5	16%	14.8	4.0	27%
Delinquency filing (violence)	11.6	3.2	27%	9.0	3.7	41%
Adult incarceration (age 18-23)	18.0	6.4	35%			
Homeless Services at age 18-23						
Homeless service (any)	3.8	1.7	45%			
Emergency shelter (any)	1.9	1.4	73%			
Public assistance at age 23						
TANF (1 month or more)	3.8	1.8	49%			
SNAP (2qts or more)	28.6	4.9	18%			
Employment at age 23						
Employment (2qts or more)	62.0	-2.7 (NS)	(NS)			

*Coefficients derived from OLS regression models applied to coarsened-exact-matched groups, where 'outcome' is the dependent variable and EBLL is the binary independent variable. ** This is the estimate of model constant (no EBLL). ***This is the estimate of the coefficient on the dependent variable (with EBLL). **NS** denotes impact is not statistically significant.

Moving onto grades 3-6, Table 2 also shows large differences between the group without EBLL and the EBLL group on proficiency test results. For example, in the recent cohort, the rates of passing the third grade reading and math proficiency tests are 32% and 11% lower respectively for the EBLL group compared to the group without EBLL. The proficiency test passing rates continue to be significantly depressed for the EBLL group relative to the group without EBLL through 6th grade, although at somewhat lower magnitudes than in earlier grades.

From the 8th grade forward, we have testing data for both the early and recent cohorts. Reading and math proficiency passage rates are significantly lower for the EBLL children compared to the group without EBLL. The impact estimates range from 19% to 25% lower depending on the test. The Ohio Graduation Test passage rates are significantly lower for the EBLL group in both cohorts, and the percentage difference is of similar magnitude. However, the overall passage rate on OGT is higher for the early cohort than the recent cohort, re-flecting changes the state made to the OGT test 2009.

Table 2 also displays grade repetition rates for both cohorts. Grade repetition is a low frequency event in general, but is costly to the school system and to the child. We see significant differences in repetition rates between the groups in the third grade (early cohort only) and ninth grade, with EBLL children repeating these grades more often. Repetition rates for other grades are very low, and the differences between groups are not statistically significant.

Lead poisoning also has an impact on outcomes in the juvenile justice systems as shown in Table 2. In both cohorts, youth in the EBLL group well exceed the group without EBLL on all juvenile court filings and on those specifically for violent incidents. Although the incidence rates of overall juvenile delinquency for the non-exposed groups decline in the recent cohort relative to the early cohort, the disparities between EBLL and non-EBLL groups (Δ) remain similar across cohorts. However, disparities between the groups on violent crimes have increased in the recent cohort translating into a 27% and 41% effect size (%Δ) respectively. Table 2 also displays some early adult outcomes at ages 18-23 for the early cohort. The rates of college matriculation in Ohio colleges are lower in the EBLL group compared to the group without EBLL. Moreover, the group with EBLL has much higher incarceration rates and likelihood of using homeless services and homeless shelters than the group without EBLL. At age 23, individuals in the EBLL group are more likely to have relied on public assistance programs such as TANF (for at least one month) and SNAP (for at least half the year). There was no statistically significant impact of lead poisoning on working in covered employment for at least two quarters at age 23.

CONCLUSION

This study examined the impact of early childhood lead poisoning on outcomes throughout childhood and early adulthood. By comparing carefully matched groups of children with and without elevated blood lead levels, this research demonstrates the large impact of lead poisoning on individuals and public systems. Across many outcomes, the disparities between individuals who had elevated blood lead levels in early childhood, compared to their matched counterparts without EBLLs, are in the ranges of 20-40%. All of the outcomes examined in this study are costly to the individuals who experience them, the systems that serve them and society at-large.

Our analysis also shows that black or African American youth are disproportionately poisoned by lead as young children and that this leads to a series of other disadvantages as they grow up. It is worth noting that some of the largest impacts of lead poisoning are in justice system involvement, where other factors such as societal biases, policing and judicial practices play a role in who gets into these systems. In this study, the EBLL and non-EBLL groups are matched on race and numerous other characteristics before age 3 in order to isolate the effects of lead poisoning from other confounding factors. However, it is important that future work explore within-race effects of lead poisoning with the aim of further disentangling the intrinsic impact of lead from external and systemic factors related to systemic racism.

In interpreting the results of this longitudinal study, it is useful to consider that early development and experiences set the stage for individuals' subsequent progress. For example, being less ready for kindergarten puts children at greater risk for not being proficient in reading and math during elementary school, needing to repeat a grade, and later difficulties in educational attainment and labor market success. Similarly, behavioral problems in early childhood can persist and contribute to later antisocial behavior, social dislocations and barriers to employment. From this longitudinal perspective, lead poisoning in early childhood can shift the trajectory at various developmental stages and have long-term consequences for the individual.

In considering societal costs, we see a similar cumulative effect as children with EBLLs move through various systems. When they are in elementary school, lead poisoned children have lower passage rates on proficiency exams and higher rates of grade retention, necessitating higher levels of educational supports and services. These needs persist in high school, as evidenced by increased rates of grade repetition and more difficulty in passing graduation tests. From the perspective of the justice system, the impact can be seen in the increased rates of involvement in both the juvenile justice and adult corrections systems that are attributable to elevated lead levels in early childhood. Other social service systems are also affected by lead poisoning, through increased utilization of homelessness services and public assistance as adults among individuals exposed to lead as children. Although beyond the scope of this study, the educational deficits and justice system involvement induced by lead poisoning are likely to play out over adulthood in the form of lost human capital and lifetime earnings. This study underscores the urgency of implementing lead poisoning prevention programs that reduce societal costs and move us towards a more equitable and just society.

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APPENDIX A:

Concept	Measure	Source
Predictor		
Confirmed EBLL	Geometric mean of lead tests* until 60 months is at or above 5 BLL (µg/dl) (Yes= 1)	ODH-L
Downstream outcomes		
Achievement test	Kindergarten Readiness Assessment-Literacy score is on track (R) Proficiency tests of Math, Reading at 8^{th} grade(E), at 3, 6, 8^{th} grade(R) Ohio Graduation Test of Math, Reading in high school (ER)	SD+EMIS
Grade repetition	Grade repetition at 3-9^{th} grade (ER) (Yes=1)	SD+EMIS
High school graduation	High school graduation on-time and ever (E) (Yes=1)	SD+EMIS
College matriculation	College matriculation at age 18-23 (E) (Yes=1)	SD+EMIS
Juvenile delinquency	Delinquency court filing (All or only violence) ever at age 9-16(ER) (Yes=1)	CC JC
Adult Incarceration	Adult incarceration ever at age 18-23(E) (Yes = 1)	CC SO
Homelessness	Homeless services or shelter use ever at age 18-23(E), at age 14-16(R) (Yes=1)	CC HMIS
Public assistance	Receiving TANF ever; SNAP 2 quarters or more at age 18-23 (E) (Yes=1)	CC JFS
Employment	Employed in at least 2 quarters at age 23 (Yes=1) (E)	ODJFS
Child characteristics		
DOB	Date of Birth (MM/ DD/ YYYY)	ODH-B
9th grade entry	School year entering CMSD 9th grade (ER)	SD
Gender	Female=1/ Male=0	ODH-B
Race/ethnicity	African American/ White/Hispanic/Other (Yes=1)	ODH-B
Low birth weight	Low birth weight (<2,500 grams; Yes=1)	ODH-B
Premature birth	Premature (<37 weeks gestation; Yes=1)	ODH-B
Apgar score	5 minute Apgar score (0-10)	ODH-B
Child maltreatment	Child neglect/abuse investigation (Yes=1)	CC DCFS
Foster care	Foster care placement (Yes=1)	CC DCFS
Family characteristics		
Teen mother	Born to a teen mother (Yes=1)	ODH-B
Mother's education	Born to a mother with high school diploma (Yes=1)	ODH-B
Marital status	Non-married=0/ Married=1 at child birth	ODH-B
Prenatal care	Kessner's Index (Adequate; Yes=1)	ODH-B
Risky health behavior	Tobacco use during pregnancy (Yes=1)	ODH-B
	Alcohol use during pregnancy (Yes=1)	ODH-B
Native language	Student's native language is NOT English (Yes=1)	EMIS
Housing assistance	Ever Received Housing voucher or public housing (12-18 months) in early child-hood (Yes=1)	CMHA
Public assistance	Ever Received TANF, SNAP, Medicaid (12-18 months) in early childhood (Yes=1)	CC JFS
Neighborhood characteristics		
Neighborhood	Census tract at child birth	ODH-B+C
Opportunity index**	Opportunity Atlas, census tract level, 2014-2015	ODH-B+C+T

Note. * Used capillary and venous measure (E) Early cohort only; (R) Recent cohort only; (ER) Early and Recent cohorts

**The opportunity index ranks neighborhoods by the average income level of individuals between the ages of 31 and 37 who grew up in that neighborhood and in low income families. For a detailed explanation of the index see Raj Chetty, John N. Friedman, Nathaniel Hendren, Maggie R. Jones & Sonya R. Porter, 2018. "The Opportunity Atlas: Mapping the Childhood Roots of Social Mobility," NBER Working Paper 25147: 18-42, Center for Economic Studies, U.S. Census Bureau.

Sources.
CC JC: Cuyahoga County Juvenile Court
CC SO: Cuyahoga County Sheriff's Office
CC DCFS: Cuyahoga County Division of Children and Family Services
CC JFS: Cuyahoga County Job and Family Services
CC HMIS: Cuyahoga County Homeless Management Information System
CMSD: Cleveland Metropolitan School District
SUB: Inner ring suburban School District
SD: CMSD + SUB
CMHA: Cuyahoga Metropolitan Housing Authority
ODH: Ohio Department of Health (B=birth; L=lead)
EMIS: Ohio Educational Management Information System
ODJFS: Ohio Department of Job and Family Services
C: 1990, 2000, 2010 Decennial Census, 2005-2015 American Community Survey (ACS)
T: Federal income tax returns for 1989, 1994, 1995, and 1998-2015 (opportunityatlas.org)

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