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Association between Residential Distance to Airport and Blood Lead Levels in Children under 6 Living in North Carolina, 1992–2015

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Introduction

Even with progress in lead poisoning prevention, research has consistently shown there is no safe blood lead level (BLL) for children.[1] Behavioral and cognitive deficits are associated with lead exposure, even at low levels.[2] Unfortunately, many piston-engine aircraft are still fueled by leaded aviation gas (avgas).

The US Environmental Protection Agency (EPA) estimates that $\sim$5.2 million people live within 500 m of an airport where avgas is used.[3] Our past research in six North Carolina (NC) counties indicates that children living within 500 m of airports where avgas is used have $\sim$4% higher BLLs than children who lived beyond 2,000 m (reference group); the association between avgas and children's BLLs was still detectable at 1,000 m.[4] Building on this work, this study investigates the relationship between avgas and BLLs in children across all 100 NC counties.

In October 2023, the EPA finalized an endangerment finding as the first step in using its authority to regulate the use of avgas. EPA is now required by the Clean Air Act to propose and promulgate regulatory standards for lead emissions from certain aircraft engines. Moreover, the Federal Aviation Administration (FAA) must propose avgas that will control or eliminate lead emissions. In this paper, we provide evidence that is relevant to the EPA's future regulatory proposals.

Methods

Data

We obtained BLL testing data from the NC Childhood Lead Poisoning Prevention Program. Our initial sample ($n = 3{,}092{,}452$) consisted of all children born in NC with a BLL test by age 6 (1992–2015)—composed of 60.2% on Medicaid and average BLL of 3.06 μg/dL. We restricted the sample to children with georeferenced home address ($n = 2{,}473{,}183$) and eliminated children with missing values for self-reported race (10.5%) and those who self-identified as non-Hispanic Asian (1.3%) and non-Hispanic other (3.2%), due to an insufficient number of observations for analysis. Of the children with complete information ($n = 1{,}996{,}065$), some had multiple lead tests: 2-tests (32.2%), 3-tests (5.9%), and ≥4-tests (2.1%). For these children, we used the highest recorded BLL.[5]

The residential address was used to link each child to 2010 Census block-group data for median household income and the percentage of houses built before 1980—used as a proxy for lead paint in homes. Arguably, house-specific age is a better proxy, but such tax parcel data are only available for 50 of the 100 NC counties. Therefore, we used the percentage of houses built prior to 1980 in the main analysis and house-age in 50 counties as part of a sensitivity analysis. House-specific distances to the nearest airport centroid were calculated based on the FAA's Airport Master Record (5010) dataset, which includes information on the number of general aviation aircraft, takeoffs, and landings at each airport (1998–2020). The final sample was restricted to children who live within 10 km of an airport ($n = 943{,}602$).[6]

Dose-Responsiveness of BLL to Airport Proximity

The BLL distribution was right-skewed, so we took the natural logarithm of the values to make the distribution more symmetric.

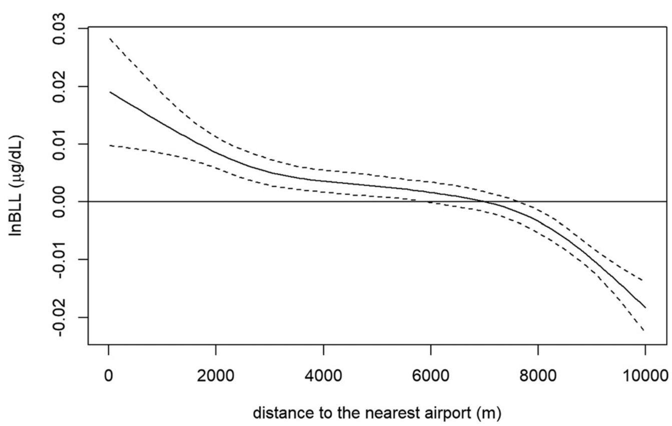

Figure 1. Dose-response relationship between child blood lead levels (BLL) and residential proximity to airport. Result of the relationship between the natural logged blood lead levels (lnBLL) in μg/dL of $n = 943{,}602$ children 6 years of age and below living in North Carolina who screened for lead between 1992 and 2015 and the distance from the child's house to the nearest airport (in meters) is given. The results is based on a general additive model fit with lnBLL as response and distance included as a cubic spline to allow for a flexible relationship between lnBLL and distance while controlling for the child's age binned into (0, 1) as reference, (1, 2), (2, 3), (3, 4), (4, 6); sex at birth (male/female, reference); self-reported race (non-Hispanic black, Hispanic/non-Hispanic white; reference), Medicaid enrollment (yes/no, reference), year of test binned into (1992–1995) as reference, (1996–1999), (2000–2005), (2006–2010), (2011–2015), and season of test (Winter, Spring, Summer/Fall; reference). The estimates from the model were all statistically significant with p-values less than 0.001. The solid middle line is the estimated curve, and the dotted lines represent its 95% pointwise confidence interval.

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Table 1. Results of the linear regression with CEM matched data based on the full and partial samples examining the association between residential proximity to airport(s) and blood lead levels (BLL) in children under 6 in North Carolina (NC), 1992–2015.

	Main analysis (sample from all 100 NC counties; $n = 210{,}246$)			Sensitivity analysis (sample from 50 NC counties, $n = 114{,}179$)		
Variable	Variable summary [n (%)]	Estimate	95% CI	Variable summary [n (%)]	Estimate	95% CI
Intercept	—	4.003	3.919, 4.089	—	3.984	3.881, 4.089
Aviation gas exposure						
Ref: No	134,201 (64%)	—	—	78,485 (69%)	—	—
Yes	76,045 (36%)	1.018	1.013, 1.024	35,694 (31%)	1.018	1.011, 1.026
Child age						
Ref: [0, 1)	8,672 (4%)	—	—	4,502 (4%)	—	—
(1, 2)	127, 010 (60%)	1.105	1.091, 1.116	71,268 (62%)	1.105	1.086, 1.124
(2, 3)	43,542 (21%)	1.371	1.353, 1.389	23,044 (20%)	1.372	1.348, 1.397
(3, 4)	6,430 (3%)	1.231	1.208, 1.254	3,125 (3%)	1.221	1.190, 1.253
(4, 6)	24,592 (12%)	1.122	1.107, 1.139	12,240 (11%)	1.115	1.093, 1.137
Sex at birth						
Ref: Female	103,262 (49%)	—	—	56,003 (49%)	—	—
Male	106,984 (51%)	1.037	1.032, 1.042	58,176 (51%)	1.034	1.027, 1.041
Race						
Ref: non-Hispanic white	123,750 (59%)	—	—	64,540 (57%)	—	—
non-Hispanic black	57,664 (27%)	1.104	1.097, 1.111	32,558 (29%)	1.110	1.101, 1.119
Hispanic	28,832 (14%)	0.933	0.926, 0.940	17,081 (14%)	0.938	0.928, 0.947
Medicaid enrollment						
Ref: No	83,089 (40%)	—	—	46,318 (41%)	—	—
Yes	127,157 (60%)	1.169	1.162, 1.176	67,861 (59%)	1.153	1.144, 1.162
Specimen type						
Ref: Capillary blood	208,472 (99%)	—	—	113,097 (99%)	—	—
Venous blood	1,774 (1%)	0.895	0.872, 0.919	1,082 (1%)	0.898	0.868, 0.929
Years screened						
Ref: 1992–1995	12,289 (6%)	—	—	6,376 (6%)	—	—
1996–1999	30,012 (14%)	0.699	0.691, 0.708	15,255 (13%)	0.709	0.697, 0.721
2000–2005	65,731 (31%)	0.584	0.577, 0.591	34,599 (30%)	0.593	0.584, 0.603
2006–2010	56,489 (27%)	0.418	0.413, 0.423	31,729 (28%)	0.429	0.422, 0.436
2011–2015	45,725 (22%)	0.286	0.282, 0.289	26,220 (23%)	0.296	0.291, 0.301
Season screened						
Ref: Fall	52,493 (25%)	—	—	28,476 (25%)	—	—
Spring	52,982 (25%)	0.985	0.978, 0.991	28,789 (25%)	0.982	0.973, 0.991
Summer	59,327 (28%)	1.035	1.028, 1.042	32,086 (28%)	1.034	1.024, 1.043
Winter	45,444 (22%)	1.013	1.006, 1.020	24,828 (22%)	1.016	1.007, 1.026
Median household income[a]	Mean: \$4.0	—	—	Mean: \$4.1	—	—
(×\$10,000)	SD: \$1.4	0.968	0.966, 0.971	SD: \$1.4	0.967	0.965, 0.970
% of houses built <1980[a]	Mean: 47%; SD: 22%	1.134	1.119, 1.149	—	—	—
Actual house age						
Ref: ≥1980	—	—	—	54,180 (47%)	—	—
<1950	—	—	—	15,818 (14%)	1.152	1.140, 1.164
1950–1980	—	—	—	44,181 (39%)	1.047	1.039, 1.055
Total n	210,246 (100%)	—	—	114,179 (100%)	—	—
R^2	—	0.325	—	—	0.320	—
R^2 adjusted	—	0.325	—	—	0.320	—

Note: We categorize children who live within 2.5 km of the nearest airport centroid as "exposed" to aviation gas, while those living between 8 and 10 km were categorized as the control. In the main (full sample) analysis, percentage (%) of houses built before 1980 was used as a proxy for lead paint in the home because it is available for all 100 NC counties. Actual house age, a better proxy for lead paint in the home, was only available for 50 of the 100 NC counties. Therefore, we used house age instead of percentage of houses built before 1980 in the sensitivity analysis based on the partial sample. The parameter estimates are exponentiated to give the exposure and partial effects on BLL instead of the natural logged BLL (lnBLL) for ease of interpretation. All estimates in both the main and sensitivity analysis have p-values smaller than 0.001. —, no data; CEM, coarsened exact matching; CI, confidence interval; Ref, reference; SD, standard deviation.
[a]Based on 2010 Census block-group data.

Then, we estimated the relationship between lnBLL and residential proximity to an airport using the generalized additive model:

$$\mathrm{lnBLL_i} = \alpha + \mathbf{X}_\mathrm{i}\beta + \mathrm{s}(\mathrm{D_i}) + \varepsilon_\mathrm{i}, \tag{1}$$

where for the ith child, $\mathbf{X}_\mathrm{i}$ is the vector of control variables [age, race, sex, Medicaid enrollment, blood specimen type (venous, capillary), test year and season, median household income, and percentage of houses built prior to 1980], $\mathrm{D_i}$ is distance to the nearest airport, $s(.)$ is a penalized cubic spline function, (α, β) are unknown parameters, and the noise ε_i is $\sim n\ (0, \sigma^2)$. The control variables have been consistently shown to be associated with BLL; their inclusion allows us to better isolate the effect of distance on BLL.[2,7]

A Spatial First-Difference Approach

To estimate the effect of residential proximity to airport on BLL, we created "exposed" and "control" groups. Based on the results from Equation 1, children living within 2.5 km of the nearest airport centroid were categorized as the "exposed" group, while those living between 8 and 10 km were categorized as the control. Children who lived between 2.5 and 8 km, not in either the exposed group or control, were eliminated from the sample. The final study sample was $n = 308{,}510$.

We estimated the effect of avgas exposure on BLL using the linear model:

$$\mathrm{lnBLL_i} = \eta + \tau \mathrm{Z_i} + \mathbf{X}_\mathrm{i}\theta + \varepsilon_\mathrm{i}, \tag{2}$$

where Z denotes the exposure indicator (1 if $D \leq 2.5$ km, 0 otherwise). τ is the effect of avgas exposure, $\mathbf{X}_i$ is the same as in Equation 1, θ is an unknown parameter, and the noise ε_i is $\sim n\ (0, \sigma^2)$.

To minimize bias in estimating τ based on observational data, we balanced the distributions of all observed confounders ($\mathbf{X}$) using a many-to-one coarsened exact matching (CEM) algorithm.[8] After CEM, we still retain a relatively large sample ($n = 210{,}246$) consisting of 60% on Medicaid and average BLL of 3.1 μg/dL.

In the sensitivity analysis, in 50 counties, we replaced the percentage of houses built prior to 1980 in $\mathbf{X}$ with house-age, binned into three categories: <1950, (1950, 1980), ≥1980.

All models were estimated using R statistical software (version 4.4.0). The parameter estimates in both the main and sensitivity analyses were exponentiated to give the exposure and partial effects on BLL instead of lnBLL for easy interpretation.

All work was conducted under the aegis of a human subjects research protocol approved by the institutional review board at the University of Notre Dame and University of Illinois Chicago.

Results and Discussion

Dose-Response Relationship between BLL and Proximity to Airport

Figure 1 indicates lower average lnBLL at distances further from the airport. The high average BLL for children who lived within 2.5 km of the airport centroid is plausibly due to increased exposure to leaded avgas. This distance gradient likely reflects exposure from both current and historical contributions of leaded avgas.

Spatial First-Difference Results

The results of the model in Equation 2 are summarized in Table 1. In the main analysis, the average BLL for "exposed" children was 1.8% (0.018 μg/dL) higher compared to those in the control group. In the sensitivity analysis, the average BLL for "exposed" children was 1.8% (0.018 μg/dL) higher than the control.

Both findings indicate that children who live near an airport have higher BLLs on average compared to those who live farther away, and this effect does not disappear when house-specific age as potential household lead exposure is used in the model. The findings are complementary to and consistent with the results of Miranda et al.,[4] who focused on six NC counties, and Zahran et al. for children in Michigan.[9]

Our study is not without limitations. First, we did not account for wind direction, which could potentially bias our estimates toward zero.[10] Second, we did not control for airport size because the traffic volume which was available in the traffic flow management system was limited in terms of airports and types of flights, and the FAA's 5010 forms were also not regularly updated. Thus, using airport proximity to measure exposure introduces the possibility of measurement error. Third, our sample was likely biased toward children at the highest risk for lead exposure because BLL testing is only mandatory for children on Medicaid.

Still, we observe a significant adverse effect of avgas use on children's BLLs that can inform the ongoing policy discussions regarding EPA's avgas endangerment finding and future FAA and EPA regulatory proposals.

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