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Proximity to Major Roadways and Asthma Symptoms in the School Inner-City Asthma Study

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Abstract

Objective: To use spatial analysis methodology to analyze residential and school proximity to major roadways and pediatric asthma morbidity.

Methods: The School Inner-City Asthma Study (n=350) recruited school-aged children with asthma. Each participant's school and home addresses were geocoded and distances from major roadways were measured to calculate a composite measurement accounting for both home and school traffic exposure. Generalized estimated equation models were clustered by subject and adjusted for age, race/ethnicity, gender, income, environmental tobacco smoke, controller medication, upper respiratory tract infections and seasonality.

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Clinical Trial Registration:

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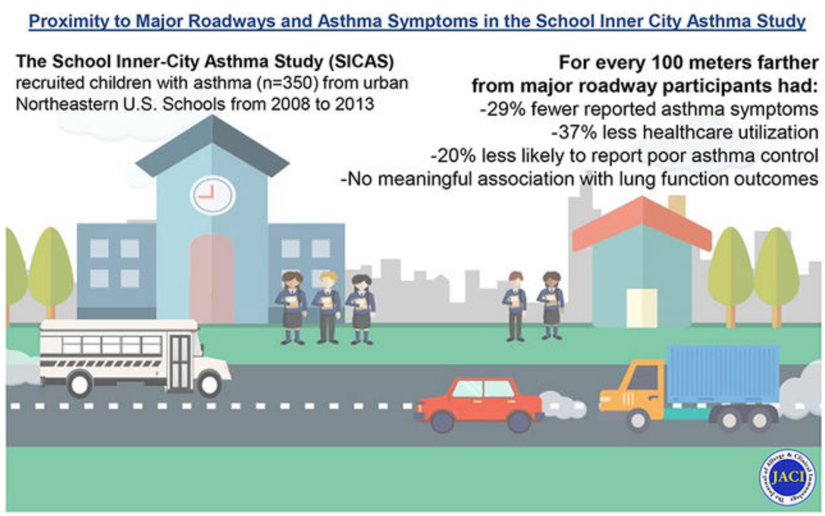
Results: The majority of participants (62%) attended schools within 100 meters from major roadways and 40% also resided within 100 meters of major roadways. In multivariate analyses, major roadway proximity was independently associated with increased asthma symptom days. Above a threshold of 100 meters, children had 29% less odds of a symptom day over the past 2 weeks for each 100 meter increase in distance from major roadway (OR 0.71; 95% CI:0.58–0.87; p <0.01). Children farther from a major roadway also had significantly less reported health care utilization (OR 0.63; 95% CI: 0.47–0.85; p<0.01); and significantly less likely to have poor asthma control (OR 0.80; 95% CI: 0.69–0.94; p< 0.01). There was not a meaningful association between distance to major roadway and lung function outcomes.

Conclusions: Proximity to major roadway, a composite measurement of home and school exposure, primarily driven by home exposure, was associated with greater asthma morbidity. More studies are needed to evaluate the independent effect of school distance to roadway on asthma morbidity.

Graphical Abstract



Capsule Summary:

This study demonstrates that proximity to major roadways, composite measurement of both home and school exposures, is associated with increased asthma symptoms, health care utilization, and poor asthma control.

Keywords

Asthma; School; GIS; Spatial Analysis; Traffic Proximity; Environmental Health Disparities; School Inner City Asthma Study; Environmental Exposure

Introduction:

Asthma is the most common non-communicable childhood disease, affecting approximately 14% of children globally and nearly 5 million children in the United States with a rising

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prevalence worldwide.(1–3) Urban minority children of low socioeconomic status endure disproportionately high asthma morbidity.(4)

Airborne pollutant, aeroallergens and mold exposures, in the inner-city home environment, are associated with significant childhood asthma morbidity.(5–7) While the home environment has been extensively studied, many studies do not account for residential mobility or daily activity patterns (e.g. school location). Additionally, the environment outside of the home is less well understood, largely due to logistical and community hurdles. Recently, several U.S. and European studies have demonstrated considerable asthma triggers present in the inner-city school environment, which serves as an occupational model for children given that children spend nearly 6–8 hours per day in school.(8–14) Previous research from this cohort has demonstrated that classroom-specific exposures to mouse allergen, endotoxin, and ambient nitrogen dioxide levels in inner-city schools are associated with worse outcomes in students with asthma.(15–17) The specific analysis presented in this study will focus on a different exposure for these inner-city children: proximity to traffic at both their homes and schools.

Close proximity to traffic is associated with increased exposures to transportation-related noise and vehicle related emissions of various pollutants such as particulate matter, mobile source air toxicants such as benzene, nitrogen oxides, hydrocarbons, carbon monoxide as well as other pollutants.(18) Prior studies have documented that chronic exposure to major highways, especially living within 100 meters,(19,20) has been associated with increased risk of respiratory infections and asthma development in children, but less is known about the school environment.(10,20–28) A meta-analysis in five European birth cohorts did not demonstrate an association with air pollution and the development of allergen sensitization.(29) Potential hypothesized mechanisms underlying the association between traffic proximity and asthma morbidity are increased allergen release, pollutants acting as adjuvants in allergic mechanisms, including DNA methylation, and/or activated respiratory reflexes through direct respiratory irritation.(30–33).

Studies have consistently demonstrated that children and pregnant women who live close to major roadways have increased risk of adverse respiratory health outcomes. Less is known about the risks of attending school near major roadways. This is a substantial exposure for approximately 3.2 million U.S. students (6.2%) who attend school less than 100 meters from major roadways.(34) This population also reflects racial and socioeconomic disparities, with higher rates of African American students and students eligible for free or reduced price meals attending the most proximal schools.(34) A study by McConnell et al., (10) demonstrated that exposure to traffic related pollutants both at home and school was associated with the development of asthma. Additionally, important findings from a Swedish birth cohort found that exposure to traffic-related air pollution during the first year of life affected lung function in children up through adolescence.(35,36) The exposure relationship with asthma symptom morbidity warrants further study.

The objectives of this study were to use geographic information systems (GIS) spatial analysis techniques to analyze the association between combined residential and school

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proximity to major roadways and pediatric asthma morbidity. We hypothesized that traffic proximity exposure at school and home contributes to asthma symptoms.

Methods

The School Inner-City Asthma Study (SICAS) is a five-year prospective cohort study of children with asthma attending urban public elementary schools in the northeastern United States from 2008–2013. Detailed methods and characteristics of this cohort have been published previously.(37) Briefly, screening questionnaires were distributed each spring in participating schools to identify eligible participants. Eligible study participants completed an initial clinical assessment during the summer prior to the next academic year, which included a detailed questionnaire, aeroallergen sensitization assessment by allergy skin testing (MultiTest device, Lincoln Diagnostic, Decatur, IL) and/or specific serum IgE testing (ImmunoCAP, Phadia AB, Uppsala, Sweden). We conducted follow-up surveys to evaluate asthma symptoms approximately every 3 months over the next 12 months.

Study Population

Children with asthma attending participating schools were recruited based on established inclusion and exclusion criterion modelled from other urban studies and adapted for SICAS: (37,38) 1) history of physician diagnosed asthma; 2) current symptoms defined as cough, wheezing, shortness of breath, or whistling in the chest in the past 12 months, daily controller medication use, or unscheduled medical visits for asthma in the past year; and 3) attendance in grades kindergarten through 6th grade at a school where permission for study participation had been obtained. The exclusion criteria included any significant pulmonary disease other than asthma. Written informed consent was obtained from each participant's parent or legal guardian, and assent was obtained from each participant. The protocol was approved by the Boston Children's Hospital Institutional Review Board.

Distance to Major Roadway Exposure Assessment

We geocoded participant's residential addresses using geographic information systems (GIS) Arc-GIS 10.2.2 (Environmental Systems Research Institute, Redlands, CA) software with 80% spelling sensitivity and 10 meter offset from roadway on the basis of a geo-referenced 2014 U.S. Census Bureau's Master Address File/Topologically Integrated Geographic Encoding and Referencing (TIGER) road inventory file.(39) We mapped a statewide school database maintained by the Office of Geographic Information to geocode school locations. (40) A manual review was then performed to geocode unmatched addresses. If the address still could not be geocoded, the study observation was excluded from the study sample. We used the above GIS software, to calculate the straight-line distance between each participant's home and school to major roadways, respectively, as well as straight-line distance of each subject's residence to their respective school. This design allowed examination of the joint effects of traffic proximity at school and home. An estimate of combined school and home exposure to traffic was made by weighting the proximity measurements by time at school (40 hour weekly, or 24% during school year) and assigning the remaining 76% and observations outside of the school year to the home.(10) Supplemental analyses evaluate the independent effect of the residential traffic exposure,

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controlling for the school and the inverse the independent effect of school, controlling for home. For these analyses, we limit the study population and observations to those that occur during the academic school year. We defined major roadways using the Department of Transportation spatial data. We defined major roadways as those with functional class 1 through 6, which includes interstates, urban principal and minor arterials and urban collector roadways, and excludes local roadways.(41) Functional class reflects a road's design and construction, and is not necessarily directly correlated to traffic volumes, but may be more important than traffic volume in influencing whether trucks and buses regularly use a road.(18) Asthma morbidity outcomes were linked with the distance to major roadway at the geocoded address at time of each respective baseline and follow up visits and the temporally closest visit address for spirometry outcomes. For confidentiality purposes, geographic masking techniques were utilized for Figure 1; the relationship between distance to major roadways and schools were preserved.(42)

The relationship between distance to major roadway and our primary outcome was evaluated with locally weighted regression (Lowess) to examine possible nonlinear relationships. On the basis of these smoothers, we then fit a linear spline of distance with a single knot at 100 meters to be used in subsequent models. Relationships between distance and health outcomes are presented as the effect of a 100 meter change in distance to major roadways greater than the threshold of 100 meters.

Outcomes of Interest

The primary outcome was maximum asthma symptom days as used in prior urban asthma studies.(15–17,43–45) Maximum symptom days is defined as the greatest result of the following 3 variables in the 2 weeks prior to each questionnaire administration: a) number of days on which child had daytime wheezing, chest tightness, or cough; b) number of days on which child had to slow down or discontinue play activities due to wheezing, chest tightness or cough; c) number of nights on which child had wheezing, chest tightness or cough leading to disturbed sleep. This variable ranges from 0 −14 days.

Secondary outcome measures included the following: missed school, defined as the number of reported days the child missed school over prior 2 weeks; health care utilization, defined as the number of hospitalizations and unscheduled health care visits for asthma averaged over year; caregiver plans changed defined as the number of days the caregiver changed plans because of the child's asthma over prior 2 weeks; caregiver lost sleep defined as the number of nights the caregiver lost sleep because of the child's asthma over prior 2 weeks; poor asthma control as identified by any of the following in the past 4 weeks: shortness of breath more than twice weekly, nighttime awakenings due to asthma at least once, limitation in activity level, or use of rescue asthma medication 2 or more times weekly. Spirometry outcomes were also included. The forced expiratory volume in one second (FEV_1)/forced vital capacity (FVC) ratio is the most sensitive marker of airflow obstruction in children with asthma.(46,47) FEV_1 percent predicted, FVC percent predicted and forced expiratory flow between the 25th and 75th percentile of forced vital capacity (FEF25–75), a measure of medium- and small-caliber airways, were also assessed. All spirometry outcomes were assessed and only included in subsequent analyses if it met American Thoracic Society

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guidelines for acceptability and repeatability by study physicians.(48,49) Reference values were derived from the National Health and Nutrition Examination Survey III reference equations, which account for age, race, ethnicity, height and sex.(50)

Covariates

Potential confounders were included based on whether the primary outcome estimates for the roadway proximity changed by greater than 10% in univariate analyses, or chosen *a* priori based on prior biological knowledge or prior studies from this cohort. The following covariates were included in the final model: age, gender, race/ethnicity, annual household income, use of asthma controller medication at baseline, seasonality, report of sneezing or cold symptoms over past 2 weeks, environmental tobacco smoke exposure.

Primary analyses assessed the joint effect of a composite measure of residential and school major roadway based on a time weighted average of exposure. Based on prior literature,(29,51–54) we tested the interaction between allergen sensitivity and major roadway proximity to determine whether there was effect modification. Allergen sensitization was defined as any sensitization by skin prick test or specific-IgE level of 0.35 kU/L or greater for any of the following environmental allergens: tree pollen, grass, ragweed, dust mites, cat, dog, mouse, rat, cockroach, and molds (Greer, Lenoir, NC). Previous research from this school-based cohort detailed the collection procedures and associated health effects of classroom exposures to mouse allergen and endotoxin, obtained by vacuumed dust and air sampling,(15,16,37) respectively, were both independently associated with increased asthma symptoms. A subset analysis of school year observations (n=282 participants) included school mouse allergen and endotoxin levels in adjusted models and evaluated the independent effects of home and school traffic proximity on asthma morbidity.

Race/ethnicity was defined by self-report (black/African American, non-Hispanic; Hispanic/Latino; Caucasian, and mixed/other). Household income levels were stratified by federal poverty levels based on a four-person household and dichotomized at the 100% federal poverty level (cutoff <$25,000). An indicator variable was created for annual household income to include participants that were missing individual income data. Seasonality was defined as a continuous measure of the number of days since the start of the calendar year started and was modeled with linear and quadratic terms.

The following variables were evaluated but not included in the final model as they did not change effect estimates by at least 10% in univariate models: prematurity; family history of asthma; overweight/obese; classroom floor level; outcome assessment frequency; parental education; parental employment; residential income by census block group; distance from home to school; and residential mobility (home address changes during study period).

Statistical Analysis

In univariate and multivariate analyses, we evaluated the exposure-outcome relationship using exposure while adjusting for confounders using generalized estimating equations (GEE) with an exchangeable correlation structure, robust variance estimates, and clustered at the participant level, given multiple observations for each study participant. We considered clustering at the school level in addition to the participant level within a multilevel random

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effects model containing both child and school random effects, but it was deemed unnecessary because there was little to no between-school variability in all outcomes (intraclass correlations between 0.00 and 0.04). We identified a single outlier observation with exposure to traffic proximity at 1418 meters. Given all other measurements were less than 600 meters, this outlier was recoded to the next highest value, 573 meters. An interaction term was created for traffic proximity and allergen sensitization; however, this was not statistically significant, so only main effects were reported. Binomial family GEEs with a logit link were used for asthma-related two-week health outcomes (i.e., two-week outcomes were modeled as the sum of 14 binomial "successes"). Statistical analyses were performed using STATA 13.1 software (StataCorp, College Station, TX). In all models, main effects were considered statistically significant at $p<0.05$ and we evaluated the interaction effect at a threshold of $p=0.10$.

Results

A total of 351 students with asthma from 38 schools participated in the baseline study visit. Of these, 350 participants with 1327 observations from 37 schools had complete data collected and were included in the analyses. Table 1 presents baseline characteristics of the study population. 282 participants with 707 observations had study observations conducted during each individual's academic school year. The mean age of the study population was 7.9 years with the majority of participants (72%) identifying as Black/African American or Hispanic/Latino. 41% of the study participants reported an annual household income less than $25,000. Almost one third of participants reported a smoker at home (32%). Most of the participants (70%) were sensitized to at least one allergen (Table 1). Participants had a mean of 3.0 days with asthma symptoms in the prior 2 weeks.

School distance to major roadways ranged from 13 meters to 509 meters. 62% of the population (n=174) attended school within 100 meters of a major roadway (Figure 1). Residential distance to major roadways ranged from 1.8 to 573 meters. 67% of the population (n=234) resided within 100 meters of a major roadway. Residential and school proximity to major roadways were not correlated (Pearson correlation 0.08).

Figure 2 illustrates the spline of the joint effect of residential and school traffic proximity and the primary outcome of interest, maximum symptom days. In adjusted analyses, roadway proximity greater than a threshold of 100 meters was significantly associated with increased asthma symptom days. The slope up to 100 meters is not statistically significant, $p=0.25$. For every 100 meters from a major roadway, study participants residing and attending school farther from major roadways reported 29% fewer asthma symptom days per 2-week period compared to children residing and attending school more proximal to major roadways (Table 2). For each 100 meters farther from major roadways, children had significantly decreased asthma symptom days (1.1 days, 1.5 days, 2.0 days, 2.6 days, and 3.3 days at 500, 400, 300, 200, and 100 meters respectively). The effect estimates for the component variables (daytime wheeze, activity limitations and nighttime wheeze) that comprise maximum asthma symptom days can be seen in Table 2. There was no evidence that the effect varied by sensitization status as there was not a significant interaction effect of traffic proximity with allergen sensitization on the primary outcome of asthma symptom

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days (p=0.20). Several covariates were significantly associated with asthma symptoms and thus were included in all adjusted models: annual household income, environmental tobacco smoke exposure, asthma controller medication at baseline, recent upper respiratory tract infection, and seasonality. Additionally, we performed a subset analysis that adjusted for endotoxin and mouse allergen levels at school that was limited to the school year observations. The main findings of our study were preserved in this subset analysis. For every 100 meters from a major roadway, study participants residing and attending school farther from major roadways reported 36% fewer asthma symptom days per 2-week period during the school year compared to children more proximal to major roadways. (Supplemental Table 1).

Analysis of secondary outcomes (Table 2) found a significant association with health care utilization, poor asthma control and markers of airflow obstruction on spirometry. In multivariate analyses, above a threshold of 100 meters, for each 100 meters increase in distance from major roadway, children had 37% less utilization of health care compared to those more proximal to major roadways (IRR 0.63, 95% CI: 0.47–0.85). Children were 20% less likely to be in poor asthma control for every 100 meter distance to major roadway compared to those more proximal (OR 0.80, 95% CI 0.69–0.94). For each 100 meters increase in distance from major roadway, children had 1.39%, (95% CI 0.18 – 2.60) significant increase in FEV1/FVC ratio. However, we also found that the greater distance from a major roadway is associated with a lower FVC, percent predicted, and that it is this association that explains the fact that distance to roadway in these particular analyses is associated with FEV_1/FVC, but not FEV_1. Collectively, there was no meaningful association between distance to major roadways and lung function outcomes.

Discussion

In this longitudinal cohort study of urban school-aged children with asthma, a composite measure of residential and school proximity to major roadways was significantly associated with increased asthma symptom days, health care utilization and poor asthma control, independent of other known risk factors. These results highlight the important relationships between exposure to major roadways and asthma morbidity in urban school-aged children. While environmental studies often focus only on the home setting, which is the predominant driver in these analyses; these findings indicate that a child’s home and potentially their school may be important environmental co-contributors to asthma morbidity.

The primary outcome, maximum symptom days, has been widely used to classify asthma morbidity in epidemiologic studies and randomized controlled trials.(15–17,43–45) The findings presented here suggest that if the time a child spends proximal to major roadways could be mitigated, asthma symptoms would be reduced by up to 57 fewer days, annually. Additionally, there would be a significant reduction in health care utilization averaged over a year and improved markers of asthma control.

This study expands prior research from this cohort that school exposure to traffic related pollutants such as nitrogen dioxide are associated with decrements in lung function.(17) Additionally, traffic proximity, whether secondary to transportation-related noise or other

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factors, is associated with self-rated stress, which is also a predictor of asthma morbidity.(55–61) Traffic proximity has also been shown to be associated with respiratory infections, which can exacerbate asthma symptomatology.(27,62) Based on prior literature evaluating the spatial extent of impact of mobile source pollution, we hypothesize that the 100 meter inflection point represents exposure that may be dominated by road dust and primary traffic pollutants like elemental carbon, fresh particulate matter mass, ultrafine particles and nitric oxide(63), though there may well be a contribution of regional pollution to the mix. Further evaluation of the specific mechanism that proximity to major roads influences asthma is important, but is beyond the scope of this study.

There has been conflicting studies on the interaction effect between traffic related air pollution and allergen sensitization on asthma morbidity, and whether pollution differentially affects children with atopic asthma than non-atopic asthma.(29,51–54) In this context, our data did not support that children with atopic asthma (or positive allergen sensitization) are differentially more susceptible to the exposure derived from traffic proximity as compared to those children with nonatopic asthma, suggesting that it is a ubiquitous risk factor for children with asthma, regardless of atopic status. The reason for this may be that pollution can both augment the allergic response, and act as a respiratory irritant, through oxidative stress and non-allergic airway inflammation, both of which can exacerbate asthma.(17,53,54,64)

The longitudinal design of this study allows us to evaluate more in depth the joint relationship between school and home distance to major roadway and asthma morbidity by serial observations during the study period. Viewing exposure as a composite measure between both the school and home environments is novel given that most childhood studies focus only one or the other of these locations. In utilizing this combination exposure method, we identified a robust association between major roadway proximity and asthma symptoms in both univariate and multivariate adjusted models. Additionally, we found a statistically significant association between major roadway proximity at home, independent of school proximity, and asthma symptom days and poor asthma control (Supplemental Table 2). For every 100 meters from a major roadway, study participants residing farther from major roadways reported 31% fewer asthma symptom days per 2-week period compared to children residing more proximal to major roadways. Although we did not find a continuous effect of school distance to major roadway (Supplemental Table 3), independent of home, we did find that children attending schools that were located within 100 meters from major roadway had a significant increased odds ratio of maximum symptom days as compared to schools located farther away, even after controlling for home exposure (Supplemental Table 4). Children were well characterized both at baseline and during follow-up visits allowing us to identify the contribution of major roadway proximity on asthma morbidity. These results strengthen a body of literature that traffic proximity contributes to exacerbation of asthma.(10,17,28,35,36)

There are some limitations to this study. The estimates of school major roadway proximity are based at the center of the school land parcel and therefore may underestimate the distance at individual classrooms or immediate effects of idling vehicles at school drop-off and pickup areas, nor does it account for diurnal school-related traffic patterns. Despite this

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potential exposure misclassification, we were still able to find a significant relationship with asthma morbidity. Importantly, the impact of potential misclassification of exposure would be expected to be non-differential with respect to asthma morbidity. Additionally, the spline modeling approach was a post-hoc approach and clustering at multiple levels may not have been fully accounted for given that the statistical methods required were not feasible given the distribution of children across the schools. We also do not have data on traffic proximity exposures while the participants were in-utero or during infancy or early childhood thus were unable to account for these exposures.(36) For analyses evaluating the independent effect of school exposure and home exposure, adjusting for school, we had to exclude 640 (47.5%) observations that occurred outside of the academic school year, greatly diminishing the power of these analyses. (Supplemental Table 1–4). The inner-city nature of our cohort represents a highly exposed population, with the exception of a single outlier observation; all observations were less than 600 meters from a major roadway at home or school. Given this, this analysis may be less generalizable to more rural locations in the United States.

To our knowledge, this is one of the first comprehensive U.S. inner-city school based studies to examine joint residential and school-based major roadway proximity and asthma morbidity in students. Major roadways may explain why inner-city children experience a higher burden of disease and higher asthma morbidity. The findings of this study highlight the potential for robust and clinically important improvements in student's asthma with public policy and home and school-based environmental interventions to minimize the effect of exposure to nearby roadways. One example of public policy is demonstrated by the State of California, which has largely prohibited siting of schools within 500 feet (152 meters) of freeways (SB 352, approved October 2003).(19) This requires further study, but changes in zoning regulations for new school, childcare facilities, or public housing and/or improved ventilation strategies at existing homes or schools built most proximal to major roadways may be considerations. Addressing school-based exposures or large residential buildings may offer an efficient means to affect the health of whole populations of vulnerable children with focused interventions, compared to individualized personal interventions.

Conclusions

Our findings provide substantial evidence that major roadway proximity plays an important role in asthma morbidity in inner-city school children. These findings suggest that exposure reduction strategies at the home and potentially at the school level may have broad and substantial health benefits for children. Further studies are warranted especially to evaluate the impact of school traffic proximity on asthma morbidity.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations:

GIS	Geographic Information Systems
SICAS	School Inner City Asthma Study
TIGER	Topologically Integrated Geographic Encoding and Referencing
μg/g	microgram per gram
EU/m^3	endotoxin unit
FEV$_1$	Forced expiratory volume in one second
FVC	Forced vital capacity
FEV$_1$/FVC	The percent of forced expiratory volume in one second over forced vital capacity
FEF$_{25–75}$	Forced expiratory flow at 25–75% of the forced vital capacity

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Clinical Implications:

This study demonstrates that proximity to major roadways, a composite measurement accounting for both home and school exposure, primarily driven by home proximity to major roadway is associated with increased asthma symptoms, health care utilization, and poor asthma control.

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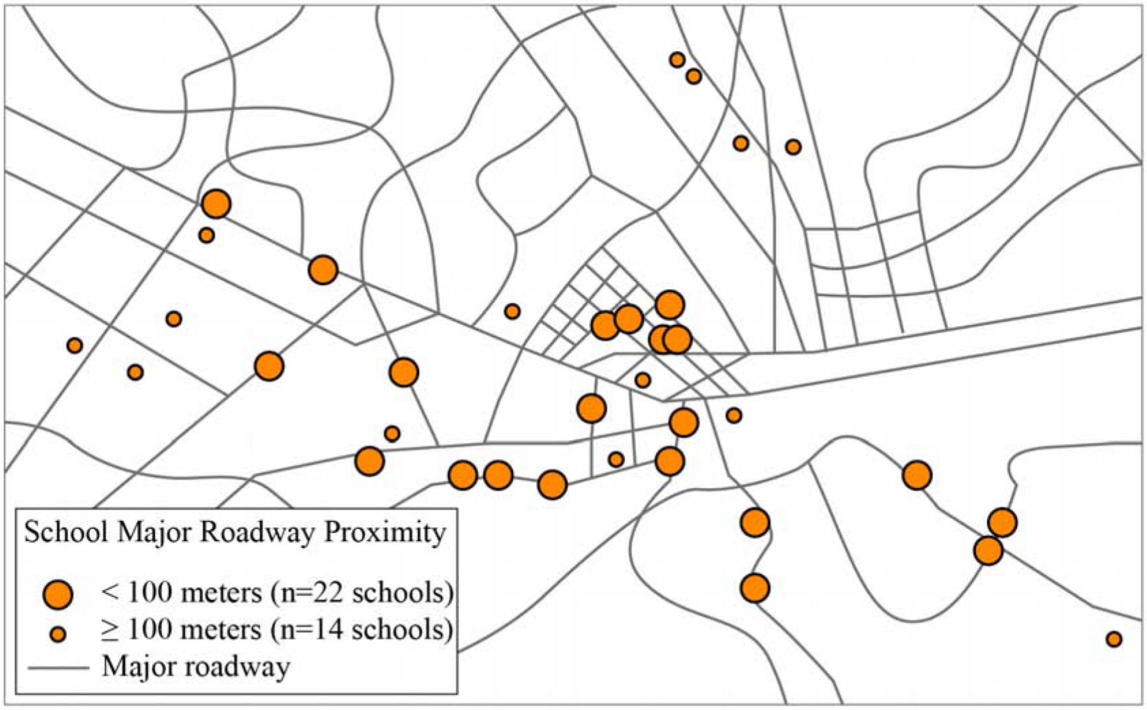

Figure 1:
School Distance to Major Roadways

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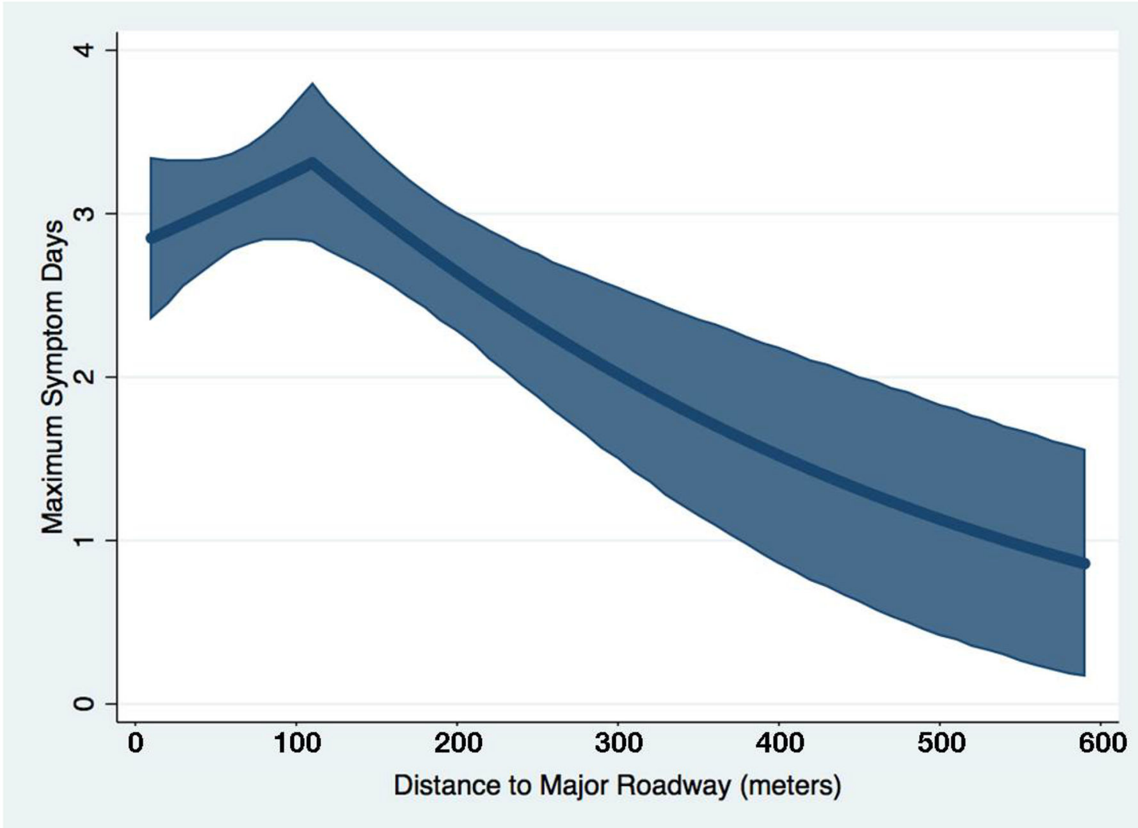

Figure 2.
Effect of Traffic Proximity on Maximum Symptom Days.
The association of traffic proximity and maximum symptom days is shown with a breakpoint at a major roadway distance of 100 meters. The shaded area represents 95% CIs.

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Table 1.

Baseline Characteristics of Study Population

	All Study Participants n(%)
Population	350
Age, Mean (Range), years	7.9 (4 – 13)
Female Gender	165 (47.1%)
Race/Ethnicity	
Black/African American	122 (35%)
Hispanic/Latino	130 (37%)
White	16 (5%)
Mixed/Other	82 (23%)
Environmental Tobacco Smoke	116 (33%)
Use of controller medication at baseline	193 (55%)
Atopic Asthma	
(Any Allergen Sensitization)	232 (70%)
Annual Household Income	
< $25,000	144 (41%)
≥ $25,000	145 (41%)
Missing	61 (17%)
Upper Respiratory Infection in Prior 2 Weeks	
Yes	79 (23%)
Traffic Proximity, Mean (Range), meters	85 (2 – 573)

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Table 2.

Effect of Combined Major Roadway Proximity on Asthma Symptoms[†]

	Unadjusted Analyses		**Adjusted[*] Analyses**	
Effect estimates are based on each 100m farther away from major roadway				
	OR (95% CI) n=350	**p-value**	**OR (95% CI) n=350**	**p-value**
Primary Outcome *Components*				
Maximum Symptom Days[***]	0.68 (0.53 – 0.87)	p<0.01	0.71 (0.58 – 0.87)	p<0.01
Daytime Wheeze[**]	0.70 (0.54 – 0.91)	p<0.01	0.76 (0.61 – 0.95)	p=0.02
Limitations in Activities[***]	0.62 (0.42 – 0.90)	p=0.01	0.61 (0.43 – 0.88)	p<0.01
Nighttime Wheeze	0.71 (0.49 – 1.04)	p=0.08	0.79 (0.59 – 1.05)	p=0.10
Secondary Outcomes				
Health Care Utilization[***]	0.69 (0.52 – 0.92)	p=0.01	0.63 (0.47 – 0.85)	p<0.01
Missed School Days	0.85 (0.41 – 1.78)	p=0.66	0.97 (0.54 – 1.74)	p=0.92
Caregiver Plans Changed	0.72 (0.41 – 1.25)	p=0.24	0.73 (0.43 – 1.24)	p=0.24
Caregiver Lost Sleep	0.69 (0.46 – 1.01)	p=0.06	0.75 (0.54 – 1.06)	p=0.10
Composite Poor Asthma[***]	0.77 (0.65 – 0.92)	p<0.01	0.80 (0.69 – 0.94)	p<0.01
Spirometry Outcomes	**β (95% CI)** n=327	**p-value**	**β (95% CI)** n=327	**p-value**
FEV_1, % predicted	−1.02 (−4.57 – 2.54)	p=0.58	−0.44 (−4.20 – 3.31)	p=0.82
FVC, % predicted	−2.77 (−5.45 - −0.10)	p=0.04	−2.26 (−5.15 – 0.64)	p=0.13
FEV_1/FVC, percent[**]	1.39 (0.18 – 2.60)	p=0.03	1.39 (0.18 – 2.60)	p=0.03
$FEF_{25–75}$, % predicted	−2.60 (−10.76 – 5.56)	p=0.53	−2.77 (−10.93 – 5.39)	p=0.51

FEV_1: Forced expiratory volume in one second; FVC: Forced Vital Capacity; FEV_1/FVC: The percent of forced expiratory volume in one second over forced vital capacity; $FEF_{25–75}$: Forced expiratory flow at 25–75% of the forced vital capacity.

[*] **Adjusted for:** age, sex, race/ethnicity, annual household income, environmental tobacco smoke, controller medication, recent upper respiratory infections, and seasonality. Models for FEV_1, % predicted and $FEF_{25–75}$, % predicted did not adjust separately for age, sex, and race/ethnicity as these are included in the percent prediction estimates.

[**] p<0.05 in adjusted analyses;

[***] p<0.01 in adjusted analyses.

[†] Includes all study participants (n=1327 observations; n=350 participants) and corresponding spirometry outcomes (n=645 observations; n=327 participants)