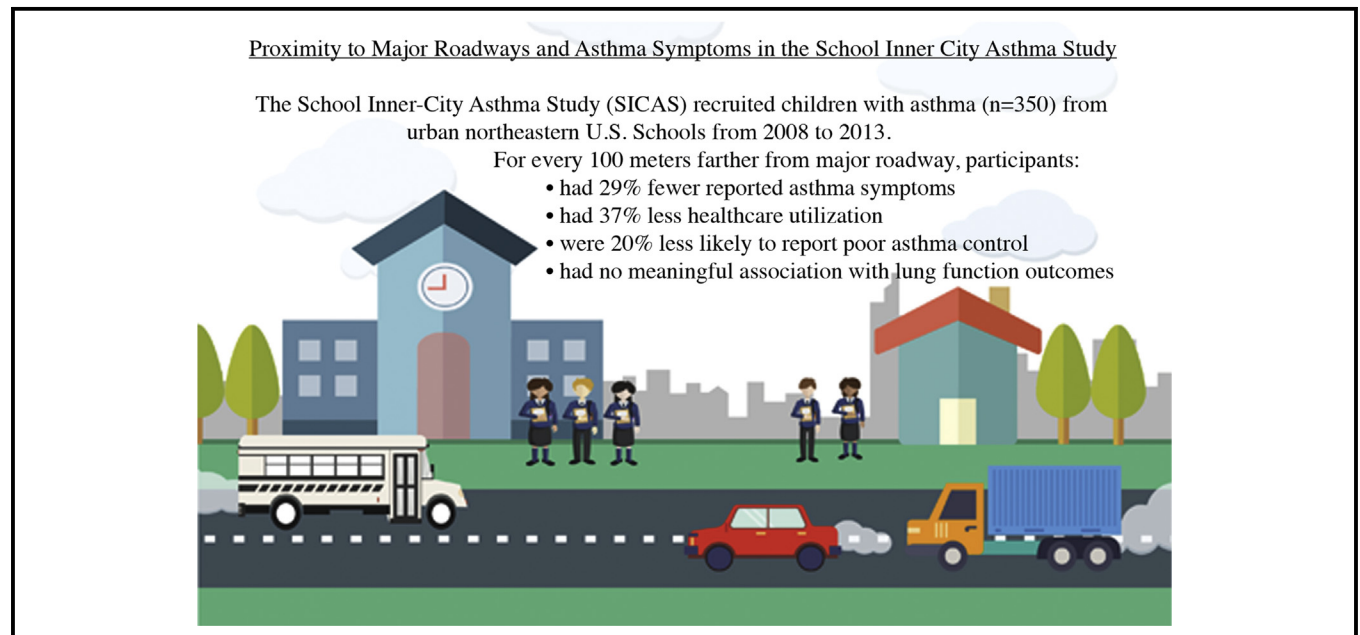


Proximity to major roadways and asthma symptoms in the School Inner-City Asthma Study

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GRAPHICAL ABSTRACT



Background: Traffic proximity has been associated with adverse respiratory health outcomes. Less is known about the combined impact of residential and school exposures on pediatric asthma.

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

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Supported by National Institutes of Health (NIH) grants R01AI073964 (to W.P.), R01AI073964-02S1 (to W.P.), K24AI106822 (to W.P.), U10HL098102 (to W.P.), U01AI110397 (to W.P.), U19AR06952 (to W.P.), 1R01HL137192 (to W.P.), K23AI106945 (to J.M.G.), K23AI104780 (to W.J.S.), K23ES023700 (to P.S.L.), P01 ES009825 (to D.R.G.), U19AR069525 (to W.P. and M.H.), and P30ES000002 (to D.R.G. and M.H.) and United States Environmental Protection Agency (USEPA) grant RD-83479801. This work was also supported in part by the American College of Allergy, Asthma & Immunology Young Faculty Award; a Boston Children's Hospital Division of Immunology Clinical Research Advisory Group Research Grant; and the Allergy and Asthma Awareness Initiative. This work was conducted with support from Harvard Catalyst/Harvard Clinical and Translational Science Center (NIH award no. UL1TR001102) and financial contributions from Harvard University and its affiliated academic healthcare centers. This work was also funded in part by cooperative agreement award number FAIN: U61TS000237 from the Agency for Toxic Substances and Disease Registry (ATSDR). The USEPA supports the Pediatric

Environmental Health Specialty Units by providing partial funding to the ATSDR under Inter-Agency Agreement no. DW-75-92301301. The content is solely the responsibility of the authors and does not necessarily represent the official views of the Harvard Catalyst, Harvard University, and its affiliated academic health care centers; the National Center for Research Resources; or the NIH. Its contents are solely the responsibility of the grantee and do not necessarily represent the official views of the ATSDR or USEPA. Furthermore, USEPA or ATSDR do not endorse the purchase of any commercial products or services mentioned in the publication. Supplies were generously donated or discounted as follows: Lincoln Diagnostics (Decatur, Ill) donated Multi-Test II devices and Greer Laboratories (Lenoir, NC) donated allergenic extracts for skin testing. Aspects of this manuscript were presented at the 2017 Pediatric Academic Societies Meeting; M.H. was awarded the 2017 Academic Pediatric Association's Michael Shannon Research Award for this work.

Disclosure of potential conflict of interest: The authors declare that they have no relevant conflicts of interest.

Clinical Trial Registration NCT01756391.

Received for publication February 1, 2018; revised July 31, 2019; accepted for publication August 22, 2019.

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<https://doi.org/10.1016/j.jaci.2019.08.038>

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 measure accounting for both home and school traffic exposure. Generalized estimating equation models were clustered by subject and adjusted for age, race/ethnicity, sex, income, environmental tobacco smoke, controller medication, upper respiratory tract infections, and seasonality.

Results: The majority of participants (62%) attended schools within 100 m from major roadways, and 40% also resided within 100 m of major roadways. In multivariate analyses major roadway proximity was independently associated with increased asthma symptom days. At greater than the threshold of 100 m, children had 29% less odds of a symptom day over the past 2 weeks for each 100-m increase in distance from a major roadway (odds ratio, 0.71; 95% CI, 0.58-0.87; $P < .01$). Children farther from a major roadway also had significantly less reported health care use (odds ratio, 0.63; 95% CI, 0.47-0.85; $P < .01$) and were significantly less likely to have poor asthma control (odds ratio, 0.80; 95% CI, 0.69-0.94; $P < .01$). There was not a meaningful association between distance to a major roadway and lung function outcomes.

Conclusions: Proximity to a major roadway, a composite measure of home and school exposure but primarily driven by home exposure, was associated with greater asthma morbidity. More studies are needed to evaluate the independent effect of school distance to a roadway on asthma morbidity. (J Allergy Clin Immunol 2019;■■■:■■■-■■■.)

Key words: Asthma, school, geographic information systems, spatial analysis, traffic proximity, environmental health disparities, School Inner-City Asthma Study, environmental exposure

Asthma is the most common noncommunicable childhood disease, affecting approximately 8% of children globally and more than 6 million children in the United States, with an increasing prevalence worldwide.¹⁻³ Urban minority children of low socioeconomic status endure disproportionately high asthma morbidity.⁴

Airborne pollutant, aeroallergen, and mold exposures in the inner-city home environment are associated with significant childhood asthma morbidity.⁵⁻⁷ Although the home environment has been extensively studied, many studies do not account for residential mobility or daily activity patterns (eg, school location). Additionally, the environment outside of the home is less well understood, largely because of logistical and community hurdles. Recently, several US 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 to 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

Abbreviations used

FVC: Forced vital capacity

GIS: Geographic information systems

emissions of various pollutants, such as particulate matter; mobile source air toxicants, such as benzene, nitrogen oxides, hydrocarbons, and carbon monoxide; and other pollutants.¹⁸ Prior studies have documented that chronic exposure to major highways, especially living within 100 m,^{19,20} has been associated with increased risk of respiratory tract infections and asthma development in children, but less is known about the school environment.^{10,20-28} A meta-analysis in 5 European birth cohorts did not demonstrate an association with air pollution and 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 US students (6.2%) who attend school less than 100 m from major roadways.³⁴ This population also reflects racial and socioeconomic disparities, with greater 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 al¹⁰ 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 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 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 is a 5-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 before the next academic year, which included a detailed questionnaire and aeroallergen sensitization assessment using allergy skin testing (Multi-Test device; Lincoln Diagnostics, Decatur, Ill) 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 criteria modeled from other urban studies and adapted for the School Inner-City Asthma Study^{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 in which 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 participants' residential addresses by using GIS Arc-GIS 10.2.2 software (Environmental Systems Research Institute, Redlands, Calif), with 80% spelling sensitivity, which allows for only minor variations in address spelling, and a 10-m offset from a roadway based on a georeferenced 2014 US Census Bureau's Master Address File/Topologically Integrated Geographic Encoding and Referencing 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 hours weekly or 24% during the 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 residential traffic exposure, controlling for school, and the inverse 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 Department of Transportation spatial data. We defined major roadways as those of 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 might be more important than traffic volume in influencing whether trucks and buses regularly use a road.¹⁸ Asthma morbidity outcomes were linked to the distance to a major roadway at the geocoded address at the time of each respective baseline and follow-up visits and the temporally closest visit address for spirometric outcomes. For confidentiality purposes, geographic masking techniques were used for Fig 1; the relationship between distance to major roadways and schools was preserved.⁴²

The relationship between distance to a major roadway and our primary outcome was evaluated with locally weighted regression 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 m to be used in subsequent models. Relationships between distance and health outcomes are presented as the effect of a 100-m change in distance to major roadways greater than the threshold value of 100 m.

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 before each questionnaire administration: (1) number of days during which the child had daytime wheezing, chest tightness, or cough; (2) number of days during which the child had to slow down or discontinue play activities because of wheezing, chest tightness, or cough; and (3) number of nights during which

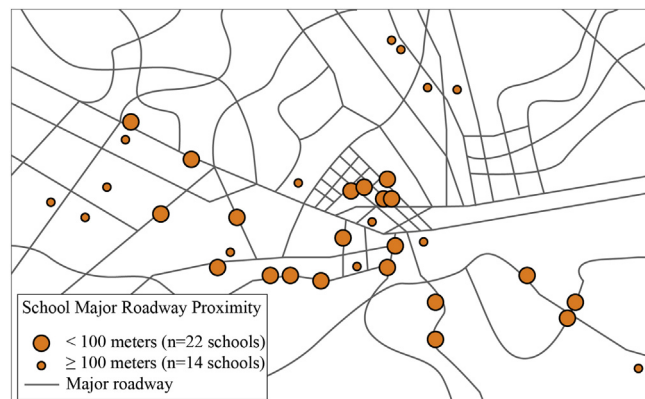


FIG 1. School distance to major roadways.

the child had wheezing, chest tightness, or cough, leading to disturbed sleep. This variable ranges from 0 to 14 days.

Secondary outcome measures included the following: missed school, defined as the number of reported days the child missed school over the prior 2 weeks; health care use, defined as the number of hospitalizations and unscheduled health care visits for asthma averaged over a year; caregiver plans changed, defined as the number of days the caregiver changed plans because of the child's asthma over the prior 2 weeks; caregiver lost sleep, defined as the number of nights the caregiver lost sleep because of the child's asthma over the prior 2 weeks; and poor asthma control as identified by any of the following in the past 4 weeks: shortness of breath more than twice weekly, nighttime awakenings caused by asthma at least once, limitation in activity level, or use of rescue asthma medication 2 or more times weekly. Spirometric outcomes were also included. The FEV₁/forced vital capacity (FVC) ratio is the most sensitive marker of airflow obstruction in children with asthma.^{46,47} FEV₁ percent predicted, FVC percent predicted, and forced expiratory flow between the 25th and 75th percentile of FVC, a measure of medium- and small-caliber airways, were also assessed. All spirometric outcomes were assessed and only included in subsequent analyses if they met American Thoracic Society guidelines for acceptability and repeatability by study physicians.^{48,49} Reference values were derived from 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 roadway proximity changed by greater than 10% in univariate analyses or were chosen *a priori* based on prior biological knowledge or prior studies from this cohort. The following covariates were included in the final model: age, sex, race/ethnicity, annual household income, use of asthma controller medication at baseline, seasonality, report of sneezing or cold symptoms over past 2 weeks, and environmental tobacco smoke exposure.

Primary analyses assessed the joint effect of a composite measure of residential and school major roadway proximity 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 based on skin prick test responses or specific IgE levels 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 Laboratories). Previous research from this school-based cohort detailed that the collection procedures and associated health effects of classroom exposures to mouse allergen and endotoxin obtained by using 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; white; and mixed/other). Household income levels were stratified by federal poverty levels based on a 4-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 who were missing individual income data. Seasonality was defined as a continuous measure of the number of days since the start of the calendar year and was modeled with linear and quadratic terms.

The following variables were evaluated but not included in the final model because they did not change effect estimates by at least 10% in univariate models: prematurity; family history of asthma; overweight/obese status; 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 the 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 with an exchangeable correlation structure, robust variance estimates, and clustering 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-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 m. Given all other measurements were less than 600 m, this outlier was recoded to the next highest value, 573 m. An interaction term was created for traffic proximity and allergen sensitization; however, this was not statistically significant, and therefore only main effects were reported. Binomial family generalized estimating equations with a logit link were used for asthma-related 2-week health outcomes (ie, 2-week outcomes were modeled as the sum of 14 binomial “successes”).

Statistical analyses were performed with Stata 13.1 software (StataCorp, College Station, Tex). In all models main effects were considered statistically significant at a *P* value of less than .05, and we evaluated the interaction effect at a threshold *P* value of .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, 36 discrete locations, had complete data collected and were included in the analyses. **Table I** presents baseline characteristics of the study population. Two hundred eighty-two participants with 707 observations had study observations conducted during each subject'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. Forty-one percent of the study participants reported an annual household income of 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 1 allergen (**Table I**). Participants had a mean of 3.0 days with asthma symptoms in the prior 2 weeks.

School distance to major roadways ranged from 13 to 509 m. Sixty-two percent of the population (*n* = 174) attended school within 100 m of a major roadway (**Fig 1**). Residential distance to major roadways ranged from 1.8 to 573 m. Sixty-seven percent of the population (*n* = 234) resided within 100 m of a major roadway. Residential and school proximity to major roadways were weakly correlated (Pearson correlation = 0.20, *P* < .001).

TABLE I. Baseline characteristics of the study population

	All study participants, no. (%)
Population	350
Age (y), mean (range)	7.9 (4-13)
Female sex	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 tract infection in the prior 2 wk, yes	79 (23%)
Traffic proximity (m), mean (range)	85 (2-573)

Fig 2 shows 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 of greater than a threshold of 100 m was significantly associated with increased asthma symptom days. The slope up to 100 m is not statistically significant (*P* = .25). For every 100 m 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 with children residing and attending school more proximal to major roadways (**Table II**). For each 100 m farther from major roadways, children had significantly decreased asthma symptom days (1.1, 1.5, 2.0, 2.6, and 3.3 days at 500, 400, 300, 200, and 100 m, respectively). Effect estimates for the component variables (daytime wheeze, activity limitations, and nighttime wheeze) that comprise maximum asthma symptom days can be seen in **Table II**. There was no evidence that the effect varied by sensitization status because there was not a significant interaction effect of traffic proximity with allergen sensitization on the primary outcome of asthma symptom days (*P* = .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 m 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 with children more proximal to major roadways (see **Table E1** in this article's Online Repository at www.jacionline.org).

Analysis of secondary outcomes (**Table II**) found a significant association with health care use, poor asthma control, and markers of airflow obstruction on spirometry. In multivariate

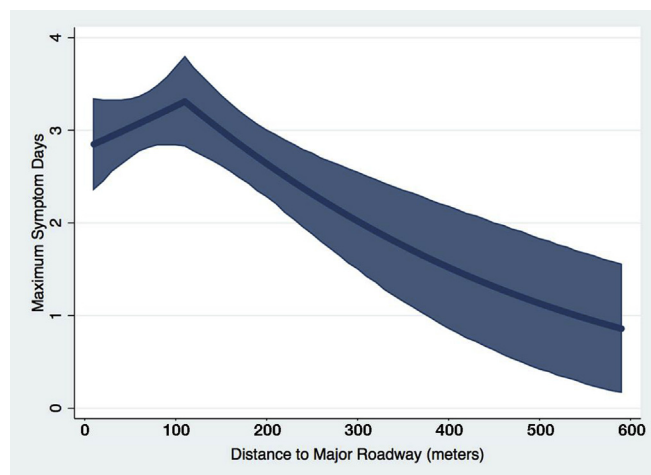


FIG 2. Effect of traffic proximity on maximum symptom days. The association of traffic proximity and maximum symptom days is shown with a breakpoint at a major roadway distance of 100 m. The shaded area represents 95% CIs.

analyses, at a threshold of greater than 100 m, for each 100-m increase in distance from a major roadway, children had 37% less health care use compared with those more proximal to major roadways (odds ratio, 0.63; 95% CI, 0.47-0.85). Children were 20% less likely to have poor asthma control for every 100-m distance to a major roadway compared with those more proximal (odds ratio, 0.80; 95% CI, 0.69-0.94). For each 100-m increase in distance from a major roadway, children had a 1.39% (95% CI, 0.18% to 2.60%) significant increase in FEV₁/FVC ratio. However, we also found that 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 FEV₁/FVC but not FEV₁. 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 use, 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. Although 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 might 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 use 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 decreases in lung function.¹⁷ Additionally, traffic proximity, whether secondary to transportation-related noise or other 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 tract infections, which can exacerbate asthma symptomatology.^{27,62} Based on prior literature evaluating the spatial extent of effect of mobile source pollution, we hypothesize that the 100-m inflection point represents exposure that might be dominated by road dust and primary traffic pollutants, such as elemental carbon, fresh particulate matter mass, ultrafine particles, and nitric oxide,⁶³ although there might 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 beyond the scope of this study.

There have 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 nonatopic 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 exposure derived from traffic proximity compared with children with nonatopic asthma, suggesting that it is a ubiquitous risk factor for children with asthma, regardless of atopic status. The reason for this might be that pollution can both augment the allergic response and act as a respiratory irritant through oxidative stress and nonallergic 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 roadways 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 on only one or the other of these locations. In using 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 (see Table E2 in this article's Online Repository at www.jacionline.org). For every 100 m from a major roadway, study participants residing farther from major roadways reported 31% fewer asthma symptom days per 2-week period compared with children residing more proximal to major roadways. Although we did not find a continuous effect of school distance to a major roadway (see Table E3 in this article's Online Repository at www.jacionline.org), independent of home distance, we did find that children attending schools that were located within 100 m from a major roadway had a significantly increased odds ratio of maximum symptom days compared with schools located farther away, even after controlling for home exposure (see Table E4 in this article's Online Repository at www.jacionline.org). 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

TABLE II. Effect of combined major roadway proximity on asthma symptoms[§]

	Unadjusted analyses		Adjusted* analyses	
	OR (95% CI), n = 350	P value	OR (95% CI), n = 350	P value
Primary outcome: components				
Maximum symptom days [‡]	0.68 (0.53 to 0.87)	<.01	0.71 (0.58 to 0.87)	<.01
Daytime wheeze [†]	0.70 (0.54 to 0.91)	<.01	0.76 (0.61 to 0.95)	.02
Limitations in activities [‡]	0.62 (0.42 to 0.90)	.01	0.61 (0.43 to 0.88)	<.01
Nighttime wheeze	0.71 (0.49 to 1.04)	.08	0.79 (0.59 to 1.05)	.10
Secondary outcomes				
Health care use [‡]	0.69 (0.52 to 0.92)	.01	0.63 (0.47 to 0.85)	<.01
Missed school days	0.85 (0.41 to 1.78)	.66	0.97 (0.54 to 1.74)	.92
Caregiver plans changed	0.72 (0.41 to 1.25)	.24	0.73 (0.43 to 1.24)	.24
Caregiver lost sleep	0.69 (0.46 to 1.01)	.06	0.75 (0.54 to 1.06)	.10
Composite poor asthma [‡]	0.77 (0.65 to 0.92)	<.01	0.80 (0.69 to 0.94)	<.01
Spirometric outcomes				
	β (95% CI), n = 327	P value	β (95% CI), n = 327	P value
FEV ₁ (% predicted)	−1.02 (−4.57 to 2.54)	.58	−0.44 (−4.20 to 3.31)	.82
FVC (% predicted)	−2.77 (−5.45 to −0.10)	.04	−2.26 (−5.15 to 0.64)	.13
FEV ₁ /FVC (% predicted) [†]	1.39 (0.18 to 2.60)	.03	1.39 (0.18 to 2.60)	.03
FEF ₂₅₋₇₅ (% predicted)	−2.60 (−10.76 to 5.56)	.53	−2.77 (−10.93 to 5.39)	.51

Effect estimates are based on each 100 m farther from a major roadway.

FEF₂₅₋₇₅, Forced expiratory flow at 25% to 75% of forced vital capacity; OR, odds ratio.

*Adjusted for age, sex, race/ethnicity, annual household income, environmental tobacco smoke, controller medication, recent upper respiratory tract infections, and seasonality. Models for FEV₁ percent predicted and FEF₂₅₋₇₅ percent predicted did not adjust separately for age, sex, and race/ethnicity because these are included in the percent prediction estimates.

[†]P < .05 in adjusted analyses.

[‡]P < .01 in adjusted analyses.

[§]Includes all study participants (n = 1327 observations; n = 350 participants) and corresponding spirometric outcomes (n = 645 observations; n = 327 participants).

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 might underestimate the distance at individual classrooms or immediate effects of idling vehicles at school drop-off and pickup areas and do not account for diurnal school-related traffic patterns. Despite this potential exposure misclassification, we were still able to find a significant relationship with asthma morbidity. Importantly, the effect of potential misclassification of exposure would be expected to be nondifferential with respect to asthma morbidity.

Additionally, the spline modeling approach was a *post hoc* approach, and clustering at multiple levels might not have been fully accounted for given that the statistical methods required were not feasible given the distribution of children across 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 (see Tables E1-E4).

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 m from a major roadway at home or school. Given this, this analysis might be less generalizable to more rural locations in the United States.

To our knowledge, this is one of the first comprehensive US inner-city school-based studies to examine joint residential and

school-based major roadway proximity and asthma morbidity in students. Major roadways might explain why inner-city children experience a greater burden of disease and greater asthma morbidity. The findings of this study highlight the potential for robust and clinically important improvements in the 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 ft (152 m) of freeways (SB 352, approved October 2003).¹⁹ This requires further study, but changes in zoning regulations for new schools, childcare facilities, or public housing and/or improved ventilation strategies at existing homes or schools built most proximal to major roadways might be considerations. Addressing school-based exposures or large residential buildings might offer an efficient means to affect the health of whole populations of vulnerable children with focused interventions compared with individualized personal interventions.

In conclusion, 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 might have broad and substantial health benefits for children. Further studies are warranted, especially to evaluate the effect of school traffic proximity on asthma morbidity.

We acknowledge the insights provided by Sachin Baxi, MD; Lisa Bartnikas, MD; Meredith Dilley, MD; Margee Louisias, MD, MPH; Jeffrey Blossom, MS; Steve Melly, MA; Perdita Permaul, MD; Maritha Du; the Harvard University Center for Geographic Analysis, the Harvard-wide Pediatrics

Health Services Research Fellowship, and the School Inner-City Asthma study staff. We also acknowledge the community of parents, nurses, staff, and children who have contributed to this work.

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

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TABLE E1. Effect of combined major roadway proximity on asthma symptoms for all study observations and limited to within school year observations

	Adjusted analyses*‡		Adjusted analyses†§	
	OR (95% CI), n = 350 participants	P value	OR (95% CI), n = 282 participants	P value
Primary outcome: components				
Maximum symptom days	0.71 (0.58 to 0.87)	<.01	0.64 (0.49 to 0.84)	<.01
Daytime wheeze	0.76 (0.61 to 0.95)	.02	0.67 (0.50 to 0.89)	<.01
Limitations in activities	0.61 (0.43 to 0.88)	<.01	0.39 (0.19 to 0.79)	<.01
Nighttime wheeze	0.79 (0.59 to 1.05)	.10	0.68 (0.46 to 1.01)	.05
Secondary outcomes				
Health care use	0.63 (0.47 to 0.85)	<.01	0.64 (0.40 to 1.01)	.05
Missed school days	0.97 (0.54 to 1.74)	.92	0.57 (0.24 to 1.31)	.18
Caregiver plans changed	0.73 (0.43 to 1.24)	.24	0.54 (0.22 to 1.33)	.18
Caregiver lost sleep	0.75 (0.54 to 1.06)	.10	0.58 (0.34 to 1.00)	.05
Composite poor asthma control	0.80 (0.69 to 0.94)	<.01	0.74 (0.62 to 0.88)	<.01
Spirometric outcomes				
	β (95% CI), n = 327	P value	β (95% CI), n = 188	P value
FEV ₁ (% predicted)	−0.44 (−4.20 to 3.31)	.82	−3.10 (−7.07 to 0.86)	.13
FVC (% predicted)	−2.26 (−5.15 to 0.64)	.13	−4.27 (−6.71 to −1.84)	<.01
FEV ₁ /FVC (%)	1.39 (0.18 to 2.60)	.03	0.50 (−1.31 to 2.31)	.59
FEF ₂₅₋₇₅ (% predicted)	−2.77 (−10.93 to 5.39)	.51	−8.31 (−20.45 to 3.82)	.18

Effect estimates are based on each 100 m farther from a major roadway.

FEF₂₅₋₇₅, Forced expiratory flow at 25% to 75% of forced vital capacity; OR, odds ratio.

*Adjusted for age, sex, race/ethnicity, annual household income, environmental tobacco smoke, controller medication, recent upper respiratory tract infections, and seasonality. Models for FEV₁ percent predicted and FEF₂₅₋₇₅ percent predicted did not adjust separately for age, sex, and race/ethnicity because these are included in the percent prediction estimates (as presented in Table II).

†Adjusted for age, sex, race/ethnicity, annual household income, environmental tobacco smoke, controller medication, recent upper respiratory tract infections, endotoxin and mouse allergen levels, and seasonality. Models for FEV₁ percent predicted and FEF₂₅₋₇₅ percent predicted did not adjust separately for age, sex, and race/ethnicity because these are included in the percent prediction estimates.

‡Includes all study participants (n = 1327 observations; n = 350 participants) and corresponding spirometric outcomes (n = 645 observations; n = 327 participants).

§Limited to within school year observations (n = 707 observations; n = 282 participants) and corresponding spirometric outcomes (n = 321 observations; n = 188 participants).

TABLE E2. Effect of residential major roadway proximity on asthma symptoms

	Unadjusted analyses [§]		Adjusted analyses [*]	
	OR (95% CI), n = 350 participants	P value	OR (95% CI), n = 282 participants	P value
Primary outcome: components				
Maximum symptom days [†]	0.73 (0.59 to 0.91)	<.01	0.69 (0.55 to 0.86)	<.01
Daytime wheeze [†]	0.75 (0.60 to 0.94)	.01	0.70 (0.56 to 0.88)	<.01
Limitations in activities [‡]	0.63 (0.44 to 0.88)	<.01	0.45 (0.29 to 0.68)	<.001
Nighttime wheeze	0.80 (0.57 to 1.12)	.19	0.87 (0.60 to 1.27)	.47
Secondary outcomes				
Health care use	0.62 (0.47 to 0.83)	<.01	0.83 (0.52 to 1.31)	.42
Missed school days	0.98 (0.55 to 1.73)	.94	0.61 (0.34 to 1.10)	.10
Caregiver plans changed	0.78 (0.47 to 1.32)	.36	0.99 (0.45 to 2.17)	.97
Caregiver lost sleep	0.77 (0.53 to 1.10)	.15	0.84 (0.52 to 1.37)	.48
Composite poor asthma [†]	0.80 (0.68 to 0.94)	<.01	0.81 (0.69 to 0.94)	<.01
Spirometric outcomes				
	β (95% CI), n = 327 participants	P value	β (95% CI), n = 188 participants	P value
FEV ₁ (% predicted)	0.94 (−2.92 to 4.80)	.63	0.44 (−5.26 to 4.39)	.86
FVC (% predicted)	−0.82 (−3.81 to 2.16)	.59	−2.38 (−5.42 to 0.65)	.12
FEV ₁ /FVC (%)	1.45 (0.36 to 2.54)	<.01	0.32 (−1.22 to 1.86)	.68
FEF ₂₅₋₇₅ (% predicted)	−0.96 (−8.29 to 6.37)	.80	−2.62 (−11.81 to 6.58)	.58

Effect estimates are based on each 100 m farther from a major roadway.

FEF₂₅₋₇₅, Forced expiratory flow at 25% to 75% of forced vital capacity; OR, odds ratio.

*Adjusted for distance from major roadway at school, age, sex, race/ethnicity, annual household income, environmental tobacco smoke, controller medication, recent upper respiratory tract infections, endotoxin and mouse allergen levels, and seasonality. Models for FEV₁ percent predicted, FVC percent predicted, and FEF₂₅₋₇₅ percent predicted did not adjust separately for age, sex, and race/ethnicity because these are included in the percent prediction estimates.

[†]P < .01 in adjusted analyses.

[‡]P < .001 in adjusted analyses.

[§]Unadjusted estimates include all study participants (n = 1327 observations; n = 350 participants) and corresponding spirometric outcomes (n = 645 observations; n = 327 participants).

^{||}Limited to within school year observations (n = 707 observations; n = 282 participants) as models adjusted for distance from a major roadway at school and corresponding spirometric outcomes (n = 321 observations; n = 188 participants).

TABLE E3. Effect of school major roadway proximity on asthma symptoms‡

	Unadjusted analyses		Adjusted* analyses	
	OR (95% CI), n = 282 participants	P value	OR (95% CI), n = 282 participants	P value
Primary outcome: components				
Maximum symptom days	0.91 (0.75 to 1.11)	.38	0.98 (0.79 to 1.20)	.82
Daytime wheeze	0.94 (0.77 to 1.15)	.57	1.01 (0.82 to 1.25)	.90
Limitations in activities	0.87 (0.63 to 1.22)	.42	0.93 (0.65 to 1.33)	.69
Nighttime wheeze	0.83 (0.57 to 1.20)	.31	0.79 (0.56 to 1.11)	.18
Secondary outcomes				
Health care use	0.73 (0.43 to 1.24)	.24	0.70 (0.39 to 1.27)	.24
Missed school days	0.88 (0.55 to 1.40)	.58	0.94 (0.62 to 1.42)	.76
Caregiver plans changed†	0.49 (0.27 to 0.92)	.03	0.49 (0.27 to 0.89)	.02
Caregiver lost sleep	0.69 (0.42 to 1.14)	.15	0.64 (0.39 to 1.03)	.07
Composite poor asthma	0.95 (0.82 to 1.09)	.43	0.97 (0.85 to 1.10)	.62
Spirometric outcomes				
	β (95% CI), n = 188 participants	P value	β (95% CI), n = 188 participants	P value
FEV ₁ (% predicted)	−3.24 (−6.04 to −0.44)	.02	−3.0 (−6.11 to 0.13)	.06
FVC (% predicted)†	−3.56 (−5.73 to −1.40)	<.01	−2.58 (−4.78 to −0.38)	.02
FEV ₁ /FVC (%)	0.15 (−0.89 to 1.19)	.78	0.37 (−0.55 to 1.28)	.43
FEF ₂₅₋₇₅ (% predicted)	−5.95 (−15.58 to 3.68)	.23	−4.95 (−14.21 to 4.30)	.29

FEF₂₅₋₇₅, Forced expiratory flow at 25% to 75% of forced vital capacity; OR, odds ratio.

*Adjusted for distance from major roadway at home, age, sex, race/ethnicity, annual household income, environmental tobacco smoke, controller medication, recent upper respiratory tract infections, endotoxin and mouse allergen levels, and seasonality.

†P < .05 in adjusted analyses.

‡Limited to within school year observations (n = 707 observations; n = 282 participants) for health outcomes and corresponding spirometric outcomes (n = 321 observations; n = 188 participants).

TABLE E4. Effect of stratified school major roadway proximity on asthma symptoms§

	Unadjusted analyses		Adjusted* analyses	
	OR (95% CI), n = 282	P value	OR (95% CI), n = 282	P value
Primary outcome: components				
Maximum symptom days†	0.70 (0.51 to 0.95)	.02	0.68 (0.51 to 0.91)	.01
Daytime wheeze†	0.75 (0.54 to 1.05)	.09	0.66 (0.49 to 0.91)	.01
Limitations in activities†	0.68 (0.44 to 1.04)	.07	0.66 (0.44 to 0.98)	.04
Nighttime wheeze†	0.61 (0.40 to 0.94)	.03	0.59 (0.39 to 0.89)	.01
Secondary outcomes				
Health care use	0.85 (0.46 to 1.58)	.61	0.71 (0.41 to 1.23)	.23
Missed school days‡	0.50 (0.29 to 0.84)	.01	0.48 (0.29 to 0.78)	<.01
Caregiver plans changed†	0.58 (0.34 to 0.98)	.04	0.56 (0.32 to 0.97)	.04
Caregiver lost sleep	0.66 (0.42 to 1.03)	.07	0.65 (0.41 to 1.01)	.06
Composite poor asthma	0.95 (0.78 to 1.15)	.58	0.93 (0.77 to 1.12)	.43
Spirometric outcomes				
	β (95% CI), n = 188	P value	β (95% CI), n = 188	P value
FEV ₁ (% predicted)	−2.06 (−7.41 to 3.28)	.45	−1.52 (−6.84 to 3.80)	.58
FVC (% predicted)	−2.53 (−7.31 to 2.25)	.30	−3.33 (−7.87 to 1.21)	.15
FEV ₁ /FVC (%)	0.52 (−1.35 to 2.39)	.59	0.81 (−1.20 to 2.81)	.43
FEF ₂₅₋₇₅ (% predicted)	11.28 (−11.15 to 33.71)	.32	9.58 (−8.29 to 27.45)	.29

Reference population: attending school less than 100 m from a major roadway.

FEF₂₅₋₇₅, Forced expiratory flow at 25% to 75% of forced vital capacity; OR, odds ratio.

*Adjusted for distance from a major roadway at home, age, sex, race/ethnicity, annual household income, environmental tobacco smoke, controller medication, recent upper respiratory tract infections, endotoxin and mouse allergen levels, and seasonality. Models for FEV₁ percent predicted and FEF₂₅₋₇₅ percent predicted did not adjust separately for age, sex, and race/ethnicity because these are included in the percent prediction estimates.

†P < .05 in adjusted analyses.

‡P < .01 in adjusted analyses.

§Limited to within school year observations (n = 707 observations; n = 282 participants) for health outcomes and corresponding spirometric outcomes (n = 321 observations; n = 188 participants).

000 Proximity to major roadways and asthma symptoms in the School Inner-City Asthma Study

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