

Is it traffic type, volume, or distance? Wheezing in infants living near truck and bus traffic

Patrick H. Ryan, MS,^a Grace LeMasters, PhD,^a Jocelyn Biagini, MS,^a
David Bernstein, MD,^b Sergey A. Grinshpun, PhD,^a Rakesh Shukla, PhD,^a
Kimberly Wilson, MS,^a Manuel Villareal, MD,^b Jeff Burkle, BS,^a and James Lockey, MD^a
Cincinnati, Ohio

Background: Previous studies of air pollution have not examined the association between exposure to varying types, distance, and amounts of traffic and wheezing in very young infants.

Objective: We sought to determine the relationship between types of traffic, traffic volume, and distance and wheezing among infants less than 1 year of age.

Methods: A geographic information system and a classification scheme were developed to categorize infants enrolled in the study as living near moving truck and bus traffic (highway >50 miles per hour, >1000 trucks daily, <400 m), stop-and-go truck and bus traffic (<50 miles per hour, <100 m), or unexposed and not residing near either. Symptom data were based on health questionnaires administered to parents when the infants were 6 months of age and monthly health diaries.

Results: Infants living very near (<100 m) stop-and-go bus and truck traffic had a significantly increased prevalence of wheezing (adjusted odds ratio, 2.50; 95% CI, 1.15-5.42) when compared with unexposed infants. The prevalence of wheezing among nonwhite infants was at least twice that of white infants, regardless of exposure. Infants living less than 400 m from a high volume of moving traffic, however, did not have an increased prevalence of wheezing.

Conclusion: These results suggest that the distance from and type of traffic exposures are more significant risk factors than traffic volume for wheezing in early infancy. (*J Allergy Clin Immunol* 2005;116:279-84.)

Key words: Diesel, traffic, truck, bus, wheezing, Geographic Information System, infants

Abbreviations used

CCAAPS: Cincinnati Childhood Allergy and Air Pollution Study
DEP: Diesel exhaust particle
GIS: Geographic information system
mph: Miles per hour
OR: Odds ratio
PM: Particulate matter
SPT: Skin prick test

Recent articles in this journal have reviewed the epidemiology and biology of air pollution and diesel exhaust and their effects on asthma risk and respiratory function.^{1,2} Diesel exhaust particles (DEPs) have been studied with respect to both the development and exacerbation of allergic rhinitis and asthma because of their unique capability to enhance those T_H2 cells that direct allergic immune responses (ie, T_H2 cells) and production of IgE.³ Although the mechanism by which DEPs might influence allergy and asthma development and exacerbation is still under investigation, the immunologic effects of DEPs have been recently reviewed.^{4,5} DEPs are respirable particles with a large surface area per unit mass that provide an excellent medium for absorbing and transporting proteins into the peripheral airways.⁶ Studies have demonstrated that DEPs are capable of binding with grass pollen allergen (Lol p 1), and this might be similar with other aeroallergens.^{7,8} In human studies exposure to DEPs has been shown to enhance allergic nasal cytokine and inflammatory responses after direct challenge with allergen extracts.⁹⁻¹¹

Previous studies of traffic pollutants have focused on roadways with high truck and automobile traffic and minimal bus traffic as the source of air pollution, and these studies have been conducted primarily on school-age children. The purpose of this study was to determine whether distance, volume, and/or type of traffic might be associated with wheezing in infants younger than 1 year. The hypothesis was that infants who reside near major highways with heavy truck traffic, as well as infants who reside near local roads with stop-and-go truck and bus traffic will have a significantly increased risk of wheezing

From ^athe Department of Environmental Health, and ^bthe Department of Internal Medicine, Division of Immunology, University of Cincinnati.

Supported by grants ES11170 and ES10957 from the National Institute of Environmental Health Sciences.

Disclosure of potential conflict of interest: S. A. Grinshpun has received grants—research support from the National Institute of Environmental Health Sciences. M. Villareal has consultant arrangements with Aventis, has stock or other equity ownership with Pfizer, and is on the speakers' bureaus for AstraZeneca, UCB Pharma, Pfizer, Aventis, and GlaxoSmithKline. There are no other potential conflicts to disclose.

Received for publication March 15, 2005; revised May 9, 2005; accepted for publication May 10, 2005.

Available online June 17, 2005.

Reprint requests: Patrick H. Ryan, MS, Department of Environmental Health, University of Cincinnati, Cincinnati, OH 45267-0056. E-mail: ryanph@email.uc.edu.

0091-6749/\$30.00

© 2005 American Academy of Allergy, Asthma and Immunology

doi:10.1016/j.jaci.2005.05.014

when compared with infants residing far from truck and bus traffic.

METHODS

Subject recruitment

The Cincinnati Childhood Allergy and Air Pollution Study (CCAAPS) is an ongoing birth cohort study. Infants enrolled in CCAAPS were identified from birth records, and the addresses obtained from these records were geocoded with EZLocate from TeleAtlas for the ArcView Geographic Information System (GIS) 3.2 (Environmental Systems Research Institute, Redlands, Calif). The distance to the nearest major highway or interstate (defined as >1000 trucks daily) was computed for all infants by using the Geoprocessing extension. Infants whose birth records indicated residency less than 400 m or greater than 1500 m from the nearest major highway or interstate were eligible.

Parents were recruited when infants were 6 months of age or older and screened for allergy symptoms.¹² Parents with likely atopy were subsequently tested with skin prick tests (SPTs) with a panel of 15 common indoor and outdoor regional aeroallergens. Infants with at least one atopic parent were enrolled.

Outcome variables

At the time of the parent SPT, an interviewer administered the baseline health questionnaire at a physician's office. This questionnaire gathered demographic information, occupants in the home and their smoking status, animal ownership, and information on other possible risk factors. The general health of the infant was queried from birth until the infants' age at enrollment. These questions were based on the well-validated International Study of Allergy and Asthma in Children questionnaire for children ages 4 to 5 years, which was adapted for use with infants.¹³ In addition, monthly diaries were distributed to the parents of all enrolled infants at the time of the parental SPT. These diaries recorded parental observation of the infants' illnesses and were returned by mail monthly until the child's first visit at age 1 year. Wheeze with a cold and wheezing without a cold were assessed on both questionnaires. Wheezing without symptoms of a cold was the outcome variable for this study. To increase the reliability of parental report of wheezing, an infant whose parent reported wheezing (without a cold) on the parent questionnaire and returned at least one monthly diary indicating the identical symptom was designated to have wheezed.

Traffic exposure classification

ArcView shapefiles containing the location of all state roads, interstates, and traffic counts (both truck and car) were obtained from the Ohio Department of Transportation and the Kentucky Transportation Cabinet. Shapefiles containing the location of public transportation (bus) routes and bus counts for the city of Cincinnati and Northern Kentucky were obtained from the Cincinnati Area Geographic Information Systems database, the Northern Kentucky Area Planning Commission, the Southwest Ohio Regional Transit Authority, and the Transit Authority of Northern Kentucky. The distance to the nearest federal interstate, state route, and bus route from the primary residence of the infant at the time of parent enrollment was derived by using the Geoprocessing extension for ArcView GIS 3.2. A traffic exposure classification scheme was subsequently applied to each infant by using the distance to the 3 types of traffic, the speed limit on the roadway closest to the infant, and the amount of DEPs producing traffic (trucks or buses) on the road type nearest each infant.

Classification of exposure by distance was based on the methods of others, with distances of less than 100 m,^{14,15} 150 m,^{16,17} 200 m,¹⁸

and 400 m.¹⁹ Fewer than 3% (n = 10) of residences of infants in this study, however, were within 100 m of an interstate; fewer than 10% (n = 88) were within 200 m of an interstate, whereas 28% (n = 248) of the population resided within 400 m of an interstate. Also, approximately 26% (n = 174) of the infants resided within 100 m of a state route or a bus route. Hence on the basis of our population's geographic distribution and our pilot study, which revealed that the concentration of ultrafine particles decreased by one half between 50 m and 150 m downwind from a highway and an observable sulfur concentration gradient up to 400 m from a highway, infants were classified as exposed to interstate traffic if their residence was within 400 m.²⁰ Exposure to a state or bus route was determined if their residence was within 100 m from one of these routes. If an infant resided greater than 400 m from the nearest interstate, greater than 100 m from the nearest state route, and greater than 100 m from the nearest bus route, the infant was placed in the unexposed category. Furthermore, exposure to moving traffic was determined if an infant's residence was within 400 m of an interstate or within 100 m of a state route with a speed limit of greater than or equal to 50 miles per hour (mph). Fifty miles per hour was used as the cutoff because in Ohio this is the designation used for classification of an urban (greater traffic) or rural (less traffic) route. Exposure to stop-and-go traffic was determined if an infant's residence was within 100 m of a bus route, within 100 m of a state route with a speed limit of less than 50 mph, or both.

Statistical analyses

To determine the presence of an association between traffic exposure and wheezing, conditional logistic regression was performed with SAS software (version 8.2 for Windows; SAS Institute Inc, Cary, NC), adjusting for sex, race (white/nonwhite), breast-feeding (maternal report of breast-feeding <1 week, 1-4 weeks, or >5 weeks), pet ownership, income (<\$40,000/≥\$40,000), child care outside of the home (parent report of infant attending day care or babysitter), number of siblings, visible mold in the home, maternal and paternal self-report of asthma, and the number of monthly diaries returned.

RESULTS

Recruitment for the CCAAPS study was completed on December 13, 2003. During year 1 of the study, 633 families had returned at least one monthly diary before January 1, 2004. Eleven (1.7%) of the 633 eligible families were excluded because of inaccuracy in the geocoding of their residence at the time of exposure classification. The average age of the infants in this study (at the time of their enrollment) was 7.5 months (± 2.4 months).

Exposure classification

Table I displays the demographic characteristics of the infants and their families in the 3 exposure groups; 60.1% (n = 374) of the infants were unexposed, whereas the moving traffic category included 28.3% (n = 176) of the infants, and the stop-and-go category included 15.9% (n = 99) of the infants. As shown in Table I, the infants exposed to stop-and-go traffic were more likely to be African American, to have care outside their home, and to have had a father with asthma, whereas they were less likely to have been breast-fed. Because of these differences, these and other possible covariates were adjusted

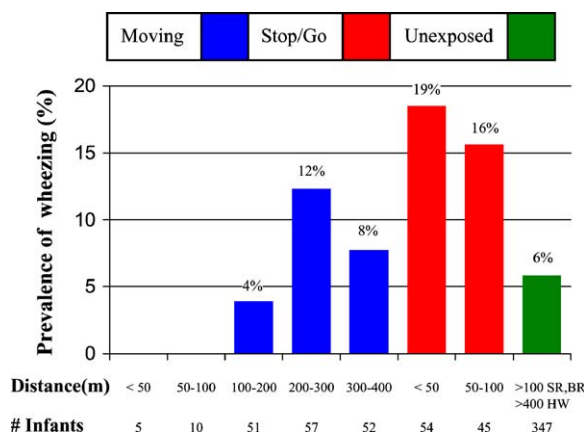
TABLE I. Prevalence of demographic characteristics by exposure categorization

Characteristic	Unexposed (n = 347), %	Moving (n = 176), %	Stop and go (n = 99), %
White	83.3	78.7	56.6
Income <\$40,000	24.6	35.7	54.2
Male sex	51.3	50.6	61.2
Current smoking mother	11.8	16.5	17.2
Care outside home	28.5	24.3	36.2
Owns dog	33.9	39.0	26.9
Owns cat	27.8	24.4	16.1
Weeks breast-fed			
0	26.3	35.2	49.5
1-4	6.9	9.7	14.1
≥5	66.8	55.1	36.4
Diaries returned			
1	27.7	29.6	43.4
2	18.4	11.9	13.1
≥3	53.9	58.5	43.5
No. of siblings			
0	37.5	34.3	36.2
1	33.0	40.7	34.0
≥2	29.5	25.0	29.8
Has visible mold	65.4	58.0	58.6
Paternal asthma	11.1	13.0	23.6
Maternal asthma	20.6	25.8	17.4

for in the logistic model. In the unexposed category the median distances to the nearest highway, state route, and bus route were 3287 m, 743 m, and 543 m, respectively. For those infants classified as exposed to moving traffic, the median distances to the nearest highway, state route, and bus route were 252 m, 696 m, and 341 m, respectively. Infants exposed to stop-and-go traffic resided a median distance of 2303 m, 439 m, and 43 m from the nearest highway, state route, and bus route, respectively. The median number of trucks on the highway nearest infants (n = 170) in the moving category was 11,820 daily. For those infants (n = 6) exposed to moving traffic on a state route, the median number of trucks per day was 1050. Infants exposed to buses (n = 71) or trucks (n = 9) only in the stop-and-go category had a median of 44 buses daily and 1250 trucks, respectively, on the route nearest their residence. Infants exposed to both buses and trucks (n = 19) had a median of 72 and 390, respectively.

Wheeze (without cold)

Of the 622 infants, 50 (8.0%) reported wheezing without a cold. In the unexposed category 5.8% of infants reported wheezing without a cold compared with 7.4% in the moving category and 17.2% in the stop-and-go exposure category ($P < .01$). The prevalence of wheezing in the infants who were categorized into the 3 exposure categories was subsequently examined by distance from the nearest road and type of traffic (Fig 1). The prevalence of wheezing was 3 times higher (19%) in the infants who resided less than 50 m from stop-and-go traffic compared with those infants who were unexposed (6%). The prevalence of wheezing in infants who reside 200 to 300 m

**FIG 1.** Prevalence of wheeze (without cold) among infants within exposure categories by distance from the nearest DEP source. SR, State route; BR, bus route; HW, highway.

from moving traffic (12%) was more than doubled when compared with that of infants who were classified as unexposed.

Unadjusted and adjusted odds ratios (ORs) are shown in Table II. Living within 100 m of stop-and-go truck and bus traffic was the most important risk factor for early infant wheeze (adjusted OR, 2.50; 95% CI, 1.15-5.42). An infant with no siblings was at a decreased risk for wheezing (adjusted OR, 0.42; 95% CI, 0.19-0.93), and nonwhite infants were at an increased risk for wheezing (adjusted OR, 2.39; 95% CI, 1.20-4.76, respectively). Male sex and paternal self-report of asthma (although not maternal self-report of asthma) were also significantly associated with wheezing (Table II). Infants classified as exposed to moving traffic did not have a significant association with wheezing without a cold when compared with infants classified as unexposed. A univariate analysis was conducted comparing wheezing without a cold and the season (winter [January-March], spring [April-June], summer [July-September], autumn [October-December]) in which it was first reported to address the possibility of a cold as a possible cause of wheezing. In this analysis there were no differences in the prevalence of wheezing among season ($P = .50$), and the same was true when season was added to the multivariate model.

DISCUSSION

Infants exposed to stop-and-go bus and truck traffic had a significantly increased risk for wheezing without a cold compared with infants unexposed to truck or bus traffic or compared with infants exposed to moving truck traffic with a larger volume of trucks. Infants with immature lungs residing in close proximity to stop-and-go truck and bus traffic might be exposed to greater amounts of fine and ultrafine particulates.²¹⁻²⁴ Sampling for fine particulate matter (PM 2.5 μm) and black carbon inside a bus and a car traveling ahead of the bus showed that the average DEP levels were approximately 20 $\mu\text{g}/\text{m}^3$ and 5 $\mu\text{g}/\text{m}^3$,

TABLE II. Unadjusted and adjusted* ORs and 95% CIs for wheezing without a cold

	Unadjusted OR		Adjusted OR	
	OR	95% CI	OR	95% CI
Stop-and-go exposure†	3.41	1.71-6.81	2.50	1.15-5.42
Nonwhite	2.80	1.54-5.08	2.39	1.20-4.76
Paternal asthma	2.63	1.29-5.37	2.35	1.08-5.13
Male sex	1.93	1.04-3.58	2.49	1.21-5.10
Only child‡	0.47	0.23-0.96	0.42	0.19-0.93

*Adjusted for maternal smoking, breast-feeding, pet ownership, visible mold, maternal asthma, care outside the home, and monthly diaries returned.

†Reference category = unexposed.

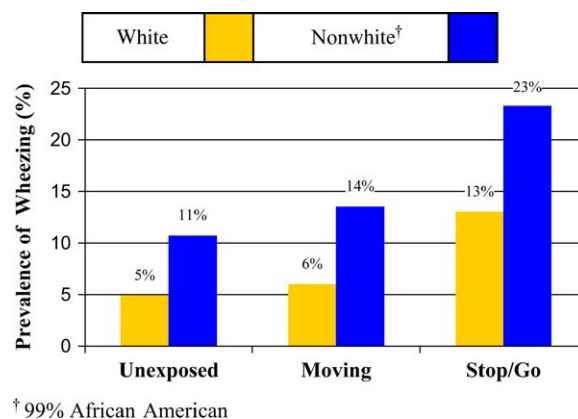
‡Reference category = 2 or more siblings.

but during stop-and-go traffic, the levels increased to more than $30 \mu\text{g}/\text{m}^3$ and $20 \mu\text{g}/\text{m}^3$, respectively.²¹ Other studies have also found acceleration, deceleration, and stop-and-go traffic to be associated with higher emissions of organic carbon, elemental carbon, carbon monoxide, nitric oxide, hydrocarbons, and soot when compared with cruising traffic.²²⁻²⁴

To our knowledge, the present study is the first to prospectively examine the effect of living in close proximity to roads with stop-and-go bus and truck traffic on infants' respiratory health. Although our results are consistent with those of other investigations,^{14,15,18,25-28} this study improves on previous investigations. This prospective design during early infancy minimizes parental recall bias by allowing simultaneous measurements of exposure and outcome, whereas most previous studies have relied on parental recall of infant illness. The GIS database also accurately geocoded the infant's residence, as well as the distance from the nearest traffic source. With the integration of county traffic data, the GIS minimized response bias by the parents who might inaccurately report the frequency or proximity of traffic.

Although our *a priori* hypothesis also expected to find an effect with exposure to moving traffic, no association was found. Hence high intermittent exposures to pollutants might have a greater detrimental health effect on infants than exposure to lower continuous exposure. These findings, however, could be related to study limitations. Infants living near moving traffic were exposed to wide variations in the number of trucks. In addition, the median distance to stop-and-go traffic was 43 m, whereas the median distance to moving traffic was 252 m, and although state routes might have posted speed limits of greater than 50 mph and be classified as a rural route, the possibility exists that traffic might accelerate and decelerate at times of congestion. This scenario is also likely for short periods on highways where we have designated the traffic as moving.

PM, a primary constituent of DEPs, has been significantly associated with emergency department visits for asthma, wheezing bronchitis, lower respiratory tract



† 99% African American

FIG 2. Prevalence of wheeze (without cold) among infants stratified by race.

symptoms, and physician visits for asthma.²⁹⁻³⁴ Others have found that fine and ultrafine particles ($\text{PM}_{2.5}$ and PM_{10} , respectively) have a greater association with respiratory symptoms than coarse particles ($\text{PM} > 2.5 \mu\text{m}$) and are associated with pulmonary retention of particles.^{3,35,36} Induction of oxidative stress and mitochondrial damage by ultrafine particulates has been proposed.^{2,37} Thus whether the mechanism is total load or oxidative stress, infants who reside less than 100 m away are likely receiving a high dose of particulates. It is not possible, however, to separate the contributions of diesel and gasoline engines.

Previous studies have found maternal asthma,³⁸ paternal asthma,³⁹ or both to be a significant risk factor for the development of asthma and wheezing in children.^{40,41} In our study only paternal asthma was significant. Although studies have found associations between parental smoking and wheezing in infants, the multivariate model showed no additional smoking effect. Also, multivariate analyses of maternal smoking found no associations with wheezing in the unexposed subpopulation. However, only 14% ($n = 87$) of the cohort were exposed to maternal smoking (Table I). Of particular interest are the findings regarding the high prevalence of wheezing among nonwhite infants in all exposure categories. As shown in Fig 2, the prevalence of wheezing in nonwhite infants was nearly 2 or more times higher in all groups, suggesting a health disparity beginning early in infancy. Thus increased susceptibility to wheezing is consistent with national statistics of asthma prevalence, as well as other studies.⁴²⁻⁴⁴ Because wheezing in the first year of life is generally a poor predictor of later development of childhood asthma, results must be interpreted cautiously.⁴⁵

In conclusion, this is the first epidemiologic study to examine the risk of wheezing in infants younger than 1 year who are exposed to varying types and amounts of urban traffic. It demonstrated that even within an urban environment, the risk of wheezing varies with the type of and distance from traffic. A health disparity between races is also evident: nearly one fourth of African American infants exposed to stop-and-go traffic are wheezing before

age 1 year. This risk will be further investigated as the cohort ages and asthma and atopy can be diagnosed.

We thank Stephanie Maier and Sherry Stanforth for their help with family interviews and testing.

REFERENCES

- Peden DB. The epidemiology and genetics of asthma risk associated with air pollution. *J Allergy Clin Immunol* 2005;115:213-9.
- Riedl M, Diaz-Sanchez D. Biology of diesel exhaust effects on respiratory function. *J Allergy Clin Immunol* 2005;115:221-8.
- Peden DB. Development of atopy and asthma: candidate environmental influences and important periods of exposure. *Environ Health Perspect* 2000;108:475-82.
- Pandya RJ, Solomon G, Kinner A, Balmes JR. Diesel exhaust and asthma: hypotheses and molecular mechanisms of action. *Environ Health Perspect* 2002;110:103-12.
- Diaz-Sanchez D, Tsien A, Casillas A, Dotson AR, Saxon A. Enhanced nasal cytokine production in human beings after in vivo challenge with diesel exhaust particles. *J Allergy Clin Immunol* 1996;98:114-23.
- US Environmental Protection Agency (EPA). Health assessment document for diesel engine exhaust. Prepared by the National Center for Environmental Assessment, Washington, DC, for the Office of Transportation and Air Quality; EPA/600/8-90/057F. 2002. Available at: <http://www.epa.gov/ncea>.
- Knox RB, Suphioglu C, Taylor P, Desai R, Watson HC, Peng JL, et al. Major grass pollen allergen Lol p I binds to diesel exhaust particles: implications for asthma and air pollution. *Clin Exp Allergy* 1997;27:246-51.
- Ormstad H. Suspended particulate matter in indoor air: adjuvants and allergen carriers. *Toxicology* 2000;152:53-68.
- Diaz-Sanchez D, Tsien A, Fleming J, Saxon A. Combined diesel exhaust particulate and ragweed allergen challenge enhances human in vivo nasal ragweed-specific IgE and skews cytokine production to a T helper cell 2 type pattern. *J Immunol* 1997;158:2406-13.
- Fujieda S, Diaz-Sanchez D, Saxon A. Combined nasal challenge with diesel exhaust particles and allergen induces in vivo IgE isotype switching. *Am J Respir Cell Mol Biol* 1998;19:507-12.
- Fujimaki H, Nohara O, Ichinose T, Watanabe N, Saito S. IL-4 production in mediastinal lymph node cells in mice intratracheally instilled with diesel exhaust particulates and antigen. *Toxicology* 1994;92:261-8.
- LeMasters GK, Wilson KA, Levin L, Bernstein DI, Lockey JE, Villareal M, et al. Validation of a population-based brief allergy symptoms questionnaire. Abstract presented at: American Thoracic Society International Conference; May 16-21, 2003; Seattle (WA).
- Jenkins MA, Clarke JR, Carlin JB, Robertson CF, Hopper JL, Dalton MF, et al. Validation of questionnaire and bronchial hyperresponsiveness against respiratory physician assessment in the diagnosis of asthma. *Int J Epidemiol* 1996;25:609-16.
- Brunekreef B, Janssen NAH, de Hartog J, Harssema H, Knape M van Vliet P. Air pollution from truck traffic and lung function in children living near motorways. *Epidemiology* 1997;8:298-303.
- van Vliet P, Knape M, de Hartog J, Janssen N, Harssema H, Brunekreef B. Motor vehicle exhaust and chronic respiratory symptoms in children living near freeways. *Environ Res* 1997;74:122-32.
- Venn AJ, Lewis SA, Cooper M, Hubbard R, Britton J. Living near a main road and the risk of wheezing illness in children. *Am J Respir Crit Care Med* 2001;164:2177-80.
- Wilkinson P, Elliott P, Grundy C, Shaddick G, Thakrar B, Walls P, et al. Case-control study of hospital admission with asthma in children aged 5-14 years: relation with road traffic in north west London. *Thorax* 1999;54:1070-4.
- Lin S, Munsie JP, Hwang S, Fitzgerald E, Cayo MR. Childhood asthma: hospitalization and residential exposure to state route traffic. *Environ Res* 2002;88:73-81.
- Janssen NAH, Brunekreef B, van Vliet P, Aarts F, Meliefste K, Harssema H, et al. The relationship between air pollution from heavy traffic and allergic sensitization, bronchial hyperresponsiveness, and respiratory symptoms in Dutch schoolchildren. *Environ Health Perspect* 2003;111:1512-8.
- Reponen T, Grinshpun SA, Trakumas S, Martuzevicius D, Wang Z, LeMasters G, et al. Concentration gradient patterns of aerosol particles near interstate highways in the Greater Cincinnati airshed. *J Environ Monit* 2003;5:557-62.
- Solomon G, Campbell T, Feuer G, Masters J, Samkian A, Paul K. No breathing in the aisles: Diesel exhaust inside school buses. Natural Resources Defense Council, Coalition for Clean Air. 2001. Available at: <http://www.nrdc.org/air/transportation/schoolbus/sbusinx.asp>.
- Shah S, Cocker D, Miller JW, Norbeck JM. Emission rates of particulate matter and elemental and organic carbon from in-use diesel engines. *Environ Sci Technol* 2004;38:2544-50.
- Tong HY, Hung WT, Cheung CS. On-road vehicle emissions and fuel consumption in urban driving conditions. *J Air Waste Manag Assoc* 2000;50:543-54.
- Unal A, Frey HC, Roupail NM. Quantification of highway vehicle emissions hot spots based upon on-board measurements. *J Air Waste Manag Assoc* 2004;54:130-40.
- Hirsch T, Weiland SK, von Mutius E, Safeca AF, Grafe H, Csaplovics E, et al. Inner city air pollution and respiratory health and atopy in children. *Eur Respir J* 1999;14:669-77.
- Ciccone G, Forastiere F, Agabiti N, Biggeri A, Bisanti L, Chellini E, et al. Road traffic and adverse respiratory effects in children. SIDRIA Collaborative Group. *Occup Environ Med* 1998;55:771-8.
- Shima M, Nitta Y, Adachi M. Traffic related air pollution and respiratory symptoms in children living along trunk roads in Chiba Prefecture, Japan. *J Epidemiol* 2003;13:108-19.
- Brauer M, Hoek G, Van Vliet P, Meliefste K, Fischer PH, Wijga A, et al. Air pollution from traffic and the development of respiratory infections and asthmatic and allergic symptoms in children. *Am J Respir Crit Care Med* 2002;166:1092-8.
- Norris G, YoungPong S, Koenig J, Larson T, Sheppard L, Stout J. An association between fine particles and asthma emergency department visits for children in Seattle. *Environ Health Perspect* 1999;110:489-93.
- Pino P, Walter T, Oyarzun M, Villegas R, Romieu I. Fine particulate matter and wheezing illnesses in the first year of life. *Epidemiology* 2004;15:702-8.
- Shima M, Nitta Y, Ando M, Adachi M. Effects of air pollution on the prevalence and incidence of asthma in children. *Arch Environ Health* 2002;57:529-35.
- van der Zee S, Hoek G, Boezen HM, Shouten J, van Wijnen JH, Brunekreef B. Acute effects of urban air pollution on respiratory health of children with and without chronic respiratory symptoms. *Occup Environ Med* 1999;56:802-13.
- Jalaludin BB, O'Toole BI, Leeder SR. Acute effects of urban ambient air pollution on respiratory symptoms, asthma medication use, and doctor visits for asthma in a cohort of Australian children. *Environ Res* 2004;95:32-42.
- Penttinen P, Timonen KL, Tiittanen P, Mirme A, Ruuskanen J, Pekkanen J. Ultrafine particles in urban air and respiratory health among adult asthmatics. *Eur Respir J* 2001;17:428-35.
- Schwartz J, Neas LM. Fine particles are more strongly associated than coarse particles with acute respiratory health effects in schoolchildren. *Epidemiology* 2000;11:6-10.
- Brauer M, Avila-Casado C, Fortoul TI, Vedal S, Stevens B, Chung A. Air pollution and retained particles in the lung. *Environ Health Perspect* 2001;109:1039-43.
- Li N, Sioutas C, Cho A, Schmitz D, Misra C, Sempf J, et al. Ultrafine particulate pollutants induce oxidative stress and mitochondrial damage. *Environ Health Perspect* 2003;111:455-60.
- Sherriff A, Peters TJ, Henderson J, Strachan D, ALSPAC Study Team. Risk factor associations with wheezing patterns in children followed longitudinally from birth to 3(1/2) years. *Int J Epidemiol* 2001;30:1473-84.
- El-Sharif N, Abdeen Z, Barghuthy F, Nemery B. Familial and environmental determinants for wheezing and asthma in a case-control study of school children in Palestine. *Clin Exp Allergy* 2003;33:176-86.
- Arshad SH, Kurukulaaratchy RJ, Fenn M, Matthews S. Early life risk factors for current wheeze, asthma, and bronchial hyperresponsiveness at 10 years of age. *Chest* 2005;127:502-8.
- London SJ, Gauderman J, Avol E, Rappaport EB, Peters JM. Family history and the risk of early-onset persistent, early onset transient, and late-onset asthma. *Epidemiology* 2001;12:577-83.

42. Grant EN, Lyttle CS, Weiss KB. The relation of socioeconomic factors and racial/ethnic differences in the US asthma mortality. *Am J Public Health* 2000;90:1923-5.
43. Joseph CLM, Ownby DR, Peterson EL, Johnson CC. Racial differences in physiologic parameters related to asthma among middle-class children. *Chest* 2000;117:1336-44.
44. Simon PA, Zeng Z, Wold CM, Haddock W, Fielding JE. Rate of childhood asthma and associated morbidity in Los Angeles County: impacts of race/ethnicity and income. *J Asthma* 2003;40:535-43.
45. Taussig L, Wright A, Holberg C, Halonen M, Morgan W, Martinez F. Tucson Children's Respiratory Study: 1980 to present. *J Allergy Clin Immunol* 2003;111:661-75.