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Asthma Symptoms in Hispanic Children and Daily Ambient Exposures to Toxic and Criteria Air Pollutants

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Although acute adverse effects on asthma have been frequently found for the U.S. Environmental Protection Agency's principal criteria air pollutants, there is little epidemiologic information on specific hydrocarbons from toxic emission sources. We conducted a panel study of 22 Hispanic children with asthma who were 10–16 years old and living in a Los Angeles community with high traffic density. Subjects filled out symptom diaries daily for up to 3 months (November 1999 through January 2000). Pollutants included ambient hourly values of ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide and 24-hr values of volatile organic compounds (VOCs), particulate matter with aerodynamic diameter < 10 μm (PM_{10}), and elemental carbon (EC) and organic carbon (OC) PM_{10} fractions. Asthma symptom severity was regressed on pollutants using generalized estimating equations, and peak expiratory flow (PEF) was regressed on pollutants using mixed models. We found positive associations of symptoms with criteria air pollutants (O_3, NO_2, SO_2, PM_{10}), EC–OC, and VOCs (benzene, ethylbenzene, formaldehyde, acetaldehyde, acetone, 1,3-butadiene, tetrachloroethylene, toluene, *m*,*p*-xylene, and *o*-xylene). Selected adjusted odds ratios for bothersome or more severe asthma symptoms from interquartile range increases in pollutants were, for 1.4 ppb 8-hr NO_2, 1.27 [95% confidence interval (CI), 1.05–1.54]; 1.00 ppb benzene, 1.23 (95% CI, 1.02–1.48); 3.16 ppb formaldehyde, 1.37 (95% CI, 1.04–1.80); 37 μg/m^3 PM_{10}, 1.45 (95% CI, 1.11–1.90); 2.91 μg/m^3 EC, 1.85 (95% CI, 1.11–3.08); and 4.64 μg/m^3 OC, 1.88 (95% CI, 1.12–3.17). Two-pollutant models of EC or OC with PM_{10} showed little change in odds ratios for EC (to 1.83) or OC (to 1.89), but PM_{10} decreased from 1.45 to 1.0. There were no significant associations with PEF. Findings support the view that air toxics in the pollutant mix from traffic and industrial sources may have adverse effects on asthma in children. *Key words:* environmental air pollutants, hydrocarbons, longitudinal studies, nitrogen dioxide, ozone, statistical models, sulfur dioxide, vehicle emissions. *Environ Health Perspect* **111:647–656 (2003). doi:10.1289/ehp.5992 available via *http://dx.doi.org/* [Online 19 December 2002]**

Acute exacerbations of asthma in children as measured by hospital use, symptoms, or lung function deficits have been frequently associated with the principal criteria air pollutants regulated by the U.S. Environmental Protection Agency (U.S. EPA; American Thoracic Society 1996). These pollutants include particulate matter < 10 μm in aerodynamic diameter (PM_{10}), particulate matter < 2.5 μm in aerodynamic diameter ($PM_{2.5}$), and the gases ozone, nitrogen dioxide, and sulfur dioxide. Many other air pollutants frequently coexist with criteria pollutants, but they have been infrequently evaluated in epidemiologic studies of ambient air pollution. These include aromatic and other hydrocarbons listed among the 188 toxic air pollutants in the U.S. Clean Air Act Amendments (U.S. Congress 1990). Examples include volatile organic compounds (VOCs) such as benzene and formaldehyde, and polycyclic aromatic hydrocarbons (PAHs), which are semivolatile and make up part of PM_{10} and $PM_{2.5}$. An important source of toxic air pollutants as well as the criteria air pollutants is the combustion of fossil fuel from automobiles and trucks. A growing body of experimental data suggests that certain organic components of petroleum combustion products can elicit allergic and inflammatory responses seen in asthma (Nel et al. 2001). Epidemiologic associations between asthma and criteria air pollutants may be attributable to particulate organic matter and some VOCs, but causal components in the pollutant mix remain to be identified.

In the present study we address the need to evaluate respiratory health effects of air toxics in communities in proximity to major emission sources. We examined the acute relationship of asthma in schoolchildren to concentrations of ambient criteria air pollutant gases, VOCs, PM_{10}, and elemental carbon and organic carbon (EC–OC) fractions. Subjects lived in an area of east Los Angeles County, California, flanked by major freeways and trucking routes, and with among the highest VOC levels in the Los Angeles air basin [South Coast Air Quality Management District (SCAQMD) 2000].

Materials and Methods

In this panel study we investigated the relationship of repeated daily measurements of health outcomes and exposures in Hispanic schoolchildren with asthma. Subjects reported in diaries the severity of their asthma symptoms and results of morning and evening peak expiratory flow (PEF) maneuvers. Subjects and at least one legal guardian were followed up weekly at their homes over a 3-month period from 4 November 1999 through 23 January 2000. This period has the highest monthly average concentrations of VOCs in the Los Angeles air basin (SCAQMD 2000).

Population. We aimed to follow a panel of 24 children. Subjects were recruited through referrals from area schools using the following eligibility criteria: *a*) a minimum 1-year history of physician-diagnosed asthma; *b*) age 10–15 years—children old enough to complete diaries but too young to work or drive, limiting occupational exposures and frequent exposures traveling out of the study region; *c*) nonsmokers who live in nonsmoking households, limiting active and passive tobacco smoke exposure that could obscure effects of ambient air pollutant exposures; *d*) home and school addresses within a 3-mile radius of the central air monitoring site, enhancing the relevance of ambient exposures to personal exposures; and *e*) at least two symptomatic days per week requiring as-needed β-agonist inhaler use to treat bothersome asthma symptoms.

Subjects were recruited within a 2.6-mile radius study area in the Huntington Park region (Huntington Park, Maywood, Bell, South Gate, and Florence-Graham), except one subject at 3.8 miles. We relaxed the fifth criterion after it became evident the recruitment target of 24 subjects would not be met unless subjects with more intermittent asthma

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were recruited (17 subjects). Two 16-year-olds were recruited to attain the target number. We recruited 26 Hispanic children. Two subjects were excluded from the study because they did not complete their diaries. Evidence of falsified PEF data led to exclusion of two additional subjects, who repeatedly wrote down replicate numbers for the three PEF maneuvers in the morning and the three PEF in the evening. Respiratory infection reports for another two subjects were invalid because of a frequent off-and-on appearance of responses, which is inconsistent with the usual course and frequency of respiratory infections. This left 22 subjects for univariate regression models and 20 subjects for models including the respiratory infection variable.

Institutional review boards of the University of California, Irvine, and Los Amigos Research and Education Institute approved the study protocol. Informed written consent in Spanish or English was obtained from all subjects and one of their legal guardians. Initially, subjects volunteered to participate for 2 months from November–December 1999. Eleven subjects later volunteered to continue through January.

Health outcomes. Participants reported the daily severity of asthma using a scale that incorporates the impact of the clinical severity of asthma symptoms on daily activities. Subjects rated asthma symptoms (cough, wheeze, sputum production, shortness of breath, and chest tightness) in terms of their combined severity on a six-level ordinal scale, as follows: 0: no asthma symptoms present; 1: asthma symptoms present but caused no discomfort; 2: asthma symptoms caused discomfort but did not interfere with daily activities or sleep; 3: asthma symptoms interfered somewhat with daily activities or sleep; 4: asthma symptoms interfered with most activities and may have required that the participants stay home in bed, return home early from school or work, or call a doctor or nurse for advice; 5: asthma symptoms required going to a hospital, emergency room, or outpatient clinic.

Subjects also recorded the daily number of as-needed β-agonist inhaler puffs and preventive asthma medications. They recorded PEF in L/min using the Mini-Wright peak flow meter (Clement Clarke International, Ltd., Harlow, UK) before the use of inhaled bronchodilators. The highest of the three PEF maneuvers in the morning and in the evening were retained for the analysis. We excluded 17.8% of PEF that did not meet the reproducibility criterion of ≤ 10% difference between the highest and second highest PEF (Enright et al. 1995). Trained research assistants also administered baseline and an end-of-study spirometry (MicroLab 3300 Spirometer; Micro Medical Ltd., Rochester, UK).

Subjects also entered yes or no to a question on whether they had a respiratory infection that day. Diary text below this question clarified it as follows:

> Were any of the following conditions present today: a cold, sore throat, fever, doctor-diagnosed flu, doctor diagnosed respiratory infection (pneumonia, bronchitis, croup, pharyngitis, laryngitis, middle ear infection, upper respiratory tract infection, or a sinus infection)?

Air pollution measurements. There was a delay in the start of outdoor air sampling at the chosen Huntington Park central site until 19 November 1999. An alternate site nearer to eight volunteers in Maywood was available and operational starting 4 November 1999. Data collection for criteria air pollutant gases began on 11 November 1999. Particle mass sampling was limited to 24 days, 4–26 November 1999 and 8 and 14 December 1999. Seven days were not monitored for VOCs.

Outdoor 24-hr air samples for noncarbonyl VOCs were collected in canisters with the XonTech 910A (XonTech Inc., Van Nuys, CA) and analyzed using U.S. EPA TO-14 methodology (SCAQMD 2000). The 910A injects inlet air into an evacuated canister at a constant flow rate for 24 hr. Outdoor 24-hr air samples for carbonyls were collected with the XonTech 920 (XonTech Inc.) and analyzed using U.S. EPA method TO-11 (SCAQMD 2000). Criteria air pollutant gases (O_3, NO_2, SO_2, and CO) were measured continuously using U.S. EPA reference methods. Gravimetric 24-hr PM_{10} was measured with quartz filters in a Sierra-Andersen Size Selective Inlet high volume sampler (Thermo Andersen, Smyrna, GA). Concentrations of EC–OC from these filters were analyzed using Desert Research Institute's (Reno, NV) Thermal/Optical Carbon Analyzer (Chow et al. 1993).

Analysis. The regression analysis of the relationships between air pollutants and asthma symptoms reported in the diary was based on two dichotomous outcome variables with different cutoff points across the asthma symptom score: *a*) no symptoms or symptoms not bothersome (score 0 or 1) versus bothersome or more severe asthma symptoms (symptom scores > 1), and *b*) none-to-bothersome symptoms but no interference with daily activities (score 0–2) versus asthma symptoms that interfered with daily activities (symptom scores > 2). We have used this approach successfully to detect associations of these clinically relevant symptom outcomes with criteria air pollutants and aeroallergens in asthmatic children studied in previous panels (Delfino et al. 1996, 1997, 1998, 2002). Estimates of association for asthma symptoms are expressed as odds ratios (ORs) with 95% confidence intervals (CI) for interquartile range increases in the air pollutant.

Regression analyses of the symptom variables were performed with generalized estimating equations (GEEs) (Liang and Zeger 1986) in the SAS procedure Genmod (version 8.2; SAS Institute, Cary, NC). The fit of the models was tested with deviance statistics. We found the best working correlation matrix of the correlated within-subject observations to be autoregressive lag 1, which modeled the autocorrelated errors. Regression analyses of morning and evening PEF were performed separately with the general linear mixed model, which estimates both fixed and random effects for correlated (not independent) data in individuals (Jennrich and Schluchter 1986). We used the SAS Mixed Procedure (version 8; SAS Institute, Cary, NC) (Littell et al. 1996). Random intercepts were estimated for each individual. The fit of the models was tested with Akaike's information criterion (Littell et al. 1996). An autoregressive parameter was needed to adjust for autocorrelated (serially correlated) error terms.

We examined models with air pollutant concentrations on the same day (exposure lag 0) and on up to 4 days before the day that health outcomes were reported (exposure lags 1–4). Outcomes were more strongly associated with lag 0 pollutants, followed by lag 1. There were no associations for lags 2–3, and the only associations at lag 4 were for formaldehyde, acetaldehyde, and *p*-dichlorobenzene. Therefore, results focus on lag 0 and 1 exposures. Multivariate regression models for the air pollutants were then tested for confounding by weekend versus weekday, maximum temperature, and respiratory infections. Confounding was considered a 10% or greater change in the regression parameter estimate for the pollutant. We first tested interaction of air pollutants with respiratory infection in a regression equation with the pollutant variable, a binary indicator for infection, and a product term between the pollutant variable and respiratory infection as predictors. Statistical interaction was considered present if the product term was $p < 0.05$. We also tested a product term model for interaction of air pollutants with a binary indicator for whether a subject was taking versus not taking anti-inflammatory medications during the panel period.

We tested between-pollutant confounding with two-pollutant regression models, including an individual VOC with a criteria air pollutant gas or particulate variable, or including PM_{10} with either EC or OC. We first tested interaction between VOCs and criteria gases or particulates in a regression equation with the two pollutant variables and a product term between the pollutants as predictors. Only 12–17 out of 24 days overlapped for both particulate data and criteria gases. Because of this limitation in South Coast Air Quality Management District data, two-pollutant models for PM included only the PM variables

themselves (PM_{10} with EC or OC) or the PM variables with VOCs.

Results

Descriptive statistics. Table 1 shows subject characteristics. Five subjects were asymptomatic, and one other had no asthma symptom scores > 1. Thus, 16 subjects contribute symptom event information to regression models incorporating the binary outcome for asthma symptom scores > 1. Seven subjects reported symptom scores > 2. Thus, only these subjects contribute symptom event information to regression models incorporating this binary variable. Fourteen subjects had < 80%-predicted forced expiratory volume in 1 sec (FEV_1) from normal tables for Hispanic children (Hankinson et al. 1999). Although this level of percentage predicted FEV_1 has been defined as evidence of moderate persistent asthma (NHLBI 1997), only four of these 14 subjects had asthma symptoms more than two times per week on average. Only six subjects were taking anti-inflammatory medications regularly (four on inhaled corticosteroids, one on a leukotriene inhibitor plus inhaled corticosteroid, and one on a leukotriene inhibitor alone). Subjects taking anti-inflammatory medications were two times more likely to have bothersome or more severe asthma symptoms ($p = 0.18$).

Table 2 shows descriptive data for exposures. None of the observed days exceeded the U.S. National Ambient Air Quality Standards (NAAQS) for criteria air pollutants (U.S. EPA 1990). The VOC levels are typical of the high fall to winter concentrations for the region (SCAQMD 2000). Styrene was not included in the regression analysis because 37 days (50%) were below the method detection limit. Particle mass and EC–OC data are shown for the subset of available days.

Table 3 shows a correlation matrix for selected VOC compounds and averaging times only as a point of reference for the regression analysis. There were moderate correlations between criteria air pollutant gases other than O_3 and several VOCs, including acetaldehyde, formaldehyde, toluene, and *m,p*-xylene. Acetone was weakly correlated with all criteria gases. The VOCs showed moderate to strong correlations between them. In addition, NO_2 and SO_2 were strongly correlated. The above positive correlations likely represent common sources from fossil fuel combustion and common meteorologic determinants such as air stagnation. Generally, most pollutants were positively correlated with temperature and negatively correlated with wind speed.

We also examined Spearman rank correlations between gravimetric PM_{10}, EC, OC, and VOCs (Table 3). Only 12–17 out of 24 days overlapped for both gravimetric data and criteria gases. Gravimetric PM_{10} moderately correlated with most of the VOCs ($r = 0.50$–0.66) and weakly correlated with acetone ($r = 0.32$). Gravimetric PM_{10} was not correlated with formaldehyde. OC and EC were both moderately correlated with most of the VOCs, including acetone ($r = 0.60$–0.78), as graphically shown with time plots for *m,p*-xylene in

Table 1. Descriptive statistics for 22 children with asthma, 4 November 1999 through 23 January 2000, Huntington Park region, Los Angeles County, California.

Subject characteristic	
Median age (age range)	12 (10–16)
No. males/females	18/4
No. days with bothersome or more severe asthma symptoms (symptom scores > 1)/person-days (%)[a]	79/1,123 (7.0)
No. days with asthma symptoms that interfered with daily activities (symptom scores > 2)/person-days (%)[a]	26/1,123 (2.3)
No. subjects with percent predicted FEV_1 < 80% at panel beginning or end (%)[b]	14 (64)
No. subjects taking regularly scheduled anti-inflammatory medications (%)	6 (27)
Mean daily as-needed β-agonist inhaler puffs (SD)	1.32 (1.79)

[a]Person-days examined are those when ambient measurements of air pollutants were available. [b]Predicted from normal tables for Hispanic children from Hankinson et al. (1999).

Table 2. Daily air pollution measurements, 4 November 1999 through 23 January 2000, Huntington Park region, Los Angeles County, California.

Exposure and averaging time[a]	No. observations	Mean (SD)	Minimum/maximum	Interquartile range	90th percentile
O_3 1-hr max (ppb)	74	25.4 (9.6)	4/52	14.0	38.0
O_3 8-hr max (ppb)	74	17.1 (7.2)	3/37	10.8	26.1
NO_2 1-hr max (ppb)[b]	69	7.2 (2.1)	3/14	2.0	9.0
NO_2 8-hr max (ppb)[b]	69	5.9 (1.6)	3/11	1.4	7.9
SO_2 1-hr max (ppb)	74	7.0 (4.0)	2/26	4.0	11.0
SO_2 8-hr max (ppb)	74	4.6 (3.0)	1/20	2.5	6.5
CO 1-hr max (ppb)	74	7.7 (3.1)	2/17	5.0	12.0
CO 8-hr max (ppb)	74	5.0 (2.0)	1/10	3.0	7.9
Acetaldehyde (ppb)[b]	69	3.11 (1.00)	1.05/5.79	1.31	4.55
Acetone (ppb)[b]	69	7.11 (3.74)	1.64/17.12	5.39	12.32
Formaldehyde (ppb)[b]	69	7.21 (2.41)	4.27/14.02	3.16	10.09
Benzene (ppb)	74	1.82 (0.79)	0.03/4.30	1.00	2.90
1,3-Butadiene (ppb)	74	0.51 (0.28)	0.05/1.50	0.30	1.00
Chloromethane (ppb)	73	0.58 (0.14)	0.40/1.10	0.10	0.70
p-Dichlorobenzene (ppb)[c]	74	0.15 (0.09)	0.05/0.50	0.15	0.30
Ethylbenzene (ppb)	74	0.59 (0.36)	0.05/2.20	0.50	1.10
Methylene chloride (ppb)	74	1.22 (0.86)	0.30/4.70	0.90	2.40
Styrene (ppb)[c]	74	0.10 (0.07)	0.05/0.40	0.05	0.20
Tetrachloroethylene (ppb)	74	0.51 (0.28)	0.05/1.40	0.40	0.90
Toluene (ppb)	74	7.17 (3.49)	1.90/19.40	4.90	12.40
m,p-Xylene (ppb)	74	3.07 (1.61)	0.30/9.10	2.20	4.80
o-Xylene (ppb)	74	0.94 (0.53)	0.10/3.00	0.70	1.60
Temperature 1-hr max (°F)	80	71.0 (6.1)	50/82	8.5	79.0
Gravimetric PM_{10} (μg/m^3)	24	59.9 (24.7)	20/126	37.0	86.0
EC (μg/m^3)	24	5.09 (1.86)	1.79/9.42	2.91	7.36
OC (μg/m^3)	24	9.47 (3.08)	4.29/17.05	4.64	13.03

max, maximum.
[a]Exposure measurements were made by the South Coast Air Quality Management District at the stationary outdoor monitoring sites. There was no VOC monitoring 25 and 26 December and 31 December through 4 January. Monitoring of criteria pollutant gases (O_3, NO_2, SO_2, and CO) began 11 November. Samplers for particle mass and carbon were operated only on a subset of days during the panel study. Except for criteria gases, pollutant-averaging times are 24 hr. [b]Fewer days of observation than noncarbonyl VOCs were because of sampling or deployment problems. [c]A total of 37 days for styrene (50%) and 21 days for *p*-dichlorobenzene (28%) were below the method detection limit (MDL); for these days, values were set at half the MDL, which was 0.1 ppb for all VOCs.

relation to OC and EC (Figures 1 and 2, respectively). EC and OC were weakly correlated with acetaldehyde and not correlated with formaldehyde. Gravimetric PM_{10} was strongly correlated with OC and EC (Figures 3 and 4, respectively).

Regression analysis. **Single-pollutant models for asthma symptoms.** Including a weekend indicator or the maximum temperature did not have a significant effect on the regression parameters for air pollutants. Respiratory infection reports were significantly associated with bothersome or more severe asthma symptoms (symptom score > 1) (OR = 3.40; 95% CI, 1.74–6.64) and with asthma symptoms interfering with daily activities (symptom score > 2) (OR = 5.62; 95% CI, 1.97–16.0). In multivariate GEE models, respiratory infection positively confounded the air pollutants. For instance, the log odds per parts per billion 8-hr NO_2 increased from 0.1469 (SE, 0.0656) to 0.1706 (SE, 0.0716), and the model deviance decreased by 10 after adding the respiratory infection variable to the model (excluding two subjects with invalid respiratory infection data and person-days with missing respiratory infection data). Product terms between the air pollutants and respiratory infections did not improve model fit. For most univariate pollutant models, regression parameters increased after excluding the two subjects with invalid respiratory infection data.

Table 4 shows results of the multivariate GEE models for the two binary symptom score variables in relation to increases in interquartile range concentrations of lag 0 and lag 1 criteria air pollutant gases, ambient VOCs, and the particulate air pollution variables (PM_{10}, EC, and OC). Models for symptom scores > 2 in relation to the particulate variables were not examined because of a limited sample size (nine symptom responses). All models control for respiratory infections. Positive associations were found for criteria air pollutant gases, with stronger associations for lag 0 than for lag 1 exposures. Lag 0 O_3 was associated with symptom scores > 2 but not symptom scores > 1. Positive associations between both asthma symptom variables and lag 0 NO_2 were stronger for the 8-hr than the 1-hr averaging time. Both symptom variables were positively associated with lag 0 SO_2. Asthma symptoms were not associated with CO. Symptom scores > 1 and > 2 were associated with carbonyl compounds (acetaldehyde, acetone, and formaldehyde). Many models for the relationship between asthma symptom scores > 1 and the noncarbonyl VOCs suggested an increased risk with exposure, including benzene, 1,3-butadiene, ethylbenzene, tetrachloroethylene, toluene, *m,p*-xylene, and *o*-xylene. Most ORs were close to 1.0 for chloromethane, *p*-dichlorobenzene, and methylene chloride. There was little evidence that the noncarbonyl VOCs were associated with asthma symptom scores > 2. The particulate air pollution variables were positively associated with symptom scores > 1. Strengths of association were OC ≅ EC > PM_{10}. Lagged particulate exposures were not associated with symptoms.

Models were tested excluding individual subjects to assess whether associations were sensitive to subject-specific data. A symptomatic 13-year-old male was influential in regression models for symptom scores > 2. He was not on anti-inflammatory medications and had the worst predicted FEV_1: prestudy, 40%; poststudy, 63%. After dropping the subject from models, ORs were in some cases halved or more. The OR for 8-hr NO_2 was 1.08 (1.40 with subject), for acetone was 1.44

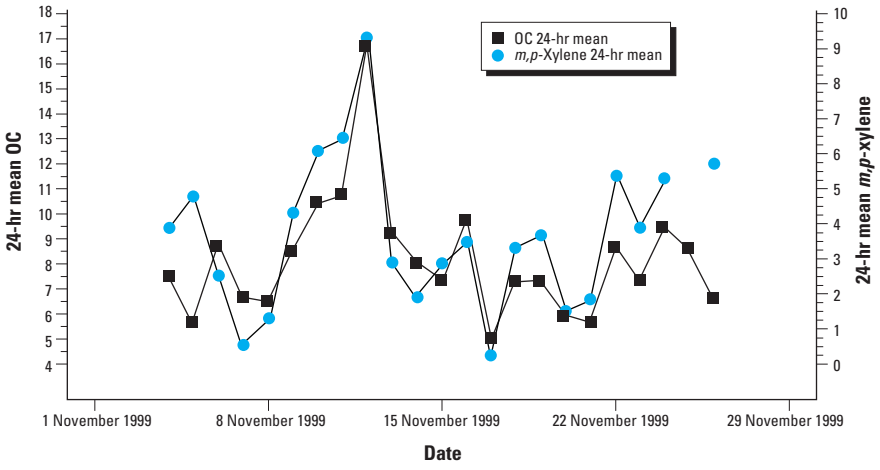

Figure 1. Time plot of daily 24-hr mean OC (μg/m^3) compared with 24-hr mean *m,p*-xylene (ppb), 4–26 November 1999, Huntington Park region, Los Angeles County, California.

Table 3. Outdoor air pollution and weather correlation matrix,[a] 4 November 1999 through 23 January 2000, Huntington Park region, Los Angeles County, California.

	8-hr max O_3	8-hr max CO	8-hr max SO_2	Acetaldehyde	Acetone	Formaldehyde	Benzene	Ethylbenzene	Tetrachloroethylene	Toluene	*m,p*-Xylene	PM_{10}	EC	OC	8-hr max temp	8-hr max wind speed
8-hr max NO_2	–0.20	0.65#	0.89#	0.69#	0.29*	0.57#	0.57#	0.66#	0.65#	0.70#	0.72#	0.38	0.54	0.62*	0.32**	–0.21
8-hr max O_3		–0.17	–0.19	–0.22	0.33**	0.09	0.03	–0.12	–0.13	–0.15	–0.08	–0.16	–0.38	–0.23	0.11	0.36**
8-hr max CO			0.69#	0.51#	0.28*	0.41#	0.50#	0.62#	0.63#	0.71#	0.72#	0.50*	0.60*	0.55*	0.41#	–0.33**
8-hr max SO_2				0.54#	0.31*	0.39**	0.59#	0.63#	0.62#	0.69#	0.72#	0.73#	0.87#	0.83#	0.43#	–0.26*
Acetaldehyde					0.28*	0.79#	0.50#	0.63#	0.52#	0.68#	0.65#	0.31	0.36	0.36	0.34**	–0.25*
Acetone						0.59#	0.27*	0.37**	0.46#	0.37**	0.42#	0.53*	0.61**	0.67#	0.41#	–0.01
Formaldehyde							0.38**	0.50#	0.40#	0.52#	0.52#	–0.10	–0.11	–0.10	0.44#	0.05
Benzene								0.71#	0.62#	0.75#	0.79#	0.50*	0.69#	0.62**	0.24*	–0.07
Ethylbenzene									0.84#	0.90#	0.94#	0.50*	0.66#	0.61**	0.30**	–0.24*
Tetrachloroethylene										0.87#	0.85#	0.66#	0.78#	0.78#	0.40#	–0.24*
Toluene											0.96#	0.48*	0.68#	0.62**	0.43#	–0.32**
m,p-Xylene												0.53*	0.73#	0.69#	0.35**	–0.29*
PM_{10}													0.82#	0.81#	0.28	–0.38
EC														0.94#	0.46*	–0.30
OC															0.37	–0.38
8-hr max temp																–0.05

Abbreviations: max, maximum; temp, temperature.
[a]Spearman correlation coefficients. The number of observations is 74 for SO_2, CO, O_3, weather, and VOCs; 69 for NO_2 and carbonyls; and 24 for PM_{10}, EC, and OC. Except for criteria pollutant gases (O_3, NO_2, SO_2, and CO), pollutant-averaging times are 24 hr. *$p < 0.05$; **$p < 0.01$; #$p < 0.001$.

(2.10 with subject), and for formaldehyde was 1.36 (1.90 with subject); none was statistically significant. O_3 was an exception where the OR for 8-hr was 2.20 ($p < 0.1$) versus 1.98 ($p < 0.05$) with subject. However, dropping this subject led to just small changes in ORs for models involving symptom scores > 1.

Product terms between the air pollutants and subject classification for regular use of anti-inflammatory medications were not significant in most models for symptom scores > 1 ($p \geq 0.10$), except 8-hr CO ($p < 0.01$), acetaldehyde ($p < 0.05$), and formaldehyde ($p < 0.07$), which revealed higher symptom response magnitudes among those not on anti-inflammatory medications (14 subjects) compared with those on anti-inflammatory medications (six subjects). In contrast, for 8-hr O_3 and PM_{10} there was a higher response magnitude among those on anti-inflammatory medication compared with those not on anti-inflammatory medications ($p < 0.07$), and regression parameters were nearly the same for OC, NO_2, and SO_2. For the remaining models, those on anti-inflammatory medications generally showed regression parameters that were either slightly greater or close in magnitude to those not on anti-inflammatory medications. The product term models were robust to exclusion of individual subjects.

Two-pollutant models for asthma symptoms. The focus of two-pollutant models is on exposures with lower confidence limits near or above 1.0 in their respective single-pollutant models. The aim was to assess whether the criteria pollutant gases or particulate exposures confound associations with VOCs. Two-pollutant models for PM_{10} with either EC or OC were also tested. Lag 0 noncarbonyl VOCs (benzene, ethylbenzene, tetrachloroethylene, toluene, *m*,*p*-xylene, and *o*-xylene), lag 1 acetaldehyde, and lag 1 formaldehyde were each regressed with lag 0 8-hr NO_2 or 8-hr SO_2 in models testing for risk of asthma symptoms scores > 1. There were no significant interactions between criteria pollutant gases and VOCs, or between VOCs and the particulate exposures. Figures 5–7 show comparisons between single-pollutant models and two-pollutant models for the same subset of nonmissing person-days for both pollutants. Log odds (regression parameter times the interquartile range) and their 95% CIs are plotted to compare associations in a linear format.

In two-pollutant models, PM_{10} did not confound EC or OC, but the OR for PM_{10} was reduced to around 1.0 (log odds = 0.0) when regressed with either EC or OC (Figure 5). Confidence intervals widened for all pollutants (recall pollutant correlations were $r > 0.8$). Figure 5 also shows two-pollutant models for PM variables with selected traffic-related VOCs that were significantly associated with symptoms. Lag 0 benzene and *m*,*p*-xylene were each regressed with lag 0 PM_{10}, EC, and OC. Results show that log odds for benzene and *m*,*p*-xylene were minimally reduced when regressed with PM_{10}, whereas the log odds for PM_{10} were diminished more. Similar results were found for the other noncarbonyl VOCs (data not shown). However, regression models of benzene or *m*,*p*-xylene with EC or OC showed that log odds for both pollutants were reduced by similar magnitudes. Multicollinearity is evidenced by the variance inflation of the estimates. For two-pollutant models of a PM variable with a lag 1-day carbonyl compound, strengths of association were minimally changed from single-pollutant models (not shown).

In two-pollutant models of VOCs and criteria pollutant gases, log odds for VOCs were generally reduced more than for SO_2 (Figure 6). A similar trend is seen for models with NO_2 plus a VOC, particularly benzene, where log odds were reduced more for the VOC than for NO_2 (Figure 7). Multicollinearity is again evidenced by the variance inflation of the estimates. Log odds for formaldehyde and acetaldehyde were somewhat more stable than for NO_2 and remained significantly associated with symptoms.

PEF and air pollutants. Respiratory infections were associated with PEF deficits of –8.0 to –9.0 L/min. Mixed models were tested for morning PEF versus lag 1 air pollutants, and evening PEF versus lag 0 air pollutants, controlling for respiratory infections, which led to small reductions in pollutant regression parameters. None of the models showed any deficit in PEF in relation to VOCs or criteria pollutant gases. Model fit was marginally improved by temperature and weekend, and null associations of pollutants were not altered. Models for particulate variables showed possible inverse associations with evening PEF. Associations with an interquartile range increase were –3.67 L/min (95% CI, ⁻10.3–2.91) for PM_{10}, –4.45 L/min (95% CI, ⁻10.6–1.68) for EC, and –4.82 L/min (95% CI, ⁻11.0–1.31) for OC. Particulate air pollutant variables were not

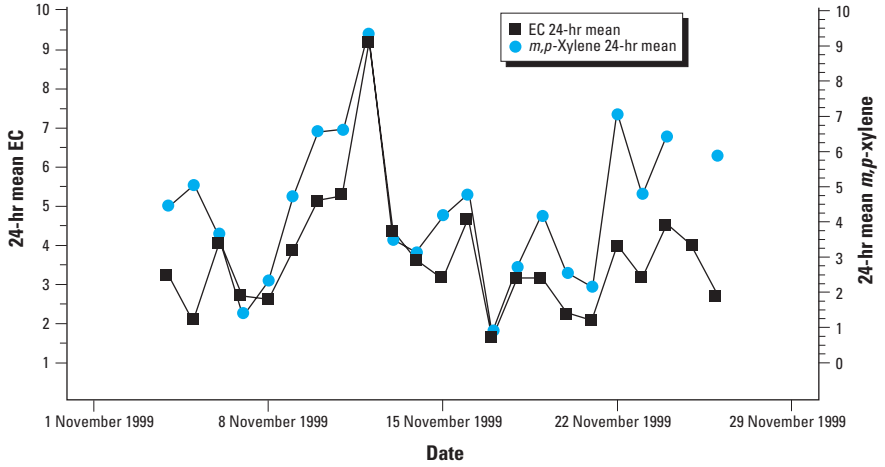

Figure 2. Time plot of daily 24-hr mean EC (μg/m^3) compared with 24-hr mean *m*,*p*-xylene (ppb), 4–26 November 1999, Huntington Park region, Los Angeles County, California.

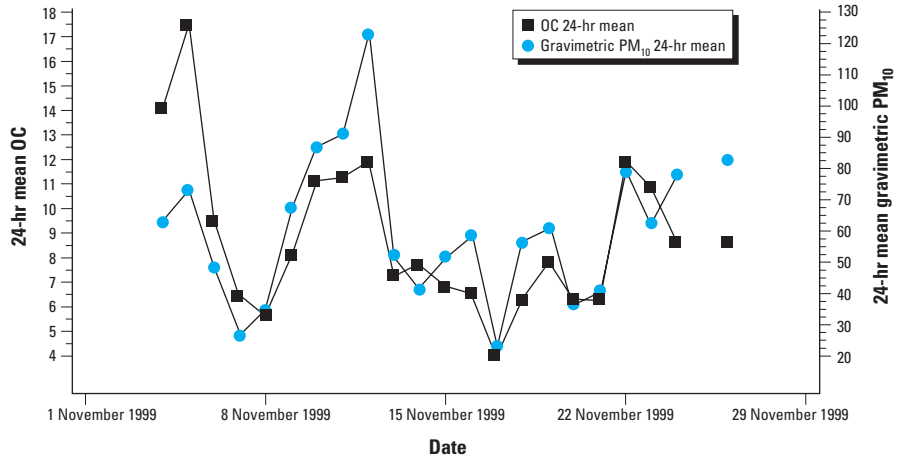

Figure 3. Time plot of daily 24-hr mean OC (μg/m^3) compared with 24-hr mean PM_{10} (μg/m^3), 4 through 26 November 1999, Huntington Park region, Los Angeles County, California.

associated with morning PEF. In addition, lag pollutant models did not show PEF deficits in relation to any lagged air pollutant.

Discussion

VOCs and criteria air pollutant gases. Our findings for criteria air pollutant gases are generally consistent with other studies of asthmatics (American Thoracic Society 1996). Although none of the measured pollutant gases was associated with PEF, we found many positive associations between asthma symptoms and exposures to criteria air pollutant gases as well as VOCs across this 3-month daily panel study (Table 4). Symptom scores > 1 were positively associated with most lag 0 petroleum-related VOCs (benzene, ethylbenzene, toluene, *m*,*p*-xylene, and *o*-xylene) and one industrial process–related VOC (tetrachloroethylene). Although CIs were wider, ORs were also positive for symptom scores > 1 in relation to lag 1 concentrations of the same VOCs as well as 1,3-butadiene. There were no associations with the process-related VOCs, *p*-dichlorobenzene, chloromethane, or methylene chloride. Carbonyl compounds (acetone, acetaldehyde, and/or formaldehyde) were positively associated with both symptom cut-points. Positive associations were found for both asthma symptom scores > 1 and > 2 in relation to 1-hr maximum and 8-hr maximum NO_2 and SO_2 at lag 0. O_3 lag 0 was only associated with asthma symptom scores > 2. Associations with lag 1 gases were weaker.

Particulate air pollutants. The present findings for particle mass are consistent with those of other panel studies of asthmatic children conducted over the past 6 years (Delfino et al. 1998, 2002; Gielen et al. 1997; Mortimer et al. 2002; Ostro et al. 2001; Pekkanen et al. 1997; Peters et al. 1997a, 1997b; Romieu et al. 1996; Segala et al. 1998; Thurston et al. 1997; Timonen and Pekkanen 1997; Vedal et al. 1998; Yu et al. 2000). We present new evidence that particle composition is important to adverse respiratory effects. We found positive associations between asthma symptoms and OC, EC, and PM_{10}, and there were possible inverse associations of evening PEF with OC, EC, and PM_{10}. Our findings suggest that particle associations were better explained by EC and OC than by PM_{10} because the magnitude of association was larger for EC and OC (Table 4), and in two-pollutant particle models for symptoms the OR for PM_{10} was reduced to 1.0 but EC and OC ORs remained virtually unchanged (Figure 5). Log odds for EC and OC were not as stable when regressed with a VOC (Figure 5). Organic compounds such as PAHs or other combustion products may have driven particle associations. This view is supported by experimental evidence that PAHs in diesel exhaust particles are capable of enhancing and possibly inducing allergic respiratory responses (Nel et al. 2001). This experimental evidence suggests that organic constituents of PM, including PAHs, are capable of generating reactive oxygen species that can then induce subsequent oxidant injury and inflammatory responses.

The actual mass of organic compounds in PM_{10} is mostly in the submicrometer fraction. Therefore, these compounds can reach target sites in the small airways and alveoli. Ultrafine (< 0.1 μm) and accumulation mode (0.1–1.0 μm) particles in nearby Downey, California, are largely made up of EC and OC (Kim et al. 2002). There is sufficient reason to believe that ultrafine particles are capable of inducing the greatest amount of inflammation per unit of PM mass because of high particle number, high deposition efficiency, and surface chemistry, which includes a high surface area that can carry adsorbed or condensed toxic air pollutants (organic compounds, oxidant gases, and transition metals) (Oberdörster 2001). This is important given that airway inflammation is a hallmark of asthma. Penttinen et al. (2001) showed that daily ambient particle number concentration, but not particle mass, was associated with PEF in 57 adult asthmatics. Of two other studies of asthmatic populations, one showed stronger associations of ambient ultrafine particle counts with daily PEF measurements in asthmatic adults than with either $PM_{2.5}$ or PM_{10} (Peters et al. 1997c), whereas another showed little difference in association of daily PEF deficits in asthmatic children with PM_{10} or ultrafine particle counts (Pekkanen et al. 1997).

Diesel exhaust particles likely contributed considerable mass and particle numbers to the ultrafine and accumulation mode fractions of PM_{10} in our study region, possibly explaining the more robust finding for OC and EC than for PM_{10}. However, our findings for two-pollutant models with particle mass and EC or OC may have been altered had $PM_{2.5}$ data been available. Schwartz and Neas (2000) reported data from three panel studies that showed that adverse respiratory outcomes in schoolchildren were associated with ambient $PM_{2.5}$ but not coarse particles ($PM_{2.5–10}$).

Anti-inflammatory medications. There was some limited evidence of stronger associations of symptoms with VOCs and CO among those not taking anti-inflammatory medications. However, this was not the case for other pollutants, including OC, NO_2, and SO_2. O_3 and PM_{10} showed an opposite interaction. Note, however, that symptom severity was greater among subjects on anti-inflammatory medications, showing that prescriptions for maintenance medications were used by more severe asthmatics. The problem illustrated here is that between-subject severity of asthma during follow-up can confound the expected protective effects of anti-inflammatory medications against the putative proinflammatory effects of air pollutants such as O_3. One of our previous asthma panel studies showed significantly stronger associations between asthma symptoms and O_3 in seven mild asthmatics not taking anti-inflammatory medications compared with seven similarly mild asthmatics taking them (Delfino et al. 1998).

Limitations. Although we feel the associations found in this study are internally valid, the small number of subjects limits the external validity of results. As discussed above, only seven subjects reported symptom scores > 2 compared with 16 reporting symptom scores > 1. Also, associations for symptom scores > 2 were strongly influenced by one subject with moderate persistent asthma. Thus, differing results for the two symptom cut-points could have resulted from different sets of subjects with positive symptom responses. Furthermore, results for EC–OC were based on a relatively short time series of 24 days. Particle associations in other periods could not be assessed.

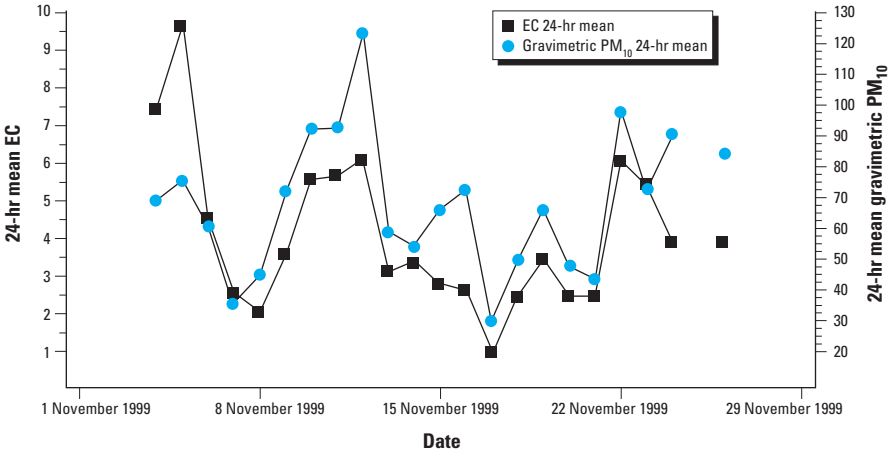

Figure 4. Time plot of daily 24-hr mean EC (μg/m³) compared with 24-hr mean PM_{10} (μg/m³), 4 through 26 November 1999, Huntington Park region, Los Angeles County, California.

The magnitude of misclassification of VOC exposures using ambient measurements may have been large for some VOCs such as formaldehyde with important indoor sources. On the other hand, data from other studies support the view that motor vehicle emissions may have had a strong influence on personal exposures to other VOCs such as benzene, ethylbenzene, toluene, and xylenes (Kinney et al. 2002; Weisel 2002). For this reason, it is conceivable that the ambient VOCs were acting as surrogates for criteria air pollutants, although there are important indoor sources for NO_2 and PM as well. Exploratory results of two-pollutant regression models of a VOC with a criteria air pollutant gas did not clarify whether associations were attributable to an individual pollutant, although parameter estimates were generally more stable for SO_2, and for NO_2 to a lesser extent (Figures 6 and 7). When regressing SO_2 or NO_2 with a VOC compound, moderate to high levels of correlation between pollutant variables (Table 3) led to multicollinearity in regression models, as indicated by variance inflation and reductions in regression parameters for both coregressed pollutants in most models (Figures 6 and 7).

The use of air pollution data from regional ambient sites such as those in the present study can lead to exposure misclassification as well as high correlations between different pollutants. Both of these problems can be addressed with measurements of personal exposure, which are considerably less subject to exposure misclassification and show less intercorrelation between major pollutants (Sarnat et al. 2000, 2001). Nevertheless, it may be inappropriate to use multipollutant modeling to test independent air pollutant associations by treating one or the other pollutant as a confounder if the pollutants are surrogates for some underlying causal mixture.

Table 4. Relationship of symptoms in children with asthma to interquartile range increases in ambient VOCs and criteria air pollutant gases.

Pollutant variable[a]	ORs (95% CI)[b] for symptom scores > 1[c]	ORs (95% CI) for symptom scores > 2[d]
O_3 1-hr max, lag 0	1.03 (0.72–1.48)	1.99 (1.06–3.72)*
lag 1	1.02 (0.70–1.50)	0.85 (0.56–1.28)
O_3 8-hr max, lag 0	0.90 (0.60–1.36)	1.98 (1.03–3.80)*
lag 1	1.18 (0.79–1.75)	1.05 (0.73–1.52)
NO_2 1-hr max, lag 0	1.18 (0.96–1.43)	1.27 (0.81–1.99)
lag 1	1.22 (0.97–1.53)	0.91 (0.52–1.62)
NO_2 8-hr max, lag 0	1.27 (1.05–1.54)*	1.40 (1.02–1.92)*
lag 1	1.17 (0.92–1.49)	1.04 (0.55–1.97)
SO_2 1-hr max, lag 0	1.31 (1.10–1.55)**	1.37 (0.87–2.18)
lag 1	1.11 (0.91–1.36)	0.76 (0.35–1.64)
SO_2 8-hr max, lag 0	1.23 (1.06–1.41)**	1.36 (1.08–1.71)**
lag 1	1.11 (0.97–1.28)	0.91 (0.51–1.60)
CO 1-hr max, lag 0	0.95 (0.52–1.75)	0.48 (0.07–3.53)
lag 1	1.11 (0.75–1.65)	1.28 (0.53–3.12)
CO 8-hr max, lag 0	0.95 (0.55–1.62)	0.53 (0.10–2.92)
lag 1	1.20 (0.77–1.86)	1.43 (0.41–5.00)
Acetaldehyde, lag 0	1.39 (0.80–2.41)	1.57 (0.70–3.54)
lag 1	1.48 (1.16–1.87)**	1.36 (0.87–2.14)
Acetone, lag 0	1.12 (0.72–1.74)	2.10 (1.16–3.81)*
lag 1	1.13 (0.80–1.60)	1.82 (1.14–2.93)*
Formaldehyde, lag 0	1.09 (0.70–1.68)	1.90 (1.13–3.19)*
lag 1	1.37 (1.04–1.80)*	1.30 (0.76–2.22)
Benzene, lag 0	1.23 (1.02–1.48)*	0.74 (0.35–1.53)
lag 1	1.06 (0.83–1.36)	0.96 (0.63–1.46)
1,3-Butadiene, lag 0	1.16 (0.90–1.49)	0.76 (0.34–1.71)
lag 1	1.32 (0.97–1.80)	1.10 (0.57–2.13)
Chloromethane, lag 0	1.07 (0.92–1.23)	0.92 (0.75–1.12)
lag 1	1.00 (0.79–1.26)	0.87 (0.69–1.10)
p-Dichlorobenzene, lag 0	1.18 (0.86–1.62)	0.75 (0.33–1.74)
lag 1	1.20 (0.86–1.67)	1.04 (0.60–1.78)
Ethylbenzene, lag 0	1.38 (1.09–1.75)**	1.08 (0.54–2.16)
lag 1	1.18 (0.90–1.55)	1.14 (0.66–1.98)
Methylene chloride, lag 0	1.09 (0.91–1.30)	0.79 (0.50–1.24)
lag 1	0.96 (0.82–1.14)	0.85 (0.71–1.01)
Tetrachloroethylene, lag 0	1.37 (1.09–1.71)**	0.90 (0.50–1.64)
lag 1	1.13 (0.81–1.57)	1.22 (0.65–2.30)
Toluene, lag 0	1.35 (0.99–1.84)	0.91 (0.38–2.22)
lag 1	1.16 (0.86–1.58)	0.88 (0.39–1.97)
m,p-Xylene, lag 0	1.35 (1.01–1.80)*	0.92 (0.34–2.51)
lag 1	1.19 (0.89–1.58)	1.06 (0.54–2.10)
o-Xylene, lag 0	1.28 (1.00–1.66)	0.92 (0.38–2.25)
lag 1	1.18 (0.90–1.53)	1.07 (0.60–1.92)
PM_{10}, lag 0	1.45 (1.11–1.90)**	—[e]
lag 1	1.07 (0.64–1.77)	—
EC, lag 0	1.85 (1.11–3.08)*	—
lag 1	1.01 (0.66–1.53)	—
OC, lag 0	1.88 (1.12–3.17)*	—
lag 1	1.08 (0.80–1.46)	—

max, maximum.
[a]Air pollution measurements were made by the SCAQMD at the stationary outdoor monitoring sites. Except for criteria pollutant gases (O_3, NO_2, SO_2, and CO), pollutant-averaging times are 24 hr. Pollutant concentrations are from the same day as symptom reports (lag 0) or the previous day (lag 1). [b]ORs and 95% CIs are from generalized estimating equations, and estimate the relative risk of a symptom response for an interquartile range change in the air pollutant, controlling for respiratory infections (two subjects with invalid respiratory infection data are excluded). Regression models involve data from 20 children over 74 days for SO_2, CO, and O_3 (887 person-days), 69 days for NO_2 (817 person-days), 74 days for VOCs (938 person-days), 69 days for carbonyls (860 person-days), and 24 days for PM_{10}, elemental carbon (EC) and organic carbon (OC) (351 person-days). [c]The asthma symptom severity score was dichotomized to *a*) no symptoms, symptoms not bothersome (scores 0,1) versus *b*) symptoms bothersome or more severe, including symptoms interfering with daily activities (scores > 1). [d]The asthma symptom severity score was dichotomized to *a*) no symptoms or symptoms not interfering with daily activities (scores 0,1,2) versus *b*) symptoms interfering with daily activities (scores > 2). [e]There were an insufficient number of responses to estimate associations with PM_{10}, EC, and OC. *$p < 0.05$; **$p < 0.01$.

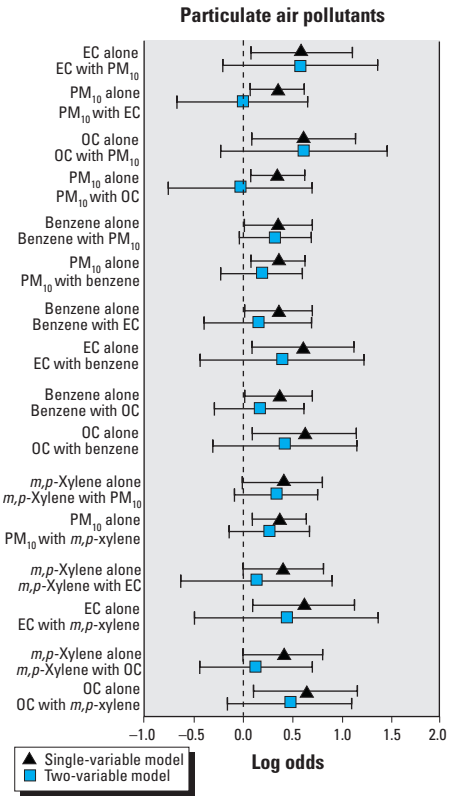

Figure 5. Single- versus two-pollutant models for particulate air pollution variables and VOCs. Log odds and their 95% CIs are plotted for bothersome or more severe asthma symptoms (symptom scores > 1) per interquartile range of pollutant concentration on the same day.

There was no consistency between the analysis of asthma symptoms and the analysis of PEF in relation to ambient VOCs or criteria pollutant gases. Also, although gravimetric PM_{10}, EC, and OC showed inverse relationships with evening PEF, none was significant and there was no suggestion of an association with morning PEF.

These findings could derive from biases in performing or reporting PEF by children. We presented evidence that two subjects repeatedly falsified PEF data. Although these data were excluded in analyses, we could not verify that other PEF data were valid. Falsification of PEF data is a strong possibility with nonelectronic methods. Evidence from two studies showed that around one-third of nonelectronic PEF data were falsified (Kamps et al. 2001; Redline et al. 1996; Verschelden et al. 1996). Also, PEF is intended as a surrogate measure of FEV_1, but studies have shown that PEF does not accurately reflect FEV_1 (Meltzer et al. 1989) or reflect bronchial hyperresponsiveness as measured by FEV_1 (Malmberg et al. 2001). PEF has a high probability of false negative detection of abnormal FEV_1 and of forced expiratory flow rate at 50% or at 25–75% of forced vital capacity (Ferguson 1988; Goldberg et al. 2001; Sly et al. 1994), particularly as air trapping increases (residual volume/total lung capacity) (Eid et al. 2000). This may have a considerable impact on the small exposure–response relationships expected in panel studies of air pollutant effects.

The inability to confirm that lung function maneuvers were performed correctly or even performed at all, along with a lack of FEV_1 data, may explain part of the inconsistency between results of the analysis of symptoms and lung function. In addition, the symptom scoring system we use allows the asthmatic subject to gauge his or her daily quality of life resulting from asthma, whereas PEF represents a snapshot in time of one physiologic parameter, which may not be representative of the daily severity of asthma. This is particularly likely if the patient has been using as-needed β-agonist inhalers. In a large study of more than 1,500 patients in clinical trials, correlation coefficients between airway obstruction (FEV_1 and PEF) and patient-reported end points (asthma symptoms and as-needed β-agonist use) was low (–0.13 to –0.23) (Shingo et al. 2001). The within-subject Spearman rank correlations between evening PEF and ordinal symptom score in the present study ranged widely, from 0.46 to –0.62 (mean, –0.07). Finally, PEF represents large-airway function, whereas asthma is thought to be a mixture of large- and small-airway obstruction. Some asthma symptoms may be driven more by small-airway obstruction. Chan-Yeung et al. (1996) found in 41 asthmatics that a significant increase in asthma symptoms occurred before a significant reduction in PEF in both children and adults with acute exacerbations leading to physician contact.

Consistency with other epidemiologic studies of air toxics. High home or school traffic density (particularly trucks) has been associated with asthma symptoms, allergic rhinitis symptoms, and prevalence of asthma or allergic sensitization in cross-sectional and case–control studies of children (reviewed in Delfino 2002). Our findings are consistent with these studies in that the air toxics exposures in the population studied were attributable predominantly to high traffic density. The advantage of the

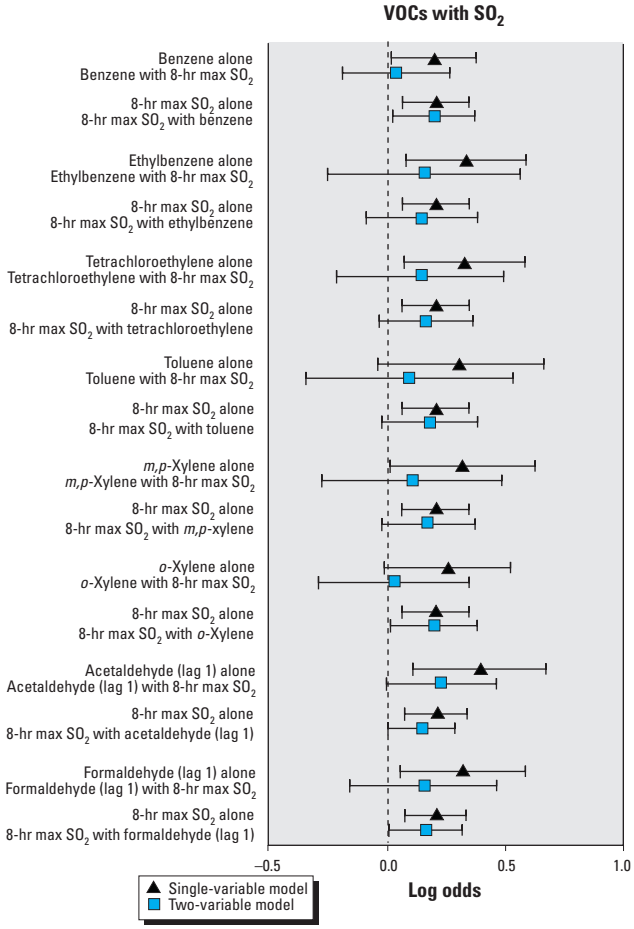

Figure 6. Single- versus two-pollutant models for VOCs and SO_2. max, maximum. Log odds and their 95% CIs are plotted for bothersome or more severe asthma symptoms (symptom scores > 1) per interquartile range of pollutant concentration on the same day.

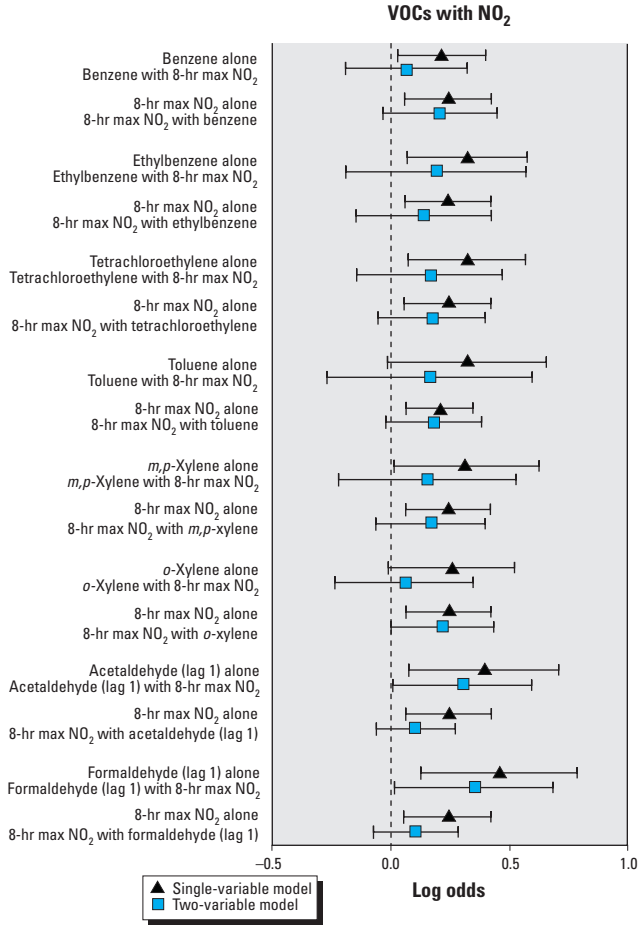

Figure 7. Single- versus two-pollutant models for VOCs and NO_2. max, maximum. Log odds and their 95% CIs are plotted for bothersome or more severe asthma symptoms (symptom scores > 1) per interquartile range of pollutant concentration on the same day.

present design is the ability to assess acute exposure–response relationships. Few studies have examined the health effects of community exposures to specific air toxics among asthmatic children. One epidemiologic study in the United States showed positive cross-sectional associations between respiratory health in children and ambient VOCs in the industrial area of Kanawha Valley, West Virginia (Ware et al. 1993). Three epidemiologic time-series investigations of hospital admissions or emergency room visits for asthma or wheeze found that criteria air pollutants did not clearly show stronger or more robust associations than did VOCs such as benzene (Buchdahl et al. 2000; Hagen et al. 2000; Thompson et al. 2001). Epidemiologic evidence linking indoor home VOCs with asthma prevalence or related respiratory outcomes is found in two cross-sectional studies (Norback et al. 1995; Wieslander et al. 1997).

Whether our findings for VOCs are due to irritant effects of the VOCs or of other correlated pollutants cannot be determined. Experimental data on VOC respiratory effects in humans are limited and inconsistent (Koren et al. 1992; Molhave et al. 1986). Some VOCs are believed to act as haptens that are involved in immunoglobulin E–mediated reactions. Workplace exposure to formaldehyde has been linked to the onset of occupational asthma, but the mechanism is unclear (Bernstein et al. 1999). Formaldehyde may combine with albumen to induce allergic sensitization to the hapten. Formaldehyde also occurs in outdoor air primarily because of automobile and diesel exhaust emissions. However, most epidemiologic studies have focused on indoor air concentrations of formaldehyde, which have been associated with childhood asthma prevalence (Garrett et al. 1999; Krzyzanowski et al. 1990), respiratory symptoms (Garrett et al. 1999), atopic sensitization (Garrett et al. 1999), and expired nitric oxide as a marker for lower airway inflammation (Franklin et al. 2000).

Our results for EC are roughly comparable with European studies that use a nongravimetric measurement called black smoke (Ulrich and Israel 1992). In a panel study of 61 children (77% on asthma medications), stronger associations were found for outdoor black smoke than for PM_{10} in relation to PEF, respiratory symptoms, and bronchodilator use (Gielen et al. 1997). However, preliminary results of a time series investigation in Atlanta, Georgia (USA), showed no association between adult emergency room visits for asthma and total polar VOCs, EC, or OC (Tolbert et al. 2000).

Conclusions

Adverse health effects have been found repeatedly in epidemiologic studies in relation to community exposures to PM_{10} or $PM_{2.5}$, but the causal components and susceptible subgroups have yet to be defined clearly. The present findings shed some light on this in that surrogate measures for organic compounds in PM_{10} (OC) and diesel exhaust particles (EC) (Cass and Gray 1995) showed more robust associations than did PM_{10}. Some of the VOCs, NO_2, SO_2, OC, and EC may all be markers for a causal mixture of traffic-related pollutants in an area with high traffic density. Our view that criteria pollutant gases function at least partly as surrogate indicators for a causal mixture of toxic air pollutants is supported by our findings that associations for SO_2 and NO_2 were found at very low concentrations relative to concentrations that induce adverse respiratory effects in human clinical studies (Peden 1997). The same can be said for the measured VOCs, although fewer clinical data are available to assess which, if any, of the VOC compounds are causally related to asthma. Our findings of adverse respiratory effects in asthmatic children may have been produced by the proinflammatory and irritant nature of traffic-related pollutants (Leikauf 2002; Nel et al. 2001). Results suggest that further study on potentially causal air toxics in the pollutant mix from traffic and industrial sources is needed.

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