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Merced / Mariposa County Asthma Coalition
Controlling asthma through awareness and education

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APR 27 2009
CITY OF MERCED
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April 21, 2009

Kim Espinosa
City of Merced - Planning Department
678 W. 18th
Merced, CA 95340

Re: The Merced/Mariposa County Asthma Coalition Opposes the Proposed Wal-Mart Distribution Center

Dear Ms. Espinosa,

The Merced/Mariposa County Asthma Coalition (MMCAC) is a community-based health organization that is composed of a diverse membership of over 150 volunteer members that seek to fulfill our mission of *controlling asthma through awareness and education.* Since 1997, the coalition has implemented both clinical and environmental interventions which help to reduce the prevalence of asthma in our community by working with schools, health care professionals, policymakers and residents. MMCAC members have a proud history of advocating for the strongest, most health-protective policies possible on the local, regional and statewide levels.

Since plans for the Wal-Mart distribution center were first announced in August 2005, a broad cross-section of Merced residents have expressed their concerns related to local and regional air quality impacts from this project. In January 2007, MMCAC members voted to formally oppose the project. We believed then that the project's negative impacts to the health and quality of life of Valley and local residents outweighed its employment benefits. **We still have serious concerns that the negative consequences of the project on local residents most affected by the project's impacts 1) are not adequately addressed and 2) are not adequately reduced to a less than significant level.**

Put simply, we submit these comments because the health of our members and our community is directly affected by the project.

The most recent California Health Interview Survey (CHIS) shows that out of 51,000 Merced County residents diagnosed with asthma, 17,000 are children. In 2006, over 700 children visited local Emergency Rooms due to asthma-related illnesses. In 2007, at least two Merced County residents died from asthma attacks (one pregnant, single mother in the City of Merced and one mother in Los Banos). A recent study by Cal State Fullerton Professor Jane Hall estimated that the public would save $5.8 billion in health costs if air pollution in the San Joaquin Valley met federal health-based standards. We must do everything in our power, and we ask you to do the same, to ensure Merced County residents, especially children, are able to live, learn and grow up in a healthy environment, which is why we oppose the proposed Wal-Mart Distribution Center.

737 W. Childs Ave. Merced, California 95341 **TELEPHONE** 209-385-5490 **FAX** 209-384-3966 **WEBSITE** www.mmcac.com

Air pollution is the number one environmental concern for the people of the Valley. It endangers the health of residents, retards the growth of crops, and threatens the overall economy and quality of life in the region. The economic benefits of the project should be studied and weighed against the economic costs of its air quality impacts. As stated, we oppose the proposed WMDC due to both the negative consequences to residents' health and the burden that will be placed on the economy if 100% of the pollution generated by the proposed project is not fully mitigated through proactive measures (locally and regionally).

We have three main areas of concern:

1. Assumptions made in the Draft Environmental Impact Review (DEIR) are based on confusing and dubious studies.
2. The DEIR does not "identify and discuss all feasible measures that will reduce air quality impacts generated by the project," as requested by the Air District in their Notice of Preparation letter and as required by CEQA.
3. The full extent of the Valley's air quality public health crisis has not been taken into account on all levels of planning.

The DEIR's underlying analysis is flawed and inadequate.

Despite the many pages of technical writing included in the DEIR, we are left with a number of questions. We feel that the urgent reality our members experience in Merced County classrooms, living rooms and emergency rooms is not adequately reflected in this document. Without a reliable set of studies, we question the adequacy of any subsequent mitigation measures, permitting actions, or voluntary agreement.

There are fundamental questions that still need to be answered.

How many trucks precisely will use the facility?

The WMDC's Notice of Preparation released July 7, 2006, states that "The project is expected to accommodate up to 900 tractor/trailer trips per day (450 in and 450 out)." However, there is no reference to this number, nor does the DEIR at any point make reference to a maximum peak hour number of truck trips. Instead, the authors of the studies rely on an e-mail communication from Lynn McAlexander, Wal-Mart's former Project Manager for Distribution Center Design. McAlexander's e-mail apparently states that Wal-Mart's distribution center in Apple Valley generates an average of 644 truck trips per day.

A rough daily average of 644 truck trips does not preclude a maximum of 900 truck trips in a day – an additional 28.5% truck trips. This alone renders the 2010 and 2030 traffic studies and subsequent mitigation measures flawed and virtually useless as a document to be used as the basis for such an important decision.

- What would the project's impact be if the traffic study studied the actual PM Peak Hour traffic with the project? What further mitigation would be required if the actual number of PM Peak Hour trucks were studied? If the suggested mitigation is inadequate for actual PM Peak Hour traffic, what will happen?
- How many more idling trucks would sit at the intersection? How long would the trucks wait for the stoplight to change? How much more carcinogenic diesel soot would students, teachers and staff breathe?

- Will traffic back up onto SR 99? If traffic backs up, or if the Mission and SR 99 intersection becomes known as a problematic intersection, what other routes will trucks use to avoid it?

These, or similar questions can be asked of each intersection that the traffic analysis claims to study. The studies that depend on a rough estimate of truck trips should be redone to include a peak hour number of maximum truck trips, their associated emissions and further mitigation measures. These new studies should not be speculative; they should instead provide an accurate assessment of impacts to an already overburdened neighborhood.

Where will trucks using the Merced WMDC travel to and from?

The DEIR's measurement of truck trips is internally inconsistent and appears to avoid a good faith effort at full disclosure of impacts to Air Districts outside the San Joaquin Valley.

The DEIR again bases its operational emission estimates on an e-mail from former Wal-Mart Project Manager for Distribution Center Design Lynn McAlexander. According to McAlexander's data for trip distances for the proposed project:

	Operation-related emissions of criteria air pollutants and precursors	**Operation-related emissions of carbon dioxide**
Average inbound receivable truck trip distance	**106.2 miles/trip** "in the San Joaquin Valley Air Basin" between the 49 existing Wal-Mart stores and existing DC in Red Bluff or Porterville	**171.5 miles/trip** "in *and beyond* the San Joaquin Valley Air Basin" between 49 existing Wal-Mart stores and existing DC in Red Bluff or Porterville
Average outbound delivery truck trip distance	**83 miles/trip** "in the San Joaquin Valley Air Basin" to the 49 existing Wal-Mart stores	**109.1 miles/trip** "in *and beyond* the San Joaquin Valley Air Basin" to the 49 existing Wal-Mart stores

We note that Table 4.2-7 shows a stunning amount of existing operational emissions contributing to criteria air pollutants. Wal-Mart's truck traffic that would travel to 49 existing stores, which would be supplied by the Merced WMDC, will be responsible for **343 tons/year of NOx and 207 tons/year of PM10.**

We need more information about three assumptions made in the DEIR's operational emissions study.

1. The DEIR measures trip distance outside the San Joaquin Valley Air Basin when determining CO2 emissions, but not for criteria air pollutants. If the trucks travel outside the San Joaquin Valley Air Basin then the DEIR should a) state the attainment status of each Air District, b) estimate the amount of emissions that will pollute each Air Basin as a result of this project, and c) contact each Air Basin for comment. Any change in truck route from the Port of Oakland should be studied as well.

2. In order to understand how many miles trucks using the Merced WMDC would actually travel, we would need to know which stores the distribution center is intended to serve. Please provide a list of the 49 existing stores in the San Joaquin Valley Air Basin upon which the DEIR's traffic studies are based.

3. It is unclear why Inbound Receivable net emissions total precisely 0.0 TPY of all criteria air pollutants and precursors. Even if all trucks using the Merced WMDC were already delivering goods to the supposed 49 existing stores in the San Joaquin Valley Air Basin, the trucks still need to travel over 1 mile from SR 99 to the Gerard Ave. entrance. These emissions must be acknowledged, assessed and appropriately mitigated.

A full Health Risk Assessment needs to be conducted by trained Air District staff with community input.

We call for a full Health Risk Assessment (HRA) to be completed with specific attention paid to the local area "sensitive sites" (Farmdale Elementary School, Pioneer Elementary School and Weaver Middle School as well as the proposed school site in the area).

In order to adequately understand the health impacts introduced by the project, a full Health Risk Assessment that includes a study of cancer risk caused by off-site WMDC project traffic should be conducted. The 7.3 in 1 million elevated cancer risk should not be dismissed as insignificant. The DEIR should include concrete measures that will be taken to reduce this cancer risk to a minimum. as low as feasible.

In order to assess the actual cancer risk introduced by this project, two additional sources of emissions should be included:

1) Off-site traffic-related emissions generated by the project should be included. The proposed truck route passes within approximately 1,000 feet from Pioneer Elementary school and appears to be adjacent to a planned Weaver School District elementary school site between Childs Ave. and Gerard Ave.

2) A thorough HRA, one that allows residents to understand the health risks posed to our community by this project, would include a study of sensitive receptors' exposure to Toxic Air Contaminants from 2030 traffic conditions projected to come about with the project.

We note that the project is less than half of the Heavy Industrial zoned land in southeast Merced that was added to the City in 1997 as part of the Lyons Annexation. Other proposed industrial uses in the Annexation area include a 350 megawatt peaking power plant and an industrial park on the eastern side of Kibby and Childs Ave. The traffic study ignores the build-out of these uses and the cumulative health impacts of all proposed projects.

The Public must be involved in the Air Impact Assessment, Rule 9510 and voluntary emissions reduction agreement

The Coalition has several concerns about the Air Impact Assessment process as described in the DEIR. The MMCAC requests to participate and consult with the San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) as local stakeholders and experts on any voluntary agreement between Wal-Mart and the SJVUAPCD.

Any agreement between Wal-Mart and the SJVUAPCD should be noticed and circulated for public review and given ample time for comment by the public and relevant agencies. Specific details regarding *how* mitigation is performed and monitored are a critical component of the decision-making process. Simply stating that at some point in the future, dozens of tons per year of criteria air pollutants will be mitigated is inadequate and inappropriately defers mitigation. Because we live in one of the country's most polluted air basins with four times the National asthma rates, it is absolutely critical that mitigation happen immediately (locally and regionally).

The MMCAC encourages the use of on-site mitigation that reduces actual emissions from vehicles entering and exiting the Merced WMDC.

A majority of trucks using the Merced WMDC would be non-Wal-Mart trucks. We encourage the development of an enforceable mitigation program that monitors *all* trucks using the facility.

Indirect Source Review (ISR) compliance and any voluntary agreement should consider that the Merced WMDC, if approved, would operate in Merced for decades. For example, an off-site in-lieu fee used to replace an agricultural pump with a seven- year lifespan is not an adequate mitigation measure in itself. **The SJVUAPCD should require Wal-Mart to mitigate each type of criteria pollutant to zero for the life of the project.**

The DEIR's claim that the SJVUAPCD "has not identified mass emissions thresholds for operational emissions of PM10 and PM2.5" is disputable. MMCAC members participated in the SJVUAPCD's process for writing the strongest possible State Implementation Plan (SIP) for attaining health protective fine particulate standards. Even assuming that the DEIR's estimate of 16.5 TPY of PM10 after ISR mitigation is accurate, it is inappropriate and dangerous to state that this is not worth mitigating.

Given the extreme air quality public health crisis that our members experience on a daily basis, the SJVUAPCD should require 2:1 mitigation per ton of pollutant.

If the City of Merced is going to monitor the voluntary agreement mitigation measures, we ask that the SJVUAPCD and California Air Resources Board (CARB) staff train City of Merced staff in appropriate fields to assist in gaining expertise in recognizing and mitigating criteria pollutants.

One such field could be training City public services staff to inspect heavy duty diesel trucks for proper tags, compliance with idling regulations, etc. MMCAC members could be available to train City of Merced staff in indoor and outdoor air quality conditions and related areas.

Finally, we again emphasize that localized coarse, fine and ultrafine PM emissions must be fully accounted for and reduced to the maximum extent possible using the Best Available Control Technology (BACT). **If Wal-Mart chooses to pay an in-lieu fee, we request 1) that PM emissions be mitigated at a 2:1 ratio and 2) that on-site fees be directed towards helping Merced residents cope with the real world health impacts of local PM emissions.**

The DEIR should also discuss how this project may interfere with regional or countywide emission reduction goals set under SB 375. These goals should be included in the City of Merced's updated General Plan.

The City of Merced has been in the process of updating its General Plan for nearly two years. The current City of Merced Vision 2015 General Plan, written in 1995-6 and approved in 1997, is out-of-date. The City is out of compliance with the letter and intent of AB 170. This project contradicts the "Toxic and Hazardous Emissions" section of the SJVAPCD's *Air Quality Guidelines for General Plans.*

As stated in the DEIR, Wal-Mart intends to "take advantage of the local labor force". As a good-faith commitment and in order to reduce the Vehicle Miles Traveled (VMTs) as required by SB 375, the Wal-Mart Corporation must hire 90% of all WMDC employees from Merced County (residents who live in Merced County prior to employment). Specific attention should be paid to Merced County's unemployed. If training is required for new employees, then the Wal-Mart Corporation must implement a training program that will educate the majority of the unemployed labor force in Merced County on the basics of the job and how to do it.

Wal-Mart must also pay for and provide alternative modes of transportation for its employees, such as:

- Purchasing carpool vehicles to create WMDC's "Carless Commute" which would serve employees and the various shifts
- Providing on-site services such as postal, banking services and showers for bicycle commuters
- Providing and encouraging "Bike-to-Work" days, weeks, seasons, etc.
- Installing one state-of-the-art bike locker for every 20 employees

As discussed, the MMCAC supports full mitigation of project impacts in a manner that corresponds to the project's real world health impacts. Any voluntary agreement between Wal-Mart and the SJVUAPCD should prioritize on-site measures that reduce the project's air pollutants to a less than significant level.

For example:

- No truck with an engine older than 2007 Model Year (MY) will be permitted to use the facility. Wal-Mart staff will be required to submit monthly reports to City staff detailing the model year of the trucks entering the facility.
- A fund will be created to retrofit or replace the trucks that will enter the project site.
- As a good-faith measure, Wal-Mart will need to purchase at least two PM2.5 forecasting monitors to assist the SJVUAPCD in "improving the health and quality of life for all Valley residents through effective and cooperative air quality programs".

If these are determined to be somehow infeasible or unacceptable, we request that funds be directed to specific programs that create a healthier and more livable community for Merced residents directly affected by the project's impacts.

For example:

- Funds designated to hire three full-time nurses to staff Weaver and Pioneer schools and administer a program that will help students live a healthy and successful life even in the most polluted air basin in the U.S.
- Funds designated to staffing the urgent care facility in Mercy Hospital as well as training and hiring additional respiratory therapists.
- Funds designated to assist southeast Merced residents in purchasing asthma equipment such as inhalers and spacers.

- Funds designated to build publicly-owned infrastructure in southeast Merced that encourages healthy exercise and community building. This could include a Community Center with the most efficient, state-of-the-art Heating Ventilating Air Conditioning (HVAC) system.
- Funds designated to the Weaver School District to offset the cost of the site selection process of a new school site.
- Funds to plant a perimeter of redwood, deodar cedar trees, and/or broad-leaf live oaks around the 1.1 Million Sq. Ft. property and along the project truck route. These types of trees are "highly effective in filtering some of the most toxic particles in auto exhaust." (Sacbee / News: Published May 6, 2008)
- Merced needs to move towards becoming more "green", not "green washing" as Wal-Mart seems to do. We need to be at the fore front of the green movement not lag behind. All of the green issues with Wal-Mart need to be resolved before it moves forward.
- Wal-Mart should pay for the entire cost for all asthma, heart disease, allergy and cancer treatment and medication for residents living within a two mile radius of the proposed Wal-Mart Distribution Center who are diagnosed with the listed diseases or ailments if diagnosis is given on or after the start of WMDC construction.
- As Wal-Mart actively pursues community involvement, we request a management representative from Wal-Mart be required to join the Merced/Mariposa County Asthma Coalition with 80%attendance/annually of all meetings.
- In addition, Wal-Mart needs to be required to fly the Asthma-Friendly Air Quality flags in front of their building and provide mandatory staff presentations explaining the importance of the flag program and asthma education. The Merced/Mariposa County Asthma Coalition will be available to provide the staff presentations.

Any mitigation measures as a result of this project should be binding with a clear timetable for implementation and benchmarks to measure their success.

A measure stating that "the project shall include as many clean alternative energy features as possible to promote energy self-sufficiency" (2-17) is too vague. Please note, natural gas is not the Best Available Technology for alternative energy and will also create a more localized, cumulative air pollution burden on the area.

Mitigation Measure 4.2-2d states that "If, however, the additional measures listed below are technologically or economically infeasible, the Applicant shall submit a written report to the City of Merced Planning & Permitting demonstrating such infeasibility. Approval of this report shall be received by the Applicant prior to receiving final discretionary approval of the project from the City of Merced Planning & Permitting."

We request that 1) if Wal-Mart submits such a written report it be made available for public review and a reasonable amount of time be given to comment on such a report (30 days minimum), and 2) that knowledgeable independent experts determine whether additional measures are truly technologically or economically infeasible.

Thank you for taking our comments and recommendations seriously. As stated above, the Merced/Mariposa County Asthma Coalition adamantly opposes the proposed Wal-Mart Distribution Center due to the negative health impacts the project will create. As the process moves forward, we urge the City to make the process as open, inclusive and accessible as possible to all Merced residents. We have full confidence that if the City of Merced chooses to move forward and approve the project, that the recommendations above will be implemented into an agreement between the City of Merced (its residents) and the Wal-Mart Corporation.

Please contact us if you have any questions.

Sincerely,

Connie Mull, RN
Chair

Attachments:

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10. "Merced/Mariposa County Asthma Coalition - Report to the Community on Asthma". Released May, 2008.

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Original Contribution

Association of Black Carbon with Cognition among Children in a Prospective Birth Cohort Study

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While studies show that ultrafine and fine particles can be translocated from the lungs to the central nervous system, the possible neurodegenerative effect of air pollution remains largely unexplored. The authors examined the relation between black carbon, a marker for traffic particles, and cognition among 202 Boston, Massachusetts, children (mean age = 9.7 years (standard deviation, 1.7)) in a prospective birth cohort study (1986–2001). Local black carbon levels were estimated using a validated spatiotemporal land-use regression model (mean predicted annual black carbon level, 0.56 μg/m^3 (standard deviation, 0.13)). The Wide Range Assessment of Memory and Learning and the Kaufman Brief Intelligence Test were administered for assessment of cognitive constructs. In analysis adjusting for sociodemographic factors, birth weight, blood lead level, and tobacco smoke exposure, black carbon (per interquartile-range increase) was associated with decreases in the vocabulary (−2.2, 95% confidence interval (CI): −5.5, 1.1), matrices (−4.0, 95% CI: −7.6, −0.5), and composite intelligence quotient (−3.4, 95% CI: −6.6, −0.3) scores of the Kaufman Brief Intelligence Test and with decreases on the visual subscale (−5.4, 95% CI: −8.9, −1.9) and general index (−3.9, 95% CI: −7.5, −0.3) of the Wide Range Assessment of Memory and Learning. Higher levels of black carbon predicted decreased cognitive function across assessments of verbal and nonverbal intelligence and memory constructs.

air pollution; child; cognition; intelligence; neurotoxicity syndromes; particulate matter; soot; vehicle emissions

Abbreviations: CI, confidence interval; IQ, intelligence quotient; K-BIT, Kaufman Brief Intelligence Test; SD, standard deviation; WRAML, Wide Range Assessment of Memory and Learning.

It is well documented that air pollution is associated with a number of adverse respiratory and cardiovascular health effects (1–3). Many of these effects seem to be more strongly associated with particles from traffic (1), which are rich in elemental carbon and are the principal source of ultrafine particle exposure. However, the possible neurodegenerative effect of air pollution remains largely unexplored. The potential effect of translocation of particles from the lung to other organs has been documented. Researchers have shown that ultrafine and fine particles can be translocated from the lungs when they penetrate pulmonary tissue and enter the capillaries, reaching other organs (i.e., liver, spleen, kidneys, heart, brain) through circulation (4). In addition, fine and coarse particles can be phagocytized by macrophages and dendritic cells carrying the particles to the lymph nodes (5).

Animal studies have shown that inhaled particles can be translocated from the respiratory system directly to the central nervous system. In rats, Oberdorster et al. (6) found ultrafine carbon-13 particles in the olfactory bulb and the

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cerebrum and cerebellum after inhalation exposure of ultrafine elemental carbon-13 particles. More recently, Elder et al. (4) confirmed that ultrafine particles can reach the brain, either through circulation or directly translocated to the olfactory nerve from the nose to the brain. This raises the question of whether traffic particles can have neurotoxic effects.

The few studies that have focused on the potentially neurotoxic effects of particulate matter have focused on pathologic lesions that are generally present in neurodegenerative diseases (i.e., Parkinson's disease and Alzheimer's disease). Researchers have proposed that damage mediated by the particles is probably related to the oxidative stress pathway. Calderón-Garcidueñas et al. (7) presented histologic evidence of chronic brain inflammation (i.e., nuclear factor-κB activation and inducible nitric oxide synthase production) and an acceleration of Alzheimer-like pathology (i.e., apoptotic glial white matter cells, nonneuritic plaques, neurofibrillary tangles) among canines chronically exposed to high levels of air pollutants in Mexico City. Levels of proinflammatory cytokines, including interleukin-1α and tumor necrosis factor-α, were higher in the brain tissues of mice exposed to particulate matter than in mice that were not exposed (8). In humans, exposure to severe air pollution has been associated with increased levels of cyclooxygenase-2, an inflammatory mediator, and accumulation of the 42-amino-acid form of β-amyloid, a cause of neuronal dysfunction (9). Changes in brain cytokine and chemokine expression in mice have been directly linked to intranasal exposure to ultrafine black carbon, suggesting a more general inflammatory response (10). Changes in cognitive function have been shown to be associated with relatively low doses of heavy metal exposure (11), which in high doses can produce some of the lesions cited above. Those low doses have also been associated with increased inflammation and oxidative stress.

Taken together, these results suggested that further examination of possible associations between markers of traffic particles and cognitive function would be worthwhile. Thus, we examined the relation between black carbon from traffic sources, a component of particulate matter, and cognition among children followed in a prospective birth cohort study. This provided us with the opportunity to adjust for markers of socioeconomic status and other environmental factors known to affect cognitive development.

MATERIALS AND METHODS

Study population

The sample for these analyses was drawn from participants in the Maternal-Infant Smoking Study of East Boston, a prospective cohort study designed to evaluate the effects of pre- and postnatal tobacco smoke exposure on childhood lung growth and development and respiratory health. The study has been described in detail previously (12). In brief, pregnant women receiving prenatal care (<20th week of gestation) at an urban community health center in Boston, Massachusetts, between March 1986 and October 1992 were eligible for enrollment. Women who did not speak either English or Spanish, who did not plan to have pediatric follow-up at the clinic, and who were less than 18 years of age at the time were excluded. One thousand women were eligible and enrolled, of whom 848 continued participation and delivered a live infant. In November 1996, new study initiatives were implemented, including the assessment of social stressors and neurocognitive assessment, at which time 500 women and their children continued active follow-up. All active subjects were approached to participate in the cognitive battery, and 218 children completed the neurocognitive assessment. Notably, there were no significant differences between those who participated in the cognitive assessment and those who did not with regard to sociodemographic factors, birth weight, blood lead level, or tobacco smoke exposure. The study was approved by the human studies committees at the Harvard School of Public Health, Brigham and Women's Hospital, and the Beth Israel Deaconess Medical Center.

In the longitudinal study, detailed data on race/ethnicity and socioeconomic position (based on maternal educational level) had been ascertained through standardized questionnaires administered at baseline and clinic follow-up visits, as previously described (12).

Black carbon

Exposure to black carbon was estimated on the basis of the children's residence during study follow-up. In order to estimate residential black carbon level, we used a validated spatiotemporal land-use regression model to predict 24-hour measures of traffic exposure using data from more than 80 locations in the Greater Boston area. Three quarters of the monitoring sites were residential; the rest were commercial or government facilities. The data consisted of over 6,021 pollution measurements from 2,127 unique exposure days. A detailed description of all sources of exposure data is provided elsewhere (13). Predictors included in the regression analysis were the black carbon level at a central stationary monitor (to capture average concentrations in the area on that day), meteorologic conditions and other characteristics (e.g., weekday/weekend) of a particular day, and measures of the amount of traffic activity (e.g., geographic-information-system-based measures of cumulative traffic density within 100 m, population density, distance to the nearest major roadway, percentage of urbanization) at a given location. A cumulative traffic density measure was recorded once per location. We used spline regression methods to allow these factors to affect exposure levels in a potentially nonlinear way. Finally, we used thin-plate splines, a two-dimensional extension of regression splines, to model longitude and latitude and capture additional spatial variability that was unaccounted for after we included our deterministic spatial predictors in the model. This approach is a form of universal kriging (i.e., kriging extended to incorporate covariates) or a geoadditive model (14) for daily concentrations of particle levels. We had complete information on all of these factors for 2,114 of the 2,127 unique exposure days. Separate models were fitted for the warm (May–October) and cold (November–April) seasons. The R^2 value for the model (over both seasons) was 0.82, and the cross-validated R^2 between the daily measurements taken outside the residential locations and corresponding predictions obtained from fitting the model to the data after excluding data from a particular residential location was 0.36. For the purposes of these analyses, we used the average of the two seasons as a measure of average lifetime black carbon exposure. If children moved during the study period ($n = 12$), an average black carbon measure for all addresses was calculated.

Cognitive measures

When the children were aged 8–11 years, a battery of cognitive tests was administered, including the Kaufman Brief Intelligence Test (K-BIT) and the Wide Range Assessment of Memory and Learning (WRAML). The K-BIT is an individually administered test of verbal and nonverbal intelligence (15). Two subscales, vocabulary and matrices, comprise the test, as well as a composite intelligence quotient (IQ) score. The K-BIT has acceptable correlation with the widely used Wechsler verbal performance and full-scale IQ scores (16); validation studies have been conducted for children less than 7 years of age with normative data available (17). The WRAML is a well-standardized psychometric instrument that allows evaluation of a child's ability to actively learn and memorize a variety of information (18, 19). The WRAML includes subscales on verbal memory, visual memory, and learning and an overall general index scale. It has been normed for children aged 5–17 years among racially diverse groups, including minorities. All measures are expressed as standardized scores, which represent the score of the individual taking the test relative to scores obtained by children of the same age and gender in the standardization sample. All scores have a mean of 100 and a standard deviation of 15.

Tobacco smoke exposure

At each clinic visit during pregnancy, mothers were asked about their smoking status and the smoking habits of members of their households. A urine specimen was obtained for determination of a creatinine-corrected cotinine level, as previously detailed (12). A mother was classified as never smoking during her pregnancy if she always reported that she had never smoked on the standardized questionnaire and each of her urinary cotinine levels was less than 200 ng/mg creatinine (12). At any visit, if the report of nonsmoking by the mother was contradicted by the urinary cotinine measure, the mother was classified as a current smoker for that interval. Maternally reported postnatal exposure of the child to secondhand smoke was assessed by questionnaire (monthly through age 26 months, every 6 months between ages 26 months and 4 years, and annually thereafter). Children were considered to have been exposed to secondhand smoke in a particular follow-up interval if the mother reported personal active smoking or active smoking by any other person living in the household. Postnatal secondhand smoke was categorized as early (occurring from birth through 25 months of age) or late (26 months of age or older). The late secondhand smoke exposure category included children exposed both early and late (54 children) and late only (13 children), given that there were relatively few children in the latter category. Children's exposure to maternal smoking during pregnancy was highly correlated with postnatal secondhand smoke exposure. Forty-two children were exposed to prenatal tobacco smoke; among these children, only two were not exposed to secondhand smoke after birth.

Blood lead level

Children in Massachusetts are mandated by law to have blood lead testing annually, starting at 9 months of age, until age 4 years, unless they are considered to be at high risk (living in pre-1978 housing that is deteriorated or undergoing construction or having a sibling with lead poisoning), in which case they are tested annually until age 6 years. Results are incorporated into the medical records at the community health centers where the children obtain pediatric follow-up. Using a standardized instrument, blood lead levels were extracted from medical records at these health centers by a physician blinded to the study aims. Because the children had varying numbers of blood lead measurements which were dependent on their lead exposure (children with higher lead exposure had more follow-up tests than children with lower lead concentrations), we used the highest blood lead level recorded up to age 6 years for each child, referred to hereafter as the "peak blood lead level."

Statistical analyses

A total of 218 children completed the cognitive assessment, of whom 214 were successfully geocoded and assigned a black carbon measure. Eleven children were removed from the data set before analysis because they had black carbon values considered to be outliers according to the extreme studentized deviation model (20); in addition, one child was missing information on socioeconomic status. This left 202 children for our analyses. Multiple imputation was used to impute missing data on birth weight (seven children) and blood lead level (12 children). Since black carbon was being used as a surrogate for traffic particle exposure, which includes more than just carbon particles, it did not make sense for us to report results on a unit mass basis. Instead, we report estimated effects of predicted black carbon level per interquartile-range increase. We conducted bivariate analyses to determine the association between cognitive outcomes and demographic and environmental measures of interest. We also tested for associations between black carbon and environmental and sociodemographic markers. The effect of predicted black carbon on cognition was estimated by linear regression while adjusting for child's age at cognitive assessment, gender, race/ethnicity, and maternal education (as a marker of socioeconomic status) (model 1). To assess the potential for confounding, we examined the sensitivity of those results to further adjustment for in-utero and postnatal secondhand tobacco smoke exposure (model 2), birth weight (model 3), and blood lead level (model 4). All analyses were conducted in SAS, version 9.0 (SAS Institute, Inc., Cary, North Carolina).

RESULTS

Among the 202 children in this study, 52 percent were female and 57 percent spoke Spanish as their primary language. Maternal educational level was less than high school graduation for 42 percent of the mothers (table 1). The mean age was 9.7 years (standard deviation (SD), 1.7), and the mean peak blood lead level was 8.5 μg/dl (SD, 6.1). Mean scores on the K-BIT subscales were as follows: composite, 94.9 (SD, 13.9); vocabulary, 89.5 (SD, 16.3); and matrices, 101.4 (SD, 14.0). WRAML mean subscale scores were: verbal memory index, 84.7 (SD, 15.1); visual memory index, 93.3 (SD, 13.8); learning index, 101.1 (SD, 15.0); and general index, 91.1 (SD, 14.5). The mean annual predicted black carbon level was 0.56 μg/m^3 (SD, 0.13).

In bivariate analyses (data not shown) of black carbon and cognitive measures, black carbon was associated with the vocabulary, matrices, and composite subscales of the K-BIT and the visual and verbal subscales and the general index of the WRAML. Primary language spoken at home and maternal education were associated with the cognitive measures and black carbon. Children who primarily spoke Spanish at home and children whose parents had a high school education or less scored lower on the composite, vocabulary, verbal, and general memory subscales of the WRAML and K-BIT. In addition, they had higher predicted black carbon levels than children who primarily spoke English at home and whose parents had more than a high school education. Marital status was not associated with any of the cognitive measures or with black carbon. Thus, in multivariate analyses, we adjusted for both parental education and primary language spoken at home, as well as birth weight, blood lead level, and in-utero and postnatal secondhand tobacco smoke exposure.

In multiple linear regression analyses (tables 2 and 3), an interquartile-range increase in log black carbon predicted a 2-point decrease (95 percent confidence interval (CI): −5.3, 1.3) on the vocabulary scale, a 4.2-point decrease (95 percent CI: −7.7, −0.7) on the matrices scale, and a 3.4-point decrease (95 percent CI: −6.6, −0.3) on the composite subscale of the K-BIT. Black carbon level also predicted a 1.1-point decrease (95 percent CI: −4.6, 2.3) on the verbal learning scale, a 5.2-point decrease (95 percent CI: −8.6, 1.7) on the visual learning scale, a 2.7-point decrease (95 percent CI: −6.5, 1.1) on the learning scale, and a 3.7-point decrease (95 percent CI: −7.2, −0.2) on the general index scale of the WRAML. Further adjustment for tobacco smoke exposure, birth weight, and blood lead level did not attenuate these effect estimates.

TABLE 1. Demographic characteristics, environmental exposures, and scores on cognitive subscale measures (*n* = 202) in the Maternal-Infant Smoking Study of East Boston, 1986–2001

	No.	%	Mean (SD*)
Demographic characteristics			
Child's age (years)			9.7 (1.7)
Child's gender			
Male	97	48.0	
Female	105	52.0	
Primary language spoken at home			
English	87	43.1	
Spanish	115	56.9	
Mother's educational level			
Some college	37	18.3	
High school graduation/technical school	81	40.1	
Less than high school/no graduation	84	41.6	
Marital status			
Married/living with someone	155	76.7	
Separated/divorced/single	47	23.3	
Medical history and environmental exposures			
Tobacco exposure			
Nonsmoker	70	34.7	
In-utero and SHS* exposure	42	20.8	
Early SHS exposure†	23	11.4	
Late SHS exposure‡	67	33.2	
Birth weight (kg)			3.35 (0.5)
Peak blood lead level (μg/dl)			8.5 (6.1)
Black carbon (μg/m^3)			0.56 (0.13)
Cognitive subscales			
Kaufman Brief Intelligence Test			
Composite			94.9 (13.9)
Matrices			101.4 (14.0)
Vocabulary			89.5 (16.3)
Wide Range Assessment of Memory and Learning			
Verbal			84.7 (15.1)
Learning			101.1 (15.0)
Visual			93.3 (13.8)
General index			91.1 (14.5)

* SD, standard deviation; SHS, secondhand smoke.

† SHS exposure before 26 months of age.

‡ SHS exposure at 26 months of age or older.

DISCUSSION

In this prospective urban birth cohort study, long-term concentration of black carbon particles from mobile sources was associated with decreases in cognitive test scores, even after adjustment for socioeconomic status, birth weight, tobacco smoke exposure, and blood lead level. Although our linear regression-based analyses do not establish causation, only associations, a number of features strengthen our findings. Decreases in cognitive functioning were seen in verbal and nonverbal intelligence constructs as well as memory constructs. Moreover, our results are consistent in that we noted decreases across all subscales, though not all associations between black carbon and cognitive subscales were statistically significant.

TABLE 2. Relation of predicted black carbon levels (average of summer and winter) at children's residences to scores on subscales of the Kaufman Brief Intelligence Test in linear regression models ($n = 202$), Maternal Infant Smoking Study of East Boston, 1986–2001†

Black carbon model	Vocabulary		Matrices		Composite	
	Estimate	95% CI‡	Estimate	95% CI	Estimate	95% CI
Adjusted ~~for demographic factors§~~	~~−2.0~~	~~−5.3,~~ 1.3	−4.2	−7.7, −0.7*	−3.4	~~−6.6, −0.3*~~
Adjusted for above factors + in-utero tobacco smoke + secondhand smoke	−2.0	−5.3, 1.4	−4.0	−7.5, −0.4*	−3.3	−6.4, −0.1*
Adjusted for above factors + birth weight	−2.0	−5.4, 1.3	−4.0	−7.6, −0.5*	−3.3	−6.5, −0.2*
Adjusted for above factors + blood lead level	−2.2	−5.5, 1.1	−4.0	−7.6, −0.5*	−3.4	−6.6, −0.3*

* $p < 0.05$.

† Change in subscale score per interquartile-range (0.4-μg/m^3) increase in log black carbon level.

‡ CI, confidence interval.

§ Adjusted for age, gender, primary language spoken at home, and mother's education.

These results are of comparable magnitude to results found for other environmental neurotoxicants. For example, among ~~children, a 10-μg/dl increase in blood~~ lead ~~level~~ has ~~been associated with a loss of 1–5 IQ points (21). Children~~ born to mothers who smoke 10 or more cigarettes per day ~~during pregnancy have an average decrease~~ of ~~4 IQ points~~ (22). In our cohort, an interquartile-range (0.4-μg/m^3) increase in log black carbon predicted a 3-point decrease in IQ (K-BIT composite subscale).

There are several potential mechanisms that could be contributing to the associations found in this study. First, since black carbon comes almost entirely from traffic, these particles are surrogates for all traffic particles, and other components of traffic particles may play a role. For example, there is evidence that ultrafine particles are translocated up the olfactory nerve to the brain without entering the lung (6). Ultrafine particles in the brain are probably associated with increased oxidative stress, since that has been seen in other tissues (23). The carbon particles themselves are rarely pure carbon; they generally have transition metals adsorbed on the surface. These metals have been shown to induce oxidative stress in the lung (24–28). Other studies have also implicated traffic exposure in oxidative stress (29–31). There is evidence that the oxidative stress and inflammation induced by particles translates systemically (30). For example, exposure of rodents to concentrated air particles collected from a busily trafficked roadway resulted in increased oxidative stress in ~~the heart~~ as well as the ~~lung (31). Other studies comparing animal brains~~ in areas of ~~Mexico City~~ that are heavily influenced by traffic have reported histologic evidence ~~of chronic~~ brain inflammation and an acceleration of Alzheimer-like pathology (7). Taken together, the current body of knowledge suggests that inflammatory processes and increased oxidative stress (7) may play a role in the mechanism by which particles can have an impact on the nervous system; however, additional work in this area of research remains to be done.

While, to our knowledge, no other studies have examined an association between air pollution and cognition, a few have examined the role of traffic noise in cognition among children (32, 33). In the RANCH project, a cross-sectional study of 2,000 children from three European cities (Madrid, London, and Amsterdam), aircraft noise at home and at school was associated with impaired reading comprehension (32). Road traffic noise, however, was not associated with reading comprehension. It is possible that the associations found in our study could be attributable to traffic and/or aircraft noise and not to black carbon; conversely, it is also possible that the associations previously found between road and aircraft noise and cognition are actually due to air

TABLE 3. Relation of predicted black carbon levels (average of summer and winter) at children's residences to scores on subscales of the Wide Range Assessment of Memory and Learning in linear regression models ($n = 202$), Maternal Infant Smoking Study of East Boston, 1986–2001†

Black carbon model	Verbal		Visual		Learning		General	
	Estimate	95% CI‡	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Adjusted for demographic factors§	−1.1	−4.6, 2.3	−5.2	−8.6, −1.7*	−2.7	−6.5, 1.1	−3.7	−7.2, −0.2*
Adjusted for above factors + in-utero tobacco smoke + secondhand smoke	−1.2	−4.7, 2.3	−5.3	−8.8, −1.8*	−2.6	−6.5, 1.2	−3.7	−7.3, −0.1*
Adjusted for above factors + birth weight	−1.3	−4.7, 2.2	−5.3	−8.8, −1.8*	−2.6	−6.5, 1.3	−3.8	−7.4, −0.2*
Adjusted for above factors + blood lead level	−1.3	−4.8, 2.2	−5.4	−8.9, −1.9*	−2.8	−6.6, 1.1	−3.9	−7.5, −0.3*

* $p < 0.05$.

† Change in subscale score per interquartile-range (0.4-μg/m^3) increase in log black carbon level.

‡ CI, confidence interval.

§ Adjusted for age, gender, primary language spoken at home, and mother's education.

pollutants, such as black carbon. Future studies may be designed to distinguish traffic effects due to noise from those due to pollution.

The current study had a number of limitations. As is typical with longitudinal studies, there was a significant reduction in the sample available from the original cohort over time. The nonparticipation of some subjects from the longitudinal study may be seen as a limitation, although there were no differences based on race/ethnicity, maternal education, smoking status, birth weight, or blood lead level when we compared children who had cognition assessed with those who did not among the participants who remained in follow-up. Thus, this is unlikely to have influenced our findings. While we were able to adjust for a number of factors associated with cognition and air pollution, it is still possible that the associations found in this study could be attributable to unmeasured or residual confounding, perhaps most notably from socioeconomic status. Socioeconomic status has been shown to be a determinant of cognitive ability and achievement from early childhood through young adulthood (34, 35). Furthermore, socioeconomic status can determine whether a family lives in close proximity to roadways (36). In addition to adjusting for mother's educational level, the present study was somewhat restricted regarding socioeconomic status, given that all families were recruited from one neighborhood health center in Boston. This restricted the variability of income in this population, thereby reducing the potential for confounding.

Our measure of exposure was also subject to limitations. While we attempted to capture black carbon exposure from all residential addresses, it is possible that we potentially missed exposures incurred at school and/or other locations where children spend portions of their time. However, this potential misclassification of exposure was nondifferential with respect to the outcome, and thus it is unlikely to account for the associations found. Furthermore, compared with adults who work, children spend considerably longer periods of time at home or in the vicinity of their home. Furthermore, exposure studies using personal monitors indicate that home exposures are the most important in predicting personal exposure (37). While demonstrated in adults, time activity studies indicate that children spend more time at home and near home, making the finding relevant (38). Other studies (39) have shown that residential indoor concentrations of particulate matter of outdoor origin are highly correlated with outdoor concentrations. In another study (40), the personal exposures of the working spouses of persons with chronic illnesses have been shown to be highly correlated with their spouses' personal exposures. Taken together, we believe these studies indicate that personal exposures to ambient particles are driven primarily by exposures incurred at home. Moreover, we attempted to capture black carbon exposure from all residential addresses when children moved.

Another limitation of this study is the use of predicted exposure, rather than observed measurements taken outside the residences of the study participants. Since the latter approach is not practical in a large community-based study, we decided to use all available exposure data and advanced modeling approaches to predict the missing exposure at the residences of the participants. This is an approach that has become very popular in recent years. A potential statistical issue that arises when using spatial-temporal predictions of exposure rather than measured quantities is that predicted quantities are uncertain, and this could bias the resulting health effect estimates. In a previous study, Gryparis et al. (41) found that the use of predictions from spatial exposure models induces a Berkson-type measurement error. This results in unbiased parameter estimates for the association between the predicted exposure and the observed health outcome. However, the standard errors for the parameter of interest might be incorrect. In such a case, we would expect larger standard errors for the parameter of interest.

In summary, this is the first study to have found a consistent relation between exposure to black carbon and reduced neurocognitive functioning across a number of domains in urban, community-dwelling school-aged children. More studies are needed to explore the potentially neurotoxic effects of particulate matter, both to determine the possible impact on cognitive development among children and cognitive decline across the life cycle and to determine the potential contribution of air pollutants to the development and exacerbation of neurodegenerative diseases (i.e., Parkinson's disease, Alzheimer's disease).

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Research | Children's Health

Ambient Ozone Concentrations Cause Increased Hospitalizations for Asthma in Children: An 18-Year Study in Southern California

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Abstract

Background: Asthma is the most important chronic disease of childhood. The U.S. Environmental Protection Agency has concluded that children with asthma continue to be susceptible to ozone-associated adverse effects on their disease.

Objectives: This study was designed to evaluate time trends in associations between declining warm-season O_3 concentrations and hospitalization for asthma in children.

Methods: We undertook an ecologic study of hospital discharges for asthma during the high O_3 seasons in California's South Coast Air Basin (SoCAB) in children who ranged in age from birth to 19 years from 1983 to 2000. We used standard association and causal statistical analysis methods. Hospital discharge data were obtained from the State of California ; air pollution data were obtained from the California Air Resources Board, and demographic data from the 1980, 1990, and 2000 U.S. Census. SoCAB was divided into 195 spatial grids, and quarterly average O_3, sulfur dioxide, particulate matter with aerodynamic diameter ≤ 10 µm, nitrogen dioxide, and carbon monoxide were assigned to each unit for 3-month periods along with demographic variables.

Results: O_3 was the only pollutant associated with increased hospital admissions over the study period. Inclusion of a variety of demographic and weather variables accounted for all of the non-O_3 temporal changes in hospitalizations. We found a time-independent, constant effect of ambient levels of O_3 and quarterly hospital discharge rates for asthma. We estimate that the average effect of a 10-ppb mean increase in any given mean quarterly 1-hr maximum O_3 over the 18-year median of 87.7 ppb was a 4.6% increase in the same quarterly outcome.

Conclusions: Our data indicate that at current levels of O_3 experienced in Southern California, O_3 contributes to an increased risk of hospitalization for children with asthma.

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Introduction

In terms of numbers, morbidity burden, and health care costs, asthma is the most important chronic disease of childhood, with estimated medical care costs over $1 billion in 2005 (Wang et al. 2005). Based on its recent review of data on ozone-related health effects, the U.S. Environmental Protection Agency (EPA) has once again concluded that children with asthma constitute a group that is susceptible to O_3-associated adverse effects on their disease (U.S. EPA 2006). Hospitalization and visits to emergency departments are major contributors to childhood asthma-related health care costs and account for approximately 12% of care costs for asthma in children 5–17 years of age (Wanget al. 2005). Despite the large number of studies on various asthma-related outcomes (symptoms, lung function) in relation to ambient O_3, there are relatively few studies on O_3-related hospital discharges and emergency department (ED) visits in children with asthma; and the results of these studies have not been consistent [U.S. EPA 2006 (Figures 7-8, 7-9)]. Moreover, these studies have been concerned with associations between pollutant exposures over a few days before hospital admission and over relatively short periods of calendar time.

Several studies illustrate findings based on short lag periods. White and colleagues (1994) reported that ED visits for asthma (1–16 years of age) to an Atlanta, Georgia, hospital increased by 37% on the 6 days in the summer of 1990 when the maximum 1-hr O_3 concentrations exceeded 110 ppb. A subsequent Atlanta-based ecologic study reported that Medicaid claims for hospital admissions for asthma decreased during the time of the 1996 Summer Olympic Games in parallel with reductions of ambient O_3 concentrations (Friedman et al. 2001). The decline in O_3 was attributed to the marked decline in city traffic during the games, but associations with other mobile source emissions were not evaluated in the regression models. A third study from Atlanta for the summers of 1993–1995 found similar associations with ED visits, but these investigators could not separate effects due to particulate matter with aerodynamic diameter ≤ 10 µm (PM_{10}) (Tolbert et al. 2000). An approximate 33% increase in ED visits for childhood asthma was reported from eastern Canada on days when the 1-hr maximum exceeded 75 ppb over the years 1984–1992, an association that was independent of concentrations of sulfate and total suspended particulates (TSP) (Stieb et al. 1996). Data from Washington, DC; Mexico City, Mexico; and Madrid, Spain, support these findings of O_3-associated increases in ED visits, independent of pollens and PM_{10} (Babin et al. 2007; Galan et al. 2003; Romieu et al. 1995).

In contrast to the above results, several relatively recent European studies have not found these associations. Data from the APHEA (Air Pollution and Health: A European Approach) study from the period 1986–1992 from Barcelona, Spain; Helsinki, Finland; Paris, France; and London, UK, failed to find any association between ED visits and ambient O_3 in children < 15 years of age (Sunyer et al. 1997). However, these results were based on O_3 concentrations throughout all months of the year. Similarly, a study in London, based on year-long data for 12 EDs over the years 1992–1994, also failed to find any association between ED visits and hospitalizations for asthma and ambient O_3 concentrations for children from birth to 14 years of age (Atkinson et al. 1999a, 1999b).

California's South Coast Air Basin (SoCAB) has some of the highest concentrations of O_3 in the U.S. [South Coast Air Quality Management District (SCAQMD) 2006] and will continue to be a major area of noncompliance under proposed new O_3 standards (U.S. EPA 2005). Mobile source emissions are the main source of precursors for O_3 generation (Fujita et al. 1992). Because O_3 and other pollutant levels, in general, have been declining over the past 25 years (SCAQMD 2003), this area offers an excellent opportunity to study the relation between warm-season ambient O_3 concentrations and hospitalizations for asthma in a large population that spans urban and rural areas. Therefore, we undertook an ecologic study of hospital discharges for asthma in children from 0 (birth) to 19 years of age over the period 1983–2000 in the SoCAB to evaluate the effect of population-level O_3 exposure on asthma-related hospital discharge over time. Our approach is based on conventional linear modeling with adjustment for temporal factors that could confound the causal effect of interest. Our approach has several novel features: *a*) We used a very flexible, data-adaptive model fitting program that is based on multiple cross-validations (van der Laan and Dudoit 2003); *b*) pollutants other than O_3 could enter our modeling at equivalent levels of complexity, as for O_3, and *c*) we used marginal structural models (MSM) to support the interpretation of population-level effects of O_3 on the outcomes (van der Laan and Robins 2002).

Methods

Study area. The study area was the portion of California's SoCAB covered by the grids shown in Figure 1. The 20,000-km^2 area extends from 34.6° latitude at its most northern reach to 33.2° latitudeat its most southern extent. It is bounded on the west by –118.9° longitude and the Pacific Ocean, and extends to –116.8° longitude at its eastern end. We selected this location because it contained many areas that consistently exceeded National Ambient Air Quality Standards for O_3 during the 1980–2000 study period (U.S. EPA 2000). Nonetheless, the area also experienced marked reductions in 1-hr and 8-hr maximum O_3 concentrations over this time.

Ambient pollutant data and exposure methods. We estimated the population's exposure to O_3, nitrogen dioxide, sulfur dioxide, carbon monoxide, PM with aerodynamic diameter ≤ 2.5 µm ($PM_{2.5}$), and PM_{10} from ambient air quality measurements obtained from a network of stations that began monitoring for most of the pollutants before 1980. The number and locations of air monitoring stations (Figure 1) varied over the study period. The number of stations with valid air quality data in or near the grid in a given year varied from 45 to 55 for O_3, 33 to 41 for NO_2, 28 to 39 for CO, and 9 to 56 for PM_{10}. We compiled quarterly average concentrations of the 1-hr daily maximum O_3 and 24-hr average NO_2, SO_2, and CO from hourly measurements of gases. We compiled quarterly average concentrations of the 24-hr average PM_{10} and $PM_{2.5}$ from monthly averages of every sixth day PM_{10} measurements and daily, every third day, and 2-week average $PM_{2.5}$ measurements (Blanchard and Tanenbaum 2005). The air quality data were complemented with quarterly average daily 1-hr minimum and 24-hr average temperature and relative humidity data obtained from the SoCAB and National Weather Service measurements (National Climatic Data Center, NOAA Satellite and Information Service: http://www.ncdc.noaa.gov/oa/ncdc.html).

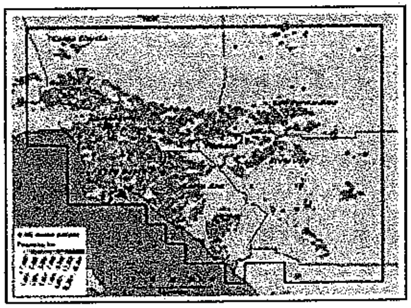
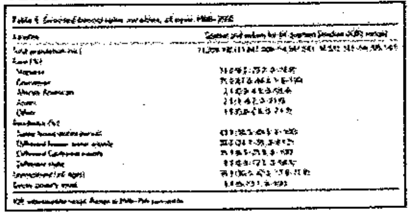


Figure 1. Study domain grid system with location of pollutant monitors and population density. AQ, air quality.

Table 1.



California PM_{10} data are not widely available before 1988. Special study PM_{10} mass data available in Burbank, downtown Los Angeles, Long Beach, Los Alamitos, Costa Mesa, Azusa, Rubidoux, Perris, and Banning were used for 1985–1987 (Solomon et al. 1988). Collocated PM_{10} and TSP data for 1988 through 1992 in Los Angeles, Orange, San Bernardino, and Riverside Counties indicated that daily PM_{10} concentrations were correlated with daily TSP and, on average, were 54% of TSP concentrations. The PM_{10} concentrations for 1980–1984 were estimated from the TSP data based on this relation. $PM_{2.5}$ data were available for only 1994–2000.

The study domain was divided into two-hundred 10 km × 10 km spatial grids that covered the populated portion of the SoCAB, of which 195 were used. The population, other demographic, and health outcome data were aggregated into the grid cells [Supplemental Material, Figure S1 (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)]. The air quality and meteorologic data were interpolated spatially from the monitoring stations to the grid cell centroids based on inverse distance-squared weighting. Maximum interpolation radii of 50 and 100 km were used for pollutants and meteorologic parameters, respectively. Although 100% of the grids had an O_3 air quality station within 50 km, 73% of the grids had a station within 5–25 km of the grid centroids and 13% of grids had a station located within the grid on average [see Supplemental Material (online at http://www.ehponline.org/members/2008/10497/suppl.pdf) for other pollutant interpolation distances]. This interpolation approach worked reasonably well in this application, because the spatial coverage in the SOCAB monitoring network is good (typically, stations located 20–30 km apart); and spatial gradients in monthly average concentrations are modest.

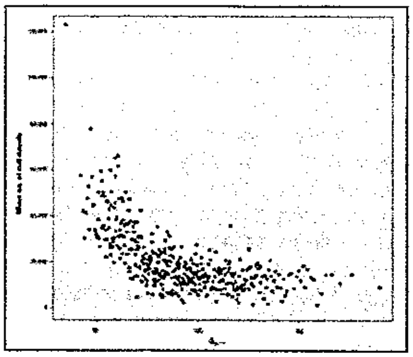


Figure 2. Distribution of population number by 400 quantiles of quarterly 1-hr maximum O_3 over quarters 2 and 3, 1983–2000.

Our principal exposure of interest was 1-hr daily, maximum O_3. We chose this measure, because the same 1-hr maximum standard was in place for most of the study period; and the 1-hr maximum is the most commonly used metric in O_3 epidemiologic studies. Quarterly, average O_3 concentrations were low and showed little variability from October through March [see Supplemental Material, Figure S6 (online at http://www.ehponline.org/members/2008/10497/suppl.pdf) for sample quarters]. Therefore, we confined our analyses to April–June (quarter 2) and July–September (quarter 3), which constitute all months with the highest and most variable O_3 concentrations.

Hospital discharge and demographic data. Since 1983, hospital discharges (diagnoses, demographic data and medical payments) have been reported semiannually by all hospitals licensed in California. Patient-level data were extracted from a CD-ROM (Healthcare Information Resource Center, Sacramento, CA) and included: patient age category, county of residence and 5-digit ZIP Code, ethnicity, sex, major diagnostic category (plus four secondary), major procedure (plus four secondary), quarter admitted, length of stay, and hospital ID number (Office of Statewide Health Planning and Development, data files e-mailed July 2003). We focused on quarterly hospital discharges for asthma [*International Classification of Diseases, 9th Revision* (ICD-9; World Health Organization 1975) code 493, ICD-10 (World Health Organization 1993) code J45/46] listed as the first discharge diagnosis for children and adolescents from birth through 19 years of age. We included discharges in which the first listed diagnoses were acute sinusitis (ICD-9 461; ICD-10 J01) or pneumonia (ICD-9 480–483, 485–487; ICD-10 J10–J18) and asthma was the second listed diagnosis, because we could not be sure of the extent to which the presence of asthma actually led to the hospitalization [see Supplemental Material (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)].

Table 2.

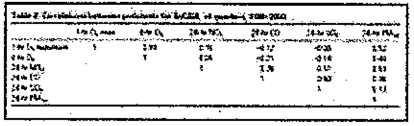
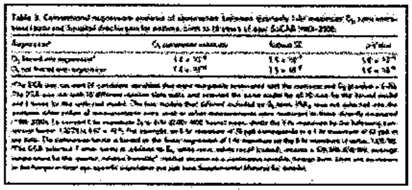


Table 3.



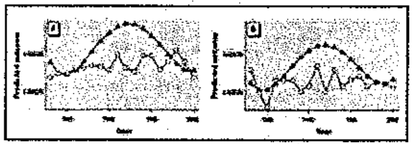
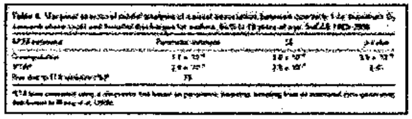


Figure 3. Predicted proportions of quarterly hospital discharges based on a model that included only time variables (triangles) and the model in Table 4 that includes O_3 and the demographic variables (squares) for quarters 2 (*A*) and 3 (*B*).

We obtained data from the U.S. Census Bureau's decadal surveys for years 1980, 1990, and 2000 [see Supplemental Material (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)]. We reviewed all income, demographic, and residential data and selected covariates that were considered likely to affect asthma morbidity and were likely to show spatial clustering and temporo-spatial trends (graphs available on request from authors). We selected 57 sociodemographic variables.

Table 4.



The finest spatial resolution for which hospital discharge data were available was the 5-digit postal ZIP code of the patient's residence; the patient's street address, 9-digit ZIP code, or census block were not available. Population-weighted ZIP-to-grid allocation factors were developed with geographic information system (GIS) tools for 1980–1984, 1995–1994, and 1995–2000. Separate allocations factors were developed for males and females for < 1 year and 1–19 years of age. [see Supplemental Material for details (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)].

Spatial allocation of demographic data to exposure grids was based on the smallest geographic unit for which census data were available. We used GIS software (ArcGIS9; ESRI, Redlands, CA) to map the demographic data to grids. Eight population variables from 1980 and one population variable from 1990 and 2000 were renormalized after the spatial allocation to insure consistency across census topics (e.g., population by race was normalized by the total population; population by sex, age, and race was normalized for consistency with population by race and population by sex). Population and other demographic parameters were estimated for the intracensus years by linear interpolation of the gridded data for 1980, 1990, and 2000.

Data analysis. **Data structure.** The data consist of 195 geographic units (grids) with quarterly measurements from 1983 through 2001 that include 14,040 records and 72 quarters for children birth to 19 years of age. We calculated the proportion of asthma-related hospital discharges as the number of asthma-related hospital discharges in each grid in each quarter divided by the total population birth to 19 years of age in the corresponding grid and quarter. After removal of nine outliers, we used data for quarters 2 and 3 only (7,011 observations).

There were no missing values for the proportion of asthma-related discharges or quarterly O_3. Among the 47 covariates considered, 35 had no missing values. Among the 12 remaining covariates, the proportion of missing values ranged from 0.4% to 6.2%.

Statistical models. We denote the observed data structure by $O = [W\text{—}(71), A\text{–}(71, Y\text{–}(72)]$ representing quarterly measurements from time 0 to 72 of the confounders, O_3 levels and proportion of asthma-related hospital discharges: *a*) The history of O_3 is denoted by $A\text{–}(71) = [A(0),\ldots,A(71)]$, and $A(t)$ represents the O_3 level measured at time t; *b*) the history of asthma-related hospital discharges as a percentage of the total area-specific population is denoted by $Y\text{–}(72) = [Y(1),\ldots,Y(72)]$, and $Y(t)$ represents the proportion of asthma discharges measured at time t; and *c*) the history of potential time-dependent confounders of the effect of O_3 on asthma-related hospital discharges is denoted by $W\text{—}(K) = [W(0),\ldots,W(K)]$, where $W(t)$ is a multivariate vector of potential confounders measured at time t: socioeconomic and demographic variables, co-pollutants, and meteorologic variables.

Our modeling approach aims at the investigation of the effect of $A(t-1)$ on $Y(t)$. In this study, the outcome at time t $[Y(t)]$ and exposure at time $t-1$ $[A(t-1)]$ are actually measured during the same quarter, which does not violate the time-ordering assumption on which are based valid causal inferences (the exposure precedes the outcome). Because we consider the effect of O_3 on asthma-related hospital discharges collected during quarters 2 and 3 only, we thus have 36 outcomes of interest rather than 72.

A typical assumption that is often not stated explicitly is that the observed data consist of n independent and identically distributed observations from the random variable O with distribution P. In this analysis, we make the assumption that the observed data consist of $n = 195$ random variables O_i that describe each spatial/geographic unit i, $i = 1,\ldots,n$, each with distribution P_i. Under this assumption, it follows that mutual independence between the random variables O_i, conditional on the exposure regimen, is a reasonable approximation [see Supplemental Material for additional details (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)].

We chose to investigate the effect of O_3 on the asthma-related hospital discharge proportion for quarterly exposure to O_3 only; that is, we did not consider the effect of an O_3 history over multiple quarters. This decision was motivated by our view that most of the effect of O_3 could be captured by the exposure period of only one quarter—by estimation of the effect of O_3 during a given quarter on the outcome during that same quarter in the seasons with the highest levels of O_3. Because the experimental units are geographic areas rather than individuals, the population in the units was constantly changing over the 18-year study period; however, within a given quarter, the population was relatively stable. Another reason for selection of the short exposure period relates to power (sample size, $n = 195$) for identification of effects that extend over a longer exposure period (Neugebauer et al. 2007).

We estimated this effect of O_3 on the proportion of asthma-related hospital discharges with two approaches: the traditional method of regression of the proportion of asthma-related hospital discharges on O_3 and confounder; and a method based on history-restricted marginal structural models (HRMSMs) (Neugebaueret al. 2007). In contrast to the usual MSM approach, HRMSMs allow the investigator to specify the time interval over which the history of exposure is to be considered—a critical issue for this analysis.

For both approaches, working models considered were semiparametric linear models. The rationale for use of linear models is presented in the Supplemental Material (online at http://www.ehponline.org/members/2008/10497/suppl.pdf). The deletion/substitution/addition (DSA) algorithm was used for all model selections required for the traditional approach and the nuisance parameters in the HRMSM approach (Sinisi and van der Laan 2004). This is a data-adaptive model selection procedure based on cross-validation that relies on deletion, substitution, and addition moves to search through a large space of possible polynomial models. The criterion for model selection is based not on p-values but on a loss function (empirical and cross-validated residual sum of squares). The DSA procedure is publicly available as an R package (http://www.stat.berkeley.edu/~laan/Software/). All 7,011 observations were provided to all DSA runs. The DSA assumes that data are missing at random when searching for the best predictive linear model of the proportion of asthma-related hospital discharges.

Traditional regression approach. The traditional approach to estimate the effect of $A(t-1)$ on $Y(t)$ is to regress the outcome, $Y(t)$, on the exposure, $A(t-1)$, and all confounders. Potential confounders are: $W\text{—}(t-1) = [W(1),\ldots,W(t-1)]$, $Y\text{–}(t-1)$, and $A\text{–}(t-1)$. Under the assumption of no unobserved confounders, this approach allows the investigation of the effects of O_3 at each quarter, $A(t-1)$, on $Y(t)$, conditional on the past confounders in the regression model. It is realistic to assume that O_3 levels before quarter t [i.e., $A\text{–}(t-1)$] do not affect the outcome in quarter t; thus, we did not consider them as confounders. Similarly, we did not consider past quarter discharges [i.e., $Y\text{–}(t-1)$]. Among all potential covariates $W\text{—}(t-1)$, we only considered as potential confounders all same-quarter covariates $W(t-1)$ and only copollutants and meteorologic variables from the previous quarter and previous year included in $W(t-2)$ and $W(t-5)$. This allowed us to maximize control of possible long-term trends in other pollutants on the current quarter's outcome. Forty-seven remaining covariates were identified as potential confounders of the effect of O_3 at quarter $t-1$ on the proportion of asthma-related hospital discharges at quarter t. Among these 47 covariates, only 29 were considered in the analysis, based on their univariate association with the proportion of asthma-related hospital discharges and O_3 levels [see Supplemental Material, Table S1 (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)]; this subset of 29 potential confounders is denoted with $W\text{—} \times (t-1)$.

We selected a pooled model for $E[Y(t)|A(t-1),W\text{—} \times (t-1)]$ across time with the DSA [see Supplemental Material (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)]. The standard errors for the coefficients in the selected model were obtained with the generalized estimation equation procedure (semiparametric modeling with the independence correlation structure).

This traditional approach does not answer directly our original question of interest: the population-level effect of $A(t-1)$ on $Y(t)$; indeed, this method provides the estimate of the effect conditional on confounders $W\text{—} \times (t-1)$ which only correspond with the population-level effect estimate of interest when confounders are not effect modifiers.

HRMSM. To obtain an estimate of the population-level, causal effect of O_3 on the proportion of asthma-related hospital discharges, we applied an HRMSM (Neugebaueret al. 2007). HRMSMs have been developed to address situations where only part of the exposure history is relevant [for details, see Supplemental Material (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)]. The exposure period considered is a single quarter as opposed to the entire exposure history.

We implemented two estimators of HRMSM causal parameters: the inverse probability of treatment weighted (IPTW) and G-computation. Confidence intervals (CIs) and *p*-values for the two estimates were obtained with 10,000 bootstrap iterations, where resampling was based on the 195 independent grids.

Results

Characteristics of the total population who resided in the study domain (Figure 1) over the 84 quarters (1980–2000) are summarized in Table 1. For a summary of the characteristics of the population of asthma discharges from birth to 19 years of age for quarters 2 and 3 for 1983–2000, see Supplemental Material, Table S4 (online at http://www.ehponline.org/members/2008/10497/suppl.pdf).

O_3 concentrations declined steadily over the entire study period [Supplemental Material, Figure S8_a (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)]. Median 1-hr maximum and 8-hr average median O_3 for quarters 2–3 declined across all grids (Figure 2). Median 1-hr maxima also declined in quarters 1 and 4 [Supplemental Material, Table S5 (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)]. Substantial declines were seen for the other pollutants as well [see Supplemental Material, Table S5, Figure S8_b (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)]. The distribution of the quarterly population was skewed toward areas at the lower two-thirds of the quarterly O_3 distributions [see Supplemental Material, Figure S9 (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)]. During 1980–2000, 25.7% of the gridded, quarterly, average 1-hr maximum O_3 concentrations exceeded the level of California's daily 1-hr standard (90 ppb), and 8.2% exceeded the federal daily 1-hr standard of 0.12 ppm. For quarters 2 and 3 and years 1983 through 2000, 47.5% and 13.2% of the quarterly, average, 1-hr maximum O_3 concentrations exceeded the California and federal daily 1-hr standard, respectively (California EPA 2008; U.S. EPA 2000).

The median 1-hr and 8-hr maximum average O_3 levels were highly correlated (*r* = 0.99) (Table 2). During 1980–2000, O_3 concentrations showed moderate correlation with PM_{10} and little correlation with the other pollutants. O_3 and PM_{10} are correlated on a quarterly averaging time, because wind-blown dust and resuspended road-dust emissions cause relatively high PM_{10} levels during the dry season when O_3 levels also are high.

In the conventional regression model, the identical model was selected when O_3 was forced into the model or when the DSA was free to choose any variable (Table 3). Of the seven [of 29; see Supplemental Material, Table S1 (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)] other variables selected into the models, none was another pollutant (Table 3) [see Supplemental Material for details of model selection (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)]. Thus, it is unlikely that the association is confounded by other pollutants. In addition, time was not selected as a main effect or interaction variable—an observation indicating that the unit effect of O_3 on the proportion of asthma-related discharges was constant over the study period, despite the decline in the levels of O_3 and all other pollutants measured. The estimated effect of a 10-ppb increase in the quarterly average 1-hr maximum O_3 was 1.4 discharges per 105 age-eligible population (95% CI, 0.71–2.09 per 105 population). The final model was used to predict the proportion of discharges at the median O3 concentration (87.7 ppb) over all grids and all quarters (3.12× 10–4). A 10-ppb increase above this level is estimated to lead to a 4.6% increase in the proportion of discharges (3.26× 10–4).

To determine the extent to which time contributed to confounding, the DSA was run first only with time variables. When the time variables selected by the DSA were forced into a model that also forced in O_3 into the same model, no other variables were selected by the DSA. This indicates that the demographic variables included in the models in Table 3 were capturing the overall temporal confounding related to population demographic and other unmeasured time-varying factors. This is seen clearly in Figure 3.The model with only time variables shows a clear temporal trend in hospital discharges. In contrast, the model with O_3 and demographic variables shows a nearly constant proportion of hospital discharges over the study quarters.

To provide population-level estimates of pollutant effects, we used G-computation and IPTW to fit an HRMSM. Treatment models (models that relate cofounders to quarterly O_3 concentrations and include other confounding variables) on which IPTW estimation relies [Supplemental Material (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)] demonstrated that the experimental treatment assignment assumption was not tenable. We applied a diagnostic tool to assess the bias in the IPTW estimator due to the experimental treatment assignment (ETA) violation (Wang et al. 2006) and showed a 76% bias in comparison to the G-computation estimate (Table 4). Therefore, we relied on the G-computation estimator. The interpretation of the MSM parameter estimate is as follows: If, contrary to fact, the population experienced a 10-ppb increase in quarterly O_3, then hospital admissions would increase by 1.4×10^5 age-eligible population at any given quarter. This would represent the same effect estimated by the conventional regression analysis. In other words, the results from the MSM and conventional analyses, in this particular analysis, give identical parameter estimates because there are no interaction terms in the conventional model.

Discussion

The most recent U.S. EPA synthesis of ambient O_3 health effects concludes that children with asthma suffer acute adverse health consequences at current ambient levels of O_3 (U.S. EPA 2006). Among these adverse outcomes, asthma-related hospital discharges are based on some of the least consistent data (see Figure 7-9, U.S. EPA 2006). In some studies, asthma discharges are not separated from other respiratory diseases of childhood (e.g., Burnett et al. 2001). Although some of the inconsistency likely relates to differences in populations and pollutant mixtures, some of it also could relate to the relatively short time periods (Atkinsonet al. 1999a, 1999b) and special circumstances (Friedmanet al. 2001) under which the data were collected and the inability to separate O_3 effects from those of other pollutants (Tolbertet al. 2000) The present ecologic study addresses these problems through evaluation of the relation between hospital discharges for asthma for infants, children, and adolescents and changes in warm-season ambient O_3 concentrations in a large, ethnically/racially diverse region of Southern California over 18 years (1983–2000). This region has seen changing pollutant levels and population structure over both time and space during the study period. Of note is the decline in the percentage of native-born residents, from 40% in 1980 to 30% in 2000, and the decline in the percentage who listed their primary race/ethnicity as Caucasian, from approximately 80% in 1980 to approximately 60% in 2000 [see Supplemental Material for additional details (online at http://www.ehponline.org/members/2008/10497/suppl.pdf)].

Our data indicate that, despite consistent and substantial declines in ambient warm-season O_3 concentrations in the area of study (Figure 3A), there has been a time-independent, constant effect of ambient levels of O_3 on quarterly hospital discharge rates for asthma. For example, we estimate that the average effect of a 10-ppb mean increase in mean quarterly 1-hr maximum O_3 over the 18-year median of 87.7 ppb was a 4.6% increase (point estimate) in quarterly hospital discharges for asthma (increase from 3.12 to 3.26 × 10^{-4} age-eligible population) over a time period in which the median age-eligible population was approximately 4 million persons. Moreover, from a regulatory policy perspective, if the national 8-hr maximum were set at 75 ppb instead of 70 ppb (~ 6.6 ppb difference in the 1-hr max), our results suggest that there could be an excess of O_3-season, asthma-related hospital admissions for children in the study area of approximately 3.0% (point estimate) above what could be expected at a more protective standard. Further, our data indicate that the O_3-related asthma discharges (the pollutant mixture remaining the same) would be affected by changes in demography that likely will occur; and caution needs to be exercised in terms of extrapolation into the future.

Several features of our analysis strengthen the quantitative estimates and the apparent lack of time dependence of the O_3 effect:

First, we used a very flexible, multiple cross-validation model fitting algorithm in which the constraints on the model were as follows: *a*) maximum model size of 10 variables; *b*) maximum power of any individual variable (includes time) of 3; and *c*) a maximum of two-way interactions between the 29 covariates considered, such that the sum of powers of each covariate in the interaction term is ≤ 3. Thus, the flexibility of the models allowed the description of complex associations between changing demography, meteorologic conditions, and all temporal confounders for which time was a surrogate. A direct by-product of this flexible model fitting is that the form of the O_3–hospital discharge relation was free to take any polynomial form over time. This approach is similar in flexibility to model fitting with spline functions.

Second, the 24-hr concentrations of PM_{10}, NO_2, and CO could enter the model at equivalent levels of complexity as O_3 and any other covariate and in interaction with time. Thus, we did not start with the *a priori* assumption that warm-season O_3 would be the only or the most important component of the four pollutants for which we warm-season data.

Third, we ran our analysis 10 separate times, each time with a different split for cross validation (equivalent to 50 splits of the data). All model runs selected O_3 and no other pollutant, and the identical model with covariates was selected 8 of 10 times (Table 3).

Fourth, we used an MSM approach to investigate the marginal (population-level) effects of O_3 on the outcome (Robins et al. 2000). This approach approximates what would have been observed if we could have randomized all of the spatial units at each time point to a quarterly mean O_3 concentration. The results of this analysis indicated that the conventional statistical association model, in this particular analysis, was equivalent to the G-computation estimates of the HRMSM parameters—an observation that is not surprising, given that there were no interactions in the association model. Therefore, under certain assumptions noted above, the O_3 parameter (Table 3) can be interpreted as a causal, unconditional (i.e., not stratum specific) population-level effect estimate. In other words, if, contrary to fact, the median quarterly average 1-hr maximum increased by 10 ppb in all geographic units, the quarterly average hospital discharge rate would be expected to increase by 1.4 discharges/10^5 age-eligible population. This causal interpretation relies on the counterfactual framework embodied in HRMSMs (Neugebaueret al. 2007), particularly the assumption of no unmeasured confounders. The fact that, in our analyses, the association between O_3 hospital discharges can be interpreted further as the population-level effect estimate of O_3 based on the G-computation estimator of an HRMSM relies on the critical assumption that the conventional associational model selected with the DSA algorithm is correctly specified (particularly the absence of interaction terms between O_3 and covariates), the assumption of correct model specification is embodied in all analyses of observational data. The inference for this causal effect estimate was obtained by bootstrap (without consideration of additional variability introduced by the model selection procedure as is the case with virtually all reports of conventional analyses). We are exploring alternate causal estimators of causal parameters that do not rely on the ETA assumption to validate the results presented in this paper to further verify the validity of the inference, and a preliminary assessment of this latter analysis is supportive. The full results of this alternative analysis are the subject of a subsequent paper.

Finally, the results demonstrate that the addition of O_3 and demographic variables to our analyses removed all of the time trend in the hospital discharge data (Figure 3). Finally, although we included discharges with a primary diagnosis of pneumonia or acute sinusitis, we do not think that this has biased our results. Our estimate of the median quarterly discharge rate for asthma is at the lower end of such estimates for all or part of the age range that we included (National Center for Health Statistics 2004).

It is difficult to compare our results with other studies because we used a different time reference—3-month intervals—in contrast to a daily time metric in most other studies (Burnettet al. 2001; Friedmanet al. 2001). The most important factor that governed the choice of the time metric related to the fact that, for practical purposes, O_3 is an outdoor pollutant whose indoor concentrations are determined by household ventilation (open windows, use of air conditioners) (Gonzales et al. 2003). Because people of all ages spend most of their days indoors (Wiley et al. 1991a, 1991b), we reasoned that a 3-month interval, based on typical patterns of O_3 concentrations to which people would be exposed during their times out of doors, would provide a more stable population-level estimate than would be the case for shorter time intervals, such as days or weeks. Several consequences stemmed from this choice. Because most studies of the health effects of short-term exposures to O_3 indicate that O_3 impacts on health occur within a few days after exposures (Galanet al. 2003; Mortimer et al. 2002), we did not feel that it was justified to lag population exposure by 3 months (i.e., one quarter). Therefore, we related O_3 concentration in a given quarter to hospital discharges in that quarter. On its face, this would appear to violate the requirement for preservation of temporal sequence. However, given that we used average hospital discharges at the end of a quarter, this choice is valid. Furthermore, each of the 195 spatial units was assigned its spatially specific average quarterly discharge rate and O_3 concentration, and the data were treated as a repeated-measures problem over the 36 quarters; we have accounted for differences in the mean exposure over space and time. In this regard, some daily time-series studies may have violated the temporality assumption in that their designation of lag 0 often includes the day of hospital admission. To be sure that longer-term trends for other pollutants did not confound our O_3 exposure estimates, we considered previous quarter and previous year PM_{10}, NO_2, and CO.

The potential for spatial correlation to result in incorrect variance estimates for exposure outcome measures in time series studies of health effects of air pollutants has been noted (Ramsay et al. 2003a, 2003b). Although we did not perform a time-series analysis, we did address the issue of spatial correlation by not assuming that the data for each unit are obtained from independent draws from a common distribution but rather from each of 195 distributions whose similarity can be explained by close geographic proximity, conditional on the exposure regimen, and thus the independence assumption is reasonable.

Although we report the results as "O_3-related effects," O_3 is likely to be the best marker (of the pollutants available for analysis) for the gaseous oxidant species produced by the complex photochemistry that occurs in the SoCAB during the warm months of the year and involves oxides of nitrogen and hydrocarbons, largely from mobile source emissions. O_3 is the most abundant oxidant in the urban atmosphere; however, the mixture also includes peroxyacetylnitrate, hydrogen peroxide, organic peroxides, and the hydroxyl, hydroperoxy, and many organic peroxy radicals (Atkinson 1997). Several epidemiologic studies have shown that the oxidant properties of ambient air contribute to adverse health outcomes in persons with and without asthma (Grievink et al. 1998; Romieu et al. 1996, 1998, 2002). For example, Romieu et al. (2002) studied asthmatics in Mexico City and demonstrated that among the pollutant measurements for SO_2, PM_{10}, NO_2, and O_3, O_3 was most closely associated with decrements in lung function in children and were reversed by antioxidant vitamin supplementation. Relevant to our study, the effects were most marked in those with severe asthma—the pool of subjects out of which hospital admissions are most likely to occur. The findings in these studies have been supported by controlled O_3 exposure studies in which subjects were placed on diets supplemented with antioxidant vitamins and vegetable oils (Samet et al. 2001) and studies of airways reactivity after controlled O_3 exposure (Trenga et al. 2001).

In summary, we conducted exhaustive analyses to address many of the outstanding issues related to reported associations between O_3 and use of hospital services for asthma. Although additional work is ongoing to buttress the causal interpretation that we have given to our results, our data support and extend other observations that ambient O_3 (highly oxidant, ambient, warm-season environments) causes increases in hospital admissions in children with asthma. Moreover, the linearity of the relation that we observed indicates that these excess asthma hospital discharges can be expected to continue at levels of air quality experienced in southern California.

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Ischemic and Thrombotic Effects of Dilute Diesel-Exhaust Inhalation in Men with Coronary Heart Disease

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ABSTRACT

BACKGROUND

Exposure to air pollution from traffic is associated with adverse cardiovascular events. The mechanisms for this association are unknown. We conducted a controlled exposure to dilute diesel exhaust in patients with stable coronary heart disease to determine the direct effect of air pollution on myocardial, vascular, and fibrinolytic function.

METHODS

In a double-blind, randomized, crossover study, 20 men with prior myocardial infarction were exposed, in two separate sessions, to dilute diesel exhaust (300 μg per cubic meter) or filtered air for 1 hour during periods of rest and moderate exercise in a controlled-exposure facility. During the exposure, myocardial ischemia was quantified by ST-segment analysis using continuous 12-lead electrocardiography. Six hours after exposure, vasomotor and fibrinolytic function were assessed by means of intraarterial agonist infusions.

RESULTS

During both exposure sessions, the heart rate increased with exercise ($P<0.001$); the increase was similar during exposure to diesel exhaust and exposure to filtered air ($P=0.67$). Exercise-induced ST-segment depression was present in all patients, but there was a greater increase in the ischemic burden during exposure to diesel exhaust (−22±4 vs. −8±6 millivolt seconds, $P<0.001$). Exposure to diesel exhaust did not aggravate preexisting vasomotor dysfunction, but it did reduce the acute release of endothelial tissue plasminogen activator ($P=0.009$; 35% decrease in the area under the curve).

CONCLUSIONS

Brief exposure to dilute diesel exhaust promotes myocardial ischemia and inhibits endogenous fibrinolytic capacity in men with stable coronary heart disease. Our findings point to ischemic and thrombotic mechanisms that may explain in part the observation that exposure to combustion-derived air pollution is associated with adverse cardiovascular events. (ClinicalTrials.gov number, NCT00437138.)

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THE WORLD HEALTH ORGANIZATION (WHO) estimates that air pollution is responsible for 800,000 premature deaths worldwide each year.[1] Short-term exposure to air pollution has been associated with increases in cardiovascular morbidity and mortality, with deaths due to ischemia, arrhythmia, and heart failure.[2] In a large cohort study from the United States, Miller et al. recently reported that long-term exposure to air pollution increases the risk of death from cardiovascular disease by 76%.[3] These associations are strongest for fine particulate air pollutants (particulate matter of less than 2.5 μm in aerodynamic diameter [$PM_{2.5}$]), of which the combustion-derived nanoparticulate in diesel exhaust is an important component.[4] Substantial improvements in air quality have occurred in the developed world over the past 50 years, yet the association between $PM_{2.5}$ and mortality has no apparent threshold and is evident below current air-quality standards.[5]

Preclinical models of exposure to particulate air pollution demonstrate accelerated atherosclerotic plaque development[6] and increased in vitro[7] and in vivo[8] platelet aggregation. Epidemiologic and observational clinical studies suggest that exposure to air pollution may worsen symptoms of angina,[9] exacerbate exercise-induced myocardial ischemia,[10,11] and trigger acute myocardial infarction.[12,13] These clinical findings are limited by imprecision in the measurement of pollution exposure, the effect of potential confounding environmental and social factors, and the lack of mechanistic data.[14] Controlled exposures to air pollutants can help address these shortcomings by providing a precisely defined exposure in a regulated environment that facilitates investigation with validated biomarkers and surrogate measures of cardiovascular health. Using a carefully characterized exposure system, we have previously shown that exposure to dilute diesel exhaust in healthy volunteers causes lung inflammation,[15] depletion of airway antioxidant defenses,[16] and impairment of vascular and fibrinolytic function.[17]

To our knowledge, there have been no controlled exposures in patients with coronary heart disease, an important population that may be particularly susceptible to the adverse cardiovascular effects of air pollution. We assessed the effect of inhalation of dilute diesel exhaust on myocardial, vascular, and fibrinolytic function in a population of patients with stable coronary heart disease.

METHODS

SUBJECTS

Twenty men with stable coronary artery disease participated in this study, which was performed with the approval of the local research ethics committee, in accordance with the Declaration of Helsinki, and with the written informed consent of all participants.

All the men had proven coronary heart disease, with a previous myocardial infarction (>6 months before enrollment) treated by primary angioplasty and stenting, and were receiving standard secondary preventive therapy. Men with angina pectoris (Canadian Cardiovascular Society class ≥2), a history of arrhythmia, diabetes mellitus, uncontrolled hypertension, or renal or hepatic failure, as well as those with unstable coronary disease (acute coronary syndrome or symptoms of instability 3 months before enrollment), were excluded. All eligible volunteers were invited to a prestudy screening for exercise stress testing; subjects who were unable to achieve stage 2 of the Bruce protocol or who had marked changes on an electrocardiogram (left bundle-branch block, early ST-segment depression >2 mm) and those in whom hypotension developed were excluded. Current smokers and men with asthma, substantial occupational exposure to air pollution, or an intercurrent illness were also excluded from the study.

STUDY DESIGN

Using a randomized, double-blind, crossover study design, we evaluated the subjects in two 8 a.m. sessions at least 2 weeks apart. In each session, the subjects were exposed to controlled amounts of dilute diesel exhaust or filtered air. Each subject was exposed for 1 hour in an exposure chamber, as previously described.[15] During each exposure, the subjects performed two 15-minute periods of exercise on a bicycle ergometer separated by two 15-minute periods of rest. For each subject, the ergometer workload was calibrated to achieve a ventilation of 15 liters per minute per square meter of body-surface area to ensure a similar exposure on both occasions. The workload was constant for both exposures and was equivalent to stage 2 of the Bruce protocol (range, 110 to 150 watts; 5 to 7 metabolic equivalents). All subjects were fitted with 12-lead Holter electrocardiographic monitors (Medical Lifecard 12 Digital Holter Recorder, Del Mar Reynolds). In accordance with previous exposure studies in healthy volunteers, vascular assessments were made 6 to 8 hours after exposure to diesel exhaust or filtered air.[17]

DIESEL-EXHAUST EXPOSURE

The diesel exhaust was generated from an idling Volvo diesel engine (Volvo TD45, 4.5 liters, 4 cylinders, 680 rpm) from low-sulfur gas-oil E10 (Preem), as described previously.[15] More than 90% of the exhaust was shunted away, and the remainder diluted with filtered air heated to 20°C (relative humidity approximately 50%) before being fed into a whole-body exposure chamber (3.0 m by 3.0 m by 2.4 m) at a steady-state concentration.

The chamber was monitored continuously for pollutants, with exposures standardized with the use of nitrogen oxide concentrations to deliver a particulate matter concentration of 300 μg per cubic meter (median particle diameter, 54 nm; range, 20 to 120). There was little variation between exposures in the mean (±SE) number of particles ($1.26\pm0.01\times10^6$ particles per cubic centimeter) or in the concentrations of nitrogen oxide (4.45±0.02 ppm), nitrogen dioxide (1.01±0.01 ppm), nitric oxide (3.45±0.03 ppm), carbon monoxide (2.9±0.1 ppm), and total hydrocarbon (2.8±0.1 ppm). The predominant polycyclic aromatic hydrocarbons (approximately 90% of the total) were phenanthrene, fluorene, 2-methylfluorene, dibenzothiophene, and different methyl-substituted phenanthrenes. Only a minor fraction of polycyclic aromatic hydrocarbons (3.5%) was associated with particulate matter: 0.04% total particulate matter and 0.06% particulate-matter organic fraction. The concentration of particulate matter of less than 10 μm in aerodynamic diameter (PM_{10}) in the exposure chamber exceeded the WHO air-quality standard of 50 μg per cubic meter by a factor of 6, and the nitrogen dioxide concentration exceeded the WHO standard of 0.105 ppm by a factor of 10.[18]

VASCULAR STUDY

All subjects underwent brachial-artery cannulation with a 27-standard wire-gauge steel needle. After a 30-minute baseline saline infusion, subjects were given infusions of acetylcholine at rates of 5, 10, and 20 μg per minute (endothelium-dependent vasodilator, Clinalfa), bradykinin at rates of 100, 300, and 1000 pmol per minute (endothelium-dependent vasodilator that releases tissue plasminogen activator [t-PA], Clinalfa), and sodium nitroprusside at rates of 2, 4, and 8 μg per minute (endothelium-independent vasodilator, David Bull Laboratories); each infusion was given for 6 minutes. Infusions of the three vasodilators were separated by 20-minute saline infusions and given in a randomized order. Therapy with angiotensin-converting–enzyme inhibitors was withdrawn

Table 1. Baseline Characteristics of the 20 Subjects with Coronary Heart Disease.*

Characteristic	Value
Age (yr)	60±1
Smoking history (no. of subjects)	
Nonsmoker	12
Former smoker	8
Current smoker	0
Hypertension (no. of subjects)	8
Height (cm)	173±6
Weight (kg)	79±3
Body-mass index	27±1
Time since index infarction (mo)	35±4
Coronary angiographic findings	
No. of diseased vessels	
1	13
2	6
3	1
Culprit lesion (no. of subjects)	
Left anterior descending coronary artery	14
Circumflex coronary artery	4
Right coronary artery	2
Cholesterol (mg/dl)	
Total	173±6
LDL	100±8
HDL	48±2
Triglycerides (mg/dl)	128±23
Fasting glucose (mg/dl)	102±6
Medications (no. of subjects)	
Aspirin	20
Statin	18
Beta-blocker	15
ACE inhibitor or angiotensin-receptor blocker†	4

* Plus–minus values are means ±SE. The body-mass index is the weight in kilograms divided by the square of the height in meters. LDL denotes low-density lipoprotein, HDL high-density lipoprotein, and ACE angiotensin-converting enzyme. To convert the values for cholesterol to millimoles per liter, multiply by 0.02586. To convert the values for triglycerides to millimoles per liter, multiply by 0.01129. To convert the values for glucose to millimoles per liter, multiply by 0.05551.

† ACE inhibitor therapy was withdrawn 7 days before each vascular study. All other regular medications were continued throughout the study.

Table 2. Effect of Exercise on Heart Rate and ST Segment in the 20 Subjects during Exposures to Filtered Air and Diesel Exhaust.*

Characteristic	Filtered Air	Diesel Exhaust	P Value†
Exercise phase 1			
Heart rate — bpm			
Baseline	63±2	61±2	0.24
Maximum	87±3	86±3	0.67
Maximum ST-segment change (μV)			
Lead II	−28±13	−56±10	0.03
Lead V_2	−28±10	−41±12	0.18
Lead V_5	−14±8	−33±9	0.04
Change in ischemic burden (mVsec)			
Lead II	−11±5	−23±4	0.004
Lead V_2	−13±5	−21±6	0.04
Lead V_5	−4±3	−12±4	0.01
Exercise phase 2			
Heart rate (bpm)			
Baseline	67±2	65±2	0.35
Maximum	91±3	87±3	0.12
Maximum ST-segment change (μV)			
Lead II	−17±15	−49±12	0.006
Lead V_2	−18±12	−41±13	0.04
Lead V_5	−7±9	−28±10	0.02
Change in ischemic burden (mVsec)			
Lead II	−8±6	−22±4	0.0007
Lead V_2	−11±5	−20±6	0.02
Lead V_5	−2±3	−12±5	0.006

* Plus–minus values are means ±SE; mVsec denotes millivolt seconds.

† P values were calculated with Student's t-test.

7 days before each vascular study, because it augments bradykinin-induced release of endothelial t-PA.[19] All other medications were continued throughout the study.

Forearm blood flow was measured in both arms by venous occlusion plethysmography with the use of mercury-in-Silastic strain gauges, as described previously.[20] Heart rate and blood pressure in the noninfused arm were monitored at intervals throughout each study while the subject was in the supine position, with the use of a semiautomated, noninvasive oscillometric sphygmomanometer.

FIBRINOLYTIC AND INFLAMMATORY MARKERS

Blood (10 ml) was withdrawn into acidified buffered citrate (Stabilyte tubes, Biopool International) for t-PA assays and into citrate (BD Vacutainer) for plasminogen activator inhibitor type 1 (PAI-1) assays. Plasma t-PA and PAI-1 antigen concentrations were determined by means of enzyme-linked immunosorbent assays (TintElize t-PA, Biopool EIA; Coaliza PAI-1; and Chromogenix AB). Serum C-reactive protein concentrations were measured with an immunonephelometric assay (BN II nephelometer, Dade Behring).

DATA ANALYSIS

Electrocardiographic recordings were analyzed with the use of the Medical Pathfinder Digital 700 Series Analysis System (Del Mar Reynolds). ST-segment deviation was calculated by comparing the ST segment during each 15-minute exercise test with the average ST segment for the 15-minute period immediately before the start of the exposure. The ST-segment amplitude was determined at the J point plus 80 msec. The ischemic burden during each exercise test was calculated as the product of the change in ST-segment amplitude and the duration of exercise. Leads II, V_2, and V_5 were selected a priori for ST-segment analysis to reflect separate regions of myocardium. The maximum ST-segment depression and ischemic burden were determined for these leads individually and as a composite.

Plethysmographic data and net t-PA release were determined as described previously.[20,21]

STATISTICAL ANALYSIS

Continuous variables are reported as means ±SE. Analysis of variance with repeated measures and a two-tailed Student's t-test were performed as appropriate with the use of GraphPad Prism software. A two-sided P value of less than 0.05 was considered to indicate statistical significance.

RESULTS

Subjects were all middle-aged men with predominantly single-vessel coronary artery disease (Table 1). They reported no symptoms of angina and had no major arrhythmias during exposure or in the subsequent 24 hours.

MYOCARDIAL ISCHEMIA

The heart rate increased with exercise during exposures to diesel exhaust and filtered air ($P<0.001$ for both comparisons with the baseline rates; $P=0.67$ for the comparison of rates during exposure to diesel exhaust and during exposure to filtered air) (Table 2). Myocardial ischemia was detected during exercise in all subjects, with greater maximum ST-segment depression during exposure to diesel exhaust than during exposure to filtered air (Table 2 and Fig. 1A and 1B) (P<0.05). The ischemic burden induced by exercise was greater during exposure to diesel exhaust (Fig. 1C).

VASOMOTOR FUNCTION

There were no significant differences in resting heart rate, blood pressure, or baseline blood flow in the noninfused forearm between or during the two study visits. Although there was a dose-dependent increase in blood flow with each vasodilator (P<0.001 for all comparisons), neither endothelium-dependent nor endothelium-independent vasodilatation was affected by inhalation of diesel exhaust (Fig. 2). Comparison of these data with the findings in a contemporary reference population of healthy male volunteers (mean age, 53±4 years) showed impaired vasodilatation in response to acetylcholine (P=0.02) but not to sodium nitroprusside (Fig. 2).

FIBRINOLYTIC AND INFLAMMATORY MARKERS

There were no significant differences in basal plasma concentrations of t-PA (10.5±1.0 and 9.5±1.0 ng per milliliter, respectively) or its endogenous inhibitor, PAI-1 (18.8±3.0 and 17.0±2.0 ng per milliliter, respectively), 6 hours after exposure to either diesel exhaust or filtered air. Likewise, leukocyte, neutrophil, and platelet counts and serum C-reactive protein concentrations were not altered at 6 or 24 hours by exposure to diesel exhaust or filtered air. Bradykinin caused a dose-dependent increase in plasma t-PA concentrations (data not shown) and net t-PA release (Fig. 3) in the infused arm (P<0.001 for both comparisons) that was suppressed after exposure to diesel exhaust (P=0.009; 35% decrease in the area under the curve).

DISCUSSION

We have demonstrated that transient exposure to dilute diesel exhaust, at concentrations occurring in urban road traffic, exacerbates exercise-induced myocardial ischemia and impairs endogenous fibrinolytic capacity in men with coronary heart disease. These findings provide a plausible explanation for the epidemiologic observation that exposure to air pollution is associated with adverse cardiovascular events.

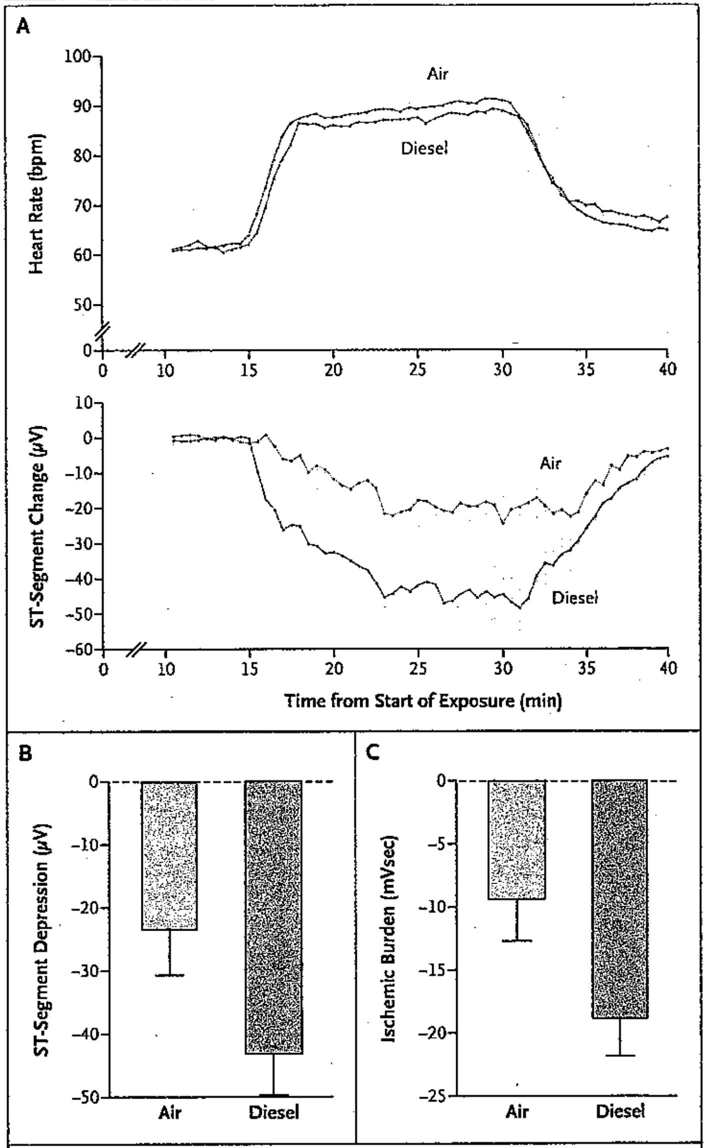

Figure 1. Myocardial Ischemia during 15-Minute Intervals of Exercise-Induced Stress and Exposure to Diesel Exhaust or Filtered Air in the 20 Subjects.

Panel A shows the average change in the heart rate and in the ST segment in lead II. Panel B shows the maximum ST-segment depression during inhalation of diesel exhaust as compared with filtered air (P=0.003), and Panel C shows the total ischemic burden during inhalation of diesel exhaust as compared with filtered air (P<0.001); the values in Panels B and C are averages of the values in leads II, V_2, and V_5. In all three panels, red indicates exposure to diesel exhaust, and blue exposure to filtered air. T bars denote standard errors, and mVsec millivolt seconds.

Concentrations of particulate matter can regularly reach levels of 300 μg per cubic meter in heavy traffic, in occupational settings, and in the world's largest cities.[22] A major proportion of this

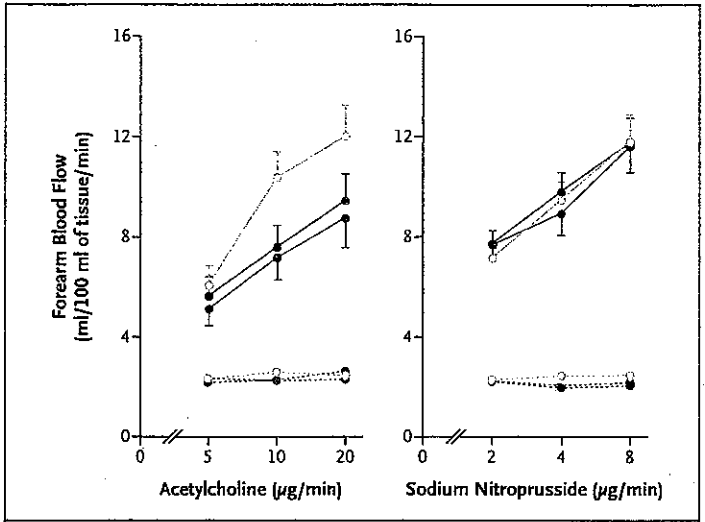

Figure 2. Forearm Blood Flow 6 to 8 Hours after Exposures to Diesel Exhaust and Filtered Air.

Values for infused (solid lines) and noninfused (dashed lines) forearm blood flow are shown for 17 subjects after exposure to diesel exhaust (red) and after exposure to filtered air (blue), as well as for a reference population of matched healthy controls (orange), during intrabrachial infusion of acetylcholine or sodium nitroprusside. $P<0.001$ for dose response to both drugs in the infused arm. Among the 17 subjects, $P=0.54$ for exposure to diesel exhaust versus filtered air during infusion of acetylcholine, and $P=0.56$ during infusion of sodium nitroprusside. For the comparison of the subjects with healthy controls, $P=0.02$ during acetylcholine infusion, and $P=0.72$ during sodium nitroprusside infusion.

mass is attributable to combustion-derived nanoparticles from traffic, ranging from 20% at remote monitoring sites[23] to 70% in a road tunnel.[24] Exposure to 300 μg of particulate matter per cubic meter for 1 hour increases a person's average exposure over a 24-hour period by only 12 μg per cubic meter. Changes of this magnitude occur on a daily basis, even in the least polluted cities, and are associated with increases in the rate of death from cardiorespiratory disorders.[25] Our model is therefore highly relevant, in terms of both the composition and the magnitude of exposure, to the assessment of short-term health effects in men.

Given potential safety concerns, we recruited patients who had stable and symptomatically well-controlled coronary heart disease, with good exercise tolerance on formal stress testing. The study participants were closely monitored throughout the exposure and reported no adverse effects. Despite similar changes in the heart rate during exposure to diesel exhaust and to filtered air, we documented asymptomatic myocardial ischemia that was increased by a factor of up to three after inhalation of diesel exhaust. This reproducible effect was present despite extensive use of maintenance beta-blocker therapy in patients without limiting angina. Thus, we have established that inhalation of diesel exhaust has an immediate, proischemic effect, and we believe this provides an important mechanism for the observed increase in myocardial infarction in the hour after exposure to traffic.[13]

Small areas of denudation and thrombus deposition are common findings on the surface of atheromatous plaques and are usually subclinical. Rosenberg and Aird have postulated that vascular-bed–specific defects in hemostasis exist and that propagation of coronary thrombosis is critically dependent on the local fibrinolytic balance.[26] The magnitude and rapidity of t-PA release from the vascular endothelium regulate the generation of plasmin and thus determine the efficacy of endogenous fibrinolysis.

We have previously reported impaired t-PA release in healthy volunteers 6 hours after inhalation of diesel exhaust, although this effect was not seen 2 hours after exposure.[17] We have now confirmed similar reductions in acute t-PA release 6 hours after inhalation of diesel exhaust in patients with coronary heart disease. This delayed effect on endogenous fibrinolysis cannot explain our findings of immediate myocardial ischemia but is consistent with the observations of Peters and colleagues, who reported a second peak in the incidence of myocardial infarction 5 to 6 hours after exposure to traffic.[13] Preclinical thrombotic models also lend support to our findings. Nemmar and colleagues reported that in a hamster model, instillation of diesel-exhaust particulate into the lungs increases venous and arterial thrombus formation at sites of vascular injury.[27] Taken together, these findings indicate an important thrombotic effect of diesel-exhaust inhalation that may promote coronary thrombosis.

Although we found important adverse effects of diesel exhaust on vascular fibrinolytic function, we did not detect an effect on vasomotor function. However, vasomotor function was assessed 6 hours after exposure and 5 hours after we documented an increase in the ischemic burden. We have previously demonstrated that exposure to diesel exhaust impairs vasomotor function in healthy volunteers.[17] This effect was most marked at 2 hours but was still present 6 hours after exposure. Therefore, we cannot exclude the possibility of a detrimental vasomotor effect in patients at an earlier point in time.

Patients with coronary heart disease are known to have impaired endothelial function,[28] and we confirm the presence of endothelial dysfunction in our patients. This may have hindered our ability to demonstrate a further impairment of vascular function after exposure to diesel exhaust. In addition, we performed our assessments while the subjects were taking medications that are known to influence endothelial vasomotor function.[29] Furthermore, Brook and colleagues reported that air pollution does not have an effect on endothelium-dependent vasodilatation.[30]

We have identified two distinct and potentially synergistic adverse cardiovascular effects of air pollution in patients with coronary heart disease. These effects may contribute to the increased incidence of myocardial infarction after exposure to traffic. However, the precise mechanisms by which diesel-exhaust inhalation induces these ischemic and thrombotic effects have not been established in our study and will need to be determined in future work.

Our findings are consistent with epidemiologic studies showing associations between ambient particulate air pollution and increased myocardial ischemia during formal exercise testing.[10,11] Myocardial ischemia occurs as a consequence of reduced myocardial oxygen supply, increased demand, or both. We hypothesize that oxidative stress and microvascular dysfunction in the resistance vessels of the myocardium may, in part, explain the adverse ischemic effects of exposure to dilute diesel exhaust. In vitro studies, animal models, and studies of exposures in humans have clearly established the oxidant and proinflammatory nature of combustion-derived particulate matter.[31] Indeed, the pattern of vascular dysfunction in our previous studies suggested that oxidative stress and reduced nitric oxide availability may play a role in mediating the adverse vascular effects of diesel-exhaust inhalation.[17]

Diesel exhaust is a complex mixture of gases and particles, and from our findings, we cannot rule out a nonparticulate cause of the adverse cardiovascular effects. However, on the basis of epidemiologic studies,[32] particulate matter is thought to be responsible for the majority of the adverse health effects of air pollution.[33] This view is supported by the recent observations of Miller and colleagues, who found that cardiovascular outcomes were strongly associated with long-term exposure to particulate matter but not with gaseous pollutants.[3] Ambient nitrogen dioxide can be considered a surrogate for pollution from traffic, but it has little adverse effect in controlled-chamber studies, even at the exposure levels in our study.[34] We therefore suggest that the cardiovascular effects described here are mediated primarily by the particulates in diesel exhaust and not by its other components. This argues for the use of diesel-exhaust particle traps to limit the adverse health effects of traffic emissions. However, the causative role of particulates must first be definitively established, and the efficacy of particle traps confirmed.

Brief exposure to dilute diesel exhaust increases myocardial ischemia and impairs endogenous fibrinolytic capacity in men with stable coronary heart disease. Our findings suggest mechanisms for the observation that exposure to combustion-derived air pollution is associated with adverse cardiovascular events, including acute myocardial infarction. Environmental health policy interventions targeting reductions in urban air pollution should be considered in order to decrease the risk of adverse cardiovascular events.

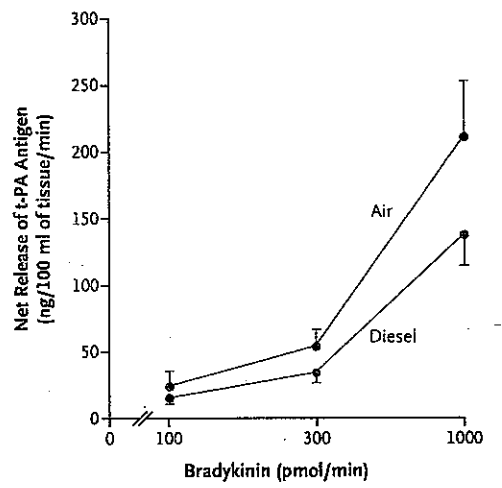

Figure 3. Release of Tissue Plasminogen Activator (t-PA) Antigen 6 to 8 Hours after Exposures to Diesel Exhaust and Filtered Air in 17 Subjects.

As compared with filtered air (blue), inhalation of diesel exhaust (red) reduced the net release of t-PA antigen (calculated as the product of forearm plasma flow and the difference in t-PA concentrations between the two arms) by 35% (P=0.009).

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ORIGINAL ARTICLE

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The Effect of Air Pollution on Lung Development from 10 to 18 Years of Age

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ABSTRACT

Background Whether exposure to air pollution adversely affects the growth of lung function during the period of rapid lung development that occurs between the ages of 10 and 18 years is unknown.

Methods In this prospective study, we recruited 1759 children (average age, 10 years) from schools in 12 southern California communities and measured lung function annually for eight years. The rate of attrition was approximately 10 percent per year. The communities represented a wide range of ambient exposures to ozone, acid vapor, nitrogen dioxide, and particulate matter. Linear regression was used to examine the relationship of air pollution to the forced expiratory volume in one second (FEV_1) and other spirometric measures.

Results Over the eight-year period, deficits in the growth of FEV_1 were associated with exposure to nitrogen dioxide (P=0.005), acid vapor (P=0.004), particulate matter with an aerodynamic diameter of less than 2.5 µm ($PM_{2.5}$) (P=0.04), and elemental carbon (P=0.007), even after adjustment for several potential confounders and effect modifiers. Associations were also observed for other spirometric measures. Exposure to pollutants was associated with clinically and statistically significant deficits in the FEV_1 attained at the age of 18 years. For example, the estimated proportion of 18-year-old subjects with a low FEV_1 (defined as a ratio of observed to expected FEV_1 of less than 80 percent) was 4.9 times as great at the highest level of exposure to $PM_{2.5}$ as at the lowest level of exposure (7.9 percent vs. 1.6 percent, P=0.002).

Conclusions The results of this study indicate that current levels of air pollution have chronic, adverse effects on lung development in children from the age of 10 to 18 years, leading to clinically significant deficits in attained FEV_1 as children reach adulthood.

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There is mounting evidence that air pollution has chronic, adverse effects on pulmonary development in children. Longitudinal studies conducted in Europe[1,2,3] and the United States[4,5,6] have demonstrated that exposure to air pollution is associated with reductions in the growth of lung function, strengthening earlier evidence[7,8,9,10,11,12] based on cross-sectional data. However, previous longitudinal studies have followed young children for relatively short periods (two to four years), leaving unresolved the question of whether the effects of air pollution persist from adolescence into adulthood. The Children's Health Study[13] enrolled children from 12 southern California communities representing a wide range of exposures to ambient air pollution. We documented the children's respiratory growth from the ages of 10 to 18 years. Over this eight-year period, children have substantial increases in lung function. By the age of 18 years, girls' lungs have nearly matured, and the growth in lung function in boys has slowed considerably, as compared with the rate in earlier adolescence.[14] We analyzed the association between long-term exposure to ambient air pollution and the growth in lung function over the eight-year period from the ages of 10 to 18 years. We also examined whether any observed effect of air pollution on this eight-year growth period results in clinically significant deficits in attained lung function at the age of 18 years.

Methods

Study Subjects

In 1993, the Children's Health Study recruited 1759 fourth-grade children (average age, 10 years) from elementary schools in 12 southern California communities as part of an investigation of the long-term effects of air pollution on children's respiratory health.[6,12,13] Data on pulmonary function were obtained by trained field technicians, who traveled to study schools annually from the spring of 1993 through the spring of 2001 to perform maximal-effort spirometric testing of the children. Details of the testing protocol have been published previously.[12] We analyzed three measures of pulmonary function: forced vital capacity (FVC), forced expiratory volume in the first second (FEV_1), and maximal midexpiratory flow rate (MMEF). Pulmonary-function tests were not performed on any child who was absent from school on the day of testing, but such a child was still eligible for testing in subsequent years. Children who moved away from their recruitment community were classified as lost to follow-up and were not tested further. From the initial sample of the 1759 children in 1993, the number of children available for follow-up was 1414 in 1995, 1252 in 1997, 1031 in 1999, and 747 in 2001, reflecting the attrition of approximately 10 percent of subjects per year.

A baseline questionnaire, completed at study entry by each child's parents or legal guardian, was used to obtain information on the children's characteristics, including race, presence or absence of Hispanic ethnic background, level of parental education, presence or absence of a history of asthma diagnosed by a doctor, exposure to maternal smoking in utero, and household exposure to gas stoves, pets, and environmental tobacco smoke. Questions administered at the time of annual pulmonary-function testing were used to update information on asthma status, personal smoking status, and exposure to environmental tobacco smoke. The distribution of baseline characteristics of all study subjects and of two subgroups defined according to the length of follow-up (all eight years or less than eight years) is shown in the Supplementary Appendix (available with the full text of this article at www.nejm.org). The length of follow-up was significantly associated with factors related to the mobility of the population, including race, presence or absence of Hispanic ethnic background, presence or absence of exposure to environmental tobacco smoke, and parents' level of education. However, the length of follow-up was not significantly associated with baseline lung function or the level of exposure to air pollution, suggesting that the loss to follow-up did not differ with respect to the primary variables of interest.

The study protocol was approved by the institutional review board for human studies at the University of Southern California, and written informed consent was provided by a parent or legal guardian for all study subjects. We did not obtain assent from minor children, since this was not standard practice when the study was initiated.

Air-Pollution Data

Air-pollution–monitoring stations were established in each of the 12 study communities and provided continuous data, beginning in 1994. Each station measured average hourly levels of ozone, nitrogen dioxide, and particulate matter with an aerodynamic diameter of less than 10 μm (PM_{10}). Stations also collected two-week integrated-filter samples for measuring acid vapor and the mass and chemical makeup of particulate matter with an aerodynamic diameter of less than 2.5 μm ($PM_{2.5}$). Acid vapor included both inorganic acids (nitric and hydrochloric) and organic acids (formic and acetic). For statistical analysis, we used total acid, computed as the sum of nitric, formic, and acetic acid levels. Hydrochloric acid was excluded from this sum, since levels were very low and close to the limit of detection. In addition to measuring $PM_{2.5}$, we determined the levels of elemental carbon and organic carbon, using method 5040 of the National Institute for Occupational Safety and Health.[15] We computed annual averages on the basis of average levels in a 24-hour period in the case of PM_{10} and nitrogen dioxide, and a two-week period in the case of $PM_{2.5}$, elemental carbon, organic carbon, and acid vapor. For ozone, we computed the annual average of the levels obtained from 10 a.m. to 6 p.m. (the eight-hour daytime average) and of the one-hour maximal levels. We also calculated long-term mean pollutant levels (from 1994 through 2000) for use in the statistical analysis of the lung-function outcomes.

Statistical Analysis

The outcome data consisted of the results of 5454 pulmonary-function tests of 876 girls and 5300 tests of 883 boys over the eight-year period. We adopted a two-stage regression approach to relate the longitudinal pulmonary-function data for each child to the average air-pollution levels in each study community.

The first-stage model was a regression of each pulmonary-function measure (values were log-transformed) on age to obtain separate, community-specific average growth curves for girls and boys. To account for the growth pattern during this period, we used a linear spline model[14] that consisted of four straight lines over the age intervals of younger than 12 years, 12 to 14 years, 14 to 16 years, and older than 16 years, constrained to be connected at the three "knot" points. The model included adjustments for log values for height; body-mass index (the weight in kilograms divided by the square of the height in meters); the square of the body-mass index; race; the presence or absence of Hispanic ethnic background, doctor-diagnosed asthma, any tobacco smoking by the child in the preceding year, exposure to environmental tobacco smoke, and exercise or respiratory tract illness on the day of the test; and indicator variables for the field technician and the spirometer. In addition to these covariates, random effects were included to account for the multiple measurements contributed by each subject. An analysis of residual values confirmed that the assumptions of the model had been satisfied. The first-stage model was used to estimate the mean and variance of the growth in lung function over the eight-year period in each of the 12 communities, separately for girls and boys.

The second-stage model was a linear regression of the 24 sex- and community-specific estimates of the growth in lung function over the eight-year period on the corresponding average levels of each air pollutant in each community. Inverses of the first-stage variances were incorporated as weights, and a community-specific random effect was included to account for residual variation between communities. A sex-by-pollutant interaction was included in the model to evaluate whether there was a difference in the effect of a given pollutant between the sexes, and when this value was nonsignificant, the model was refitted to estimate the sex-averaged effect of the pollutant. Pollutant effects are reported as the difference in the growth in lung function over the eight-year period from the least to the most polluted community, with negative differences indicative of growth deficits with increasing exposure. We also considered two-pollutant models obtained by simultaneously regressing the growth in lung function over the eight-year period on pairs of pollutants.

In addition to examining the growth in lung function over the eight-year period, we analyzed the FEV_1 measurements obtained in 746 subjects during the last year of follow-up (average age, 17.9 years) to determine whether exposure to air pollution was associated with clinically significant deficits in attained FEV_1. We defined a low FEV_1 as an attained FEV_1 below 80 percent of the predicted value, a criterion commonly used in clinical settings to identify persons who are at increased risk for adverse respiratory conditions. To determine the predicted FEV_1, we first fitted a regression model for observed FEV_1 (using log-transformed values) with the following predictors: log-transformed height, body-mass index, the square of the body-mass index, sex, race or ethnic group, asthma status, field technician, and interactions between sex and log-transformed height, sex and asthma, and sex and race or ethnic group. This model explained 71 percent of the variance in the attained FEV_1 level. For each subject, we then computed the predicted FEV_1 from the model and considered subjects to have a low FEV_1 if the ratio of observed to predicted FEV_1 was less than 80 percent. Linear regression was then used to examine the correlation between the community-specific proportion of subjects with a low FEV_1 and the average level of each pollutant from 1994 through 2000. This model included a community-specific random effect to account for residual variation. Regression procedures in SAS software[16] were used to fit all models. Associations denoted as statistically significant were those that yielded a P value of less than 0.05, assuming a two-sided alternative hypothesis.

Results

From 1994 through 2000, there was substantial variation in the average levels of study pollutants across the 12 communities, with relatively little year-to-year variation in the annual levels within each community (Figure 1). From 1994 through 2000, the average levels of ozone were not significantly correlated across communities with any other study pollutant (Table 1). However, correlations between other pairs of pollutants were all significant, ranging from an R of 0.64 ($P<0.05$) for nitrogen dioxide and organic carbon, to an R of 0.97 ($P<0.001$) for PM_{10} and organic carbon. Thus, nitrogen dioxide, acid vapor, and the particulate-matter pollutants can be regarded as a correlated "package" of pollutants with a similar pattern relative to each other across the 12 communities.

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Figure 1. Mean (+SD) Annual Average Levels of Pollutants from 1994 through 2000 in the 12 Study Communities in Southern California.

AL denotes Alpine, AT Atascadero, LE Lake Elsinore, LA Lake Arrowhead, LN Lancaster, LM Lompoc, LB Long Beach, ML Mira Loma, RV Riverside, SD San Dimas, SM Santa Maria, and UP Upland. O_3 denotes ozone, NO_2 nitrogen dioxide, and PM_{10} and $PM_{2.5}$ particulate matter with an aerodynamic diameter of less than 10 μm and less than 2.5 μm, respectively.

View this table: **Table 1.** Correlation of Mean Air-Pollution Levels from 1994 through 2000 across the 12 Study Communities.
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Among the girls, the average FEV_1 increased from 1988 ml at the age of 10 years to 3332 ml at the age of 18 years, yielding an average growth in FEV_1 of 1344 ml over the eight-year period (Table 2). The corresponding averages in boys were 2082 ml and 4464 ml, yielding an average growth in FEV_1 of 2382 ml over the eight-year period. Similar patterns of growth over the eight-year period were observed for FVC and MMEF (Table 2).

View this table: **Table 2.** Mean Levels of Growth in Pulmonary Function during the Eight-Year Study Period, from 1993 to 2001.
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Although the average growth in FEV_1 was larger in boys than in girls, the correlations of growth with air pollution did not differ significantly between the sexes, as shown for nitrogen dioxide in Figure 2. The sex-averaged analysis, depicted by the regression line in Figure 2, demonstrated a significant negative correlation between the growth in FEV_1 over the eight-year period and the average nitrogen dioxide level ($P=0.005$). The estimated difference in the average growth in FEV_1 over the eight-year period from the community with the lowest nitrogen dioxide level to the community with the highest nitrogen dioxide level, represented by the slope of the plotted regression line in Figure 2, was –101.4 ml.

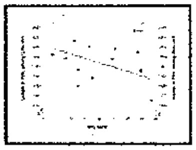

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Figure 2. Community-Specific Average Growth in FEV_1 among Girls and Boys During the Eight-Year Period from 1993 to 2001 Plotted against Average Nitrogen Dioxide (NO_2) Levels from 1994 through 2000.

Estimated differences in the growth of FEV_1, FVC, and MMEF during the eight-year period with respect to all pollutants are summarized in Table 3. Deficits in the growth of FEV_1 and FVC were observed for all pollutants, and deficits in the growth of MMEF were observed for all but ozone, with several combinations of outcome variables and pollutants attaining statistical significance. Specifically, for FEV_1 we observed significant negative correlations between the growth in this variable over the eight-year period and exposure to acid vapor ($P=0.004$), $PM_{2.5}$ ($P=0.04$), and elemental carbon ($P=0.007$), in addition to the above-mentioned correlation with nitrogen dioxide. As with FEV_1, the effects of the various pollutants on FVC and MMEF did not differ significantly between boys and girls. Significant deficits in FVC were associated with exposure to nitrogen dioxide ($P=0.05$) and acid vapor ($P=0.03$), whereas deficits in MMEF were associated with exposure to nitrogen dioxide ($P=0.02$) and elemental carbon ($P=0.04$). There was no significant evidence that ozone, either the average value obtained from 10 a.m. to 6 p.m. or the one-hour maximal level, was associated with any measure of lung function. In two-pollutant models for any of the measures of pulmonary function, adjustment for ozone did not substantially alter the effect estimates or significance levels of any other pollutant (data not shown). In general, two-pollutant models for any pair of pollutants did not provide a significantly better fit to the data than the corresponding single-pollutant models; this was not surprising, given the strong correlation between most pollutants.

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Table 3. Difference in Average Growth in Lung Function over the Eight-Year Study Period from the Least to the Most Polluted Community.

The association between pollution and the growth in FEV_1 over the eight-year period remained significant in a variety of sensitivity analyses (Table 4). For example, estimates of the effect of acid vapor and elemental carbon (model 1 in Table 4) changed little with adjustment for in-utero exposure to maternal smoking (model 2), presence in the home of a gas stove (model 3) or pets (model 4), or parental level of education (model 5). To account for possible confounding by short-term effects of air pollution, we fitted a model that adjusted for the average ozone, nitrogen dioxide, and PM_{10} levels on the three days before each child's pulmonary-function test. This adjustment also had little effect on the estimates of the long-term effects of air pollution (model 6). Table 4 also shows that the effects of pollutants remained large and significant in the subgroups of children with no history of asthma (model 7) and those with no history of smoking (model 8). The effects of pollutants were not significant among the 457 children who had a history of asthma or among the 483 children who had ever smoked (data not shown), although the sample sizes in these subgroups were small. Model 9 demonstrates that the extremes in pollutant levels did not drive the observed associations; in other words, we found similar effect estimates after eliminating the two communities with the highest and lowest levels of each pollutant. Finally, model 10 shows the effects of pollutants in the subgroup of subjects who underwent pulmonary-function testing in both 1993 and 2001 (i.e., subjects who participated in both the first and last year of the study). The magnitudes of effects in this subgroup were similar to those in the entire sample (model 1), suggesting that observed effects of pollutants in the entire sample cannot be attributed to biased losses to follow-up across communities. These sensitivity analyses were also applied to the other pollutants and to FVC and MMEF, with similar results.

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Table 4. Sensitivity Analysis of the Effects of Acid Vapor and Elemental Carbon on Growth in FEV_1 over the Eight-Year Study Period.

Pollution-related deficits in the average growth in lung function over the eight-year period resulted in clinically important deficits in attained lung function at the age of 18 years (Figure 3). Across the 12 communities, a clinically low FEV_1 was positively correlated with the level of exposure to nitrogen dioxide ($P=0.005$), acid vapor ($P=0.01$), PM_{10} ($P=0.02$), $PM_{2.5}$ ($P=0.002$), and elemental carbon ($P=0.006$). For example, the estimated proportion of children with a low FEV_1 (represented by the regression line in Figure 3) was 1.6 percent at the lowest level of exposure to $PM_{2.5}$ and was 4.9 times as great (7.9 percent) at the highest level of exposure to $PM_{2.5}$ ($P=0.002$). Similar associations between these pollutants and a low FEV_1 were observed in the subgroup of children with no history of asthma and the subgroup with no history of smoking (data not shown). A low FEV_1 was not significantly correlated with exposure to ozone in any group.

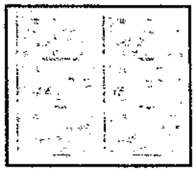

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Figure 3. Community-Specific Proportion of 18-Year-Olds with a FEV_1 below 80 Percent of the Predicted Value Plotted against the Average Levels of Pollutants from 1994 through 2000.

The correlation coefficient (R) and P value are shown for each comparison. AL denotes Alpine, AT Atascadero, LE Lake Elsinore, LA Lake Arrowhead, LN Lancaster, LM Lompoc, LB Long Beach, ML Mira Loma, RV Riverside, SD San Dimas, SM Santa Maria, and UP Upland. O_3 denotes ozone, NO_2 nitrogen dioxide, and PM_{10} and $PM_{2.5}$ particulate matter with an aerodynamic diameter of less than 10 μm and less than 2.5 μm, respectively.

Discussion

The results of this study provide robust evidence that lung development, as measured by the growth in FVC, FEV_1, and MMEF from the ages of 10 to 18 years, is reduced in children exposed to higher levels of ambient air pollution. The strongest associations were observed between FEV_1 and a correlated set of pollutants, specifically nitrogen dioxide, acid vapor, and elemental carbon. The effects of these pollutants on FEV_1 were similar in boys and girls and remained significant among children with no history of asthma and among those with no history of smoking, suggesting that most children are susceptible to the chronic respiratory effects of breathing polluted air. The magnitude of the observed effects of air pollution on the growth in lung function during this age interval was similar to those that have been reported for exposure to maternal smoking[17,18] and smaller than those reported for the effects of personal smoking.[17,19]

Cumulative deficits in the growth in lung function during the eight-year study period resulted in a strong association between exposure to air pollution and a clinically low FEV_1 at the age of 18 years. In general, lung development is essentially complete in girls by the age of 18 years, whereas in boys it continues into their early 20s, but at a much reduced rate. It is therefore unlikely that clinically significant deficits in lung function at the age of 18 years will be reversed in either girls or boys as they complete the transition into adulthood. Deficits in lung function during young adulthood may increase the risk of respiratory conditions — for example, episodic wheezing that occurs during a viral infection.[20] However, the greatest effect of pollution-related deficits may occur later in life, since reduced lung function is a strong risk factor for complications and death during adulthood.[21,22,23,24,25,26,27]

Deficits in lung function were associated with a correlated set of pollutants that included nitrogen dioxide, acid vapor, fine-particulate matter ($PM_{2.5}$), and elemental carbon. In southern California, the primary source of these pollutants is motor vehicles, either through direct tailpipe emissions or downwind physical and photochemical reactions of vehicular emissions. Both gasoline- and diesel-powered engines contribute to the tons of pollutants exhausted into southern California's air every day, with diesel vehicles responsible for disproportionate amounts of nitrogen dioxide, $PM_{2.5}$, and elemental carbon. In the current study, however, we could not discern the independent effects of pollutants because they came from common sources and there was a high degree of intercorrelation among them; similar difficulties have also been encountered in other studies of lung function and air-pollutant mixtures.[1,2,9,28,29,30] Since ozone is also formed during photochemical reactions involving fuel-combustion products, one might expect ozone to be correlated with the other study pollutants and therefore to show similar associations with lung function. However, the Children's Health Study was specifically designed to minimize the correlation of ozone with other pollutants across the 12 study communities. Thus, although ozone has been convincingly linked to acute health effects in many other studies,[11] our results provide little evidence that ambient ozone at current levels is associated with chronic deficits in the growth of lung function in children. Only a few other studies have addressed the long-term effects of ozone on lung development in children, and results have been inconsistent.[31] Although we found little evidence of an effect of ozone, this result needs to be interpreted with caution given the potential for substantial misclassification of exposure to ozone.[32,33]

The mechanism whereby exposure to pollutants could lead to reduced lung development is unknown, but there are many possibilities. Our observation of associations between air pollution and all three measures of lung function — FVC, FEV_1, and MMEF — suggests that more than one process is involved. FVC is largely a function of the number and size of alveoli, with differences in volume primarily attributable to differences in the number of alveoli, since their size is relatively constant.[34] However, since the postnatal increase in the number of alveoli is complete by the age of 10 years, pollution-related deficits in the growth of FVC and FEV_1 during adolescence may, in part, reflect a reduction in the growth of alveoli. Another plausible mechanism of the effect of air pollution on lung development is airway inflammation, such as occurs in bronchiolitis; such changes have been observed in the airways of smokers and of subjects who lived in polluted environments.[35,36]

A strength of our study was the long-term, prospective follow-up of a large cohort, with exposure and outcome data collected in a consistent manner throughout the study period. As in any epidemiologic study, however, the observed effects could be biased by underlying associations of the exposure and outcome to some confounding variables. We adjusted for known potential confounders, including personal characteristics and other sources of exposure to pollutants, but the possibility of confounding by other factors still exists. Over the eight-year follow-up period, approximately 10 percent of study subjects were lost to follow-up each year. Attrition is a potential source of bias in a cohort study if loss to follow-up is related to both exposure and outcome. However, we did not see evidence that the loss of subjects was related to either baseline lung function or exposure to air pollution. In addition, we observed significant associations between air pollution and lung growth in the subgroup of children who were followed for the full eight years of the study, with effects that were similar in magnitude to those in the group as a whole, thus making loss of subjects an unlikely source of bias.

We have shown that exposure to ambient air pollution is correlated with significant deficits in respiratory growth over an eight-year period, leading to clinically important deficits in lung function at the age of 18 years. The specific pollutants that were associated with these deficits included nitrogen dioxide, acid vapor, $PM_{2.5}$, and elemental carbon. These pollutants are products of primary fuel combustion, and since they are present at similar levels in many other areas,[37,38] we believe that our results can be generalized to children living outside southern California. Given the magnitude of the observed effects and the importance of lung function as a determinant of morbidity and mortality during adulthood, continued emphasis on the identification of strategies for reducing levels of urban air pollutants is warranted.

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Source Information

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Association between Air Pollution and Lung Function Growth in Southern California Children

Results from a Second Cohort

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A cohort of 1,678 Southern California children, enrolled as fourth graders in 1996, was followed for 4 years to determine whether the growth in lung function of the children was associated with their exposure to ambient air pollutants. These subjects comprised the second cohort of fourth grade children participating in the Children's Health Study. Significant deficits in lung function growth rate were associated with exposure to acid vapor, NO_2, particles with aerodynamic diameter less than 2.5 μm ($PM_{2.5}$), and elemental carbon. For example, the average annual growth rates of maximal midexpiratory flow and forced expiratory volume in 1 second were reduced by approximately 11% ($p = 0.005$) and 5% ($p = 0.03$), respectively, across the observed range of acid exposure. Exposure to acid vapor was also associated with reductions in the ratio of maximal midexpiratory flow to forced vital capacity ($p = 0.02$), whereas exposure to ozone was correlated with reduced growth in peak flow rate ($p = 0.006$). Larger deficits in lung function growth rate were observed in children who reported spending more time outdoors. These findings provide important replication of our previous findings of an effect of air pollution on lung function growth that were based on the first fourth-grade cohort from the Children's Health Study (*Am J Respir Crit Care Med* 2000;162:1383–1390).

Keywords: lung function growth; children; air pollution

In a recent report, we described an association in children between long-term exposure to outdoor air pollutants and reductions in the growth of lung function (1). The data were obtained from the Children's Health Study (CHS), a 10-year investigation of children's respiratory health in 12 Southern California communities. On the basis of data on 1,498 children who entered the CHS as fourth graders in 1993 and who were followed for 4 years until 1997 (Cohort 1), we found a nearly 10% reduction in the growth rate per year of FEV_1 and maximal midexpiratory flow (MMEF) in the most polluted communities compared with that in the least polluted communities. The pollutants linked to these reductions were particles with aerodynamic diameter less than 10 μm (PM_{10}), $PM_{2.5}$, NO_2, and inorganic acid vapor. We were unable to disentangle the independent effects of these pollutants due to their high degree of correlation across communities. No significant associations were observed between lung function growth and ozone. Two other studies, one conducted in Austria (2) and the other in Poland (3), have also reported associations between ambient air pollutants and lung function growth in children. Collectively, these studies strengthen earlier evidence (4–7) that long-term exposure to air pollution can produce chronic health effects.

The design of the CHS has provided us the opportunity to attempt replication of our earlier findings. In 1996, we enrolled a second cohort of 2,081 fourth grade children (Cohort 2) from the same 12 study communities. Data collection protocols were the same as those used for Cohort 1. This report focuses on the relationship between air pollution and lung function development of the children in Cohort 2 over the 4-year period from 1996 to 2000. Side-by-side comparisons of pollutant-effect estimates from Cohorts 1 and 2 will also be provided.

METHODS

Study Subjects

Details of the CHS community selection, subject recruitment, and study design have been published previously (7, 8). Cohort 2 consisted of 2,081 fourth grade children (average age, 9.9 years) enrolled in 1996 from 12 Southern California communities. Baseline information for each child, including medical history and housing characteristics, was obtained via questionnaires filled out by a parent or guardian. In the spring of 1996, and every spring thereafter, a team of CHS field technicians traveled to study schools to measure participants' lung function. A rolling-seal spirometer (Spiroflow; P.K. Morgan Ltd., Gillingham, UK) was used to obtain up to seven maximal forced expiratory maneuvers on each child. A more detailed description of the pulmonary function testing protocol has been reported previously (7). A total of 1,678 children had at least two pulmonary function tests (PFT) from 1996 to 2000 and had complete data on all adjustment variables (described below). Outcome measures analyzed in this report include FVC, FEV_1, MMEF (also known as $FEF_{25-75\%}$), the ratio MMEF/FVC, and peak expiratory flow rate (PEFR). The study protocol was approved by the institutional review board for human studies at the University of Southern California, and consent was provided by parents for all study subjects.

Air Pollution Data

Air pollution monitoring stations were in place in each of the 12 study communities for the duration of subject follow-up, and pollution levels were monitored continuously throughout each study year. Stations measured hourly concentrations of ozone (O_3), PM_{10}, and NO_2 and obtained filter-based 2-week integrated samples for measuring $PM_{2.5}$ and acid vapor. The latter included both inorganic (nitric, hydrochloric) and organic (formic, acetic) acids. For statistical analysis, we created an acid vapor metric as the sum of nitric, formic, and acetic acid concentrations. Hydrochloric acid was excluded from this sum because the concentrations over a 2-week period were very low and close to the detection limit. In addition to measuring $PM_{2.5}$ mass, we determined concentrations of elemental carbon (EC) and organic carbon (OC) using the NIOSH 5040 method (9). The $PM_{2.5}$ filter was also analyzed for concentrations of nitrate, sulfate, and ammonium, but

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these levels were so highly correlated with $PM_{2.5}$ mass across communities that we chose not to include them in this report. We computed the annual average of the 24-hour (O_3, PM_{10}, NO_2) or 2-week ($PM_{2.5}$, EC, OC, acid) average concentrations. For O_3, we also computed the annual average of the 10:00 A.M. to 6:00 P.M. average. Analogous hour-specific averages for PM_{10} and NO_2 were not used, as they were highly correlated with their corresponding 24-hour averages. We computed the mean over 4 years (1996–1999) of the annual average concentrations in each community and used these in the statistical analysis of lung function growth.

Statistical Analysis

To investigate the relationship between lung function growth and air pollution, we applied the same analytic approach as that previously applied to Cohort 1 (1). The data consisted of 7,106 PFT obtained over the 4-year period on 1,678 study subjects. We used a 3-level regression modeling approach to investigate variation in lung function growth across the 12 communities in relation to variation in average air quality, with adjustment for individual and time-varying covariates. Details of each regression model are given below.

The first model was a linear regression of 7,106 log-transformed lung function measures on age, to estimate each subject's intercept and growth slope. This model included adjustment for time-varying covariates, including height, body mass index, subject report of doctor-diagnosed asthma and cigarette smoking in the previous year, report of respiratory illness and exercise on the day of the test, and interactions of each of these variables with sex to allow for male–female differences. The models also included barometric pressure, temperature at test time, and sets of indicator variables for field technician and spirometer.

The second model was a linear regression of the 1,678 person-specific adjusted growth slopes from the first model on a set of community indicators, to obtain the mean growth slope for children in each of the 12 communities. Adjustments were made for person-specific covariates, including sex, race/ethnicity, and baseline report of asthma. Residuals from both the first and second linear regression models satisfied the model assumptions of normality and homoscedasticity.

The final model was a linear regression of the 12 community-average lung function growth rates on 4-year community-average pollution level. The parameter of interest was the slope from this third regression, which was reported as the difference in estimated percent growth rate per year between the most and the least polluted communities. Negative pollutant-effect estimates indicate reduced lung function growth with increased exposure. The pollutant-specific range from the least to the most polluted community was used for scaling to facilitate comparison of effect estimates among different pollutants. Each pollutant was analyzed separately for its relationship to lung function growth, and scatterplots were used to display the relationships graphically. We also estimated the effect of each pollutant after adjustment for each of the other pollutants, by regressing the community-average growth rates on pairs of pollutants.

A single mixed model that combined all three of the aforementioned regression models was used to estimate pollutant effects and to test hypotheses. The MIXED procedure in SAS (10) was used to fit the models. A two-sided alternative hypothesis and a 0.05 significance level were assumed in all testing. The primary analyses used all study subjects. However, we also conducted separate analyses in strata defined by time spent outdoors, as this factor was believed *a priori* to be important in determining a given child's exposure to the ambient pollutants under study. Children were asked how much time they spent outdoors between 3:00 P.M. and 6:00 P.M. on each of five weekday afternoons. We classified each child as "more outdoors" or "less outdoors" on the basis of whether the average time spent outdoors over the 5-day period was above or below the median time for all children. We also considered sex, baseline asthma status, and race/ethnicity as possible pollutant-effect modifiers, and we added appropriate interaction terms to the mixed model to test these hypotheses.

In addition to our analysis of Cohort 2, we show pollutant-effect estimates for Cohort 1 for comparison. The lung function and air pollutant data used for Cohort 1 were based on the first 4 years of follow-up of that cohort (1993–1997), as described in our previous report (1). However, that report did not include analysis of EC, as data on EC concentrations have only recently become available. To facilitate direct comparison across cohorts, we scaled pollutant effects for Cohort 1 to the same range as that used for Cohort 2 (i.e., to the difference from the least to the most polluted community over the Cohort 2 study period).

RESULTS

Annual average pollutant levels for each community during the Cohort 2 study period are shown in Figure E1 (*see* online data supplement). Compared with the variation between communities, there was relatively little variation within communities over the 4-year observation period. Table 1 shows pairwise correlations between community average air pollution levels over the study period. Ozone concentrations (both 24-hour and 10 A.M.–6 P.M. average) were not significantly correlated with any other pollutant, with the exception of a negative correlation between 24-hour ozone and NO_2 ($r = -0.60$). However, the remaining pollutants were correlated with one another, with coefficients ranging from $r = 0.58$ (OC with NO_2) to $r = 0.97$ (OC with PM_{10}).

The Cohort 2 sample consisted of roughly equal numbers of males and females and included 52% white non-Hispanics, 32% Hispanics, and approximately 5% each of black, Asian, and other ethnic groups (Table 2). Overall, 14% of subjects reported doctor diagnosis of asthma at baseline, ranging from 8% (Riverside) to 19% (San Dimas). Between the weekday hours of 3:00 P.M. and 6:00 P.M., children spent an average of 1.3 hours outdoors, with most children spending between 0.5 and 2.3 hours outdoors during this time. An average of 4.3 PFT (of a possible 5) was recorded on each study subject.

TABLE 1. CORRELATIONS AMONG COMMUNITY MEAN POLLUTION LEVELS

Pollutant[†]	O_3	NO_2	Acid Vapor	PM_{10}	$PM_{2.5}$	PM_{10}–$PM_{2.5}$	Elemental Carbon	Organic Carbon
O_3, 10 A.M.–6 P.M.	0.77**	−0.23	0.30	0.13	0.14	0.10	−0.05	0.11
O_3		−0.60*	−0.22	−0.37	−0.39	−0.31	−0.48	−0.34
NO_2			0.83***	0.64*	0.77**	0.46	0.93***	0.58*
Acid vapor[‡]				0.79**	0.87***	0.63*	0.90***	0.74*
PM_{10}					0.95***	0.95***	0.86***	0.97***
$PM_{2.5}$						0.81**	0.93***	0.89***
PM_{10}–$PM_{2.5}$							0.71*	0.96***
Elemental carbon								0.81**

Definition of abbreviation: PM_{10} = particles with aerodynamic diameter less than 10 μm.

*$p < 0.05$.

**$p < 0.005$.

***$p < 0.0005$.

[†] 24-hour average (unless otherwise noted) pollution level from 1996 to 1999.

[‡] Acid vapor is the sum of nitric, formic, and acetic acid vapor concentrations.

TABLE 2. CHARACTERISTICS OF THE STUDY POPULATION

	No. of Subjects*	Mean No. of PFTs	Female Sex (%)	Race Distribution, %					Ever Asthma† (%)	No. of Hours Outdoors‡	
				White	Hispanic	Asian	Black	Other		Median	10th, 90th
Alpine	157	4.2	50	76	19	1	0	3	14	1.7	(0.8, 2.6)
Alascadero	144	4.3	44	74	17	1	1	8	18	1.4	(0.7, 2.4)
Lake Elsinore	139	4.2	53	55	32	4	1	6	13	1.4	(0.6, 2.4)
Lake Arrowhead	145	4.3	52	71	22	0	1	6	14	1.1	(0.4, 1.8)
Lancaster	159	3.8	52	51	30	3	10	6	16	1.4	(0.6, 2.3)
Lompoc	147	4.3	47	46	37	9	5	3	10	1.1	(0.3, 2.1)
Long Beach	133	4.2	44	33	22	14	23	8	15	1.2	(0.5, 2.3)
Mira Loma	125	4.3	51	40	54	2	1	2	15	1.2	(0.6, 2.1)
Riverside	126	4.3	55	41	39	1	11	8	8	1.4	(0.6, 2.6)
San Dimas	141	4.5	52	48	36	10	1	5	19	1.1	(0.3, 2.3)
Santa Maria	133	4.0	51	20	62	9	2	7	13	1.1	(0.5, 2.4)
Upland	129	4.4	50	66	18	9	5	3	12	1.2	(0.3, 2.0)
All	1,678	4.3	50	52	32	5	5	6	14	1.3	(0.5, 2.3)

Definition of abbreviation: PFT = pulmonary function test.

* Number of subjects with at least two PFTs from 1996 to 2000.

† Doctor-diagnosed asthma at baseline.

‡ Number of hours spent outdoors on weekdays between 3:00 P.M. and 6:00 P.M.; values are the median and the 10th and 90th percentiles.

Over the 4-year study period, FEV_1 increased at an average rate of 11.8% per year in the cohort, with equivalent growth rates in males and females. However, the average FEV_1 growth rates varied across the 12 communities, from 11.0 to 12.4%. Figure 1 shows a plot of the community-specific growth rates versus the corresponding 4-year average pollutant concentrations. There was a significant negative correlation between FEV_1 growth rates and acid vapor ($r = -0.55$, $p = 0.03$). The predicted growth rates, depicted by the plotted regression line, decreased from 12.1 to 11.5% across the range of observed acid concentrations. This absolute difference of 0.6% corresponds to a relative reduction of 5% in average FEV_1 growth rate for those exposed to the highest compared with those exposed to the lowest observed acid concentration (i.e., 0.6%/12.1%). Negative correlations were also observed between FEV_1 growth rates and the other pollutants, but none achieved statistical significance. Analogous plots are shown for MMEF growth in Figure 2. MMEF growth rates were negatively correlated with concentrations of acid vapor ($p = 0.005$), NO_2 ($p = 0.02$), $PM_{2.5}$ ($p = 0.05$), and EC ($p = 0.04$). The predicted MMEF growth rates declined from approximately 11.6 to 10.3% across the range of observed acid concentrations, with this absolute difference of 1.3% corresponding to a relative reduction of 11%.

Table 3 shows the estimated absolute differences in growth rates from the most to the least polluted community for the five PFT measures and for all pollutants. Although most pollutant-effect estimates were negative for FVC, none achieve statistical significance. The associations of FEV_1 and MMEF with acid vapor shown in Figures 1 and 2, respectively, also held for nitric and formic acids separately and to a smaller extent for acetic acid. The ratio MMEF/FVC was correlated with NO_2 ($p = 0.04$), acid vapor ($p = 0.02$), and nitric ($p = 0.01$) and formic acids ($p = 0.02$). Each pollutant-effect estimate for MMEF/FVC (e.g., −0.96% for acid vapor) was approximately equal to the difference between the corresponding pollutant-effect estimates for MMEF (e.g., −1.28%) and FVC (e.g., −0.33%). The predicted PEFR growth declined by 1.2% across the range of 10 A.M.–6 P.M. O_3 ($p = 0.006$). None of the PFT measures was significantly associated with 24-hour O_3, PM_{10}, PM_{10}–$PM_{2.5}$, or OC. Adjustment for indoor sources of air pollution, including a gas stove, any pet, a cat, a dog, or a tobacco-smoking parent in the home, did not alter any pollutant-effect estimate by more than 10% of its unadjusted values (data not shown). We therefore concluded that any differences among communities in the prevalence of these indoor sources of air pollution did not confound the ambient pollutant-effect estimates. Additionally, there was no significant evidence of pollutant-effect modification by sex, ethnicity, or asthma status. As an example of the similarity in pollutant-effect estimates by asthma status, the decline in FEV_1 growth rate across the observed range of acid vapor was 0.50% in individuals with asthma and 0.63% in individuals without asthma, a difference that was not statistically significant ($p = 0.75$).

In two-pollutant models for FEV_1, effect estimates for acid vapor remained negative after adjustment for any other pollutant (Table 4, third row). On the other hand, adjustment for acid (Table 4, third column) substantially changed the univariate estimates (Table 4, main diagonal) of all other pollutants except for O_3. Table 5 shows similar two-pollutant analysis of MMEF. Here again, estimates of the acid vapor–effect remained negative with adjustment for any other pollutant, whereas adjustment for acid altered the effect estimate of every other pollutant. For example, the estimated univariate NO_2 effect (−1.10%) dropped in magnitude (0.03%) and became nonsignificant with adjustment for acid. For both FEV_1 and MMEF, the only two-pollutant model in which both pollutants were statistically significant predictors of growth included 10 A.M.–6 P.M. O_3 and NO_2, indicating that these pollutants might each contribute independently to reduced lung function growth. For example, the estimated effects on MMEF from this two-pollutant model were −1.11% ($p = 0.02$) for O_3 (Table 5, row 1, column 2) and −1.31% ($p = 0.003$) for NO_2 (Table 5, row 2, column 1). In additional models, inclusion of an O_3-by-NO_2 interaction did not significantly improve model fit for either FEV_1 or MMEF.

The directions and magnitudes of pollutant effects observed in Cohort 2 were generally comparable to those observed in Cohort 1 (Table 6). As an example, for FEV_1, the acid-effect estimates in Cohorts 1 and 2 were −0.82% ($p = 0.01$) and −0.63% ($p = 0.03$), respectively, and the corresponding acid-effect estimates for MMEF were −1.16% ($p = 0.02$) and −1.28% ($p = 0.005$), respectively. For all combinations of PFT and pollutant shown in Table 6, we formally tested whether the pollutant-effect estimates were different between the two cohorts; no significant differences were detected.

In each cohort, the strength of the pollutant effects was greater in children who reported spending more time out-

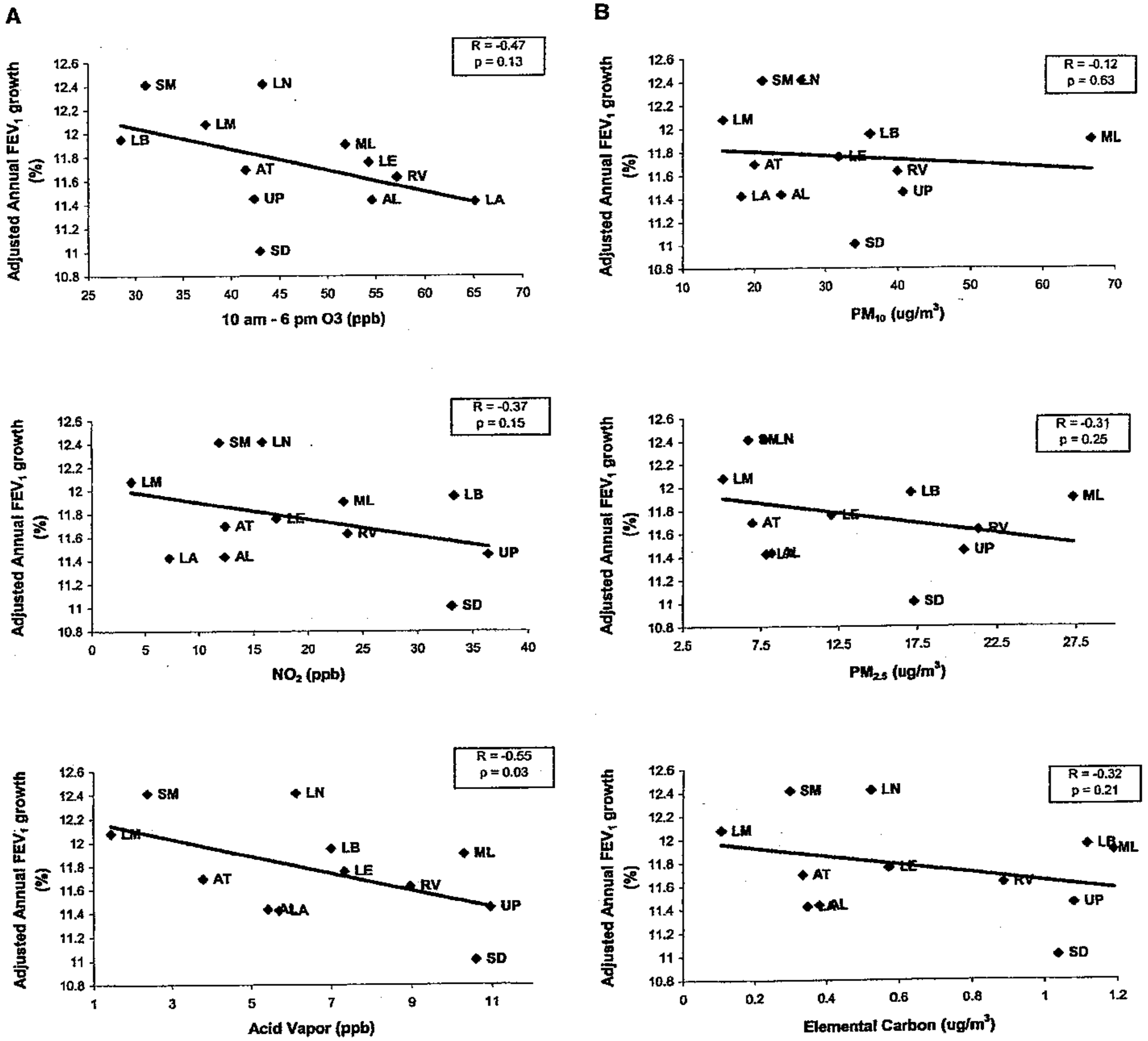

Figure 1. Adjusted average annual FEV_1 growth rates in the 12 communities versus the mean pollutant concentrations over the study period. AL = Alpine; AT = Atascadero; LE = Lake Elsinore; LA = Lake Arrowhead; LN = Lancaster; LM = Lompoc; LB = Long Beach; ML = Mira Loma; RV = Riverside; SD = San Dimas; SM = Santa Maria; UP = Upland.

doors (Table 7). For example, across the range of acid vapor, FEV_1 growth rates in the more-outdoors children declined by 1.1% in Cohort 1 ($p = 0.02$) and by 1.0% in Cohort 2 ($p = 0.002$). The corresponding declines in growth rate in the less-outdoors children were only 0.4% in Cohort 1 ($p = 0.18$) and 0.3% in Cohort 2 ($p = 0.45$). Several other statistically significant associations between PFT growth and pollutants were observed in the more-outdoors children, whereas no significant associations were observed in the more-indoors children.

DISCUSSION

The results, based on the second fourth-grade cohort from the CHS, provide further evidence that ambient levels of air pollution in southern California have a detrimental effect on lung function growth in children. These findings are in general agreement with the results that were based on the first fourth-grade cohort (1). Also replicated from the Cohort 1 analysis is the finding of larger pollutant effects in children who reported spending more time outdoors. The replication of a previous result and the observation of a larger health effect in those who were more exposed are results that support a causal association. Additional studies in other populations are needed to further assess causal relationships.

Across cohorts and lung function measures, we observed significant associations with several of the pollutants, including both particles and gases. Although the correlations among pollutants were generally high, some trends emerged from the analysis of the two cohorts. For example, fine particles ($PM_{2.5}$) and the EC portion of $PM_{2.5}$ generally showed stronger associations

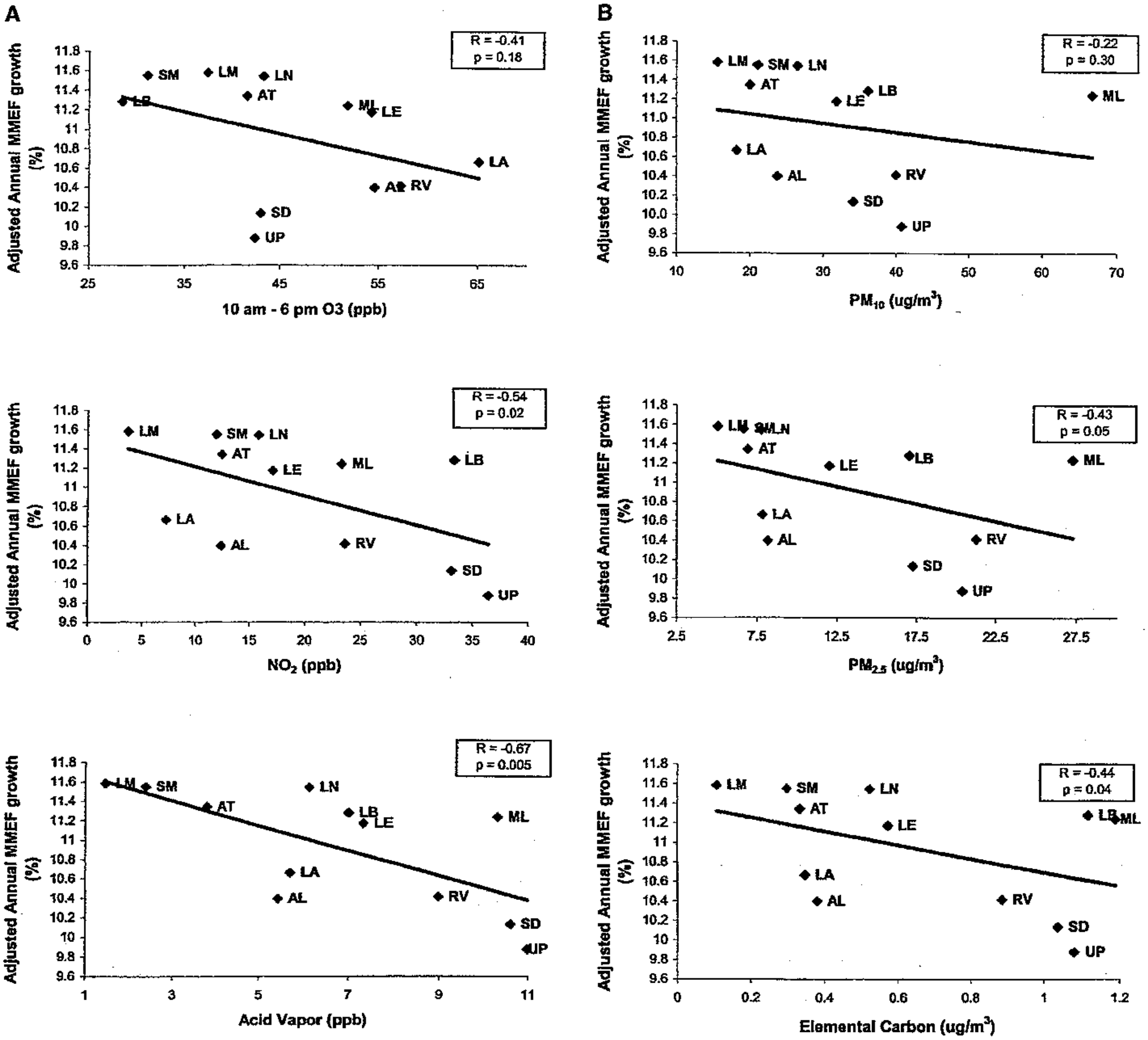

Figure 2. Adjusted average annual MMEF growth rates in the 12 communities versus the mean pollutant concentrations over the study period. AL = Alpine; AT = Atascadero; LE = Lake Elsinore; LA = Lake Arrowhead; LN = Lancaster; LM = Lompoc; LB = Long Beach; ML = Mira Loma; RV = Riverside; SD = San Dimas; SM = Santa Maria; UP = Upland.

with lung function growth than did PM_{10}, PM_{10}–$PM_{2.5}$, and OC. Associations with PM_{10} observed in Cohort 1 were not replicated in Cohort 2. For PM_{10}, as well as for PM_{10}–$PM_{2.5}$ and OC, Mira Loma had very high levels relative to the other communities (Figures 1 and 2). As an example of how this one community influenced the Cohort 2 results, elimination of Mira Loma from the analysis of MMEF changed the PM_{10}-effect estimate from −0.67% ($p = 0.30$, Table 3) to −2.32% ($p = 0.01$). However, we had no *a priori* reason to exclude Mira Loma from the analysis, and we therefore relied on the full 12-community analysis for our inferences. Of the gaseous pollutants, associations with acid vapor and NO_2 observed in Cohort 1 were replicated in Cohort 2. However, the associations observed with ozone in Cohort 2 were not previously observed in Cohort 1.

A major source of ambient EC in Southern California is the combustion of diesel fuel (11, 12). The observed associations with EC may therefore indicate a more general association between lung function and exposure to diesel exhaust particles. A previous study of children in the Netherlands also provided evidence of a relationship between diesel exhaust particles and reduced lung function. Specifically, reductions in FEV_1, MMEF, and PEFR were associated with exposure to two proxies for diesel emissions, including truck-traffic on nearby roads and levels of black smoke (13). Given that EC largely resides in the fine particle fraction of PM and thus is transported much like a gas, concentrations of EC in any given location will depend on a combination of both local and upwind sources of diesel exhaust particles.

Our finding of an association in Cohort 2 between ozone and PEFR, and between ozone and other lung function measures in children spending more time outdoors, also has some support from prior studies. In a study of Swiss children, expo-

TABLE 3. DIFFERENCE IN ANNUAL PERCENT GROWTH RATES FROM THE LEAST TO THE MOST POLLUTED COMMUNITY

	Differences in Growth Rate[†]				
Pollutant[§]	FVC % (*95% CI*)	FEV_1 % (*95% CI*)	MMEF % (*95% CI*)	MMEF/FVC % (*95% CI*)	PEFR % (*95% CI*)
O_3, 10 A.M.–6 P.M.	−0.33 (−0.90, 0.24)	−0.55 (−1.27, 0.16)	−0.80 (−1.94, 0.36)	−0.44 (−1.39, 0.52)	−1.21 (−2.06, −0.36)[†]
O_3	−0.10 (−0.73, 0.54)	−0.17 (−1.00, 0.67)	−0.09 (−1.41, 1.24)	0.02 (−0.99, 1.04)	−0.65 (−1.77, 0.49)
NO_2	−0.23 (−0.76, 0.29)	−0.48 (−1.12, 0.17)	−1.10 (−2.00, −0.20)*	−0.88 (−1.71, −0.04)*	−0.17 (−1.18, 0.84)
Acid vapor	−0.33 (−0.82, 0.17)	−0.63 (−1.21, −0.05)*	−1.28 (−2.16, −0.40)[‡]	−0.96 (−1.77, −0.14)*	−0.74 (−1.62, 0.14)
Nitric	−0.36 (−0.84, 0.13)	−0.71 (−1.25, −0.17)[†]	−1.41 (−2.29, −0.53)[‡]	−1.06 (−1.87, −0.24)*	−0.76 (−1.62, 0.12)
Formic	−0.39 (−0.89, 0.11)	−0.70 (−1.28, −0.12)*	−1.41 (−2.32, −0.49)[‡]	−1.03 (−1.88, −0.18)*	−0.62 (−1.58, 0.35)
Acetic	−0.28 (−0.84, 0.28)	−0.56 (−1.24, 0.13)	−1.17 (−2.14, −0.20)*	−0.89 (−1.78, 0.02)	−0.80 (−1.77, 0.17)
PM_{10}	−0.03 (−0.68, 0.62)	−0.21 (−1.04, 0.64)	−0.67 (−1.92, 0.59)	−0.63 (−1.63, 0.38)	−0.42 (−1.60, 0.77)
$PM_{2.5}$	−0.14 (−0.67, 0.40)	−0.39 (−1.06, 0.28)	−0.94 (−1.87, 0.00)*	−0.78 (−1.62, 0.06)	−0.44 (−1.41, 0.55)
PM_{10}–$PM_{2.5}$	0.11 (−0.58, 0.80)	0.07 (−0.83, 0.98)	−0.19 (−1.60, 1.24)	−0.29 (−1.36, 0.08)	−0.30 (−1.57, 0.99)
EC	−0.17 (−0.67, 0.33)	−0.40 (−1.02, 0.23)	−0.92 (−1.78, −0.05)*	−0.74 (−1.53, 0.05)	−0.20 (−1.15, 0.76)
OC	0.01 (−0.67, 0.70)	−0.15 (−1.04, 0.75)	−0.55 (−1.90, 0.83)	−0.55 (−1.61, 0.52)	−0.36 (−1.62, 0.91)

Definition of abbreviations: CI = confidence interval; EC = elemental carbon; MMEF = maximal midexpiratory flow; OC = organic carbon; PEFR = peak expiratory flow rate.

* $p < 0.05$.

[†] $p < 0.01$.

[‡] $p < 0.005$.

[§] All pollutant-effect estimates are based on single-pollutant models. Differences in average annual percent growth rates are shown per increase in annual average of 36.6 ppb of O_3 (10 A.M.–6 P.M.), 39.8 ppb of O_3, 32.7 of NO_2, 9.5 ppb of acid vapor, 3.5 ppb of nitric acid, 1.8 ppb of formic acid, 5.0 ppb of acetic acid, 51.5 $\mu g/m^3$ of PM_{10}, 22.2 $\mu g/m^3$ of $PM_{2.5}$, 29.1 $\mu g/m^3$ of PM_{10}–$PM_{2.5}$, 1.1 $\mu g/m^3$ of EC, and 10.2 $\mu g/m^3$ of OC.

sure to outdoor ozone was associated with significant reduction in peak flow after 10 minutes of heavy exercise (14). A similar study of children in the Netherlands observed a negative correlation between post-training peak flow and ozone on the day before the experiment, but it found no association with ozone concentration during exercise (15, 16). In a study of children with mild asthma in Mexico City, decreases in evening peak flow were associated with both same-day and previous-day concentrations of 1-hour maximum ozone (17). A number of summer camp studies, performed in different geographic locations by several research teams, have reported acute decrements in PEFR or FEV_1 associated with exposure to ambient O_3 (18–24). The longer-term effect of exposure to ambient ozone on children's lung function was investigated by Austrian researchers (2). They obtained repeated PFT over a 3-year period from children in nine Austrian cities and reported associations between ozone and reduced growth in FEV_1 and FVC. Collectively, these studies indicate that ozone might have both short- and long-term effects on children's lung function.

Of all the pollutants studied, acid vapor showed the most consistent effect on lung function growth in Cohort 2 and across both cohorts. There are some prior reports on the relationship between acid air pollutants and lung function, although the results are, in general, equivocal. Koenig and coworkers demonstrated reductions in pulmonary function after exposure to high concentrations of nitric acid (25) and with exposure to nitric or sulfuric acid in combination with oxidants (26). However, similarly conducted studies were unable to replicate these results (27, 28). A study of Dutch schoolchildren reported associations between pulmonary function in children and same-day concentrations of nitrous acid that exists in equilibrium with nitric acid (29). In a cross-sectional study of children in 24 North American cities, Raizenne and coworkers (30) showed decrements in FVC and FEV_1 with increased exposure to acid sulfate aerosol. No prior studies, though, have investigated the longitudinal effects of acid exposure on the developing lungs of children.

Acid vapor in our study was defined as the sum of nitric, formic, and acetic acids concentrations, each of which was individually associated with decreased lung function growth. The two-pollutant models in Cohort 2 indicated that adjustment for any other pollutant did not qualitatively change the estimated acid effect. Thus, it does not appear that the observed acid effect is simply due to its being correlated with another of the observed pollutants. In fact, the reverse is indicated, specifically that the univariate associations of other pollutants (e.g., NO_2, $PM_{2.5}$) with FEV_1 and MMEF may be

TABLE 4. DIFFERENCE IN ANNUAL FEV_1 PERCENT GROWTH RATES FROM THE LEAST TO THE MOST POLLUTED COMMUNITY, TWO-POLLUTANT MODELS

	Adjustment Pollutant					
Main Pollutant[‡]	O_3 (10 A.M.–6 P.M.)	NO_2	Acid Vapor	PM_{10}	$PM_{2.5}$	EC
O_3, 10 A.M.–6 P.M	**−0.55**	−0.71*	−0.38	−0.54	−0.50	−0.57
NO_2	−0.62*	**−0.48**	0.21	−0.64	−0.44	−0.64
Acid vapor	−0.53	−0.80	**−0.63***	−1.34[†]	−1.27*	−1.43*
PM_{10}	−0.13*	0.29	1.10	**−0.21**	2.40*	0.91
$PM_{2.5}$	−0.33	−0.05	0.76	−2.26*	**−0.39**	0.01
EC	−0.42	0.16	0.86	−1.01	−0.41	**−0.40**

Definition of abbreviations: EC = elemental carbon; PM_{10} = particles with aerodynamic diameter less than 10 µm.

* $p < 0.05$.

[†] $p < 0.01$.

[‡] Each row gives effect estimates for the indicated pollutant after adjustment for the pollutant listed at the top of the column. Boldface estimates are from the single-pollutant models shown in Table 3. *See* Table 3 footnote for the description of units.

TABLE 5. DIFFERENCE IN ANNUAL MMEF PERCENT GROWTH RATES FROM THE LEAST TO THE MOST POLLUTED COMMUNITY, TWO-POLLUTANT MODELS

Main Pollutant§	Adjustment Pollutant					
	O_3 (10 A.M.–6 P.M.)	NO_2	Acid Vapor	PM_{10}	$PM_{2.5}$	EC
O_3, 10 A.M.–6 P.M	**−0.80**	−1.11*	−0.40	−0.73	−0.65	−0.83
NO_2	−1.31†	**−1.10***	0.03	−1.30*	−0.96	−1.45*
Acid vapor	−1.18*	−1.31	**−1.28‡**	−2.33†	−2.14*	−2.44*
PM_{10}	−0.57	0.36	1.63	**−0.67**	3.98*	1.38
$PM_{2.5}$	−0.86†	−0.18	1.02	−3.97	**−0.94***	−0.20
EC	−0.94*	0.36	1.25	−1.85*	−0.74†	**−0.92***

Definition of abbreviations: EC = elemental carbon; MMEF = maximal midexpiratory flow.

* $p < 0.05$.

† $p < 0.01$.

‡ $p < 0.005$.

§ Each row gives effect estimates for the indicated pollutant after adjustment for the pollutant listed at the top of the column. Boldface estimates are from the single-pollutant models shown in Table 3. *See* Table 3 footnote for the description of units.

due to the correlation of these pollutants with acid vapor. However, we cannot rule out the possibility that some pollutant(s) we did not measure is responsible for the observed health effects and that acid vapor is simply our best marker of that pollutant or pollutant mixture. More specifically, acid vapor concentration may be our best indicator of downwind transport coupled with atmospheric chemical processes. This conjecture is supported by the observation that acid vapor is the pollutant we studied that most clearly distinguishes the four communities downwind of the greater Los Angeles area (Mira Loma, Riverside, San Dimas, Upland) from the remaining eight communities (*see* Figure E1 or Figure 1). Whether acid vapor is causally related to reduced lung function development or whether it is simply our best marker for another causative substance or mixture, this pollutant deserves further study.

TABLE 6. DIFFERENCE IN ANNUAL PERCENT GROWTH RATES FROM THE LEAST TO THE MOST POLLUTED COMMUNITY: COMPARISON OF COHORTS 1 AND 2

PFT	Pollutant†	Cohort 1 (*n = 1,457‡*, *%, 95% CI*)	Cohort 2 (*n = 1,678‡*, *%, 95% CI*)
FVC	O_3, 10 A.M.–6 P.M.	−0.22 (−0.77, 0.33)	−0.33 (−0.90, 0.24)
	NO_2	−0.46 (−0.92, 0.00)	−0.23 (−0.76, 0.29)
	Total acid	−0.55 (−0.97, −0.11)*	−0.33 (−0.82, 0.17)
	PM_{10}	−0.60 (−1.18, −0.01)*	−0.03 (−0.68, 0.62)
	$PM_{2.5}$	−0.42 (−0.86, 0.03)	−0.14 (−0.67, 0.40)
	EC	−0.49 (−0.88, −0.09)*	−0.17 (−0.67, 0.33)
FEV_1	O_3, 10 A.M.–6 P.M.	−0.32 (−1.14, 0.50)	−0.55 (−1.27, 0.16)
	NO_2	−0.66 (−1.34, 0.02)	−0.48 (−1.12, 0.17)
	Total acid	−0.82 (−1.44, −0.19)*	−0.63 (−1.21, −0.05)*
	PM_{10}	−0.94 (−1.78, −0.10)*	−0.21 (−1.04, 0.64)
	$PM_{2.5}$	−0.63 (−1.28, 0.02)	−0.39 (−1.06, 0.28)
	EC	−0.71 (−1.30, −0.12)*	−0.40 (−1.02, 0.23)
MMEF	O_3, 10 A.M.–6 P.M	−0.43 (−1.64, 0.80)	−0.80 (−1.94, 0.36)
	NO_2	−0.92 (−1.95, 0.12)	−1.10 (−2.00, −0.20)*
	Total acid	−1.16 (−2.12, −0.19)*	−1.28 (−2.16, −0.40)***
	PM_{10}	−1.41 (−2.61, −0.21)*	−0.67 (−1.92, 0.59)
	$PM_{2.5}$	−0.94 (−1.88, 0.01)	−0.94 (−1.87, 0.00)*
	EC	−1.07 (−1.94, −0.19)*	−0.92 (−1.78, −0.05)*
PEFR	O_3, 10 A.M.–6 P.M	−0.36 (−1.34, 0.63)	−1.21 (−2.06, −0.36)**
	NO_2	−0.82 (−1.62, −0.02)*	−0.17 (−1.18, 0.84)
	Total acid	−1.00 (−1.75, −0.25)**	−0.74 (−1.62, 0.14)
	PM_{10}	−1.27 (−2.15, −0.37)**	−0.42 (−1.60, 0.77)
	$PM_{2.5}$	−0.82 (−1.55, −0.09)*	−0.44 (−1.41, 0.55)
	EC	−0.89 (−1.57, −0.20)*	−0.20 (−1.15, 0.76)

Definition of abbreviations: CI = confidence interval; EC = elemental carbon; MMEF = maximal midexpiratory flow; PEFR = peak expiratory flow rate; PFT = pulmonary function test.

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.005$.

† All pollutant-effect estimates are based on single-pollutant models. Differences in average annual percent growth rates are shown per increase in annual average of 36.6 ppb of O_3 (10 A.M.–6 P.M.), 39.8 ppb of O_3, 32.7 of NO_2, 9.5 ppb of acid vapor, 3.5 ppb of nitric acid, 1.8 ppb of formic acid, 5.0 ppb of acetic acid, 51.5 μg/m^3 of PM_{10}, 22.2 μg/m^3 of $PM_{2.5}$, 29.1 μg/m^3 of PM_{10}–$PM_{2.5}$, 1.1 μg/m^3 of EC, and 10.2 μg/m^3 of OC.

‡ Cohort 1 includes children enrolled in 1993 as fourth graders and followed through 1997. Cohort 2 includes children enrolled in 1996 as fourth graders and followed through 2000. The results shown for Cohort 2 are equivalent to those shown in Table 3.

Generally speaking, children in a community with high pollution will be more likely than children in a lower-pollution community to be exposed to short-term episodes of very high concentrations of pollutants. In southern California, concentrations of most of the pollutants we studied are highest in the afternoon hours, and therefore children who spend time outdoors during this time may receive a substantially higher dose to their lungs on a polluted day than children who remain indoors. At least 70% of the subjects reported having a home air conditioner in our polluted communities, a factor that can further increase the discrepancy between indoor and outdoor concentrations of ozone and some other pollutants. Prior reports, some of which have been summarized previously in this article, indicate that short-term exposure to high pollution can have acute effects on respiratory symptoms and lung function. A study of children in Poland has shown a link between repeated respiratory symptoms and reduced lung function growth (31). Our observations of reduced lung function growth with increasing annual average pollution level may thus be a consequence of repeated acute respiratory events after short-term increases in pollution levels. Our finding of larger deficits in children who reported spending more time outdoors in the afternoon adds some support to this possibility. However, additional study is needed to investigate the temporal relationship between acute respiratory events and lung function development.

In summary, the observed associations in this second fourth-grade cohort of the CHS generally replicated the findings from the first CHS fourth-grade cohort. Analysis of Cohort 2 showed the strongest associations with acid vapor. The observed pollutant-effect estimates were larger for MMEF than for the other PFT measures. This finding, in conjunction with significant associations between pollution and the volume-corrected measure, MMEF/FVC, indicates that long-term pollution exposure may affect the development of small airways in the lung. Further follow-up of CHS participants will allow determination of whether pollution-related deficits in lung function growth persist into adulthood, resulting in lower maximal attained lung function, and perhaps, leading to increased risk of respiratory illness.

TABLE 7. DIFFERENCE IN ANNUAL PERCENT GROWTH RATES FROM THE LEAST TO THE MOST POLLUTED COMMUNITY

		Cohort 1				Cohort 2			
		More Outdoors†		Less Outdoors		More Outdoors†		Less Outdoors	
		Difference in Growth‡		Difference in Growth		Difference in Growth‡		Difference in Growth	
PFT	Pollutant‡	%	*(95% CI)*	%	*(95% CI)*	%	*(95% CI)*	%	*(95% CI)*
FVC	O_3, 10 A.M.–6 P.M.	−0.02	(−0.70, 0.66)	−0.05	(−0.55, 0.45)	−0.69	(−1.26, −0.11)*	−0.07	(−0.93, 0.80)
	NO_2	−0.45	(−1.01, 0.12)	−0.14	(−0.63, 0.36)	−0.44	(−0.99, 0.12)	−0.15	(−0.92, 0.62)
	Acid vapor	−0.43	(−1.01, 0.15)	−0.25	(−0.75, 0.25)	−0.63	(−1.13, −0.13)*	−0.12	(−0.88, 0.64)
	PM_{10}	−0.35	(−1.10, 0.42)	−0.52	(−1.10, 0.07)	−0.44	(−1.11, 0.22)	0.32	(−0.60, 1.24)
	$PM_{2.5}$	−0.23	(−0.80, 0.35)	−0.32	(−0.76, 0.12)	−0.47	(−0.99, 0.06)	0.14	(−0.65, 0.93)
	EC	−0.43	(−0.94, 0.08)	−0.28	(−0.73, 0.16)	−0.44	(−0.94, 0.08)	0.01	(−0.73, 0.75)
FEV_1	O_3, 10 A.M.–6 P.M.	−0.31	(−1.44, 0.83)	−0.06	(−0.71, 0.60)	−0.83	(−1.66, 0.00)	−0.35	(−1.25, 0.56)
	NO_2	−0.96	(−1.83, −0.08)*	−0.36	(−0.97, 0.26)	−0.82	(−1.56, −0.08)*	−0.21	(−1.03, 0.61)
	Acid vapor	−1.10	(−1.94, −0.25)*	−0.44	(−1.07, 0.20)	−1.01	(−1.65, −0.38)***	−0.31	(−1.11, 0.49)
	PM_{10}	−1.12	(−2.24, 0.01)	−0.65	(−1.39, 0.09)	−0.63	(−1.60, 0.35)	0.20	(−0.80, 1.21)
	$PM_{2.5}$	−0.74	(−1.63, 0.14)	−0.49	(−1.05, 0.07)	−0.80	(−1.51, −0.08)*	−0.01	(−0.86, 0.84)
	EC	−0.97	(−1.72, −0.21)*	−0.40	(−0.97, 0.17)	−0.74	(−1.44, −0.03)*	−0.09	(−0.87, 0.71)
MMEF	O_3, 10 A.M.–6 P.M.	−0.67	(−2.54, 1.23)	0.28	(−1.09, 1.66)	−0.58	(−2.09, 0.95)	−0.97	(−2.52, 0.61)
	NO_2	−1.59	(−2.95, −0.20)*	−0.72	(−2.09, 0.66)	−1.48	(−2.84, −0.11)*	−0.51	(−1.92, 0.93)
	Acid vapor	−1.83	(−3.20, −0.43)*	−0.66	(−2.07, 0.76)	−1.35	(−2.65, −0.03)*	−0.99	(−2.28, 0.32)
	PM_{10}	−2.05	(−3.69, −0.37)*	−0.89	(−2.53, 0.78)	−0.54	(−2.14, 1.09)	−0.64	(−2.36, 1.12)
	$PM_{2.5}$	−1.46	(−2.70, −0.20)*	−0.71	(−1.96, 0.55)	−0.95	(−2.26, 0.39)	−0.74	(−2.16, 0.70)
	EC	−1.74	(−2.98, −0.49)**	−0.57	(−1.83, 0.70)	−1.03	(−2.29, 0.25)	−0.54	(−1.89, 0.82)
PEFR	O_3, 10 A.M.–6 P.M.	−0.94	(−2.48, 0.63)	0.31	(−0.79, 1.42)	−1.62	(−2.93, −0.29)*	−0.87	(−2.09, 0.37)
	NO_2	−1.42	(−2.52, −0.30)*	−0.36	(−1.46, 0.75)	−0.52	(−1.98, 0.96)	0.38	(−0.77, 1.55)
	Acid vapor	−1.74	(−2.82, −0.66)***	−0.32	(−1.45, 0.82)	−1.27	(−2.51, −0.01)*	−0.01	(−1.18, 1.17)
	PM_{10}	−1.81	(−3.11, −0.49)**	−0.87	(−2.19, 0.46)	−0.71	(−2.41, 1.03)	0.22	(−1.21, 1.66)
	$PM_{2.5}$	−1.33	(−2.34, −0.31)*	−0.47	(−1.47, 0.54)	−0.73	(−2.12, 0.69)	0.13	(−1.08, 1.35)
	EC	−1.36	(−2.34, −0.37)**	−0.41	(−1.42, 0.61)	−0.52	(−1.88, 0.86)	0.41	(−0.69, 1.52)

Definition of abbreviations: CI = confidence interval; EC = elemental carbon; MMEF = maximal midexpiratory flow; PEFR = peak expiratory flow rate; PFT = pulmonary function test.

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.005$.

† More/less outdoors is based on reported time spent outdoors during weekday afternoons. Subjects were split into the two groups on the basis of the median of reported time outdoors with each cohort.

‡ All pollutant-effect estimates are based on single-pollutant models. Differences in average annual percent growth rates are shown per increase in annual average of 36.6 ppb of O_3 (10 A.M.–6 P.M.), 39.8 ppb of O_3, 32.7 of NO_2, 9.5 ppb of acid vapor, 3.5 ppb of nitric acid, 1.8 ppb of formic acid, 5.0 ppb of acetic acid, 51.5 $\mu g/m^3$ of PM_{10}, 22.2 $\mu g/m^3$ of $PM_{2.5}$, 29.1 $\mu g/m^3$ of PM_{10}–$PM_{2.5}$, 1.1 $\mu g/m^3$ of EC, and 10.2 $\mu g/m^3$ of OC.

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The Effects of Ambient Air Pollution on School Absenteeism Due to Respiratory Illnesses

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We investigated the relations between ozone (O_3), nitrogen dioxide (NO_2), and respirable particles less than 10 μm in diameter (PM_{10}) and school absenteeism in a cohort of 4th-grade school children who resided in 12 southern California communities. An active surveillance system ascertained the numbers and types of absences during the first 6 months of 1996. Pollutants were measured hourly at central-site monitors in each of the 12 communities. To examine acute effects of air pollution on absence rates, we fitted a two-stage time-series model to the absence count data that included distributed lag effects of exposure adjusted for long-term pollutant levels. Short-term change in O_3, but not NO_2 or PM_{10}, was associated with a substantial increase in school absences from both upper and lower respiratory illness. An increase of 20 ppb of O_3 was associated with an increase of 62.9% [95% confidence interval (95% CI) = 18.4–124.1%] for illness-related absence rates, 82.9% (95% CI = 3.9–222.0%) for respiratory illnesses, 45.1% (95% CI = 21.3–73.7%) for upper respiratory illnesses, and 173.9% (95% CI = 91.3–292.3%) for lower respiratory illnesses with wet cough. The short-term effects of a 20-ppb change of O_3 on illness-related absenteeism were larger in communities with lower long-term average PM_{10} [223.5% (95% CI = 90.4–449.7)] compared with communities with high average levels [38.1% (95% CI = 8.5–75.8)]. Increased school absenteeism from O_3 exposure in children is an important adverse effect of ambient air pollution worthy of public policy consideration. (Epidemiology 2001;12:43–54)

Keywords: air pollution, ozone, respiratory illnesses and children, school absenteeism.

Ambient air pollutants including ozone (O_3), nitrogen dioxide (NO_2), and respirable particles less than 10 μm in diameter (PM_{10}) contribute to the occurrence of respiratory symptoms and diseases including increased occurrence and severity of symptoms, transient changes in lung function, and increased respiratory infections, more visits to physicians and emergency rooms and increased hospital admissions, and changes in lung function and increased mortality.[1–5] Consideration of a broader group of outcomes, such as school absenteeism, provides a more comprehensive assessment of the adverse impact of ambient air pollution.[6,7]

Illness-related school absenteeism is an important but insufficiently studied outcome in children, a group identified as especially sensitive to the adverse effects of ambient air pollution.[8] Illness-related absences are common events that represent a broad spectrum of morbidity from mild transient illnesses to the most severe and prolonged illnesses that require emergency room visits or hospital admissions.[9] Although most absences are associated with illnesses at the low end of the morbidity spectrum, an absence indicates an illness of sufficient severity to affect the child's daily functioning, as well as child and family coping strategies.[9–13]

Population-based studies show that absence rates vary by school, age, grade, and gender, and are affected by family structure, function, and other social factors.[14,15] Although the non-health-related influences on absenteeism limit its usefulness as a measure of the adverse effects of air pollution, the majority of school absences are illness related and attributable to either respiratory infections or gastroenteritis, suggesting that illness is the dominant factor for school absenteeism.[10,14] Because the

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effects of air pollution on school absences are likely to be due to increases in respiratory illnesses, respiratory illness-related absenteeism can be an important and relatively specific integrative outcome for the assessment of the effects of air pollution on children.

Most research on the effects of air pollution on children's health has focused on self-reported symptoms, indices of respiratory infections derived from clinical visits, medical records reviews, and lung function as outcome measures.[6,16] Few studies have examined the effects of ambient air pollution on school absenteeism, and none has examined the effects on respiratory-related absences in school-aged children residing in communities with large variations in pollutant levels.

The Children's Health Study (CHS) offers an opportunity to investigate the effects of three ambient pollutants, O_3, PM_{10}, and NO_2, on school absenteeism with a focus on respiratory illness-related absences.[17] We conducted a substudy within the CHS cohort, the Air Pollution and Absence Study, and examined data on type-specific absence incidence collected by an active surveillance system for a cohort of 4th-grade school children 9–10 years of age who attended schools in the 12 CHS study communities during January through June 1996.

Subjects and Methods

Study Design

The CHS is a 10-year longitudinal study that includes school children who reside in 12 communities within a 200-mile radius of Los Angeles that were selected to represent the broadest range in concentration of the ambient pollutants of interest. Details on the design, site selection, subject recruitment, and assessment of health effects are reported elsewhere.[17] In this report, we focus on school absences among 2,081 children in the 4th grade during the first 6 months of 1996.

Participant Characteristics

Sociodemographic information, indoor exposures, and medical histories were obtained from questionnaires completed by parents or guardians at study entry in the fall of 1995. Environmental tobacco smoke (ETS) exposure was classified as exposure to a current household smoker or not. The subset of participants with asthma was defined using parent-reported history of physician-diagnosed asthma. Children with wheezing were defined as having any lifetime history of wheezing. Information regarding the number of hours spent outdoors over a 1-week period was collected by self-administered questionnaire. Children were stratified into "more outdoors" or "less outdoors" groups on the basis of whether they were above or below the median number of hours spent outside (11.25 hours).

Absence Surveillance

We collected school absence reports from the 27 elementary schools attended by the newly recruited 4th-grade children for the period January 1 through June 30, 1996. Of the 2,081 children in the 4th-grade group, 2,068 were eligible for the absence surveillance because they were enrolled in the CHS at the beginning of the surveillance period. Of these 2,068 children, we excluded 135 from the analysis for the following reasons: 32 withdrew from the study, 90 changed schools during the study period, and 13 did not have absence data because of administrative errors.

Daily absence information was collected using two methods depending on school confidentiality policies. In 12 schools, attendance reports for entire classrooms were collected, and study staff identified absences for participating students. In the remaining 15 schools, school staff members supplied subject-specific absence reports based on lists of subjects provided to them at the beginning of the surveillance period. Study staff requested that absence reports be completed every 2–4 weeks, with the interval depending on the availability of personnel and electronic data systems at individual schools. We defined an absence as a day or an adjacent series of school days in which a participant did not attend school when the school was in session. Over the period of study, we ascertained 8,971 absences.

We established an active surveillance system to collect information about the reasons for absences; we categorized absences as illness-related and non-illness-related (these included injuries) and classified illness-related absences into gastrointestinal (GI) and respiratory categories. School reports classified absences with nonstandard codes including indicators for non-illness-related absences. Non-illness-related absences were not investigated by telephone interviews. Using school reports, study staff assigned daily absence reports to one of two categories: (1) non-illness related and (2) potentially illness related. To ensure adequate parental recall of events associated with the absence of interest, interviews were conducted only for absences that were reported within 4 weeks of occurrence. Of the 3,294 absences reported within 4 weeks, 536 were classified as non-illness absences on the basis of school reports, and 2,758 absences required telephone follow-up.

Telephone interviews were conducted in English or Spanish by trained interviewers using a standardized protocol. Parents were contacted after each absence that was reported within 4 weeks to inquire whether the absence was illness related and if so, what the symptoms were; what the physician diagnoses were, if any; and what medications were used for the reported illness. The interviewers used a list of symptoms to categorize respiratory illnesses (runny nose and sneezing, fever, sore throat, cough, wet cough, dry cough, earache, wheezing, and asthma attack) in addition to stomach problems; head and muscle aches with fatigue; rash or skin problems; watery, itchy, or burning eyes; allergies; and other symptoms. Repeat interviews were conducted for approximately 5% of absences for quality-control purposes.

Each illness-related absence was classified as respiratory or nonrespiratory on the basis of the reported symptoms. We defined a respiratory illness as an illness that included one or more of the following symptoms: runny nose/sneezing, sore throat, cough (any, wet, or dry), earache, wheezing, or asthma attack. Respiratory absences were further classified into non-mutually exclusive categories of upper respiratory illness and/or as one of two types of lower respiratory illness (LRI): LRI with wet cough or LRI with wet cough/wheeze/asthma. We defined an upper respiratory illness as a respiratory illness with one or more of the following symptoms: runny nose/sneezing, sore throat, and earache. GI illnesses included illnesses with "stomach problems" such as vomiting and diarrhea as one of the reported symptoms.

ABSENCE INCIDENCE RATES

We categorized each absence day as an incident or prevalent absence day using absence reports and school calendars to identify the days each school was in session. We defined an incident absence as an absence that followed attendance on the preceding school day. We defined a prevalent absence day as an absence that occurred after an absence on the preceding school day. The date of an absence occurrence was assigned to the incident day of each series of absence days.

We used the daily number of incident absences in each community and the corresponding daily number of children at risk for an absence in each community to calculate daily community-specific incident absence rates. We defined the number of students attending a school as the number of participants enrolled in a school on a day that the school was in session less the number of prevalent absences. We calculated daily community-specific incidence rates of absence by pooling the data from the reporting schools in each community and dividing the community-specific number of incident absences by the number of students attending schools in that community on the day of interest. The average incidence rate for school absences was computed for each community by averaging daily rates and for the entire cohort by averaging across days and communities. Stratified rates (for example, by asthma status) were calculated by identifying the number of absences and number of students at risk within each stratum and calculating daily community-specific rates and average rates as described.

On the basis of data collected by the active surveillance system, absences were divided into three mutually exclusive outcomes: non-illness-related absences, illness-related absences, and absences of unknown type (due to failure to obtain necessary classification information). Because some absences were of unknown type, the type-specific absence incidence rates were adjusted for ascertainment failure. To adjust the type-specific incident absence rates, we calculated a daily community-specific information success ratio, which we defined as the daily proportion of timely absence reports in each community for which sufficient information was obtained to assign the absence as illness related or non-illness related. This success ratio was then smoothed over time using a very rough smoother (using 10 degrees of freedom). The smoothing was intended to reduce the random fluctuation due to the limited number of events on each day within a community but in such a way that it did not substantially alter the overall trend in the data or the observed values. A symptom-specific incidence rate corrected for ascertainment is of the form: (number of incident cases)/(number at risk × smoothed success ratio).

ASSESSMENT OF AIR POLLUTION LEVELS

Levels for O_3, PM_{10}, and NO_2 were measured continuously with hourly averaging at central-site monitors in each of the 12 communities.[18] We calculated the daily 1-hour maximum O_3, the 24-hour average of O_3, and the 10 am–6 pm average of O_3, as well as the 24-hour averages of PM_{10} and NO_2. We focused on the 10 am–6 pm average of O_3 because it is an index of exposure during the temporal peak of ozone and outdoor activity. The 24-hour averages of PM_{10} and NO_2 were used because they lack the temporal peak exhibited by O_3. The monitoring program also reported daily 24-hour average, 24-hour maximum, and 24-hour minimum temperatures at each of the 12 monitoring locations. To assess the effects of long-term average levels of O_3, PM_{10}, and NO_2 on acute effects, we divided communities into high and low groups for each pollutant on the basis of its ranking on average levels for 1995. The high and low groups included the same communities for PM_{10} and NO_2.

STATISTICAL METHODS

To examine acute effects of each air pollutant on the rate of absences, we fitted a two-stage time-series model to the absence count data.[19–23] Letting $\mu_c(t)$ denote the expectation of these absence counts and $R_c(t)$ denote the number of children at risk in community c on day t, the first-stage Poisson log-linear model has the form

$$\text{Stage 1: } \ln[\mu_c(t)] = \ln(R_c(t)) + s(t) + b_c + d_c[X_c(t) - X_c] + \gamma Z_c(t)$$

where b_c denotes the average absence rate in community c, adjusted for the effects of time-dependent covariates $Z_c(t)$ (for example, temperature, day of the week), and d_c is the within-community slope of the regression of change in daily absence rates with change in daily pollution $X_c(t)$ centered at the 6-month average for the study period X_c. The centering assumes a log-linear relation between the pollutants and absences. Here, $s(t)$ denotes a smooth function of time to account properly for autocorrelation and long- and short-term time trends in the multiple time series of counts. We use 5 degrees of freedom for the 6-month period to remove any temporal cycles of up to 2 weeks.[20] The first-stage model was also adjusted for day of the week (with Friday as the reference day) and temperature (24-hour average, daily minimum, and daily maximum). The offset term, $R_c(t)$, in the Poisson model was adjusted by using a smoothed version of the success ratio as described above.

Because the effects of pollutant exposure on a given day are likely to occur over several days, we fit models that allowed acute effects to be distributed over time. To account for a lag structure of the pollution effect, we modified the first-stage model by including community-specific polynomial distributed lag terms[24–27] leading to a model of the form:

$$\ln[\mu_c(t)] = \ln[R_c(t)] + s(t) + b_c + \gamma Z_c(t) + \Sigma_k g_{ck} \Sigma_j [X_c(t-j) - X_c] j^k$$

where $j = 1, ..., L$; $d_{cj} = \Sigma_k g_{ck} j^k$, and $k = 0, ..., D$, implying that the effects of each of the previous L days are distributed over subsequent days following a polynomial function of degree D. Appropriate values for L and D are optimally selected by comparing the Akaike Information Criterion[22,28] of the models based on a grid of L and D values assuming the same D and L values for all communities. This assumption is based on biological considerations indicating that the effects of pollutants should have the same lag structure in different communities in the Los Angeles region. The quantity $d_{cj} = \Sigma_k g_{ck} j^k$ is then interpretable as the polynomially smoothed estimate of the effect of air pollution on lagged j days, and their sum $d_c = \Sigma_j d_{cj}$ is the overall effect of pollution over the entire lag period. The estimates of d_{cj} and their variance estimates are then recovered through the explicit relation between d_{cj} and g_{ck}.[26]

The first-stage regression is followed by an ecologic linear regression model given by:

$$\text{Stage 2: } d_c = \delta_0 + \delta X_c + \eta_c$$

The stage 2 regression takes the sum of the lagged community-specific effects, d_c, and the appropriate variance estimates from stage 1. The parameter δ_0, the mean of the within-community slopes d_c, serves as an aggregated acute-effect estimate and is the quantity of primary interest for testing acute effects of air pollutants. Because long-term pollution levels may affect responses to acute changes in exposure level, the stage 2 model includes long-term average levels of any of the pollutants of interest and allows modification of the community-specific slopes for the acute effects by long-term average pollution levels. The parameter δ characterizes the modifying effect of the long-term average pollution levels on the relation between change in absences and change in daily within-community pollution levels. Note that we use the deviation of the daily exposure values, $X_c(t)$, from X_c in the first-stage model to make the within- and between-community comparisons of pollution effects independent. The second-stage "ecologic" regression is weighted by the inverses of the variances of d_c.

Using this framework, we fitted separate models for three pollutants; O_3 (24-hour average, daily maximum, and 10 am–6 pm daily average), PM_{10} (24-hour average), and NO_2 (24-hour average). To account for effects of long-term ambient pollutant levels, regression models were fitted and the overall summary of acute effect of a pollutant across communities was estimated, adjusted for the 1995 community-specific average levels of a pollutant. The estimate of δ_0 provides an overall summary of the acute effects from January through June 1996, adjusted for 1995 average levels of pollution or any other community-specific ecologic factor.

To assess further whether long-term average pollutant levels modify the acute effects of a pollutant, stratified models were fit using categories of high- and low-pollution communities. For any given number of strata, S, the stage 2 model becomes $d_c = \delta_{0s} + \eta_c$, where $s = 1, \ldots S$ and summary estimates are obtained as above. Strata of communities were formed on the basis of rankings using 1995 average pollution levels. We divided communities into high and low based on long-term average levels of O_3 and PM_{10} or NO_2.

Results

The distribution of sociodemographic characteristics, medical conditions, ETS exposure, and outdoor activity varied among the communities (Table 1). The average daily incidence rate for all types of absences combined was 3.07 per 100 student-days based on an average daily attendance of 1,502 students (Table 2). Average daily absence rates were highest in Lake Gregory and lowest in Upland. Although the method of absence reporting by schools varied by community (Table 1), the method of school attendance reporting did not appear to have a large influence on incidence rates.

The subset of absences that was reported in a timely enough manner to be eligible for the active surveillance system was an unbiased sample of absences occurring on all days (Table 2). The distribution of determinants of absences and the average daily rates for all types of absences on days that were reported within 4 weeks did not differ substantially from the distribution and average rates on days ascertained over the period of study. The crude average daily rates per 100 participants were 1.07 for non-illness-related absences, 1.34 for illness-related absences, and 0.61 for absences of unknown type (Table 3). The daily information success ratio averaged 0.81, and exceeded 0.72, for all subgroups.

The ascertainment-adjusted daily rate for illness-related absences was higher than for non-illness-related absences for all participants combined (Table 4). Lake Gregory had the highest adjusted daily rate for illness-related absences, and Long Beach had the lowest rate. Illness-related absences were primarily due to respiratory illnesses, most of which had upper respiratory symptoms (Table 4). Adjusted daily rates of absences for respiratory illness, upper respiratory illness, LRI with wet cough/wheeze/asthma, and LRI with wet cough varied among communities and among ethnic and education groups. Rates of absences for respiratory illness and upper respiratory illness were twice as high in Lake Gregory compared with rates in Long Beach. Children with asthma, wheezing, and ETS exposure had higher absence rates for all categories of respiratory illness than children without asthma, wheezing, or ETS exposure. Adjusted absence rates for GI illness did not vary as substantially as rates for respiratory illness by children's asthma status, wheezing status, or ETS exposure (Table 4). Absences

TABLE 1. Percentage Distributions of Sociodemographic Characteristics and Selected Medical History and Exposures among Participants, Air Pollution, and Absence Study, January through June 1996

			Race/Ethnicity					Parent Education*					Conditions				Reporting Method†	
Community Reporting	N	Males	White	Hispanic	African American	Asian	Other Race	<12th Grade	12th Grade	Some College/ Technical School	4 Years College	Postgraduate	Asthma	Wheeze	ETS	Outdoor Activity >11.25 Hours	Subject-Specific Reporting	Whole Grade
Alpine	177	49.7	73.4	20.9	0	0.6	4.5	7.9	20.3	49.2	10.7	9.0	13.6	33.9	16.4	57.6	0	100.0
Lake Elsinore	171	47.4	52.0	33.9	2.3	2.9	6.4	18.1	21.1	38.0	11.1	4.1	11.1	31.6	21.1	45.0	45.6	54.4
Lake Gregory	164	52.4	71.3	22.0	0.6	0	5.5	9.8	19.5	50.6	7.3	8.5	14.6	35.4	29.9	29.9	24.4	75.6
Lancaster	176	47.2	49.4	31.3	10.8	2.3	5.1	17.6	18.2	44.9	6.8	8.0	16.5	34.7	24.4	52.3	100.0	0
Lompoc	166	49.4	44.0	36.1	6.6	9.0	4.2	12.7	19.3	48.8	9.6	5.4	10.8	29.5	19.9	33.1	34.3	65.7
Long Beach	158	54.4	32.3	23.4	21.5	13.9	8.2	10.8	19.6	39.2	13.3	12.0	13.9	27.8	20.3	38.0	66.5	33.5
Mira Loma	152	48.0	40.8	52.6	2.0	1.3	2.6	27.0	24.3	31.6	7.9	1.3	14.5	34.2	24.3	42.8	100.0	0
Riverside	152	49.3	40.1	40.8	10.5	1.3	5.9	15.1	23.0	32.9	9.2	17.1	11.8	26.3	12.5	52.6	0	100.0
San Dimas	162	48.8	48.8	35.2	1.9	8.6	5.6	6.2	15.4	53.7	10.5	9.3	18.5	30.9	17.3	38.9	0	100.0
Atascadero	157	56.1	72.6	17.2	1.9	1.3	7.0	4.5	17.8	50.3	8.9	17.2	19.7	43.3	13.4	50.3	0	100.0
Santa Maria	156	49.4	22.4	62.8	0.6	7.1	3.2	21.2	22.4	30.8	7.1	5.1	12.2	19.2	12.8	34.6	100.0	0
Upland	144	47.2	66.7	17.4	4.2	7.6	4.2	2.1	7.6	46.5	22.9	20.8	11.8	27.8	8.3	34.0	100.0	0
Total	1,935	49.9	51.4	32.7	5.2	4.6	5.2	12.8	19.1	43.2	10.3	9.7	14.1	31.3	18.6	42.6	46.9	53.1

ETS = environmental tobacco smoke.

* Refers to parent/guardian who completed the subject's baseline questionnaire.

† Reporting methods included schools that provided lists of whole grades and those that provided study subject-specific reports.

due to GI illness showed a different pattern among ethnic groups and communities from that of respiratory illnesses, with Alpine having approximately 2.5-fold higher rates than Santa Maria and Long Beach.

AIR POLLUTION

The patterns of O_3, NO_2, and PM_{10} varied markedly within and among the communities (Figure 1). The average 10 am–6 pm ozone was highest in Riverside and lowest in Long Beach. The communities with the largest daily variations were Mira Loma, Riverside, and San Dimas, with daily levels ranging from lower than the levels observed in unpolluted regions to greater than 150 ppb.

The 24-hour average PM_{10} varied by approximately the same magnitude as O_3; however, several of the towns with the higher O_3 had lower PM_{10} (Figure 1). Mira Loma had the highest level and largest range in 24-hour average PM_{10}, and several communities had median levels below 20 $\mu g/m^3$. The 24-hour average NO_2 levels varied among the communities, and some communities (Lake Gregory and Lompoc) had very low levels (Figure 1). Long Beach, which had low O_3, had comparatively high NO_2. Lompoc, Santa Maria, and Atascadero had lower levels of all three of the pollutants of interest. The communities showed a large range of long-term average pollutant levels on the basis of 1995 pollution levels (Table 5). The same six communities were in the high stratum for both NO_2 and PM_{10}.

TIME-SERIES REGRESSION

We found that a 30-day lag period with a cubic polynomial-constrained distributed lag model best described the data for all absences, non-illness-related absences, and respiratory absences for all three pollutant metrics of interest. A 15-day lag period provided the best fit for upper and lower respiratory absences for all three of the pollutant metrics.

OZONE

Average O_3 for 10 am–6 pm was strongly associated with illness-related absences and especially respiratory absences. The summary estimates of the percentage increase in absence rates associated with O_3 on each of the 30 lag days are shown scaled to a 20-ppb change in O_3, a change that is less than the smallest range in any of the 12 communities during the 6-month period of study (Figure 2). The acute effects of O_3 were increased at a 3-day lag, peaked at a 5-day lag, and subsequently showed a slow decrease. Overall estimates of the effect of acute change in O_3 on absences are obtained by summing the area under the distributed lag curve over the 30-day lag period. Daily 1-hour peak O_3 produced the same overall results as analyses using the 10 am–6 pm average O_3.

A 20-ppb increase in O_3 was associated with a 62.9% absence rate increase for illness, 82.9% increase for respiratory illnesses, 45.1% increase for upper respiratory illnesses, 173.9% increase for LRI with wet cough, and

TABLE 2. Average Daily Absence Incidence Rates per 100 Children-Days and Average Number of Children at Risk per Day on All Days and Days with Active Surveillance for Type of Absence by Selected Participant Characteristics, Air Pollution and Absence Study, January through June 1996

	All Days			Active Surveillance Days		
	Absence Rate/100	Average No. Children at Risk/Day	%	Absence Rate/100	Average No. Children at Risk/Day	%
All	3.07	1,502.2	100.0	3.02	996.4	100.0
Sex						
Females	3.08	751.2	50.0	3.10	500.9	50.3
Males	3.06	751.0	50.0	2.93	495.4	49.7
Ethnicity/race						
Missing	2.40	12.5	0.8	2.04	8.0	0.8
White, non-Hispanic	3.13	776.5	51.7	3.10	498.7	50.1
Hispanic	3.16	483.1	32.2	3.20	327.6	32.9
Black (African-American)	1.84	82.0	5.5	2.02	61.7	6.2
Asian/Pacific Isle	2.00	71.2	4.7	1.29	50.2	5.0
Other	3.62	78.1	5.2	3.89	51.0	5.1
Education of signer						
Missing	3.14	71.2	4.7	2.97	45.1	4.5
<12th grade	3.59	182.5	12.1	3.73	124.9	12.5
12th grade	3.25	287.2	19.1	3.19	189.9	19.1
Some college/technical school	3.16	651.4	43.4	3.05	426.9	42.8
4 years of college	2.45	159.2	10.6	2.96	110.0	11.0
Postgraduate	2.39	150.8	10.0	2.35	99.9	10.0
Community						
Alpine	3.23	158.6	10.6	3.22	116.0	11.6
Lake Elsinore	3.78	109.3	7.3	3.82	93.6	9.4
Lake Gregory	4.34	129.1	8.6	4.36	105.3	10.6
Lancaster	3.06	128.4	8.5	3.10	90.3	9.1
Lompoc	2.84	151.4	10.1	3.17	106.1	10.7
Long Beach	2.35	149.7	10.0	2.37	124.2	12.5
Mira Loma	3.30	149.5	10.0	3.35	143.1	14.4
Riverside	2.97	151.5	10.1	2.94	143.8	14.4
San Dimas	2.80	159.7	10.6	2.50	86.0	8.6
Atascadero	2.82	134.6	9.0	3.06	103.7	10.4
Santa Maria	2.83	112.9	7.5	2.57	83.0	8.3
Upland	2.29	143.0	9.5	2.36	114.6	11.5
Diagnosed asthma						
Missing	3.15	45.4	3.0	3.24	30.5	3.1
No	2.98	1,243.3	82.8	2.94	827.1	83.0
Yes	3.65	213.5	14.2	3.61	138.7	13.9
Reported wheeze						
Missing	2.55	89.6	6.0	2.73	61.3	6.2
No	2.88	943.2	62.8	2.81	630.2	63.2
Yes	3.55	469.4	31.2	3.55	304.9	30.6
Any ETS						
Missing	3.17	49.7	3.3	3.02	32.8	3.3
No	2.93	1,181.0	78.6	2.86	786.4	78.9
Yes	3.67	271.5	18.1	3.72	177.2	17.8
7-day outdoor activities						
Missing	3.66	174.2	11.6	3.61	117.2	11.8
≤11.25 hours	3.04	863.3	57.5	3.03	580.0	58.2
>11.25 hours	3.10	638.9	42.5	3.00	416.4	41.8
School report method						
Whole grade	3.19	793.4	52.8	3.03	464.0	46.6
Participants	3.12	721.2	48.0	3.08	545.8	54.8

ETS = environmental tobacco smoke.

68.4% increase for LRI with wet cough/wheeze/asthma (Table 6). To determine the sensitivity of our estimates to the amount of smoothing used to remove seasonal variation, we refitted the models using 3 degrees of freedom and found that the estimates were essentially unchanged. For example, the effect of ozone on respiratory absences changed from an 82.9% increase to an 81.3% increase. Ozone-related increases in all absences and illness-related absences were larger in communities with lower levels of NO$_2$ or PM$_{10}$ than in communities with higher levels of NO$_2$ or PM$_{10}$ (Table 7). The acute effects of O$_3$ on respiratory illness-related absenteeism were also larger in communities with lower long-term average PM$_{10}$ (454.9%) compared with communities with high average PM$_{10}$ (42.9%).

PM$_{10}$ AND NO$_2$

Daily 24-hour PM$_{10}$ was associated with all absences (Table 6). However, increased daily PM$_{10}$ was only associated with increases in non-illness-related absences. A change of 10 $\mu g/m^3$ in PM$_{10}$ was associated with a 22.8% increase in all types of school absences combined and with a 97.7% increase in non-illness-related ab-

TABLE 3. Average Crude Daily Absence Incidence Rates per 100 Children-Days and Performance Characteristics of the Active Surveillance System by Selected Participant Characteristics, Air Pollution and Absence Study, January to June 1996

	Absence Rate/100			Information Success	
	Crude Non-Illness	Crude Any Illness	Unknown Type	Mean Success Ratio	Range
All	1.07	1.34	0.61	0.81	0.70–0.99
Sex					
Females	1.10	1.40	0.59	0.81	0.68–0.99
Males	1.05	1.27	0.61	0.81	0.65–0.99
Ethnicity/race					
Missing	1.25	0.07	0.73	0.72	0.57–0.93
White/non-Hispanic	1.03	1.42	0.65	0.82	0.70–0.99
Hispanic	1.15	1.35	0.70	0.81	0.57–0.99
Black (African-American)	1.05	0.71	0.26	0.81	0.59–0.93
Asian/Pacific Isle	0.39	0.81	0.10	0.82	0.67–0.94
Other	1.66	1.65	0.58	0.81	0.43–1.01
Education of signer					
Missing	1.01	1.20	0.76	0.81	0.56–0.96
<12th grade	1.46	1.37	0.89	0.80	0.49–0.91
12th grade	1.08	1.56	0.55	0.80	0.44–0.92
Some college/technical school	1.09	1.36	0.60	0.82	0.69–0.99
4 years of college	1.33	1.23	0.40	0.82	0.56–0.94
Postgraduate	0.67	1.20	0.47	0.81	0.54–0.97
Community					
Alpine	0.92	1.43	0.87	0.75	0.57–1.00
Lake Elsinore	1.34	1.80	0.67	0.84	0.44–1.02
Lake Gregory	1.47	1.83	1.06	0.76	0.54–0.94
Lancaster	1.14	1.24	0.73	0.82	0.67–1.02
Lompoc	0.88	1.74	0.55	0.83	0.66–0.99
Long Beach	1.16	0.81	0.40	0.85	0.75–0.97
Mira Loma	1.20	1.58	0.56	0.82	0.72–0.89
Riverside	0.87	1.37	0.69	0.76	0.55–0.90
San Dimas	0.78	1.19	0.52	0.82	0.69–0.92
Atascadero	1.01	1.32	0.72	0.80	0.30–0.96
Santa Maria	0.77	1.29	0.51	0.81	0.57–0.95
Upland	0.79	1.19	0.37	0.86	0.74–0.99
Diagnosed asthma					
Missing	1.44	1.19	0.61	0.81	0.58–0.95
No	1.08	1.26	0.60	0.81	0.70–0.99
Yes	1.02	1.88	0.71	0.81	0.61–0.97
Reported wheeze					
Missing	0.90	0.88	0.95	0.80	0.61–0.95
No	1.03	1.23	0.55	0.81	0.70–0.99
Yes	1.24	1.68	0.63	0.81	0.65–0.97
Any ETS					
Missing	1.37	0.98	0.68	0.79	0.44–0.94
No	1.00	1.28	0.59	0.81	0.70–0.99
Yes	1.29	1.79	0.65	0.81	0.65–0.95
7-day outdoor activities					
Missing	1.32	1.57	0.71	0.82	0.62–0.99
≤11.25 hours	1.10	1.35	0.58	0.81	0.44–0.99
>11.25 hours	1.05	1.36	0.58	0.81	0.65–0.90
School report method					
Whole grade	1.15	1.22	0.66	0.79	0.56–0.91
Participants	1.08	1.41	0.58	0.83	0.70–0.99

ETS = environmental tobacco smoke.

sences, but a 5.7% increase in illness-related absences. Daily PM_{10} was not materially associated with any of the categories of respiratory illness-related absences. NO_2 had only a weak association with school absenteeism (Table 6).

Discussion

We found that day-to-day changes in O_3 were associated with a substantial increase in school absences from both upper and lower respiratory illnesses. Absences were increased 2–3 days after exposure and reached a peak on day 5 after exposure. The short-term effects of O_3 on respiratory illness-related absences are consistent with a large body of evidence on the acute adverse effects of O_3 on children's respiratory health.[3] Exposure to O_3 is known to be associated with increased hospital admissions for respiratory infections among children. Hospital admission ranks as a severe outcome in the range of adverse effects, and most respiratory illnesses do not lead to hospital admission for treatment. School absences due to respiratory illnesses may usefully represent the first tier of adverse effects that are far more common than severe adverse effects.

A limited number of studies have examined the relation between O_3 exposure and school absenteeism. In a study in Mexico City of 111 preschool children, O_3 was associated with higher rates of absenteeism due to respiratory illnesses.[29] Children exposed to more than 130 ppb of O_3 on 2 consecutive days had a 20% increase in the occurrence of preschool-reported respiratory ill-

TABLE 4. Type-Specific Adjusted* Absence Incidence Rates per 100 Children-Days by Selected Participant Characteristics, Air Pollution and Absence Study, January through June 1996

	Adjusted Non-Illness	Adjusted Any Illness	Adjusted Non-Respiratory	Adjusted Respiratory	Adjusted Upper Respiratory	Adjusted Lower Respiratory with Wet Cough	Adjusted Lower Respiratory with Wheeze	Adjusted GI Symptoms
All	1.34	1.64	0.60	1.04	0.93	0.18	0.30	0.63
Sex								
Females	1.36	1.71	0.62	1.09	1.00	0.19	0.30	0.65
Males	1.31	1.56	0.59	0.97	0.86	0.18	0.30	0.61
Ethnicity/race								
Missing	1.71	0.10	0.00	0.10	0.10	0.00	0.00	0.00
White/non-Hispanic	1.27	1.73	0.67	1.06	0.98	0.21	0.33	0.75
Hispanic	1.40	1.65	0.57	1.08	0.98	0.19	0.26	0.57
Black (African-American)	1.35	0.86	0.10	0.75	0.68	0.13	0.47	0.21
Asian/Pacific Isle	0.45	1.00	0.21	0.79	0.68	0.10	0.17	0.14
Other	2.11	2.01	0.89	1.13	1.01	0.25	0.34	0.82
Education of signer								
Missing	1.27	1.49	0.87	0.63	0.58	0.13	0.17	0.76
<12th grade	1.79	1.66	0.44	1.22	0.93	0.21	0.44	0.50
12th grade	1.35	1.90	0.75	1.15	1.01	0.19	0.33	0.70
Some college/technical school	1.35	1.67	0.59	1.07	0.97	0.18	0.31	0.65
4 years of college	1.76	1.47	0.37	1.10	0.99	0.14	0.38	0.48
Postgraduate	0.82	1.46	0.45	1.01	1.01	0.28	0.29	0.63
Community								
Alpine	1.20	1.90	0.91	1.00	0.85	0.19	0.26	0.98
Lake Elsinore	1.67	2.08	0.76	1.32	1.17	0.28	0.56	0.90
Lake Gregory	1.90	2.28	0.88	1.41	1.29	0.30	0.35	0.88
Lancaster	1.42	1.47	0.49	0.98	0.91	0.12	0.24	0.64
Lompoc	1.08	2.09	0.71	1.38	1.24	0.24	0.30	0.73
Long Beach	1.36	0.96	0.24	0.72	0.61	0.21	0.31	0.35
Mira Loma	1.48	1.92	0.86	1.06	0.89	0.24	0.41	0.77
Riverside	1.20	1.82	0.72	1.09	1.06	0.20	0.31	0.85
San Dimas	0.94	1.44	0.31	1.13	0.94	0.16	0.36	0.38
Atascadero	1.27	1.61	0.83	0.78	0.60	0.11	0.28	0.66
Santa Maria	0.93	1.62	0.57	1.05	1.04	0.14	0.24	0.40
Upland	0.92	1.38	0.48	0.90	0.84	0.13	0.26	0.55
Diagnosed asthma								
Missing	1.78	1.49	0.51	0.98	0.91	0.35	0.42	0.63
No	1.34	1.54	0.59	0.95	0.89	0.16	0.20	0.61
Yes	1.25	2.28	0.70	1.58	1.25	0.30	0.89	0.76
Reported wheeze								
Missing	1.15	1.06	0.36	0.70	0.67	0.09	0.11	0.49
No	1.28	1.51	0.63	0.88	0.82	0.14	0.17	0.61
Yes	1.53	2.05	0.61	1.44	1.24	0.28	0.59	0.68
Any ETS								
Missing	1.86	1.23	0.68	0.54	0.40	0.07	0.19	0.64
No	1.22	1.56	0.55	1.01	0.92	0.18	0.28	0.59
Yes	1.62	2.17	0.83	1.35	1.21	0.23	0.46	0.82
7-day outdoor activities								
Missing	1.60	1.93	0.80	1.14	1.08	0.21	0.28	0.79
≤11.25 hours	1.38	1.65	0.63	1.03	0.92	0.18	0.28	0.63
>11.25 hours	1.30	1.66	0.58	1.08	0.97	0.18	0.34	0.64
School report method								
Whole grade	1.45	1.55	0.52	1.03	0.91	0.20	0.31	0.64
Participants	1.33	1.69	0.61	1.08	0.98	0.19	0.32	0.60

GI = gastrointestinal; ETS = environmental tobacco smoke.

* Adjusted for interview failure using the success ratio as described in the methods section.

nesses. Studies of school absenteeism in California failed to find an association with oxidants or other pollutants, but these studies did not assess the effects of daily changes in pollutant levels on respiratory absences.[30] The relations between other air pollutants, such as SO_2, and school absences have also been investigated; however, the effects of O_3 were not examined, because levels were considered too low to have adverse effects.[31] We lack data to investigate further the reasons for the smaller effect of acute changes in O_3 on respiratory illness-related absences in communities with high long-term average PM_{10} levels. One possible explanation is seasonal attenuation of children's responses to air pollution. Seasonal attenuation of the acute lung function response to O_3 exposure during high-pollution months has been reported, suggesting that long-term exposure to elevated levels of PM can affect acute response to O_3.[32,33]

The association of daily 24-hour average PM_{10} with all absences in this study was primarily due to a relation with non-illness-related absences. The small association with illness-related absences was unexpected, because studies have shown that particulate pollution is associated with reduction in lung function, increased rates of acute bronchitis in children, increased incidence of respiratory symptoms, increased emergency room visits and hospitalizations for respiratory disease, and increased mortality.[5,17,34,35] Our study is consistent with a report by Ransom and Pope,[36] who studied the relation between school absenteeism and PM_{10} in Utah Valley for 6 years between 1985 and 1990, using weekly absenteeism data

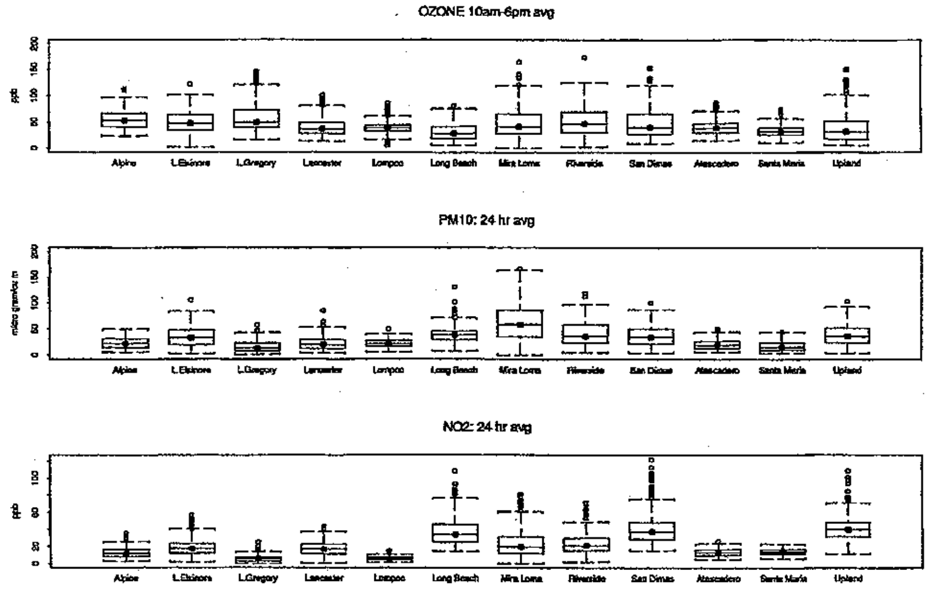

FIGURE 1. Boxplots of 10 am–6 pm average O_3, 24-hour average NO_2, and 24-hour average PM_{10} in study communities (Air Pollution and Absence Study, January 1 through June 30, 1996). In the box plots, the median, first quartile, and third quartiles form the box, and the whiskers depict ±1.5 × interquartile range. Any other extreme values outside of the whiskers are plotted individually.

from one school district and daily data from one elementary school. They observed that a 100 $\mu g/m^3$ increase in the 28-day moving average of PM_{10} was associated with a 40% increase in overall absences and that the effect was larger in younger children. The study did not, however, distinguish between illness and non-illness-related absenteeism. We were unable to investigate directly non-illness absences, because we did not ask about reasons for non-illness absences during interviews. We considered a number of potential sources of bias, such as incomplete control of temporal trends and the effects of temperature and differences in the effects among the communities, by conducting sensitivity analyses. We found the relations were consistent between communities and robust regardless of adjustments for temporal trends and temperature.

Acute effects of NO_2 on school absenteeism were not observed at the levels measured in communities during the period of study. Although NO_2 exposure may be associated with respiratory symptoms, little evidence exists that symptoms from NO_2 exposure result in school absences.[2,4,37] In a study of the relation between air pollution and absenteeism in Helsinki, Ponka[38] reported that mean weekly NO_2 concentrations were associated with absenteeism among adults; however, low ambient temperature accounted for the associations with absences among children in day care centers and school children.[38] In the present study, the lack of association may also reflect the narrow range of NO_2 exposure and possible exposure misclassification due to the use of a central site monitor to assign exposure levels. Misclassification of exposure is likely to be the same on different days within each community, suggesting that misclassification is likely to be nondifferential.[39]

In preliminary analyses, we used a bidirectional case-crossover approach to assess the air pollution and absence relation; however, the time-series analysis provides an analytic framework that efficiently uses all available information and does not have some of the conceptual drawbacks of the case-crossover approach.[40–43] The distributed lag model constrained the

TABLE 5. Annual Average Air Pollution and Community Rankings for Ozone (O_3), Nitrogen Dioxide (NO_2), and Respirable Particles (PM_{10}) Based on 1995 Levels, Children's Health Study, 1995

Community	Annual Mean 10 am–6 pm O_3 (ppb)	Rank	Annual Mean Daily NO_2 (ppb)	Rank	Annual Mean Daily PM_{10} ($\mu g/m^3$)	Rank	Stratum* (O_3, PM_{10}/NO_2)
Santa Maria	31	1	12	3	20	2	LL
Long Beach	33	2	37	10	39	9	LH
Atascadero	43	3	13	4	22	4	LL
Lompoc	45	4	5	1	15	1	LL
Lancaster	48	5	19	6	24	5	LL
Mira Loma	54	6	23	8	65	12	LH
Upland	55	7	45	12	45	11	HH
Lake Elsinore	57	8	20	7	35	7	HH
Alpine	58	9	13	5	24	6	HL
San Dimas	60	10	44	11	37	8	HH
Riverside	62	11	25	9	44	10	HH
Lake Gregory	65	12	7	2	21	3	HL

* Strata were defined by ranking communities on 1995 average pollution levels and dichotomizing communities into high (H) and low (L) groups. LL = low O_3 and low PM_{10} or NO_2, LH = low O_3 and high PM_{10} or NO_2, HL = high O_3 and low PM_{10} or NO_2, and HH = high O_3 and high PM_{10} or NO_2.

TABLE 6. **Short-Term Effects of 10 am–6 pm Average Ozone (O_3), 24-Hour Average Respirable Particles (PM_{10}) and 24-Hour Average Nitrogen Dioxide (NO_2) on School Absence Incidence Rates [Percentage Change and 95% Confidence Limits (CL)], Air Pollution and Absence Study, January through June 1996***

	Pollutant					
	O_3		PM_{10}		NO_2	
Type of Absence	% Change	95% CL	% Change	95% CL	% Change	95% CL
All absences	16.3	−2.6, 38.9	22.8	11.6, 35.2	3.4	−30.6, 54.0
Non-illness	21.2	−12.9, 69.0	97.7	72.6, 126.5	34.6	−43.0, 218.2
Illness	62.9	18.4, 124.1	5.7	−12.1, 27.0	−4.6	−42.4, 57.8
Nonrespiratory	37.3	5.7, 78.3	10.2	−14.6, 42.3	−36.8	−69.5, 30.8
Respiratory†	82.9	3.9, 222.0	−4.3	−32.2, 35.0	19.6	−36.2, 124.4
URI	45.1	21.3, 73.7	5.5	−6.8, 19.4	−7.4	−30.3, 23.0
LRI/wc	173.9	91.3, 292.3	−7.7	−49.2, 67.7	−37.5	−73.9, 49.4
LRI/W/A	68.4	43.4, 97.8	−7.1	−34.1, 30.8	5.1	−60.3, 178.0

URI = upper respiratory illness; LRI = lower respiratory illness; wc = wet cough; W/A = wet cough/wheeze or asthma attack.

* Results are reported for 20 ppb O_3, 10 $\mu g/m^3$ PM_{10}, and 10 ppb NO_2. Models are fitted using community-specific polynomial-distributed lag models (degree 3) with 30-day lag period except URI, LRI/wc$^+$, and LRI/W/A had 15-day lag periods.

† Fifteen-day lag periods used.

acute effects of pollutants to follow a polynomial function of air pollution. Based on an objective criterion for choice of the number of lag days, minimizing the Akaike Information Criterion, a cubic polynomial that included either 15 or 30 lag days, best described the lagged effects. Other choices of the lag period length would produce consistent results for the O_3 effect on respiratory illness-related absences. The 15- to 30-day lag periods for the O_3 effects on respiratory illness-related absences are consistent with data from a number of studies showing that effects of air pollution on respiratory health outcomes may persist for up to 5 weeks.[36,44,45]

Our study enrolled and actively followed more than 2,000 4th-grade school children. The active surveillance system and modeling strategy did, however, have some limitations. Although the restriction of absences to those reported within 1 month of occurrence may have introduced bias into our study, it was adopted to minimize any recall bias of absence events by parents. On the basis of the distributions of the study population in the full and restricted sample of absence days, we found little evidence of any selection bias from the restriction. To account for the effects of incomplete ascertainment, we adjusted the denominator of the rates and the offset in the Poisson time-series models for the proportion of absences with information on absence type. To investigate the robustness of our estimates to the assumptions implicit in this adjustment, we conducted sensitivity analyses by limiting the analyses to those days with greater than 70% ascertainment. Restriction to days with nearly complete information had little effect on the magnitude of the associations. To assess further the potential for bias from the variation in ascertainment, we also examined the relations between the daily pollution and callback rates as well as absence rates and callback rates. We found that the community-specific smooth success ratios showed, in general, a weak negative correlation with ozone. Because ozone was positively correlated with absence rates over the period of study, a negative bias toward the null would be expected and cannot explain our ozone results. The correlations for NO_2 and PM_{10} were generally smaller, making the potential for bias less likely.

We also attempted to examine variation in the relations using models stratified by asthma, ETS exposure, or other sociodemographic factors, but were unsuccessful owing to the short length of time series

TABLE 7. **Short-Term Effects of Ozone (O_3) [Percentage Change and 95% Confidence Limits (CL)] on School Absence Incidence Rates, Stratified by Long-Term Average 10 am–6 pm O_3 and 24-Hour Average Respirable Particles (PM_{10}) or Nitrogen Dioxide (NO_2),* Air Pollution and Absence Study, January through June 1996†**

	Community Ranking							
	Based on O_3				Based on PM_{10}/NO_2			
	Low O_3		High O_3		Low PM_{10} (NO_2)		High PM_{10} (NO_2)	
Type of Absence	% Change	95% CL	% Change	95% CL	% Change	95% CL	% Change	95% CL
All absences	14.0	−16.7, 56.1	16.2	−5.8, 43.3	68.2	25.9, 124.8	6.4	−7.1, 21.9
Non-illness	17.0	−35.3, 111.9	20.1	−19.2, 78.6	49.8	−30.7, 223.7	13.6	−20.3, 61.8
Illness	87.6	8.3, 225.2	48.8	3.0, 115.0	223.5	90.4, 449.7	38.1	8.5, 75.8
Nonrespiratory	29.9	−19.8, 110.6	31.5	−5.6, 83.0	29.6	−32.2, 147.9	31.3	−2.8, 77.4
Respiratory	136.8	−11.5, 533.1	57.7	−18.1, 203.9	454.9	90.0, 1520.0	42.9	−11.2, 130.1

* High and low strata included the same communities for either PM_{10} or NO_2.

† Results are reported for 20 ppb O_3, 10 $\mu g/m^3$ PM_{10}, and 10 ppb NO_2. Models are fitted using community-specific polynomial-distributed lag models (degree 3) with 30-day lag period.

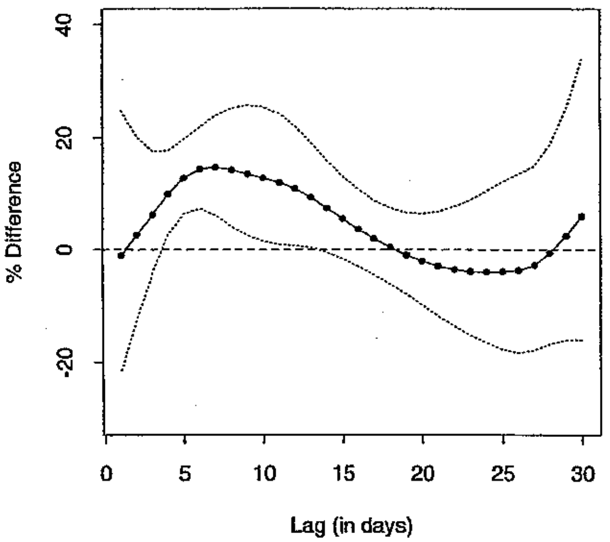

FIGURE 2. Distributed lag estimates and 95% confidence intervals for the effect of 10 am–6 pm O_3 (per 20 ppb) on respiratory illness-related absences (Air Pollution and Absence Study, January 1 through June 30, 1996).

and the low number of events within community-specific strata. Lastly, it was not feasible to examine simultaneously the acute effects of multiple pollutants using the two-stage distributed lag framework developed for this analysis. Future development of a binomial time-series model with a flexible distributed lag structure would provide the framework to include individual-level covariates and multipollutant effects in time-series analyses.

In conclusion, relatively small short-term changes in O_3 were associated with increases in respiratory illness-related school absences in children 9–10 years of age. Because exposures at the levels observed in this study are common, the increase in school absenteeism from respiratory illnesses associated with relatively modest day-to-day changes in O_3 concentration documents an important adverse impact of O_3 on children's health and well-being.

Acknowledgment

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Association between Air Pollution and Lung Function Growth in Southern California Children

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Average growth of lung function over a 4-yr period, in three cohorts of southern California children who were in the fourth, seventh, or tenth grade in 1993, was modeled as a function of average exposure to ambient air pollutants. In the fourth-grade cohort, significant deficits in growth of lung function (FEV_1, FVC, maximal midexpiratory flow [MMEF], and FEF_{75}) were associated with exposure to particles with aerodynamic diameter less than 10 μm (PM_{10}), $PM_{2.5}$, PM_{10}–$PM_{2.5}$, NO_2, and inorganic acid vapor ($p < 0.05$). No significant associations were observed with ozone. The estimated growth rate for children in the most polluted of the communities as compared with the least polluted was predicted to result in a cumulative reduction of 3.4% in FEV_1 and 5.0% in MMEF over the 4-yr study period. The estimated deficits were generally larger for children spending more time outdoors. In the seventh- and tenth-grade cohorts, the estimated pollutant effects were also negative for most lung function measures, but sample sizes were lower in these groups and none achieved statistical significance. The results suggest that significant negative effects on lung function growth in children occur at current ambient concentrations of particles, NO_2, and inorganic acid vapor.

The acute health consequences of breathing polluted air are well documented, ranging from increased cardiorespiratory morbidity and mortality to increased prevalence of respiratory symptoms and decrements in lung function (1–4). Chronic health effects from exposure to air pollution have been suggested by previous studies, although whether chronic effects occur at current ambient concentrations remains uncertain (1, 2, 5–7). Children may be a particularly vulnerable population because they spend more time outdoors, are generally more active, and have higher ventilation rates than adults (8).

One approach to assessing the potential chronic effects of air pollution is to determine how pollution affects lung function growth. The broad range of air quality in southern California offers the opportunity to investigate the health effects of exposure to several pollutants, including ozone, nitrogen oxides, particles, and acids. In 1993, we initiated a 10-yr prospective study of respiratory health in children from 12 southern California communities. In this report, we examine the longitudinal lung function data from the first 4 yr of follow-up and analyze the relationship between air pollution concentrations and lung function growth.

METHODS

Study Subjects

Twelve communities within a 200-mile radius of Los Angeles were selected in 1993 based on their historical air pollution levels. In each community, approximately 150 children in grade four, 75 in grade seven, and 75 in grade 10 were selected from public schools. Information concerning medical history, residential history, housing characteristics, and time spent outdoors was obtained by questionnaire. Additional characteristics of the study design have been previously described (6, 7). Spirometric evaluations of the children were conducted annually from 1993 to 1997 for the fourth- and seventh-grade cohorts, and from 1993 to 1995 for the tenth-grade cohort. A total of 3,035 children had at least two evaluations during this period. The study protocol was approved by the institutional review board for human studies at the University of Southern California, and informed written consent was provided by parents for all study subjects.

Pulmonary Function Testing

Pulmonary function tests (PFTs) were performed at schools during the morning and early afternoon hours of spring. Each subject was asked to perform up to seven maximal forced expiratory flow–volume maneuvers using one of six rolling-seal spirometers (Spiroflow; P.K. Morgan Ltd., Gillingham, UK), from which FVC, FEV_1, maximal midexpiratory flow (MMEF), and forced expiratory flow rate at 75% of expired FVC (FEF_{75}) were recorded. A more detailed description and procedures for maneuver selection, spirometer calibration, and quality control have been previously reported (7).

Air Pollution Data

Air pollution monitoring stations were established in each of the 12 communities as a part of the study design, with measurements for all pollutants at all sites available from 1994 onward. All stations monitored hourly concentrations of ozone (O_3), nitrogen dioxide (NO_2), and particles with aerodynamic diameter less than 10 μm (PM_{10}). Two-week integrated samplers were used to measure $PM_{2.5}$ and acid vapor. For statistical analysis, we computed the annual averages of the 24 h averages of O_3, PM_{10}, and NO_2, the annual average of 10:00 A.M. to 6:00 P.M. levels of O_3, the annual averages of the 2-wk averages of $PM_{2.5}$ and inorganic acid vapor ($HCl + HNO_3$), and the difference between annual average PM_{10} and $PM_{2.5}$. In addition, 3-yr mean levels (1994 to 1996) in each community were computed for all pollutants.

Statistical Analysis

Linear regression methods were used to determine whether, over the 4 yr of follow-up, average lung function growth rates of the children in each community were associated with the corresponding average pollutant levels in those communities. The outcome data consisted of 11,536 PFTs recorded from 1993 to 1997 on 3,035 study subjects in the 12 communities. Because lung function increases nonlinearly from childhood through adolescence (9), all analyses were performed separately within grade cohort (fourth, seventh, or tenth grade in 1993). A set of three regression models was used to adequately account for time, subject, and community-specific effects.

The first model was a linear regression of PFT (natural-log transformed) on age, with indicator variables for subject to obtain a separate intercept and growth slope for each child. Adjustment was made for subject- and time-specific covariates, including height (natural-log

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TABLE 1

CHARACTERISTICS OF THE STUDY POPULATION

		No. of Subjects*	Mean No. PFTs	Female Sex (%)	Grade Cohort (%)			Ever Asthma (%)	Gas Stove (%)	Passive Smoke (%)	Pets (%)	Time Outdoors† (%)
					4th	7th	10th					
Alpine	(AL)	252	3.8	51	51	25	24	14	46	19	88	51
Atascadero	(AT)	233	3.9	59	49	30	21	22	76	12	91	58
Lake Arrowhead	(LA)	286	3.9	52	52	27	21	14	86	19	86	48
Lake Elsinore	(LE)	258	3.7	45	49	24	27	16	75	30	87	56
Lancaster	(LN)	212	3.6	51	52	26	22	14	89	23	72	54
Lompoc	(LM)	248	3.6	50	39	27	34	12	82	18	78	60
Long Beach	(LB)	257	3.7	53	53	25	22	12	82	15	58	45
Mira Loma	(ML)	262	3.8	52	52	27	21	11	94	27	90	52
Riverside	(RV)	285	3.8	53	49	30	21	16	89	19	76	49
San Dimas	(SD)	252	3.9	53	47	27	26	18	90	21	74	52
Santa Maria	(SM)	248	3.6	52	48	26	26	14	85	18	55	49
Upland	(UP)	242	4.0	49	51	24	25	16	73	13	79	52
All		3,035	3.8	52	50	26	24	15	81	20	78	52

* Number of subjects with at least 2 pulmonary function tests from 1993 to 1997.

† Percent of hours spent outdoors between 2:00 P.M. and 6:00 P.M.. over 10 weekdays.

transformed), weight, body mass index, height-by-age interaction, report of asthma activity or cigarette smoking in the previous year, report of recent exercise, and interactions of each of these variables with sex. Also included as adjustment variables were room temperature and barometric pressure on the day of the test, sets of dummy variables for field technician and spirometer. Lung function growth slopes were scaled to a child with average height growth within each cohort.

The second model was a linear regression of the subject-specific adjusted growth slopes estimated from the first model on indicator variables for community, to obtain the annual average lung function growth rate in each community. Adjustment was made for subject-specific covariates, including sex, race/ethnicity (Asian, African-American, non-Hispanic white, Hispanic, other), and baseline report of doctor-diagnosed asthma. Additional variables, including report of hay fever, health insurance, regular vitamin use, and the presence in the home of mildew, pests, cockroaches, house plants, an air conditioner, or water damage were not significantly associated with any lung function growth measure at the 0.15 significance level, making them unlikely confounding variables. Because incorporation of these covariates would reduce sample sizes owing to missing values, they were excluded as adjustment variables in all models. Carpeting in the home was marginally associated with reduced MMEF ($p = 0.09$) and FEF_{75} ($p = 0.09$). Models for these PFTs were estimated both with and without adjustment for carpeting, but in no case did adjustment alter an air pollution effect by more than 3% of the unadjusted estimate. For this reason, and because 7% of subjects would be excluded for missing carpet information, results described in the next section are based on the models without adjustment for this covariate. The residuals from both the first and second regression models satisfied the

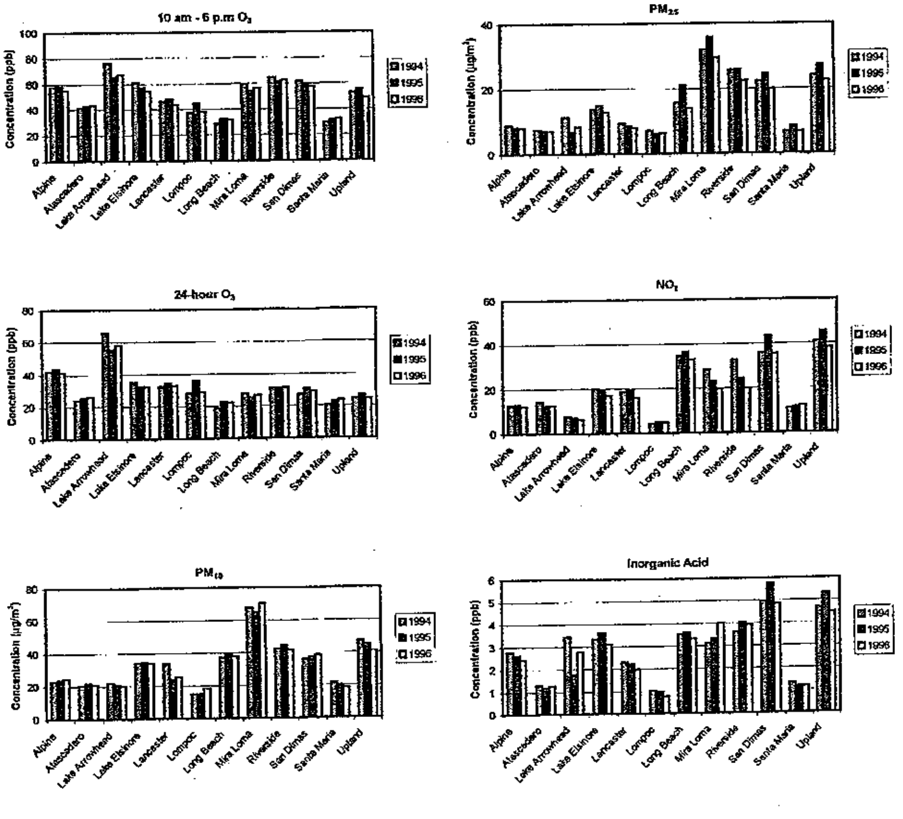

Figure 1. Average annual pollutant concentrations in the 12 study communities.

TABLE 2

CORRELATIONS AMONG COMMUNITY MEAN POLLUTANT LEVELS OVER THE STUDY PERIOD

Pollutant*	O_3	PM_{10}	$PM_{2.5}$	PM_{10}–$PM_{2.5}$	NO_2	Inorganic Acid
O_3 (10 A.M.–6 P.M.)	0.69[†]	0.28	0.35	0.15	0.06	0.50
O_3	—	−0.32	−0.32	−0.29	−0.49	−0.07
PM_{10}	—	—	0.96[‡]	0.92[‡]	0.65[§]	0.68[§]
$PM_{2.5}$	—	—	—	0.76[†]	0.74[§]	0.79[†]
PM_{10}–$PM_{2.5}$	—	—	—	—	0.44	0.43
NO_2	—	—	—	—	—	0.87[‡]

[*] 24-h average (unless otherwise noted) pollution level from 1994–1996.
[†] $p < 0.005$.
[‡] $p < 0.0005$.
[§] $p < 0.05$.

assumptions of normality and homoscedasticity, indicating a good fit of the linear models to the lung function data.

The 12 adjusted community-average lung growth rates from the second model were compared graphically with community mean concentrations of each pollutant, and a third linear regression was used to quantify the change in annual growth per unit increase in pollutant level. The parameter of primary interest was the slope from this third regression. These slopes were reported as the difference in estimated percent growth rate per year between the highest and lowest observed community mean levels of each pollutant, with negative differences indicating reduced growth with increased exposure. In addition to modeling the effect of each pollutant univariately, we considered all possible two-pollutant models, obtained by regressing the community-average lung growth rates on a pair of pollutants simultaneously.

For estimation and testing hypotheses, the three regression models described previously were combined into a single, linear mixed model, so that all parameters were mutually adjusted for one another and the resulting pollution effect estimates properly accounted for the different number of observations provided by each subject. The MIXED procedure in SAS (10) was utilized to fit the models, and a two-sided alternative and 0.05 significance level were used for each hypothesis test.

Additional analyses were conducted to explore the robustness of pollutant effect estimates. Models were also estimated after stratifying the data based on sex, asthma status at baseline, and time spent outdoors. The latter variable was obtained from the baseline questionnaire as the number of weekday hours spent outdoors between 2:00 P.M. and 6:00 P.M. over a 10-weekday period. Responses to this question were used to stratify subjects into either a "more outdoors" or "less outdoors" group, based on whether they fell above or below the mean of 20.8 h (52% of 40 h).

RESULTS

The distribution of subjects with at least two PFTs during the study period is shown in Table 1. The sample included 1,498 fourth-graders in 1993, 802 seventh-graders, and 735 tenth-graders, with an average of 3.8 PFTs per child. Approximately 15% of subjects reported a history of doctor-diagnosed asthma at baseline, a proportion that varied from 11% (Mira Loma) to 22% (Atascadero) across communities. The prevalence of three indoor sources of air pollutants, passive tobacco smoke, gas stove, and the presence of pets, also varied across communities.

There was substantial variation in annual average pollutant concentrations across the 12 communities, with little year-to-year deviation in levels within each community (Figure 1). From least to most polluted community, pollutant concentrations varied by a factor of approximately 2.5 for daytime and 24-h ozone, 4 for PM_{10}, 5 for $PM_{2.5}$, 8 for NO_2, and 5 for inorganic acid. Table 2 shows correlation coefficients between community mean pollutant levels over the study period. Four of the pollutants (PM_{10}, $PM_{2.5}$, NO_2, and inorganic acid) were

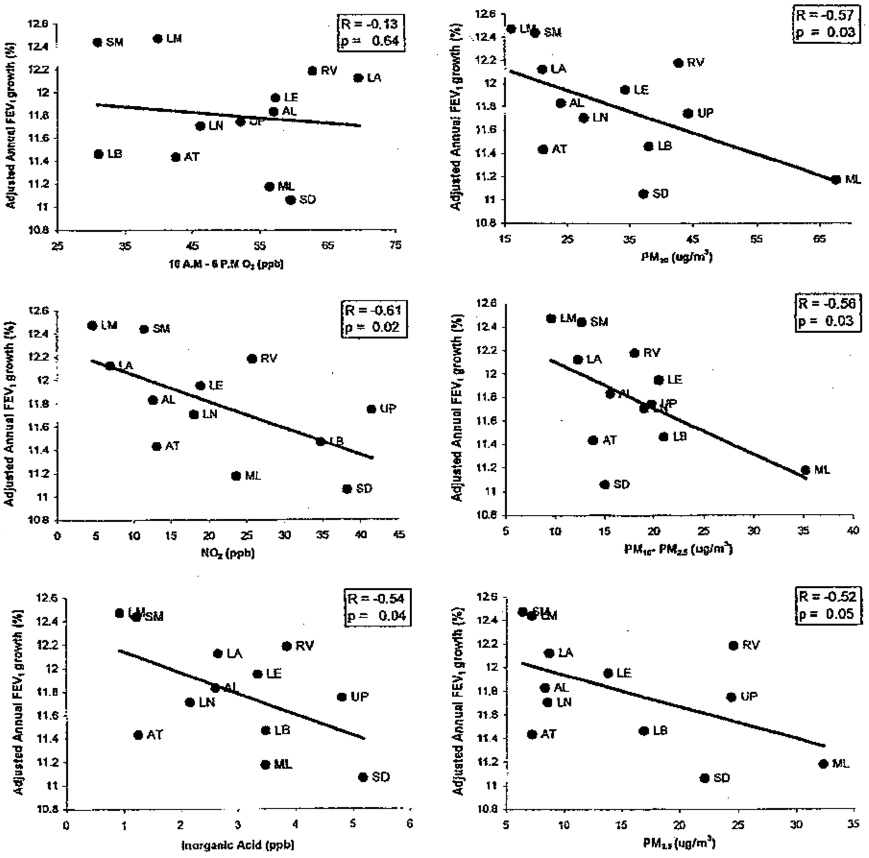

Figure 2. Adjusted average annual FEV_1 growth rates for the fourth-grade cohort in the 12 communities versus the mean pollutant levels over the study period. The two-letter abbreviations for each community are shown in Table 1.

TABLE 3

DIFFERENCE IN ANNUAL PERCENT GROWTH RATES FROM THE LEAST TO MOST POLLUTED COMMUNITY, BY GRADE COHORT

		4th Grade		7th Grade		10th Grade	
		Difference in Growth*		Difference in Growth*		Difference in Growth*	
Pollutant	PFT	%	(95% CI)	%	(95% CI)	%	(95% CI)
O_3 (10–6)	FVC	−0.22	(−0.79, 0.36)	−0.10	(−0.68, 0.47)	0.11	(−0.84, 1.07)
	FEV_1	−0.19	(−0.99, 0.62)	0.20	(−0.41, 0.81)	0.24	(−1.03, 1.54)
	MMEF	−0.24	(−1.41, 0.95)	−0.37	(−2.20, 1.50)	0.29	(−3.50, 4.23)
	FEF_{75}	−0.85	(−2.38, 0.70)	−0.31	(−1.95, 1.35)	0.49	(−3.36, 4.49)
O_3	FVC	0.17	(−0.79, 1.15)	0.39	(−0.51, 1.29)	0.03	(−1.57, 1.65)
	FEV_1	0.56	(−0.73, 1.87)	0.83	(−0.12, 1.79)	0.79	(−1.33, 2.95)
	MMEF	0.96	(−0.84, 2.79)	0.51	(−2.45, 3.56)	0.35	(−5.94, 7.07)
	FEF_{75}	0.69	(−1.88, 3.32)	0.38	(−2.13, 2.95)	1.08	(−5.34, 7.92)
PM_{10}	FVC	−0.58	(−1.14, −0.02)†	−0.45	(−1.03, 0.13)	0.07	(−0.99, 1.13)
	FEV_1	−0.85	(−1.59, −0.10)†	−0.44	(−1.10, 0.23)	−0.46	(−1.84, 0.94)
	MMEF	−1.32	(−2.43, −0.20)†	−0.48	(−2.51, 1.59)	−0.71	(−4.87, 3.63)
	FEF_{75}	−1.63	(−3.14, −0.11)†	−0.50	(−2.26, 1.29)	−1.54	(−5.61, 2.71)
$PM_{2.5}$	FVC	−0.47	(−0.94, 0.01)	−0.42	(−0.89, 0.05)	0.19	(−0.68, 1.07)
	FEV_1	−0.64	(−1.28, 0.01)	−0.32	(−0.88, 0.24)	−0.25	(−1.41, 0.93)
	MMEF	−1.03	(−1.95, −0.09)†	−0.29	(−1.99, 1.44)	−0.17	(−3.66, 3.46)
	FEF_{75}	−1.31	(−2.57, −0.03)†	−0.26	(−1.75, 1.25)	−0.79	(−4.27, 2.82)
PM_{10}–$PM_{2.5}$	FVC	−0.57	(−1.20, 0.06)	−0.35	(−1.02, 0.31)	−0.17	(−1.32, 0.99)
	FEV_1	−0.90	(−1.71, −0.09)†	−0.49	(−1.21, 0.24)	−0.68	(−2.15, 0.81)
	MMEF	−1.37	(−2.57, −0.15)†	−0.64	(−2.83, 1.60)	−1.41	(−5.85, 3.25)
	FEF_{75}	−1.62	(−3.24, 0.04)	−0.74	(−2.65, 1.20)	−2.32	(−6.60, 2.17)
NO_2	FVC	−0.53	(−1.01, −0.05)†	−0.43	(−0.93, 0.07)	−0.23	(−1.13, 0.68)
	FEV_1	−0.77	(−1.41, −0.13)†	−0.41	(−1.00, 0.17)	−0.75	(−1.89, 0.41)
	MMEF	−1.08	(−2.07, −0.08)†	−0.30	(−2.07, 1.49)	−1.13	(−4.68, 2.56)
	FEF_{75}	−1.37	(−2.71, −0.01)†	−0.32	(−1.88, 1.26)	−1.28	(−4.87, 2.44)
Acid	FVC	−0.57	(−1.06, −0.07)†	−0.39	(−0.93, 0.15)	−0.23	(−1.15, 0.70)
	FEV_1	−0.73	(−1.42, −0.03)†	−0.18	(−0.81, 0.44)	−0.65	(−1.84, 0.56)
	MMEF	−1.03	(−2.09, 0.05)	−0.30	(−2.14, 1.57)	−1.31	(−4.93, 2.44)
	FEF_{75}	−1.47	(−2.87, −0.05)†	−0.35	(−1.99, 1.32)	−1.11	(−4.80, 2.71)

* Community-average growth rates were adjusted for the covariates listed in METHODS. Differences in annual percent growth rate are shown per increase in annual average of 38.6 ppb of O_3 (10:00 A.M.–6:00 P.M.), 55 ppb of O_3, 51.5 μg/m^3 of PM_{10}, 25.9 μg/m^3 of $PM_{2.5}$, 25.6 μg/m^3 of PM_{10}–$PM_{2.5}$, 36.8 ppb of NO_2, and 4.3 ppb of inorganic acid vapor.

† $p < 0.05$.

strongly correlated with one another. Coarse thoracic particle level (PM_{10}–$PM_{2.5}$) was significantly correlated with PM_{10} ($r = 0.92$) and $PM_{2.5}$ ($r = 0.76$), but not with any other pollutant. The two O_3 metrics were significantly correlated with each other ($r = 0.69$), but not with any of the remaining pollutants.

In the fourth-grade cohort, FEV_1 increased at an average rate of 11.8% per year during the study period, with comparable growth rates in males (11.7%) and females (11.9%). The average annual FEV_1 growth rates were lower in the seventh-grade (8.0%) and tenth-grade (1.7%) cohorts. In both the seventh- and tenth-grade cohorts, average growth rates for boys (12.3% and 3.3%, respectively) were higher than for girls (4.6% and 0.4%, respectively). The magnitudes and patterns of cohort- and sex-specific growth rates were similar for the other PFTs.

For the fourth-grade cohort, Figure 2 shows the adjusted mean FEV_1 growth rates in each community, plotted against the corresponding mean concentrations of PM_{10}, $PM_{2.5}$, PM_{10}–$PM_{2.5}$, O_3, NO_2, and inorganic acid vapor, with the fitted regression line and correlation coefficient. Across the 12 communities, FEV_1 growth rates ranged from 11.1% (San Dimas) to 12.5% (Lompoc). From the lowest to highest observed concentrations of each pollutant, the predicted differences in annual growth rate were −0.85% for PM_{10} ($p = 0.026$), −0.64% for $PM_{2.5}$ ($p = 0.052$), −0.90% for PM_{10}–$PM_{2.5}$ ($p = 0.030$), −0.77% for NO_2 ($p = 0.019$), and −0.73% for inorganic acid vapor ($p = 0.042$). The slope with 10:00 A.M.–6:00 P.M. average O_3 was negative but nonsignificant. Approximately 35% of the variance in adjusted community-average growth rates was explained by either PM_{10} or NO_2 concentrations. For PM_{10} and PM_{10}–$PM_{2.5}$, the high concentrations in Mira Loma gave this community a large potential influence on the effect estimates. However, elimination of this community from the analysis resulted in slightly larger effect estimates for both PM_{10} (−0.9%) and PM_{10}–$PM_{2.5}$ (−1.2%), although the statistical significance for each was reduced ($p = 0.19$ and $p = 0.18$, respectively) owing to the reduced sample size and range of exposure.

Table 3 shows the corresponding differences in growth rate for all the PFTs in the fourth-, seventh-, and tenth-grade cohorts. In the fourth-grade cohort, significant associations were observed between lung function growth and PM_{10}, $PM_{2.5}$, PM_{10}–$PM_{2.5}$, NO_2, and inorganic acid, with the largest deficits observed for the flow rate measures (MMEF and FEF_{75}). Neither metric of ozone was significantly associated with growth in any of the PFTs. In the seventh- and tenth-grade cohorts, almost all effect estimates for PM_{10}, $PM_{2.5}$, PM_{10}–$PM_{2.5}$, NO_2, and inorganic acid vapor were negative, but the confidence intervals were wide and none of them achieved statistical significance.

The associations observed in the fourth-grade cohort remained significant in a variety of sensitivity analyses. Table 4

TABLE 4

DIFFERENCE IN ANNUAL FEV_1 PERCENT GROWTH RATES FROM THE LEAST TO MOST POLLUTED COMMUNITY FOR PM_{10} AND NO_2, FOURTH GRADE COHORT, FROM A VARIETY OF MODELS

	Ambient PM_{10}		Ambient NO_2	
	Difference in Growth*		Difference in Growth*	
Model	%	(95% CI)	%	(95% CI)
1. Main model†	−0.85	(−1.59, −0.10)‡	−0.77	(−1.41, −0.13)‡
2. 1 + gas stove	−0.88	(−1.63, −0.13)‡	−0.79	(−1.43, −0.15)‡
3. 1 + passive smoke	−0.94	(−1.71, −0.17)‡	−0.83	(−1.50, −0.16)‡
4. 1 + pets	−0.80	(−1.52, −0.08)‡	−0.76	(−1.36, −0.15)‡
5. 1, nonasthmatics only	−0.82	(−1.48, −0.15)‡	−0.68	(−1.30, −0.05)‡
6. 1, asthmatics only	−0.75	(−2.84, 1.38)	−1.39	(−2.96, 0.20)

* *See* footnote to Table 3.

† Equivalent to the results for FEV_1 in fourth graders shown in Table 3.

‡ $p < 0.05$.

shows effect estimates for PM_{10} and NO_2 on FEV_1 from several models, with the corresponding estimates from Table 3 included for comparison (Model 1). Adjustment for gas stove (Model 2), passive smoke (Model 3), or pets (Model 4) resulted in little change in effect estimates or statistical significance. The associations also remained significant in the subset of nonasthmatic children (Model 5). In asthmatic children (Model 6), although the effect estimates were as large for PM_{10} and larger for NO_2, the sample size was small (n = 207) and neither association achieved statistical significance. Analogous sensitivity modeling of the other PFTs produced results similar to those shown for FEV_1.

In two-pollutant models for FEV_1, adjustment for community mean concentration of 10:00 A.M.–6:00 P.M. O_3 had little impact on the effect estimates or significance levels of any other pollutant (Table 5, column 1). The O_3 effect estimates with adjustment for any other pollutant were all close to zero and nonsignificant (Table 5, row 1). In a two-pollutant particle model, both the $PM_{2.5}$ and PM_{10}–$PM_{2.5}$ effect estimates were negative (−0.54 and −0.63, respectively), but each was lower than its corresponding univariate estimate (−0.64 and −0.90, respectively). This reduction of the particle effect estimates in the two-pollutant model is expected given the positive correlation between these pollutants (Table 2). Similarly, the effect estimates for other two-pollutant combinations are less than their corresponding univariate estimates, although in almost all cases they retain their negative sign.

TABLE 5

DIFFERENCE IN ANNUAL FEV_1 PERCENT GROWTH RATES FROM THE LEAST TO THE MOST POLLUTED COMMUNITY, FOURTH-GRADE COHORT, TWO-POLLUTANT MODELS

	Adjustment Pollutant					
Main Pollutant*	O_3 (10–6)	PM_{10}	$PM_{2.5}$	PM_{10}–$PM_{2.5}$	NO_2	Acid
1. O_3 (10–6)	**−0.19**	0.03	0.06	−0.08	0.15	0.24
2. PM_{10}	−0.86†	**−0.85**†	−1.27	−0.54	−0.48	−0.56
3. $PM_{2.5}$	−0.67‡	0.37	**−0.64**‡	−0.54	−0.45	−0.61
4. PM_{10}–$PM_{2.5}$	−0.89†	−0.37	−0.63	**−0.90**†	−0.61	−0.65
5. NO_2	−0.76†	−0.50	−0.60	−0.56	**−0.77**†	−0.65
6. Acid	−0.86†	−0.39	−0.47	−0.50	−0.14	**−0.73**†

* Each row gives effect estimates for the indicated pollutant, after adjustment for the pollutant listed at the top of the column. Boldface estimates are from the single-pollutant models shown in Table 3. *See* Table 3, footnote *, for a description of units.

† $p < 0.05$.

‡ $p < 0.10$.

The magnitude of air pollutant effects in the fourth-grade cohort was greater in those who spent more time outdoors than in those who spent more time indoors (Table 6). For example, the difference in annual FEF_{75} growth rate from highest to lowest NO_2 concentrations was −2.49% (p = 0.02) in more-outdoors children, but only −1.12% (p = 0.35) in less-outdoors children. There were no clear trends in the relationships between lung function growth and ozone as they related to time spent outdoors. In a separate analysis, stratification by sex in the fourth-grade cohort revealed negative effect estimates for particulates, NO_2, and inorganic acid vapor in both males and females (data not shown), with no significant difference in effect between the sexes.

Based on the estimated adjusted annual growth rates in the fourth-grade cohort, Table 7 shows estimates of the cumulative deficit in lung function caused by 4 yr of air pollution exposure. Predicted lung function in 1997 for a child exposed to the highest observed concentrations of PM_{10} or NO_2 since 1993 were between 93.9% and 97.9% of those predicted for the same child exposed to the lowest observed concentrations. The flow rates (MMEF and FEF_{75}) showed larger deficits in predicted lung function than the volume measures (FVC and FEV_1).

TABLE 6

DIFFERENCE IN ANNUAL PERCENT GROWTH RATES FROM LEAST TO MOST POLLUTED COMMUNITY FOR CHILDREN IN THE FOURTH-GRADE COHORT, STRATIFIED BY TIME OUTDOORS

		More Outdoors* (*n* = *532*)		Less Outdoors* (*n* = *642*)	
		Difference in Growth†		Difference in Growth†	
Pollutant	PFT	%	(95% CI)	%	(95% CI)
O_3 (10–6)	FVC	0.12	(−0.54, 0.78)	−0.05	(−0.63, 0.53)
	FEV_1	−0.11	(−1.19, 0.99)	−0.10	(−0.79, 0.60)
	MMEF	−0.46	(−2.52, 1.64)	0.16	(−1.34, 1.69)
	FEF_{75}	−0.41	(−2.73, 1.98)	−0.76	(−3.15, 1.69)
O_3	FVC	0.41	(−0.60, 1.43)	0.23	(−0.68, 1.14)
	FEV_1	0.91	(−0.64, 2.47)	0.76	(−0.35, 1.87)
	MMEF	1.50	(−1.40, 4.48)	2.16	(−0.26, 4.64)
	FEF_{75}	1.81	(−1.72, 5.47)	1.78	(−1.97, 5.68)
PM_{10}	FVC	−0.24	(−0.91, 0.45)	−0.60	(−1.22, 0.01)
	FEV_1	−0.87	(−1.86, 0.14)	−0.81	(−1.57, −0.03)‡
	MMEF	−1.88	(−3.55, −0.17)‡	−1.20	(−2.86, 0.49)
	FEF_{75}	−2.34	(−4.65, 0.03)	−0.88	(−3.53, 1.83)
$PM_{2.5}$	FVC	−0.17	(−0.74, 0.40)	−0.45	(−0.97, 0.07)
	FEV_1	−0.67	(−1.53, 0.21)	−0.68	(−1.32, −0.03)‡
	MMEF	−1.56	(−3.00, −0.10)‡	−1.09	(−2.49, 0.33)
	FEF_{75}	−1.92	(−3.88, 0.08)	−1.15	(−3.26, 1.01)
PM_{10}–$PM_{2.5}$	FVC	−0.27	(−1.00, 0.46)	−0.65	(−1.31, 0.01)
	FEV_1	−0.93	(−1.98, 0.14)	−0.75	(−1.57, 0.07)
	MMEF	−1.83	(−3.73, 0.10)	−0.98	(−2.76, 0.83)
	FEF_{75}	−2.29	(−4.78, 0.27)	−0.15	(−3.13, 2.91)
NO_2	FVC	−0.41	(−1.02, 0.20)	−0.30	(−0.87, 0.28)
	FEV_1	−1.00	(−1.79, −0.21)‡	−0.57	(−1.29, 0.15)
	MMEF	−1.90	(−3.39, −0.39)‡	−1.13	(−2.68, 0.44)
	FEF_{75}	−2.49	(−4.57, −0.36)‡	−1.12	(−3.43, 1.25)
Acid	FVC	−0.33	(−0.97, 0.32)	−0.32	(−0.94, 0.30)
	FEV_1	−0.93	(−1.87, 0.01)	−0.55	(−1.31, 0.23)
	MMEF	−1.88	(−3.58, −0.14)‡	−0.89	(−2.55, 0.80)
	FEF_{75}	−2.34	(−4.55, −0.08)‡	−1.13	(−3.60, 1.41)

* More (less) outdoors includes subjects who reported being outdoors more than (less than) 52% of the hours between 2:00 P.M. and 6:00 P.M. over a 10-d period.

† *See* footnote to Table 3.

‡ $p < 0.05$.

TABLE 7

PREDICTED LUNG FUNCTION IN 1997 FOR A CHILD IN THE FOURTH-GRADE COHORT EXPOSED TO 4-yr OF EITHER LOW OR HIGH POLLUTION LEVELS

	FVC *(ml)*	FEV_1 *(ml)*	MMEF *(ml/s)*	FEF_{75} *(ml/s)*
Mean in 1993	2,365	2,048	2,366	1,479
Predicted in 1997*				
Lowest pollution	3,713	3,238	3,695	2,403
Highest PM_{10}	3,622 (97.5%)†	3,127 (96.6%)	3,511 (95.0%)	2,257 (93.9%)
Highest NO_2	3,637 (97.9%)	3,145 (97.1%)	3,549 (96.0%)	2,284 (95.0%)

* Predicted lung function was obtained by applying the estimated adjusted annual growth rates in the least and most polluted communities to the 1993 values. For example, rates used for FEV_1 are based on the regression line shown in Figure 2. Lowest pollution corresponds to levels in Lompoc, with average PM_{10} = 16.1 μg/m³ and NO_2 = 4.6 ppb, while highest PM_{10} = 67.6 μg/m³ (Mira Loma) and highest NO_2 = 41.4 ppb (Upland).

† Percent of the predicted value for lowest pollution exposure.

DISCUSSION

In our fourth-grade cohort of southern California children, exposure to ambient particles, NO_2, or inorganic acid vapor was associated with reduced lung function growth. Negative pollution effect estimates were observed in both asthmatic and healthy children. In contrast to our previous cross-sectional findings (7), where pollutant effects on lung function level were observed primarily in females, we found no significant difference between the sexes in the relationship between lung function growth and air pollution. Over the 4 yr of follow-up, children exposed to the highest observed concentrations of PM_{10} were estimated to experience a cumulative deficit of 3.4% in FEV_1 and 6.1% in FEF_{75}, relative to children exposed to the lowest observed levels. This indicates that pollutants may impair both large and small airway function, although there were larger estimated deficits observed in measures of small airway damage (MMEF and FEF_{75}). In the seventh- and tenth-grade cohorts, confidence intervals on the pollutant effect estimates were wide owing to the smaller sample sizes in these groups, and none of the associations was statistically significant at the 5% level. However, the pollutant effect estimates were negative in both the seventh- and tenth-grade cohorts, indicating that the deficits observed for children in the fourth-grade cohort are not likely to be reversed as they age through adolescence.

As in any epidemiologic study, it is possible that the observed results are the result of underlying associations of both the outcome and exposure to some confounding variable. In our study, several potential confounders were considered, including personal and housing characteristics and indoor sources of air pollutants, but none explained the observed associations between ambient air pollution and lung function growth. Additional analysis showed that neither air pollution concentrations on the day before to the PFT nor acute respiratory illness on the day of the PFT were confounders. Another potential source of bias in a cohort study is differential loss to follow-up with respect to both exposure and outcome. This could occur, for example, if a child in a polluted community moved away because air pollution was adversely affecting his or her respiratory health. However, baseline lung function levels and community mean ambient pollutant exposure were not significantly different between subjects who left the study within 2 yr of entry compared with those who remained on study, making this an unlikely source of bias.

Ambient air pollution was associated with larger estimated deficits in lung function growth, particularly for MMEF and FEF_{75}, in children who spent more time outdoors than in children who spent more time indoors. Provided exposures are higher in children spending more time outdoors than indoors, this finding is consistent with a detrimental effect of ambient pollutants on lung function growth. The indoor/outdoor (I/O) ratio, i.e., the amount of outdoor air pollutant that penetrates indoors, has an upper bound of 1.0 (complete penetration) and a lower bound of 0.0 (no penetration). Interestingly, the pollutants with lower I/O ratios (e.g., PM_{10}–$PM_{2.5}$, NO_2) show larger discrepancies in effect estimates between more- and less-outdoor children than $PM_{2.5}$, which has a high I/O ratio. This pattern is what one would expect if exposure to one or more of these ambient pollutants is having an adverse effect. Although indoor concentrations of ozone are known to be much lower than outdoor levels, there were no apparent trends in ozone effect estimates with respect to time spent outdoors.

In southern California, motor vehicle emissions, in conjunction with various photochemical reactions, are a major source of ambient particles, NO_2, and inorganic acid (primarily nitric). Due to the high correlation in concentrations across communities, we were unable to identify the independent effects of each pollutant, although our two-pollutant models do suggest that no single pollutant that we measured is responsible for the observed deficits in lung function growth. There may also be an air pollutant we did not specifically measure (e.g., diesel exhaust particles) that is correlated with those we did and that is primarily responsible for the observed health effects. Associations between lung function and mixtures of air pollutants have also been previously demonstrated (7, 11–14).

In prior studies, particulate matter has been associated with chronic respiratory symptoms (15–18) and recently with lung function growth in children (19), although previously reported associations with lung function have been inconsistent (15–17). Particle strong acidity, characterized by sulfur dioxide–derived acidic sulfate particles, has been associated with bronchitis (17) and lung function (20). It is unlikely that this pollutant is responsible for our observed effects, because ambient air during the 1990s in southern California had low concentrations of SO_2 and acidic sulfate particles. As in most regions, fine and coarse particle concentrations in the Los Angeles air basin arise from different sources (21). The primary sources that contribute to fine particle concentrations are diesel engine exhaust, food cooking operations, wood burning, and fine diameter paved and unpaved road and crustal dust (22). Emissions from gasoline power engines and other combustion sources make smaller contributions. Primary sources for coarse particle concentration are paved and unpaved road dust and crustal material, which accounts for 45% of the PM_{10} mass concentration, and transformed sea-salt particles that are formed over the ocean and transported to the basin by prevailing winds. These sources produce a background aerosol that further interacts with gas-phase combustion emissions whose chemical characteristics evolve during atmospheric reactions to produce particulate-phase ammonium nitrate, ammonium sulfate, and secondary organic carbon compounds. The gas-to-particle conversion processes continue as the aerosol ages and moves downwind resulting in increases in concentration and composition changes of particles until fine particle mass is primarily composed of secondary reaction products.

The emission sources and atmospheric processes that produce particulates have implication for the interpretation of our data. Because the processes are coupled, characteristics of the atmospheric aerosol are spatially and temporally correlated. Areas with the highest mass concentration of PM_{10} and $PM_{2.5}$ also have the highest secondary aerosol concentrations (ammonium nitrate, ammonium sulfate) and the gas phase with the greatest age from time of emission. It follows that any chronic respiratory effects associated with particulate mass concentration might be explained by particle primary sources or by particle composition or concentrations of other pollutants that are positively correlated with the age of the aerosol. Our current exposure data do not permit us to discriminate among these possibilities.

Unlike other atmospheric pollutants, the effect of NO_2 has been examined in epidemiologic studies relatively unconfounded by multiple pollutant mixes, because NO_2 is common in indoor air contaminated by emissions from pilot lights and gas stoves at concentrations that may approach outdoor levels. Animal studies suggesting that NO_2 may enhance the infectivity of respiratory pathogens have resulted in extensive study of the effects of gas stoves on illness and lung function (2). In one of the few prospective studies in humans, Dutch children were followed over a 2-yr period with serial lung function measurements, but there was no consistent relationship between growth of lung function and a single measurement of indoor NO_2 (23). In early analyses of data from the Six Cities studies, lower levels of FEV_1 and FVC were observed in children living in homes with gas stoves (24, 25), but in subsequent analysis there was no evidence that lung function growth was correlated with gas stove exposure (26). In a subsample of children from the Six Cities study for whom indoor NO_2 was measured, there was no consistent effect of measured NO_2 on lung function level in spite of a relatively strong association between respiratory symptoms and NO_2 (27). Other studies of the effect of indoor sources of NO_2 on lung function in children have also not been consistent (2).

The high ambient concentration of NO_2 is the primary source of gaseous nitric acid present in southern California air. Although there has been little previous epidemiologic study of nitric acid, exposure to 50 parts per billion (ppb) in chamber studies has been shown to result in modest acute reductions in FEV_1 among children with asthma (28). In an epidemiologic study of Dutch children, modest acute deficits in flow rates were associated with same-day exposure to low levels of ambient nitrous acid (29), a gaseous acid that exists in equilibrium with nitric acid. In a large cross-sectional study of children in 24 North American cities, decrements in FVC and FEV_1 were associated with chronic exposure to strong acid sulfate aerosols after adjustment for ozone exposure (20). Experimental and toxicologic studies of acid sulfate aerosols suggest that the irritant potential is related to the H^+ concentration, especially in association with metal ions (1). However, it is not clear that the effects of gaseous nitric acid are the same as for acid sulfate aerosols, even if H^+ is responsible for lung damage. Gaseous nitric acid may be buffered differently by oral ammonia, or variations in deposition by particle size for sulfate aerosols may result in respiratory effects that differ from those of nitric acid.

In a recent longitudinal study of children in Austria, Frischer and coworkers concluded that exposure to ambient ozone was associated with reduced lung function growth (30), although they also observed significant associations with NO_2, SO_2, and PM_{10}. Some additional epidemiologic studies have also suggested that chronic exposure to ozone has long-term effects on lung function (31, 32), findings that have some support from animal studies (1). However, interpretation of the existing epidemiologic evidence is hampered by inability to separate the effects of other copollutants from the effects of ozone (33). The present study was originally designed to assess the independent effects of ozone by minimizing its correlation with other copollutants, and, as expected, observed long-term average ozone concentrations were not significantly correlated with the other pollutants (Table 2). In light of this, our results provide little support for a substantial long-term effect of ozone on lung function growth in children. This could potentially be explained by misclassification of exposure from using central monitor pollutant levels or by low sensitivity of spirometry to detect small airway effects. However, we observed consistent effects for other pollutants using the same exposure estimation methodology, indicating that the lack of an observed ozone effect is unlikely to be the result of these factors. As shown in Figure 1, the variation across communities in mean ozone concentrations (approximately twofold from least to most polluted) was less than for the other pollutants. This modest range in ozone exposure, in conjunction with the low I/O ratio of ambient ozone, may also explain why we did not observe a significant ozone association.

In summary, we obtained annual lung function measures on a cohort of 3,035 school-aged children over a 4-yr period. After appropriate adjustment for personal and household characteristics, ambient air pollution was correlated with statistically significant, and perhaps physiologically important, decreases in lung function growth. The estimated deficit in annual FEV_1 growth rate of 0.9% per year across the range of PM_{10} exposure exceeds the 0.2% annual decrement that has been reported for passive smoke exposure in children (26). The results suggest that exposure to air pollution may lead to a reduction in maximal attained lung function, which occurs early in adult life, and ultimately to increased risk of chronic respiratory illness in adulthood. Data from the remainder of our study will help to elucidate the relationships between respiratory health and long-term exposure to ambient air pollutants, while additional follow-up of the cohort beyond graduation will be necessary to determine whether the observed air pollution–associated deficits in lung function have an impact on adult respiratory health.

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Merced/Mariposa County Asthma Coalition

Report to the Community on Asthma

The Merced/Mariposa County Asthma Coalition (MMCAC) is a community-based health organization whose mission is: Controlling asthma through awareness and education. The coalition was formed in 1997, and since then has grown into a diverse body consisting of over 120 volunteer members.

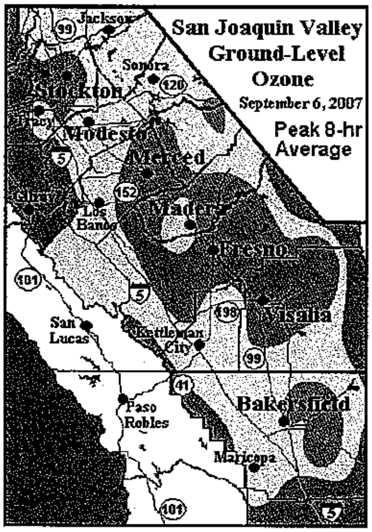
CONTROLLING ASTHMA THROUGH AWARENESS AND EDUCATION.

ASTHMA, AN INFLAMMATORY LUNG DISEASE, is one of the most common chronic diseases of children. Common symptoms include recurrent wheezing, coughing, difficulty breathing, and/or tightness of the chest. Asthma attacks can range from mild to life threatening. There is no known cure for asthma, but it can be controlled by following a medical management plan and by reducing exposure to environmental "triggers," such as air pollution, pollen, tobacco smoke, pesticides, dust mites, furry pets, mold and certain chemicals. Asthma control is essential throughout life because, contrary to popular belief, you do not grow out of asthma. Health care providers can access the updated Asthma Guidelines at www.nhlbi.nih.gov

Asthma is a problem that needs to be addressed through policy change. Because the reduction of environmental triggers is an essential component of asthma control and prevention, individuals, communities, and policy makers must work together to find solutions. This report, which includes the latest data and research, will outline the problem of asthma in Merced County, describe some of the work being done to address the problem, and highlight some specific policy recommendations.

Asthma Disparities in the San Joaquin Valley

- Asthma is among the most common chronic childhood diseases, affecting approximately 6.5 million children nationwide including 1.7 million children in California alone. The San Joaquin Valley (Valley), which includes Merced County, has four times the national average for asthma prevalence with one in five children under the age of 18 diagnosed with asthma.[1,2]
- The burden of asthma weighs heavily on children throughout the Valley. Approximately 9,600 children under the age of 18 living in the Valley visited an emergency room due to asthma-related issues of which 745 were children living in Merced County.[3]



High Levels of Ozone Pollution Persist in the San Joaquin Valley in Summer

Environmental Triggers of Asthma: Outdoor Air Pollution

Air pollution is the number one environmental concern for the people of the Valley,[4] and for good reason – the Valley has some of the most polluted air in the country.[5] Air pollution endangers the health of residents, retards the growth of crops, and threatens the overall economy and quality of life in the region.

Contrary to popular belief, the majority of pollution in the Valley does not come from outside the area. In the Northern part of the Valley, including Merced County, 73% of pollution comes from local sources as opposed to only 27% that is transported from the Bay Area and Sacramento basins.[6]

The geography of the Valley acts as a trap for outdoor air pollution. Surrounding mountains trap airborne pollutants near the Valley floor where people live and breathe. Population growth also contributes to the problem, as more people bring more activities that contribute to poor air quality.

According to the Department of Finance[7], the Valley has the fastest growing population in California. As such, land-use is rising to the top of the agenda given increasingly limited resources and an economy historically rooted in agriculture. The built environment has a tremendous impact on quantity of and exposure to air pollution. In order to maintain healthy communities, smart growth principles must be the guiding principles of all land-use plans. Smart growth policies include: mixed land uses, walkable communities, preservation of open space, the enhancement of existing communities, and a variety of transportation choices.[8]

Health Impacts of Air Pollution

Pollution impacts residents year-round with ozone (aka "smog") filling the Valley during the warm summer months, and particulate matter (PM 2.5) being the pollutant of concern in the Fall and Winter seasons. These two contaminants are devastating to lung and heart health and result in serious long term damage to our bodies that can even result in premature death. Ozone, caused from the combination of Nitrous Oxides (NOx) and Volatile Organic Compounds (VOCs) in heat can cause chest pain, shortness of breath, airway inflammation and asthma attacks.[9]

Fine particles, or PM 2.5, are microscopic solids or liquid droplets that can be breathed deep into the lungs and even absorbed into the bloodstream. When people are exposed to high levels of this type of pollution they are more likely to experience: asthma attacks, bronchitis, decreased lung function, heart attacks, and/or premature death.[10]

Findings Related to Outdoor Pollution and Health

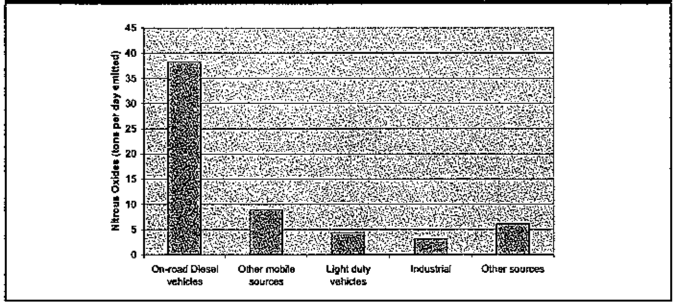
- Residential proximity to high-traffic roads has been associated with asthma hospitalizations, respiratory symptoms, and compromised lung function in children.[11]
- Children living in communities with higher concentrations of pollutants had lungs that developed and grew more slowly than other children and thus, had a reduced ability of transporting air through their lungs.[12]
- Children living in high ozone communities and who actively participated in sports were more likely to develop asthma than children who did not participate in sports.[13]
- Overall, Valley residents could expect annual benefits of $3.2 billion if both fine particulate matter and ozone Federal levels were attained.[14]

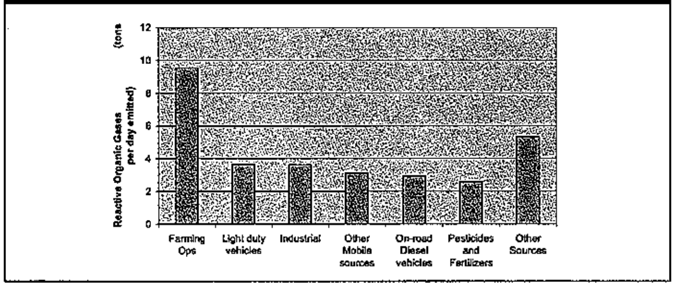
Sources of Pollution

There is a wide array of pollution sources in Merced County. The top three sources of PM 2.5 in Merced

County in 2005 were heavy duty diesel trucks (14.8%), fugitive windblown dust from agricultural land and unpaved roads (13.2%), and farming operations including dust (11.8%).[15]

Ozone Precursors: The following two graphs detail the top contributors to ozone pollution in Merced County in 2006.[16]


Merced County Nox Emissions


Merced County ROG Emissions

A Big Problem for Merced County

All of this pollution leads to the violation of health-based National and State Ambient Air Quality Standards in Merced County and the San Joaquin Valley Air Basin. For example, from 2000-2005 Merced County violated the State 8-hour ozone standard on 525 days and the National 8-hour ozone standard on 194 days![17]

BECAUSE OF THIS:

- Merced County was ranked 8th in the national list of "People at Risk in 25 Most Ozone-Polluted Counties.[18]
- The city of Merced ranked 6th in the national list of "People at Risk in 25 Most Ozone-Polluted Cities".[19] Of the top 6 most ozone-polluted cities in the nation, four (Bakersfield, Visalia-Porterville, Fresno-Madera, and Merced) are located in the San Joaquin Valley.

Keeping Children Healthy: Solutions in Schools

OUTDOOR AIR QUALITY FLAG PROGRAM

In 2004, the Merced/Mariposa County Asthma Coalition launched the Outdoor Air Quality Flag Program at Merced County Office of Education campuses. Since then, this innovative program has spread to 21 of 22 public school districts in the County, private schools, hospitals, health centers, Head Start, and Migrant Head Start sites. In total, over 130 flags are flying on local flag poles that signify daily air pollution levels in the County.

Everyday, each participating school raises a flag that corresponds with the colors of the Air Quality Index. On a 'Good' air quality day the green flag is raised on the flag pole while a yellow flag goes up on a 'Moderate' day. An orange flag means the air is 'Unhealthy for Sensitive Groups' such as children, seniors, and people with heart and/or lung disease. A red flag means the air is 'Unhealthy' for everyone.

Given the frequency of unhealthy air days throughout the year in the Valley it is essential for Merced County residents, especially children, to take measures that reduce their exposure to harmful pollutants. To that end the MMCAC has created (in partnership with other organizations) the Active Indoor Recess (AIR) curriculum that outlines indoor activities students may do on poor outdoor air quality days during recess and PE.

INDOOR AIR QUALITY PROGRAM

Merced County faces many challenges when addressing outdoor air quality issues; however, there are times when indoor air pollutants could be 2-5 times higher, and occasionally 100 times higher than outdoor levels. Poor indoor air quality (IAQ) can cause headaches, fatigue, sinus congestion, coughing, and sneezing; it can also promote the spread of airborne infectious diseases. Indoor air pollutants can be particularly harmful to students with allergies or asthma.[20]

The MMCAC collected data from 106 teachers through a "Teacher's Classroom Checklist" tool. The following data concludes there is more work to do in creating healthy classrooms and better IAQ in schools.

- 40% of participating teachers reported they did not know how their Heating, Ventilation, and Air Conditioning System worked or that they needed follow-up to ensure the unit's proper function.
- 21% of participating teachers reported there were water stains on their classroom ceilings or evidence of leaks or moisture.
- 24% of participating teachers reported their rooms were not dusted and swept or vacuumed regularly.
- 36% of participating teachers were unsure whether the cleaning products in their rooms were district approved or not.

The Merced/Mariposa County Asthma Coalition has partnered with four Merced County schools to evaluate campuses, educate teachers, and implement strategies and policies that would improve indoor air quality in classrooms. By applying the EPA's Indoor Air Quality Tools for Schools program to existing policies and procedures, schools identify no-cost / low-cost solutions that promote an "asthma-friendly" classroom free of indoor environmental triggers. Some of these solutions may include maintaining the continual and uninterrupted exchange of air through Heating, Ventilation, and Air Conditioning systems, removal of scented products in School District classrooms (candles, air fresheners, perfumes, etc.), and the purchase and use of "Environmentally-Preferred Products" in custodial practices that emit the lowest amount of odor and Volatile Organic Compounds.

POLICY RECOMMENDATIONS

Preventing people, especially children, from exposure to environmental asthma triggers, particularly indoor and outdoor air pollution, and reducing the amount of pollution being emitted into the ambient air are both critical in the reduction of the asthma burden in Merced County. Therefore, the Merced/Mariposa County Asthma Coalition proposes the following policy recommendations:

- Support expedient regional attainment of the 8-hour ozone and PM 2.5 State and National Ambient Air Quality Standards.
- Adopt standards in land use plans that incorporate smart growth principles and reject land uses that attract/emit high levels of pollutants, particularly diesel emissions, in order to protect the health of Merced County residents and downwind Valley communities.
- Adopt a uniform policy (ex. AIR) in all Merced County School Districts outlining appropriate indoor activities for unhealthy air days over Air Quality Index 100 as a component of school procedures and guidelines.
- Implement a comprehensive and effective Indoor Air Quality Management Plan in Merced County School Districts with set policies and procedures.

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CONTACT INFORMATION

For more information about this report card, please contact the Merced/Mariposa County Asthma Coalition at (209) 385-5490 or visit www.mmcac.com

CAFA

Community Action to Fight Asthma

Funded by The California Endowment

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Espinosa, Kim

From: Anna M. Garcia [agarcia@gvhc.org]
Sent: Tuesday, March 03, 2009 8:09 AM
To: Espinosa, Kim
Subject: Hello Kim Espinosa

I am emailing you to ask for an extension on the comment period for the EIR for the Wal Mart Distribution center. It is unfair for those who speak foreign languages and I do believe that translating the important part of the EIR should be done. After all it is people with language barriers who have to live near this "project" and to be fair in a nation that stands for land of the free for all.

Thank you,

Anna M Sanchez Garcia
Community Liaison
Merced/Mariposa County Asthma Coalition
Golden Valley Health Center
737 W. Childs Ave
Merced, CA 95341
209-385-5490 (Work)
209-675-0237 (Cell)
209-384-3966 (Fax)
agarcia@gvhc.org

STATE OF CALIFORNIA **Arnold Schwarzenegger, *Governor***

NATIVE AMERICAN HERITAGE COMMISSION
915 CAPITOL MALL, ROOM 364
SACRAMENTO, CA 95814
(916) 653-4082
(916) 657-5390 - Fax

19

RECEIVED
MAR - 4 2009
CITY OF MERCED
PLANNING DEPT.

March 2, 2009

Kim Espinosa
City of Merced
678 West 18th Street
Merced, CA 95340

RE: SCH# 2006071029 Wal-Mart Distribution Center; Merced County.

Dear Ms. Espinosa:

The Native American Heritage Commission has reviewed the Notice of Completion (NOC) regarding the above referenced project. The California Environmental Quality Act (CEQA) states that any project that causes a substantial adverse change in the significance of an historical resource, which includes archeological resources, is a significant effect requiring the preparation of an EIR (CEQA guidelines 15064(b)). To adequately comply with this provision and mitigate project-related impacts on archaeological resources, the Commission recommends the following actions be required:

- ✓ Contact the appropriate Information Center for a record search to determine:
  - If a part or all of the area of project effect (APE) has been previously surveyed for cultural resources.
  - If any known cultural resources have already been recorded on or adjacent to the APE.
  - If the probability is low, moderate, or high that cultural resources are located in the APE.
  - If a survey is required to determine whether previously unrecorded cultural resources are present.
- ✓ If an archaeological inventory survey is required, the final stage is the preparation of a professional report detailing the findings and recommendations of the records search and field survey.
  - The final report containing site forms, site significance, and mitigation measurers should be submitted immediately to the planning department. All information regarding site locations, Native American human remains, and associated funerary objects should be in a separate confidential addendum, and not be made available for pubic disclosure.
  - The final written report should be submitted within 3 months after work has been completed to the appropriate regional archaeological Information Center.
- ✓ Contact the Native American Heritage Commission for:
  - A Sacred Lands File Check. **Sacred Lands File check completed, no sites indicated**
  - A list of appropriate Native American Contacts for consultation concerning the project site and to assist in the mitigation measures. **Native American Contacts List attached**
- ✓ Lack of surface evidence of archeological resources does not preclude their subsurface existence.
  - Lead agencies should include in their mitigation plan provisions for the identification and evaluation of accidentally discovered archeological resources, per California Environmental Quality Act (CEQA) §15064.5(f). In areas of identified archaeological sensitivity, a certified archaeologist and a culturally affiliated Native American, with knowledge in cultural resources, should monitor all ground-disturbing activities.
  - Lead agencies should include in their mitigation plan provisions for the disposition of recovered artifacts, in consultation with culturally affiliated Native Americans.
  - Lead agencies should include provisions for discovery of Native American human remains in their mitigation plan. Health and Safety Code §7050.5, CEQA §15064.5(e), and Public Resources Code §5097.98 mandates the process to be followed in the event of an accidental discovery of any human remains in a location other than a dedicated cemetery.

Sincerely,

Katy Sanchez

Katy Sanchez
Program Analyst
(916) 653-4040

CC: State Clearinghouse

ative American Contact
Merced County
March 2, 2009

Southern Sierra Miwuk Nation
Jay Johnson, Spiritual Leader
5235 Allred Road
Mariposa , CA 95338
209-966-6038

Miwok
Pauite
Northern Valley Yokut

Southern Sierra Miwuk Nation
Les James, Spiritual Leader
PO Box 1200
Mariposa , CA 95338
209-966-3690

Miwok
Pauite
Northern Valley Yokut

North Valley Yokuts Tribe
Katherine Erolinda Perez
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Linden , CA 95236
(209) 887-3415

Ohlone/Costanoan
Northern Valley Yokuts
Bay Miwok

Amah MutsunTribal Band
Edward Ketchum
35867 Yosemite Ave
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Ohlone/Costanoan
Northern Valley Yokuts

Southern Sierra Miwuk Nation
Anthony Brochini, Chairperson
P.O. Box 1200
Mariposa , CA 95338
tony_brochini@nps.gov
209-379-1120
209-628-0085 cell

Miwok
Pauite
Northern Valley Yokut

This list is current only as of the date of this document.

Distribution of this list does not relieve any person of statutory responsibility as defined in Section 7050.5 of the Health and Safety Code, Section 5097.94 of the Public Resources Code and Section 5097.98 of the Public Resources Code.

This list is only applicable for contacting local Native Americans with regard to cultural resources for the proposed SCH# 2006071029 Wal-Mart Distribution Center; Merced County.

SOUTHERN SIERRA MIWUK NATION
JAY JOHNSON, SPIRITUAL LEADER
5235 ALLRED ROAD
MARIPOSA CA 95338

SOUTHERN SIERRA MIWUK NATION
LES JAMES, SPIRITUAL LEADER
P O BOX 1200
MARIPOSA CA 95338

NORTH VALLEY YOKUTS TRIBE
KATHERING EROLINDA PEREZ
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LINDEN CA 95236

AMAH MUTSUN TRIBAL BAND
EDWARD KETCHUM
35867 YOSEMITE AVE
DAVIS CA 95616

SOUTHERN SIERRA MIWUK NATION
ANTHONY BROCHINI, CHAIRPERSON
P O BOX 1200
MARIPOSA CA 95338

Mailed Wal-Mart Draft EIR on CD
3-4-2009 by T. Lucas

See 3-2-2009 correspondence from the
Native American Heritage Commission
Station of California (scanned)

20

Espinosa, Kim

From: Maureen McCorry [sanjoaquinetal@sbcglobal.net]
Sent: Monday, April 27, 2009 4:47 PM
To: Espinosa, Kim
Cc: mccorrymk@gmail.com
Subject: Draft Environmental Impact Report for the proposed Wal-Mart Distribution Center (SCH#2006071029)

Dear Ms. Espinosa,

Please refer to the attached document for comments on the Draft Environmental Impact Report for the proposed Wal-Mart Distribution Center.

Please contact us immediately if you experience any difficulty in downloading the attachment. We would appreciate it if you could send an email confirming receipt of the email and the attached document.

Sincerely,
Maureen McCorry, Director
San Joaquin Et Al
P.O. Box 722
Merced, CA 95341
(415) 816-8872

RECEIVED
APR 27 2009
CITY OF MERCED
PLANNING DEPT.

Maureen McCorry, Director
San Joaquin Et Al
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(415) 816-8872

RECEIVED
APR 27 2009
CITY OF MERCED
PLANNING DEPT.

April 27, 2009

Ms. Kim Espinosa, Planning Manager
City of Merced Planning Department
678 West 18th Street
Merced, CA 95340
Facsimile: (209) 725-8775
E-mail: espinosak@cityofmerced.org

Re: Comments regarding the Draft Environmental Impact Report (DEIR) for the Wal-Mart Regional Distribution Center, Merced, California (SCH No. 2006071029)

Via: E-mail 4.27.09

Dear Ms. Espinosa,

San Joaquin et al is commenting on behalf of members of the public and other community organizations of standing.

We object to the proposed Wal-Mart Regional Distribution Center in Merced, California. We disagree with the environmental checklist and oppose the accompanying mitigation measures as set forth in this DEIR. The deferral, and in many cases, outright dismissal of mitigation measures is improper and unacceptable. We demand that the DEIR be withdrawn, and a new DEIR be issued that legally analyzes alternatives and is re-circulated in order to incorporate all environmental documents for adjacent projects upon which this project is reliant. In addition, we ask that this process be deferred until the release of the long awaited and overdue General Plans for the City and County of Merced, the University of California Long Range Development Plan, and final documents for other neighboring unincorporated communities are made public.

Alternatives analysis:

Viable alternatives were not properly examined in this document. Rather than legally analyze comparable sites outside the proposed project, the DEIR narrowly construes the alternatives to a no project, a redesigned, or reduced project on the same site (with the exception of the Thornton/West Dickerson Ferry Road industrial zone). The DEIR fails to meaningfully assess how the sites listed in Table 5. 1 were rejected. Politics, proximity to residential communities, truck traffic impacts – including safety— were evidently reason enough to prevent a distribution center from being built elsewhere. Yet many of the reasons outlined in Table 5-1 are not at all relevant to the California Environmental Quality Act (CEQA) and have no place in a DEIR. For instance, why is it that political considerations were given more weight than the proposed Merced site, even in locations that already possess the required infrastructure? Why does residential impacts – including safety – rise to the level of impediment in Patterson, but not in Merced – where children in three local schools will be impacted? Other viable alternatives are completely ignored. The current economic crisis has left large industrial distribution sites vacant at Castle, and in Madera, Ceres, Stockton, and Tracy, yet these alternatives were not even considered, let alone properly analyzed in the DEIR under CEQA.

A dry storage distribution center makes little sense in the heart of an agricultural economy in the San Joaquin Valley. Project proponents did not analyze a cold storage distribution center.

We disagree with the conclusions that a "No Project" alternative on the proposed site will lead to identical or very similar impacts as a regional Walmart Distribution Center. This assertion relies on a whole series of faulty assumptions.

Tiering/Piecemealing :

This document is reliant on environmental documents which have not been made available to the public as part of this environmental review process. For example, the proposed WDC is reliant on the build-out of Campus Parkway. Relying on other project mitigation is unacceptable. In addition, the current economic crisis calls into question the availability of funding allocated for the Campus Parkway.

Maureen McCorry, Director
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A Notice of Preparation (NOP) was filed for the Merced Gateway Park East Commercial and Residential development (April 1, 2008) – but there is no indication as to how this project will interface with the WDC, the Lyons Annexation (Negative Declaration, April 20, 1998), and the City of Merced's recent approval to abandon 1.37 acres to Lyons Investments (as approved by the Merced City Planning Commission on January 7, 2008 and the Merced City Council on January 20, 2008).

Infrastructure/Utilities:

Storm-water:

The plans for addressing storm-water drainage are inadequate. This is an area that is prone to flooding without the proposed WDC, the Campus Parkway, and other developments which will compete for water drainage.

We are unable to fully evaluate the impacts of storm-water drainage as this project is reliant on land use approvals and environmental documents on adjacent properties which were not circulated with this DEIR. These impacts can't be understood without access to all environmental documents.

How does the abandonment of the storm-water detention basin improve (referenced above), detract or impact this project?

In the best of worlds, detention ponds are problematic regarding public health and safety.

The ability of the detention ponds to hold excess water is questionable at best. Documents created for the City of Merced for the WDC in July, 2005 discuss some of the challenges drainage will pose for this site – using a 10 year storm, 24 hour storm analysis (some of these conclusions have been integrated in this DEIR). This document noted that Merced Irrigation District (MID) would have to pump water from the drainage ponds in order to accommodate excess water. However, as was noted in this document, the ponds could not be drained using *the maximum* discharge rate of 2200 gpm, within a 48 hour period for a 10 year storm. In addition, the challenges that are identified in this document, the DEIR, MID comments, and drainage issues on adjacent, entitled projects all point to the inadequacy of the current plan to address a reoccurring flood problem.

The challenge to capturing storm-water run-off is compounded by the hazardous waste associated to a fully functioning distribution center. What type of water will be entering the canals and groundwater when flood waters are not captured by the detention ponds? Moreover, the propensity to flood in this region is magnified as more agricultural land in this region is converted to impervious surfaces. The current drainage plans are already stretched; it is more than reasonable to surmise that with full build-out of the WDC, the Campus Parkway, and the industrial and commercial projects immediately adjacent to this project will be unable to absorb storm-water run-off effectively. Because the cumulative impacts of these projects are effectively ignored, the environmental documents associated to these adjacent developments have not been analyzed and therefore, the public has no way to fully understand drainage and flooding issues as well as impacts to groundwater and water quality.

We can expect these impacts to be significant, but they cannot be understood in the current document. On page 2-34 of the Executive Summary, the proposal relies on a 100 year flood zone standard. Yet, the DEIR defers new state and federal flood management law as referenced in the Executive Summary (4.6-6). Deferral of state and federal law is unacceptable.

Sewer Capacity:

The current sewer system is at capacity. The City of Merced has published a Draft Sewer Master Plan (January, 2007). How does this proposal impact this plan?

In what ways does the WDC proposal enhance or detract from plans for a regional sewer system that could serve both the city of Merced and neighboring and financially strapped unincorporated service districts. Moreover, the impacts to our municipal sewer facility is stretched by residential subdivisions and commercial developments the city has entitled or approved through guidance plans, but have not yet come online (the University of California Community Plan and Yosemite Lakes are just two that come to mind). How are the City of Merced's current commitments to both residential and commercial use impacted by this project? The lack of sewer capacity would be reason enough to delay any further approvals until the new General Plan and accompanying master plans are published.

Transportation:

The assumptions underlying the traffic analysis are woefully inadequate. The DEIR narrowly frames truck traffic impacts. For example, the truck traffic impacts to Yosemite Parkway, along with a variety of country roads that will be impacted are ignored. In addition, this project will very significantly impact Childs Avenue, Gerard, Kibby, and Tower Roads. These county roads are well beyond disrepair. The traffic discussion is limited and wholly dependent on the build-out of the Campus Parkway. At the time of this writing, Campus Parkway is limited to the interchange and a very short distance forcing WDC related traffic on two land roads in a county that has been committed to building expressways rather than shoring up its deteriorating and much used county road system. Who will bear the burden of cost associated to improving the roads/parkway that will service this project?

In addition, there is no analysis in the DEIR on the impacts associated to the empty storage containers that are left on site once they are loaded or unloaded. The growth inducing impacts of increased truck traffic from the port of entry (Oakland) through Highway 99 to the proposed WDC are also ignored in this document.

We demand that all outside carriers servicing the WDC be held to 2010 California emissions standards.

Parking/Staging:

Another immediate impact that this DEIR ignores is the fact that outside carriers will not have the same accessibility to parking as Walmart trucks on the WDC site. Outside carriers are not allowed to stay on the premises while they wait to be loaded or unloaded. Outside carriers have a narrow window, from 1 – 3 hours, for loading/ unloading their trucks. They will need to remain in the vicinity of the proposed WDC during that time frame. Where will they park?

General Plan Consistency:

City of Merced: WDC is reliant on an outdated General Plan. It makes little sense to consider this project in advance of the City of Merced's updated general plan.

Moreover, there is no analysis as to how this project relates to the South Merced Specific Plan. The Master Plans associated to the updated General Plan should provide the guidance for a project of this scope and magnitude.

County of Merced: Merced County is in the process of updating its general plan. The proposed WDC will have impacts on circulation, cumulative impacts to county lands adjacent to the project – including farmland conversion, water quality, traffic, and air impacts. We disagree that the potential for growth and the impacts on farmland conversion are relevant only to the City of Merced. Moreover, most of the adjacent land that will be impacted by the project is on county land.

The University of California: The University of California is in the process of finalizing its Long Range Development Plan (LRDP). However, there are significant incongruities between the UC LRDP and the County of Merced's University Community Plan. Mitigation included for the UC includes a comprehensive conservation strategy that encompasses Eastern Merced County and is ignored in this DEIR.

Agriculture:

This project relies on an approximately 20 year old planning document. There is no mitigation proposed for this project. As the Executive Summary states on page 2.-53 in reference to "Cumulative Agricultural Land Impact": "... The project would result in a loss of approximately 158.2 acres of Prime Farmland, 57.87 acres of Farmland of Statewide Importance, and 12.61 acres of Unique Farmland, *which is considered to be a cumulatively considerable contribution to the cumulative impact when considered along the past farmland conversions identified above and planned future development proposed* in the City of Merced..."

We disagree with the conclusion in this document that a "statement of overriding consideration" is a substitute for meaningful mitigation – especially for a project of this magnitude and a project proponent with substantial resources.

Furthermore, we disagree with the conclusion that the impacts to adjacent lands is not the responsibility of this project or the City of Merced. Farmland in this region – let alone the entire county -- has not been mitigated. We wholeheartedly disagree with the reasoning and conclusions drawn in the Executive Summary at 4.1-1: "...mitigation that would eliminate the loss of agricultural land to urban development is not possible. Therefore, because no mitigation is available to reduce this impact would remain significant and unavoidable. This conclusion is consistent with the conclusion of the EIR prepared for the Merced Vision 2015 General Plan..."

While this project relies on an antiquated General Plan, an updated General Plan is waiting in the wings.

These conclusions and reliance on an antiquated General Plan ignores growing community support for protecting agricultural lands, especially in the aftermath of the plethora of partially built and thoroughly abandoned subdivisions that have lept over the traditional city limits to create urban sprawl in the heart of our precious natural resources and farmland. The unnecessary sprawl created by a real estate boom gone bust and has created real impacts to agricultural lands as noted by the lead agency on page 2-53 of the Executive Summary.

The disconnect in the DEIR (acknowledging the rapid conversion of farmland, yet choosing to avoid mitigation for this loss) underscores the importance of deferring consideration of this project until a new general plan is adopted that includes an enforceable mitigation policy for agricultural lands.

Mitigation should be developed and agreed to in advance of the project approval and should require in-kind mitigation as opposed to in-lieu fees.

Biological Resources:

Biological impacts are dismissed as insignificant based on the unsupported conclusion that agricultural and current land uses in this region do not support significant wildlife resources. These conclusions were reached without ground sleuthing or site visits. We disagree with this conclusion and request documentation that supports the conclusions in the DEIR. Deferring mitigation for biological resources is improper and illegal.

As noted above, this region is in fact adjacent to the University of California's Conservation Strategy for Eastern Merced County which is not at all analyzed in this DEIR.

Cumulative Impacts:

The discussion associated to cumulative impacts is too narrowly drawn. Conclusions drawn regarding Population and Housing (ES, 2-54) serves as a case in point. The potential for farmland conversion is determined to be "less than significant," effectively ignoring the growth inducing and cumulative impacts associated to this project in combination with other projects as outlined above (4-11.1).

We find the "cumulative impacts" analysis woefully inadequate. No impacts are associated to the project and therefore, no mitigation is required. Merced has already become the victim of another major developer, the University of California. We have been through the long on promises (in this case: jobs), short on action road before (in this case mitigation for the very real impacts the proposed WDC will bring to our community). Merced cannot afford another big developer who is unwilling to foot the bill on road/traffic impacts, sewer impacts, water impacts, and resource impacts -- Mercedians deserve better.

Maureen McCorry, Director
San Joaquin Et Al
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Merced, CA 95341
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We once again state that relevant documents/projects, upon which this document is reliant, were not circulated with this DEIR, and therefore we demand re-circulation of the DEIR as stated above. Finally, we request that any changes to the proposed project will require a re-circulation of the EIR.

Thank you in advance for your thoughtful consideration of our concerns.

Sincerely,

Maureen McCorry, Director
San Joaquin Et Al
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Merced, CA 95341

cc: Interested parties

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San Joaquin Valley
AIR POLLUTION CONTROL DISTRICT

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April 27, 2009

Kim Espinosa
City of Merced
Planning Division
678 West 18th Street
Merced, CA 95340

Subject: Comments on Proposed Project

Project: Draft Environmental Impact Report (EIR) #06-01 (SCH #2006071029) for the Wal-Mart Distribution Center

District Reference No: 20060762

Dear Ms. Espinosa:

The San Joaquin Valley Unified Air Pollution Control District (District) has reviewed the Draft Environmental Impact Report for the Merced Wal-Mart Distribution Center located at the northwest corner of Gerard Avenue and Tower Road. The proposed project would include construction of a regional distribution center consisting of approximately 1.1 million square feet, operating 24 hours per day, and employing approximately 1,200 employees. The District offers the following comments:

District Comments

1) The project will have a significant adverse impact on air quality.

2) Mitigation Measure 4.2-1b: Construction Emissions – The Draft EIR concludes that construction emissions will have a significant impact on air quality but with mitigation, the construction exhaust impacts can be reduced. In order to conclude that the construction exhaust emissions would be less than significant, mitigation measures reducing construction exhaust emissions must be fully enforceable through permit conditions, agreements, or other legally binding instruments (CEQA Guidelines §15126.4, subd.(a)(2)). Feasible mitigation of construction exhaust

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emission includes use of construction equipment powered by engines meeting, at a minimum, Tier II emission standards, as set forth in § 2423 of Title 13 of the California Code of Regulations, and Part 89 of Title 40 Code of Federal Regulations. The District recommends incorporating, as a condition of project approval, a requirement that off-road construction equipment used on site achieve fleet average emissions equal to or less than the Tier II emissions standard of 4.8 NOx g/hp-hr. This can be achieved through any combination of uncontrolled engines and engines complying with Tier II and above engine standards.

3) Mitigation Measure 4.2-1c and 2e: Implement an Emissions Reduction Agreement to Reduce Construction & Operational Emissions- The Draft EIR concludes that the applicant will fund and implement an Emissions Reduction Agreement to mitigate the projects NOx and ROG impact on air quality to below the Districts threshold. The District supports the use of emission reduction agreements as feasible mitigation of a project related cumulative impacts on air quality. However, it should be noted that emission reduction agreements do not result in on-site reductions and thus do not mitigate potential risk to near-by receptors to exposure of toxic air contaminants. The District recommends that demonstration of having successfully entered into an emission reduction agreement with the District, before the issuance of the first building permit, be made a condition of project approval.

4) The Draft EIR correctly states that the District has not adopted a threshold of significance for PM10 and concludes that PM10 emissions would have a significant impact on air quality. Although the District's Governing Board has not adopted a threshold of significance for PM10, the District recommends that lead agencies use an applied threshold of 15 tons per year (TPY). The District recommends that mitigation of PM10 emissions below the 15 TPY applied threshold be included into the Emissions Reduction Agreement.

5) Indirect Source Review (ISR)- The project is subject to District Rule 9510 (Indirect Source Review). District Rule 9510 is intended to mitigate a project's impact on air quality through project design elements or by payment of applicable off-site mitigation fees. Any applicant subject to District Rule 9510 is required to submit an Air Impact Assessment (AIA) application to the District no later than receiving final discretionary approval, and to pay any applicable off-site mitigation fees before issuance of the first building permit. The District recommends demonstration of compliance with District Rule 9510 before issuance of the first building permit for each phase of the project be made a condition of the project's approval. The District recommends demonstration of compliance with District Rule 9510 before issuance of the first building permit for each phase of the project be made a condition of the project's approval.

6) The proposed project may require District permits. Prior to the start of construction the project proponent should contact the District's Small Business Assistance Office at (559) 230-5888 to determine if an Authority to Construct (ATC) is required.

7) The proposed project may be subject to the following District rules: Regulation VIII, (Fugitive PM10 Prohibitions), Rule 4102 (Nuisance), Rule 4601 (Architectural Coatings), and Rule 4641 (Cutback, Slow Cure, and Emulsified Asphalt, Paving and Maintenance Operations). In the event an existing building will be renovated, partially demolished or removed, the project may be subject to District Rule 4002 (National Emission Standards for Hazardous Air Pollutants).

   The above list of rules is neither exhaustive nor exclusive. To identify other District rules or regulations that apply to this project or to obtain information about District permit requirements, the applicant is strongly encouraged to contact the District's Small Business Assistance Office at (559) 230-5888. Current District rules can be found online at: www.valleyair.org/rules/1ruleslist.htm.

8) ENSR Corporation performed a health risk assessment to determine the risk from diesel particulate emissions from truck travel on the site; truck idling at the gate, scale, and parking area; and operation of two stationary internal combustion engines; and emissions from the cafeteria. The San Joaquin Valley Unified Air Pollution Control District reviewed ENSR's health risk assessment. Specific comments on ENSR's health risk assessment based upon the District's review are given below:

   A. The analysis is based upon a 5-minute limit on idling at any one location. The Air Toxic Control Measure contains a number of exemptions. Therefore, this limitation should be included as an enforceable measure in the land use permit. Otherwise, a default period of 15-minutes must be used in the analysis.

   B. The HRA is based upon the use of truck engines that meet Tier 2/3 emission standards. This commitment must be included in the land use permit, or the assumption that the engines in this fleet will be the same as that for Merced County should be used in the analysis.

   C. The HRA specifies that there will be no cold storage on-site other than that used for the employees' cafeteria. This requirement should be incorporated as a condition in the land use permit.

   D. The analysis used hour-of-the-day adjustments to the emissions of diesel particulate matter from the trucks. To use this approach, appropriate limitations (e.g., number of trucks during daytime hours and number of trucks during nighttime hours) should be included in the land use permit and will be included in the Authority to Construct.

   E. All conditions in the land use permit, such as those above, that are required to ensure the integrity of the HRA should be included in the Authority to Construct for the stationary engines.

F. Travel distances were incorrectly calculated by multiplying the number of volume sources in a line source by the length of the side. The correct approach would be to calculate distances based upon the nodes in the line source. The effect of this error is to underestimate the travel distances (and the resulting travel emissions) by a factor of 2.

G. The applicant used EMFAC2007 to calculate emissions for indirect source review. The emission factors from the EMFAC2007 run should have been used for the risk modeling. The emission factor for haul trucks should have been 1.448 g/mi instead of 0.670 g/mi. Similarly, the emission factor for idling haul trucks should be 2.08 g/hr instead of 2.37 g/hr.

H. No emissions from the transportation refrigeration units (TRUs) on the trucks supplying food to the cafeteria were included in the analysis.

I. A limited number of receptors were modeled. Additional receptors should be included in the analysis. For example, single receptors at the center of industrial facilities were modeled for the two industrial facilities north of the proposed site. For those two areas, receptors should have been placed 25 meters beyond the project boundary and with a spacing of 25 meters. Similarly, receptors for agricultural workers in adjacent fields were not modeled. Additional receptors should have been modeled for the residential development and the school west of the project site. Also, the receptors for other schools and sensitive receptors should have been placed at the location on the boundary that is closest to the proposed project.

J. The District does not use the adjustments for student carcinogenic risk unless the student lives somewhere other than within the zone of impact but attends a school within the zone of impact.

K. The applicant has not specified the number of hours that the two generators will operate for maintenance and testing. The emission calculations for these two generators should conform to the limits that will be applicable based on the Air Toxics Control Measure for stationary internal combustion engines.

L. The Industrial Source Complex Short-Term (ISCST3) model in the Hot Spots Analysis and Reporting Program (HARP) was used to model emissions from the cafeteria. Use of ISCST3 is not one of the U.S. Environmental Protection Agency's (EPA's) preferred model. To use it in lieu of the preferred model (i.e., AERMOD), a model evaluation must be performed to demonstrate its superiority to the preferred model.

M. In HARP, a deposition rate of 0.05 m/s was used. This value is appropriate for uncontrolled sources. Normally, the District uses a deposition rate of 0.02 m/s for controlled sources.

N) Based upon the District's review, the maximum residential cancer risk could be well over 10 in a million because of comments in F, G, and H. The issues raised above should be addressed with a revision to the health risk assessment. The revised health risk assessment must be based upon the District's default assumptions for idling time, etc. unless a firm commitment is made to incorporate the mitigation measures identified in comments A through D in the land use permit and any air quality permit issued for the stationary internal combustion engines.

District staff is available to meet with you and/or the applicant to further discuss the regulatory requirements that are associated with this project. If you have any questions or require further information, please call Mark Montelongo at (559) 230-5905 and provide the reference number at the top of this letter.

Sincerely,

David Warner
Director of Permit Services

Arnaud Marjollet

Arnaud Marjollet
Permit Services Manager

DW: mm

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April 27, 2009

Our File Number: 15CM-130732

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Kim Espinosa, Planning Manager
City of Merced
Planning and Permitting
678 West 18th Street
Merced, CA 95340

Re: Comments on the Draft Environmental Impact Report Prepared for the Proposed Wal-Mart Regional Distribution Center (State Clearinghouse Number 2006071029)

Dear Ms. Espinosa:

On behalf of Wal-Mart Stores, Inc. ("Wal-Mart"), we are submitting the following comments on the Draft Environmental Impact Report ("Draft EIR") prepared for the proposed Wal-Mart Regional Distribution Center ("Project") in Merced, California ("City").

The Draft EIR analyzed an approximately 1.1 million square foot regional distribution center located on 230 acres in the southeast area of the City of Merced. The Project is industrial in nature and <u>does not contain any retail commercial components</u>. It would employ approximately 1,200 employees upon full operation in an area permitted for industrial uses with good access to major highways and transportation links. (Upon first opening, the Project will employ approximately 900 employees – 600 full-time and 300 part-time.)

We request reconsideration of certain of the proposed mitigations, as detailed in the following:

1. Air Quality

a. *Mitigation Measures 4.2-1(a)-(e) – Comply with SJVAPCD's Indirect Source Review Rule (Rule 9510); Implement Measures to Reduce Construction-Related Diesel Equipment Exhaust Emissions; Implement an Emissions Reduction Agreement with SJVAPCD to Reduce Construction Emissions of ROG and NOX; Comply with SJVAPCD's Regulation VIII-Fugitive Dust Prohibitions and Implement All Applicable Control Measures; Implement SJVAPCD-Recommended Enhanced and Additional Dust Control Measures.*

By law, the Project will be required to comply with the San Joaquin Valley Air Pollution Control District's ("SJVAPC") Indirect Source Review ("ISR") Rule (Rule 9510) and Regulation VIII. General mitigation requirements under the ISR Rule for construction equipment emissions and operational emissions are as follows:

> 6.0 General Mitigation Requirements
> 6.1 Construction Equipment Emissions
> 6.1.1 The exhaust emissions for construction equipment greater than fifty (50) horsepower used or associated with the development project shall be reduced by the following amounts from the statewide average as estimated by the ARB:
> 6.1.1.1 20% of the total NOx emissions, and
> 6.1.1.2 45% of the total PM10 exhaust emissions.
> 6.1.2 An applicant may reduce construction emissions on-site by using less polluting construction equipment, which can be achieved by utilizing add-on controls, cleaner fuels, or newer lower emitting equipment.
> 6.2 Operational Emissions
> 6.2.1 NOx Emissions
> Applicants shall reduce 33.3%, of the project's operational baseline NOx emissions over a period of ten years as quantified in the approved AIA as specified in Section 5.6.
> 6.2.2 PM10 Emissions.
> Applicants shall reduce of 50% of the project's operational baseline PM10 emissions over a period of ten years as quantified in the approved AIA as specified in Section 5.6.
> 6.3 The requirements listed in Sections 6.1 and 6.2 above can be met through any combination of on-site emission reduction measures or off-site fees.

First, the Draft EIR includes no nexus between the mitigation required and the air quality impact identified. Pursuant to the California Environmental Quality Act ("CEQA"), mitigation measures are required to comply with all applicable constitutional requirements. (CEQA Guidelines sec. 15126.4(a)(4).) Specifically, there must be an "essential nexus (i.e. connection) between the mitigation measure and a legitimate governmental interest. *Nollan v. California Coastal Commission,* 483 U.S. 825 (1987)." (CEQA Guidelines sec. 15126.4(a)(4)(A)) "Where the mitigation measure is an *ad hoc* exaction, it must be 'roughly proportional' to the impacts of the project. *Ehrlich v. City of Culver City* (1996) 12 Cal. 4th 854." (CEQA Guidelines sec. 15125.4(a)(4)(B).) Accordingly, all mitigation required must relate to the impacts caused by a project. Here, the proposed mitigation measures fail to meet this nexus standard.

In addition, the mitigation measures impose additional requirements beyond established programs and/or regulations, resulting in the measures being excessive and unnecessary. For example, Mitigation Measure 4.2-1(c) requires the Applicant to enter into an emission reduction agreement with the SJVAPC, which is an agreement whereby an applicant can volunteer to mitigate beyond Rule 9510 and fully offset project emissions. The Draft EIR makes this a mandatory, not voluntary requirement.

Also, Mitigation Measure 4.2-1(a) requires the submittal and approval of various applications by the SJVAPCD prior to applying for final discretionary approval with the City of Merced. However, the requirement pursuant to the ISR Rule is "[a]ny applicant subject to this rule shall submit an Air Impact Assessment (AIA) application no later than applying for a final discretionary approval with the public." There is no requirement that the application be approved prior to applying for a final discretionary approval. The measure therefore goes beyond what is required by the ISR Rule, but provides no justification for deviating from the established procedural requirement.

Further, Mitigation Measure 4.2-1(b) regarding "Construction-Related Diesel Equipment Exhaust Emissions," bans construction on forecasted Spare the Air Days and prohibits staging areas for heavy-duty construction equipment within 1,000 feet of the Project boundary. The ISR Rule general mitigation requirements already specifically address and mitigate impacts from construction equipment emissions, including impacts from diesel emissions. The Draft EIR includes no discussion or analysis of how these requirements in Mitigation Measure 4.2-1(b) would reduce the Project's air quality impacts, nor a justification why the mitigation measure must go above and beyond the ISR Rule requirements that already apply.

In some cases, the mitigation measures are also infeasible. For example, Mitigation Measure 4.2-1(b) provides for the replacement of fossil/fueled equipment with electrically driven equipment. At this time, such equipment does not exist; therefore, implementation of this measure is not technologically possible. Consequently, this measure is infeasible.

Some of measures are infeasible because they are more appropriate for a retail use located in a developed commercial area than a large industrial use located on 230 acres of land within an industrial area, such as is the case here. Requiring such measures is not feasible for an industrial use of this type and size, and no evidence is presented showing that they are feasible for the Project.

"CEQA does not require analysis of every imaginable...mitigation measure; its concern is with feasible means of reducing environmental effects..." *Concerned Citizens of South Central Los Angeles v. Los Angeles Unified School District* (2d Dist. 1994)24 Cal. App. 4th 826, 841. Here, because the proposed mitigation measures have no nexus to the impact, go beyond established procedures, are excessive and unnecessary, and no substantial evidence exists to conclude the measures are feasible, the mitigation measures should be removed.

b. *Mitigation Measure 4.2-2(b) – Develop and Implement an Employee Trip Reduction Program to Reduce Operational Emissions.*

The Project is estimated to have approximately 1,200 employees upon full operation (900 upon first opening, as previously noted), 1,050 who would work at the facility and an additional 150 employees as drivers. Mitigation Measure 4.2-2(b) requires the development and implementation of an employee trip reduction program to reduce operational emissions.

Wal-Mart already has a developed Rideshare Program designed to help improve air quality. The Rideshare Program encourages Associates to consider alternate commute methods, such as carpooling, biking, walking, and taking the bus to work. Wal-Mart's Senior Rideshare Coordinator (an existing position) would create a Rideshare Program tailored specifically to the facility, and train designated On-Site Rideshare Coordinators on program implementation and documentation. At the facility, Wal-Mart would provide a general introduction to the Rideshare Program during orientation for new hires. New hires would view Wal-Mart's Rideshare DVD, which outlines benefits of ridesharing to work: saving money, saving time, exercise, etc. Also, the Rideshare Coordinator would provide detail about the Rideshare Program incentives for their site.

Wal-Mart's efforts to promote its Rideshare Program go beyond orientation for new hires. Among the tools Wal-Mart has found effective promoting participation in the Rideshare Program are contests, educational materials, and Rideshare marketing materials promoting alternate commute methods. Further, a Rideshare bulletin board would be maintained at the facility with program information, transit information, local bike routes, etc.

Wal-Mart will continue to use its best efforts to encourage employees to carpool or use alternative transportation methods through implementation of a Rideshare Program at the facility. However, Wal-Mart cannot guarantee that within three (3) years of the Project opening, there will be a 25% reduction in single occupancy vehicle trips by employees. One initial concern with the proposed measure is that it is unclear how this reduction would be calculated or monitored. More importantly, achieving this 25% reduction would require Wal-Mart to mandate some employees to use these types of measures if not enough employees volunteer. Wal-Mart simply cannot mandate how employees travel to work. Thus, we recommend revising the Mitigation Measure to require that Wal-Mart implement its Rideshare Program at the Project, but not require a set percentage reduction in trips. If anything, a percentage reduction should be a goal, not a mandate.

c. *Mitigation Measure 4.2-2(c) – Implement Recommended Mitigation Measures to Reduce Operational Emissions.*

This mitigation measure includes specific measures to reduce operational emissions. These measures could conflict with the requirements imposed as part of the required emissions reduction agreement with the SJVAPCD.

In addition, there is no nexus between the impact and some of the measures. For example, one of the measures included is the construction of Class II Bike lanes or the payment of the Project's "fair share" of funding for these lanes. First, there is no nexus between the Project and the construction of these bike lanes. The Draft EIR does not analyze, evaluate or conclude that the construction of these bike lanes will reduce any air quality impacts associated with the Project. Further, the City of Merced does not have an established Bicycle Fee Program. Therefore, the Project cannot be required to pay any "bicycle fee" as part of its building permit fees and any such a requirement is arbitrary and capricious, and completely without merit. It appears that the motivation for the bicycle lanes may be, as stated in the mitigation measure, to "qualif[y] the City of Merced to receive state funding for bicycle projects[,]" but this is not a Project-related impact that requires mitigation.

Moreover, some of the proposals are simply infeasible. This measure requires only the use of electric-powered landscape maintenance equipment to care for the landscaped areas. Given the size of the Project site (230 acres), the ability to use electric-powered landscape maintenance equipment is infeasible. At some points, the distance between the landscape area and the building or electrical outlet would be greater than 250 feet and in many cases over 500 feet.

d. *Mitigation Measure 4.2-2(d) – Implement Additional Operational On-Site Emission Reduction Measures.*

Under Mitigation Measure 4.2-2(d), the Applicant is required to submit a written report demonstrating the infeasibility of additional operational on-site emission reduction measures. Approval of this report is required before final discretionary approval of the Project. As discussed above, this is contrary to the procedure established by the ISR Rule. As certification of the EIR and approval of the Project entitlement will be the final discretionary approval, we believe this reference is a mistake and instead should reference an administrative or non-discretionary action such as the issuance of building permits.

e. *Mitigation Measure 4.2-6(d)- Implement Additional Operational On-Site Emission Reduction Measures.*

Mitigation Measure 4.2-6(d) mandates the installation of solar panels throughout the Project site on all available areas, such as the roof, buffer areas, parking lot, covered parking areas, walkways and outdoor areas. As discussed in detail below, this Project will demand significantly less energy than comparable facilities. Also, Wal-Mart is investigating ways to meet the facilities' remaining energy demand with renewable energy sources. As such, this mitigation is excessive and unnecessary.

With regard to using solar on site, significant barriers exist to using solar power at this time in this location. These barriers include material/production costs, the net efficiency of technology, and a lack of storage capacity to fully utilize the solar energy.

Wal-Mart is investigating the feasibility of using solar power at its facilities via its solar power pilot program. Until such technology proves efficient, however, it should not be required.

Finally, the Applicant cannot legally be required to purchase electricity from a specific local provider, as is required under this mitigation measure. Such a mandate violates the Applicant's constitutional and statutory rights. In any event, mandating the selection of a specific provider lacks a nexus to a specific impact as it is unclear how using a specific provider would mitigate a potential impact.

For these reasons, this mitigation measure should be modified to *recommend*, rather than *require* the above measures, or should be removed entirely.

2. Biological Resources

a. *Mitigation Measure 4.3-2 – Implement Measures to Minimize Potential Project Effects on Swainson's Hawk and Burrowing Owl.*

The Project would result in the loss of approximately 150 acres of suitable foraging habitat for Swainson's hawk and could result in destruction or disturbance of burrowing owl burrows. The Project will be required to consult with the California Department of Fish and Game ("CDFG") and comply with any applicable guidelines, survey requirements, regulations and mitigation. Mitigation Measure 4.3-2, however, is very detailed and sets forth specific requirements for the Project that could conflict with the requirements of CDFG.

As a result, the measures infringe upon the jurisdiction of CDFG. This usurping of CDFG's power results in the City imposing measures outside its area of expertise. The end result could be that CDFG cannot impose one of its mitigation measures because it conflicts with what the City has required. Allowing the expert regulatory agency to determine the applicable mitigation would be more appropriate.

Therefore, to avoid a potential conflict and still adequately mitigate the potential impact without improperly deferring mitigation, we recommend replacing the language in this mitigation measure with the following mitigation language:

> "**Pre-Construction Survey -** No more than 15 days prior to any site-disturbing activities, including grading or woody vegetation and tree removal, the applicant will retain a qualified wildlife biologist to conduct a nesting bird survey to determine if nests are active or occupied onsite. The surveys shall be conducted a minimum of three separate days during the 15 days prior to disturbance. Any active nests observed onsite will be avoided until after the nestlings have fledged and left the nest. If avoidance is not feasible, then a biological monitor will be present if construction activities occur during the nesting season. Construction activity within the vicinity of the active nests may only be conducted at the discretion of the biological monitor. If construction activity will likely result in nest failure, the applicant will consult with CDFG and/or USFWS to determine what mitigation or permitting is required. An MBTA Special Purpose Permit will be required if occupied nests will be impacted.
>
> **Burrowing Owl -** If occupied burrowing owl burrows are found during above mentioned required pre-construction survey, a buffer shall be established around the burrows in accordance with the requirements established by the CDFG. Passive relocation shall not occur during the breeding season unless a qualified biologist, approved by CDFG, verifies that the young have fledged the nest.

> **Swainson's Hawk** - Loss of Swainson's hawk foraging habitat shall developed in consultation with CDFG.

3. Geology, Minerals, Soils and Paleontological Resources

a. *Mitigation Measure 4.5-1 – Implement Construction Personnel Training and Recover Paleontological Resources if Encountered.*

Paleontological resources could be present in the sediments underlying the Project site and this mitigation measure is intended to minimize any potentially adverse impacts to those resources. This includes informing construction personnel of the possibility of encountering fossil and the proper notification procedures if fossils are encountered. The second bullet explains the mitigation if a fossil is encountered. The language is as follows:

> If paleontological resources are discovered during earth-moving activities, the construction crew shall immediately cease work **in the vicinity of the find** and shall notify the City Planning Department. The project applicant shall retain a qualified paleontologist to evaluate the resources and prepare a proposed mitigation plan in accordance with SVP guidelines (1995)...Recommendations determined by the lead agency to be necessary and feasible shall be implemented before construction activities can resume **at the site** where the paleontological resources were discovered.

> (Emphasis added.)

Based on this language, it is unclear whether construction must stop only in the vicinity of the find or over the entire site if a paleontological resource is found. Because continuing construction at other areas of the site, away from the vicinity of the find, will not impact the paleontological resource, we recommend the following modification to the mitigation measure:

> ...Recommendations determined by the lead agency to be necessary and feasible shall be implemented before construction activities can resume in the vicinity of the find ~~at the site~~ where the paleontological resources were discovered.

This change protects the paleontological resource, and minimizes the potential adverse impact while allowing construction away from the resource to continue in the event of a paleontological find.

b. *Mitigation Measure 4.5-3(a) – Prepare a Final Geotechnical Design Report and Implement All Applicable Recommendations.*

Please note, for clarification purposes, that the final geotechnical engineering report has been prepared and all applicable recommendations will be incorporated into the Project as required. Therefore, this mitigation is not necessary and, as a result, should be removed.

4. Hydrology and Water Quality

a. *Mitigation Measure 4.6-1(b) – Establish a Maintenance Entity for BMPs.*

The Project evaluated by the Draft EIR is a single-user Project. Wal-Mart will be the sole tenant, owner and occupier of the property and Project site. Further, all construction disturbances will be located on Wal-Mart's property and Wal-Mart will be required to operate, maintain and replace stormwater best management practices ("BMPs") as set forth under its stormwater permit.

Community Facility Districts (CFD) and other maintenance entities are typically formed where multiple owners, tenants or operators will be responsible for various community or stormwater improvements. Here, because there is only one user/owner, formation of a CFD or maintenance district is not necessary. Therefore, this mitigation measure is not necessary and, as a result, should be removed.

b. *Mitigation Measure 4.6-7 – Comply with SB 5 Criteria Establishing 200-Year Urban Flood Protection.*

Senate Bill 5 required the Department of Water Resources to prepare a map of various floodplains, including the 200-year floodplain. It also requires the Central Valley Flood Protection Board to prepare a Central Valley Flood Protection Plan ("Plan") no later than July 1, 2012. This plan must describe the performance, design, risk and funding of various area flood protection facilities. Once the plan is adopted, cities have twenty-four (24) months to amend their general plans to incorporate the provisions and requirements of the Plan. Nothing in the Plan or SB 5 requires existing or proposed development to comply with future unknown flood protection requirements.

The mitigation proposed essentially requires the Project to comply with a Plan and standards that have yet to be develop and do not exist. The Project can only be required to comply with existing flood control measures adopted at the time of construction and building permit issuance.

It is also important to note that the impact to be mitigated is speculative given the Plan is not anticipated to be adopted until at least 2012 and not implemented locally until 2014. Therefore, there is no way of knowing whether the Project will have impacts under those standards at this time. The Project may only be required to mitigate for known impacts, not speculative unknown impacts based on an analysis and Plan that have yet to be developed.

5. Noise

a. *Mitigation Measure 4.8-1 – Regulate Construction before Approval of Implementation Plans*

This mitigation addresses short term noise impacts. As indicated above, the Project is the construction of a distribution center. It is a single project and does not include approval of various implementation plans or subsequent projects. As a result, the Mitigation Measure should be revised as follows:

> "**4.8-1: Short-Term Construction Noise** ~~**Regulate Construction before Approval of Implementation Plans.**~~ ~~Prior to approval of Implementation Plans and subsequent projects, t~~The City shall require the applicant to regulate short-term construction noise as follows:..."

b. *Mitigation Measure 4.8-3 – Implement Measures to Reduce Exposure to Traffic Noise from Project.*

The Draft EIR does not establish a nexus between the traffic noise impact and reduction of that noise by the installation of a sound barrier. No analysis has been conducted to establish that construction of a sound barrier will reduce traffic noise impacts to a less than significant level. Requiring a site-specific noise study for a sound barrier is deferred mitigation as it is unclear if the sound barrier will effectively mitigate the impact.

Finally, the mitigation repeatedly mentions the term "aesthetically pleasing." This is an arbitrary standard that varies person by person, and which could result in a barrier that is not consistent with the City's Design Review Guidelines.

For these reasons, the mitigation measure should be removed.

6. Traffic and Transportation

a. *Mitigation Measure 4.11-2(a) – Accommodate All Delivery Truck Parking On-Site.*

The Draft EIR lists "traffic problems" from delivery trucks arriving prior to a scheduled pick-up or delivery time. (Draft EIR, pg. 4.11-29). The "traffic problems" mentioned are not adequately analyzed, however. The only discussion is that these truck drivers may "park along local streets in the vicinity or travel on local streets until access to the distribution center is available." The impact of these activities has not been quantified or discussed qualitatively in any further detail. Therefore, the Draft EIR has not provided any nexus between the alleged impact and the need for a mitigation that requires an on-site waiting area. As such, this mitigation measure should be removed.

On a side note, the Draft EIR states in this section that these traffic problems "could create also noise and air quality problems." (Draft EIR, pg. 4.11-29). Any noise or air quality problems from delivery trucks presumable have already been addressed in those sections.

b. *Mitigation Measure 4.11-2(b) subsec. c – Manage Truck Traffic on Local Streets.*

This mitigation measure requires the development and implementation of a truck route plan. All tractor trailers approaching and departing from the Project already will be required to use Surface Transportation Assistance Act of 1982 (STAA) approved Truck Routes, however. These STAA Routes are appropriate roadways for use by tractor trailers accessing the Project. This mitigation lists several non-STAA roadways and roadways near residential areas, which would not be appropriate. Given trucks will already need to abide by STAA, this measure should be revised or deleted.

7. Utilities and Public Services

a. *Mitigation Measures 4.12-4 – Incorporate Energy Efficiency Features into Project Designs.*

Wal-Mart is committed to reducing the energy demand footprint of its facilities. Wal-Mart's approach to reducing emissions is holistic and looks at the whole project-from design to construction, to landscaping, to operations. Wal-Mart's company-wide strategy to reduce the energy demand footprint of its facilities includes implementing energy reduction, reclamation/reuse, and efficiency features. By implementing this strategy Wal-Mart facilities exceed California's Title 24 requirements. This approach of first reducing the facilities' energy footprint is consistent with recommendations made by recognized leaders in the energy efficiency and renewable energy arenas.

Leaders in the energy efficiency and renewable energy arenas also recognize that any solutions to environmental problems (such as global warming) must be founded in sound business judgment and must prove to be economically feasible. Only then can these solutions be successful in the market-place. This philosophy is the mission statement for the Energy Efficiency Center at the University of California at Davis, where Wal-Mart occupies a Board Chair and Steering Committee Chair, as well as the California Energy Commission, California Public Utilities Commission, and California leading businesses, organizations, and academia. The United States Department of Energy also has adopted this philosophy as the founding premise for the Retail Energy Alliance, which is a Department of Energy sponsored national organization of leading retailers focused on energy efficiency solutions that meet business needs. Wal-Mart sits on the Steering Committee of that organization as well.

Wal-Mart is not only committed to working with experts on policies and approaches to reduce energy consumption and increase the use of renewable resources, but it also applies those practices in its facilities. Unfortunately, the mitigation proposed includes several energy efficiency features that are infeasible or not appropriate for the Project. As technology is constantly changing, requiring specific measures potentially prevents the incorporation of the best energy efficient measures available at the time the Project is constructed. Wal-Mart therefore proposes the following mitigation language to ensure the Project contains the most up-to-date energy efficient measures available at the time of construction:

> "The Project shall employ the energy efficient measures proven effective, at the time of Plan Check submittal, in the building design and construction. However, the measures used shall, at a minimum, be as energy efficient as those proven energy efficient measures, or comparable measures, listed below:
>
> > Energy efficient HVAC units: "Super" high efficiency packaged HVAC units exceeding the industry standard EER.
> >
> > Central Energy Management: An energy management system that is monitored from the Home Office in Bentonville, Arkansas.
> >
> > Light Sensors: Occupancy sensors that detect activity in a room or rack aisle and automatically turn off the lights when the space is unoccupied.
> >
> > Interior Lighting Program: Lighting that utilizes T-8 fluorescent lamps and electronic ballasts, unless

more efficient lighting is available, and "low-mercury" lamps.

Poured Concrete: Up to 25% fly ash in the exterior concrete mixes; up to 40 % of the mix can be a combination of fly ash and ground granulated blast furnace slag.

Recycling: (A) Steel recycling: Include a substantial amount of recycled steel in construction. (B) Recycled Plastic: All of the plastic baseboards, and many of the plastic shelving, should be manufactured from recycled material.

Non-PVC Roofs: Use non-PVC roofing.

Water Conservation Landscaping Features: Landscaping plan must include at least three of the following water conservation features: low-precipitation systems, programmable irrigation controllers with automatic rain shut off sensors, matched precipitation rate nozzles that maximize the uniformity of the water distribution characteristics of the irrigation system, conservative sprinkler spacings that minimize overspray onto paved surfaces, or hydrozones that keep plants with similar water needs in the same irrigation zone.

Recycle Construction Debris: Implement a construction debris recycling program.

By incorporating measures like those listed above in the proposed mitigation measure, Wal-Mart will reduce the energy demand of the facility, thereby reducing the facility's energy demand footprint. The proposed features will result in a project that well exceeds California's Title 24 requirements and reduces greenhouse gas consumption.

8. Visual Resources

a. *Mitigation Measure 4.13-2 – Prepare and Submit a Landscaping Plan.*

The Draft EIR analyzes the visual impacts of the Project using a computer generated photo simulation of the proposed Project. This photo simulation, however, does not include any landscaping that may be planted. (Draft EIR, pg. 4.13-7). While the development of the Project will alter the visual character of the site, the impact of the Project cannot be fully analyzed without an adequate representation of the site, which will include landscaping and required street trees. Thus, there is no nexus between the alleged impact identified and the mitigation required.

Further, the tree planting requirements under this mitigation reflect requirements typically imposed on a commercial use, such as a retail store located on a small parcel in a largely developed commercial area, with the building located closer to the property boundaries and therefore being highly visible from adjacent streets/properties. Because of the nature and siting of such a use, imposing mitigations requiring significant landscaping makes sense and is feasible. When the nature of a project is an industrial use located within a 230 acre site and far removed from the property boundaries, though, as is the case here, implementing such measures typically is infeasible, not to mention unwarranted. The requirements set forth in the mitigation should be revised to reflect this situation.

b. *Mitigation Measures 4.13-3 – Prepare and Submit a Lighting Plan.*

The mitigation requires the submittal of a lighting plan to mitigate any potential impacts of **light spillage offsite**. It includes a requirement that "no illumination source (including light bulb and reflector) shall be visible beyond the property line."

The Project will include pole-mounted metal halide lamps located approximately 45 feet above the ground surface. At this height, it is infeasible that the bulb or reflector would not be visible off-site. However, there is no nexus in any event for requiring this mitigation because the mitigation would address offsite visibility, not offsite **spillage**. Requiring that the bulb and reflector not be visible off-site is irrelevant to whether light spills to adjacent uses. As there is no nexus between the mitigation and the impact, this requirement should be removed.

* * * * *

Thank you for consideration of our comments on the mitigations proposed in the Draft EIR. If you have any question or would like to discuss these comments in more detail please call me at 415-774-2993.

Very truly yours,

Judy V. Davidoff /mm

Judy V. Davidoff

for SHEPPARD, MULLIN, RICHTER & HAMPTON LLP

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cc: Colby Tanner, Wal-Mart Stores, Inc.

Jim D. Emerson, Jacobs Carter Burgess

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Espinosa, Kim

From: CALFMAN1@aol.com
Sent: Monday, April 27, 2009 5:59 PM
To: Espinosa, Kim
Cc: CALFMAN1@aol.com
Subject: DEIR Wal-Mart Comments

RECEIVED
APR 27 2009
CITY OF MERCED
PLANNING DEPT.

Received at 6:00 P.M.
FAX not received

Valley Land Alliance
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April 27, 2009

Kim Espinosa, Planning Manager
City of Merced
Planning Department
678 W. 18th Street
Merced, CA 95340
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Fax 209-725-8775

Dear Ms. Espinosa; Sent Via both email and fax

Valley Land Alliance is a grass roots nonprofit organization dedicated to Educate and Build Alliances to protect our uniquely productive California Central Valley Farmland.
Valley Land Alliance submits the following comments in response to the Draft EIR on the proposed Wal-Mart.

Mitigation; We request land loss in Agriculture to any development a 4 to 1 mitigation.

Runoff and Erosion: We have concerns about the water run off from the proposed facility. This could have substantial adverse effects upon the quality of water running off into streams, and will cause substantial, unmitigated pollution.

Traffic: We have concerns of the impact to traffic on Hwy 99 in both directions North and South, and the impact on back streets and how this will impede the shipment of agricultural products and interfere with farm and harvesting equipment. This is especially disconcerting during peak harvest times. We understand from studies from other Wal-Mart distribution centers that back roads are impacted by both trucks parking on the side of the road idling, and by using back roads to avoid traffic.

Air Quality: Air quality is under extreme scrutiny in the Central Valley and the Agricultural community is under intense pressure to comply with ever-increasing regulations. The ag community has been under tremendous attack as one of the major sources of air pollution and we are concerned that the swell in truck traffic from this project will add more pressure to the agricultural supported county. Meaning the Ag community will be taking blame for any increase in air pollution. We would like to see all trucks that are idling for a period of more than 5 minutes required to park under a filter system that eliminates air pollution.

Schools; In the light that this distribution center is so close to several schools we would request that the Wal-Mart distribution center be required to move these school to a location that would not disrupt the day to day actives of the parents and children who attend these schools. We believe that a healthy community is schools whose air and traffic are not compromise by truck traffic.

Sustainability: We would request that all power from the distribution center be from alternate sources such as solar and wind power. We would also request that the roofing be a source of this alternate energy.

Community Giving; Since we believe that this distribution center will be allowing the creations of 30 plus more Wal-Marts and that Wal-Marts are normally the reason for the loss of our locally owned and operated stores in towns, and we believe that these are also part of the reason that our downtowns die and cause a shift of buying to box stores. We would request that this distribution center be required as a mitigation to contribute back 1% of their earnings to the community in such ways as educating the public of the importance of eating healthy, local foods. Contribute to our downtown arts and local theaters.

Local Agriculture; As this distribution center will have a major effect on all our lives that live here in Merced and close to Merced. We would ask that Wal-Mart be required to source their produce from local markets to help support the local farmers that would be impacted from this distribution center.

Sincerely,

Rochelle Koch
On behalf of Valley Land Alliance
Calfman1@aol.com
