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Association of Changes in Air Quality with Bronchitic Symptoms in Children in California, 1993–2012

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Abstract

Importance—Childhood bronchitic symptoms are significant public health and clinical problems that produce a substantial burden of disease. Ambient air pollutants are important determinants of bronchitis occurrence.

Objective—To determine if improvements in ambient air quality in Southern California were associated with reductions in bronchitic symptoms in children.

Design, Setting, and Participants—A longitudinal study was conducted on 4,602 children (spanning 5–18 years of age) from three cohorts during 1993–2001, 1996–2004 and 2003–2012 in eight Southern California communities. A multilevel logistic model was used to estimate the association of changes in pollution levels with bronchitic symptoms.

Exposures—Average concentrations of nitrogen dioxide (NO_2), ozone (O_3), particulate matter with an aerodynamic diameter less than 10 μm (PM_{10}) and less than 2.5 μm ($PM_{2.5}$)

Main Outcome(s) and Measure(s)—Annual age-specific prevalence of bronchitic symptoms during the previous 12 months based on the parent's or child's report of a daily cough for 3 months in a row, congestion or phlegm other than when accompanied by a cold, or bronchitis.

Results—The three cohorts included a total of 4602 children (mean age at baseline, 8.0 years; 2268 (49.3%) girls; 2081 (45.2%) Hispanic white) who had data from two or more annual questionnaires. Among these children, 892 (19.4%) had asthma at age 10. For NO_2, the odds ratio [OR] for bronchitic symptoms among children with asthma at age 10 was 0.79 (95% CI,0.67–0.94) for median reduction of 4.9 ppb, with absolute decrease in prevalence of 10.1%. For O_3, the OR was 0.66 (95% CI,0.50–0.86) for median reduction of 3.6 ppb, with absolute decrease in prevalence of 16.3%. For PM_{10}, the OR was 0.61 (95% CI,0.48–0.78) for median reduction of 5.8 $\mu g/m^3$, with absolute decrease in prevalence of 18.7%. For $PM_{2.5}$, the OR was 0.68 (95% CI,0.53–0.86) for median reduction of 6.8 $\mu g/m^3$, with absolute decrease in prevalence of 15.4%. Among children without asthma (N=3,710), the corresponding associations were: NO_2 (OR,0.84; 95% CI,

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0.76–0.92); O_3 (OR,0.85; 95% CI,0.74–0.97), PM_{10} (OR,0.80; 95% CI,0.70–0.92), and $PM_{2.5}$ (OR,0.79; 95% CI,0.69–0.91); with absolute decrease in prevalence of 1.8%, 1.7%, 2.2%, and 2.3% respectively. The associations were similar or slightly stronger at age 15.

Conclusions and Relevance—Decreases in ambient pollution levels were associated with statistically significant decreases in bronchitic symptoms in children. While the study design does not establish causality, the findings support potential benefit of air pollution reduction on asthma control.

INTRODUCTION

Bronchitis and chronic bronchitic symptoms in children are common yet under-appreciated health issues associated with clinically important morbidity. [1–8] Several studies indicate that exposure to elevated concentrations of ambient air pollution, often at levels below regulatory standards, is associated with large increases in the prevalence of bronchitic symptoms among children with asthma, [1, 5, 9, 10] potentially resulting in a heavy burden of disease in exposed children with substantial economic cost.[11, 12]

Historically, Southern California has reported high levels of ambient air pollution due to emissions from vehicular traffic, industrial sources, two very large ports, and complex atmospheric photochemical reactions. In the last twenty years, significant improvements in air quality have been observed across Southern California due to a broad spectrum of air pollution reduction policies and strategies.[13] We hypothesized that the reductions in particulate matter with an aerodynamic diameter less than 10 μm (PM_{10}) or less than 2.5 μm ($PM_{2.5}$), nitrogen dioxide (NO_2) and Ozone (O_3) concentrations observed across southern California were associated with improvements in respiratory symptoms in children with or without asthma. We examined data from the Southern California Children's Health Study (CHS) that include twenty years of continuous air quality monitoring data and respiratory outcome information from successive cohorts of children followed during 1993–2012.

METHODS

Study Population

Twelve Southern California communities were originally selected to represent a historically diverse pollution profile of regional levels of NO_2, PM_{10}, O_3 and acid vapor [14]. Three successively recruited cohorts were used in the current study. In 1993, 1,800 fourth graders, at ages 9–10, were recruited from schools across 12 communities and followed through high school graduation in 2001. In 1996, another cohort of approximately 2,080 fourth graders from the same communities was recruited and followed through high school graduation in 2004. In 2003, a new cohort of 5,600 either kindergarten or first graders (aged 5–7) was recruited from thirteen Southern California communities. Eight communities (Alpine, Lake Elsinore, Long Beach, Mira Loma, Riverside, San Dimas, Santa Maria and Upland) had participants in all three cohorts (hereafter referred to as the 1993–2001, 1996–2004, and 2003–2012 cohorts) with air pollution data collected with consistent methods over the period of study. Two other 1993–1995 and 1993–1998 CHS cohorts were not included in the current analysis because they had relatively shorter follow-up.[14, 15] All parents or

guardians of participating children provided written informed consent. The study protocol was approved by the Institutional Review Board of the University of Southern California.

Data Collection

Bronchitic Outcomes and Asthma—Bronchitic symptoms were assessed using an annual follow-up questionnaire, as previously described.[1, 9] A child was considered to have had chronic bronchitic symptoms during the previous 12 months, based on the parent's and/or child's report of a daily cough for 3 months in a row, congestion or phlegm other than when accompanied by a cold, or bronchitis. For the 1993–2001 and 1996–2004 cohorts, children were considered to have a history of asthma before the age of 10 years, if there was a yes answer to the question on the baseline questionnaire "Has a doctor ever diagnosed this child as having asthma?" For the 2003–2012 Cohort, a child was considered to have a history of asthma before age 10 if an asthma diagnosis was made before age 10 based on annual assessment starting from age 5–7. In the models, participants were classified according to whether they had asthma before age 10 [asthma group] or did not have asthma before age 10 and during the follow-up period [non-asthma group].

Air Pollution Measurements and Metrics—Air pollution monitoring stations were established in each of the 8 communities. For each year of follow-up, measurements were made for O_3, NO_2, PM_{10} and $PM_{2.5}$, as described previously, [14, 16] and in the online supplement (eMethods). Community-specific annual averages of the 24-hour PM_{10}, $PM_{2.5}$, and NO_2 and of the 10:00 a.m. to 6:00 p.m. averages of O_3 were used to compute the cohort-specific mean levels for the relevant period of follow-up (9-yr 1992–2000 average; 9-year 1995–2003 average; and 10-year 2002–2011 average for the three successive cohorts respectively) in each community. Exposure values were lagged by one year for better alignment with bronchitic outcomes data that assessed symptoms during the prior 12 months.

Additional Covariates from Questionnaires—From the baseline and follow-up questionnaires, we evaluated potential confounders or modifiers of the associations with air pollution, including annual information on exposure to secondhand tobacco smoke in the home (SHS) and baseline information on the ownership of a dog, cat, or any pet (including dogs and cats), gender, race/ethnicity, and housing conditions. Race/ethnicity was based on self-identified information from questionnaire responses to investigator designed two fixed-category questions on race and Hispanic ethnicity. The inclusion of race/ethnicity in the models was important in order to control for any confounding effect within and across the three cohorts.

Data Analysis

To assess the associations between improvements in air quality and bronchitic symptoms in children during 1993–2012, we used a multilevel logistic model [1, 9, 17] to examine the association between cohort- and community- specific pollution levels and longitudinal data on bronchitic symptoms. Random effects were included to account for serial dependency within children and clustering effects of children by cohort and community. Effect estimates were scaled to the corresponding median of the eight community-level average changes in

each pollutant from the 1993–2001 to the 2003–2012 study periods. Time-dependent covariates included exposure to SHS, season/month of data collection and a cubic spline function of age with knots at 10 and 15 to account for any non-linear association of age with bronchitic symptoms. All results presented were obtained from asthma-specific models, which were fitted due to significant differences in prevalence of bronchitic symptoms by asthma status. Also, we examined potential effect modification by gender, race/ethnicity (limiting to Hispanic and non-Hispanic white groups), dog ownership, cat ownership, parental level of education, and exposure to SHS.[9] In all models, missing data were assumed to be missing at random. Because missingness in the adjustment variables was very modest, we used a missing indicator method as needed for any adjustment variable in order to avoid loss of sample size. [18] All of the final models were adjusted for age, gender, race/ethnicity, and exposure to second hand smoke during the follow-up period. In addition, the models for NO_2 were also adjusted for exposure to roaches at home. These models also included a fixed effect for community, and hence were used to make inferences on associations with community-specific secular changes in air pollution levels during the 1992–2011 periods. Two pollutant models were fitted whenever the correlations between covariates were found to be sufficiently low in order to avoid multi-collinearity. Robustness of main study findings were tested via sensitivity analyses by limiting the analysis *(i)* to those participants without SHS or in-utero tobacco smoke exposure, *(ii)* to those with pets, *(iii)* to those stratified by obesity status (i.e., limiting to Non-obese participants and to normal-weight participants based on age- and sex- specific $<95^{th}$ and $<85^{th}$ cutoffs respectively based on CDC percentiles[19]), *(iv)* to those filling English language questionnaire only, *(v)* to those stratified by ethnicity (limiting to Hispanic whites only or to non-Hispanic whites only), *(vi)* to those with parents completing English language questionnaire only, *(vii)* to those participants without any asthma medication use, or *(viii)* to those participants with complete data during follow-up. Additional sensitivity analyses were conducted stratified by cat ownership, or parental level of education. Post-hoc sensitivity analyses were conducted to check if areas with increased concentrations of regulated regional air pollution levels generally had increased prevalence of bronchitis within any given cohort. Graphical displays of unprocessed data were also examined to assess if the main findings were supported by general patterns in the data.

All analyses assumed a two-sided alternative hypothesis at 0.05 level of significance. All models were fitted using the R (version i386 3.0.2) or SAS (SAS 9.3) software packages.

RESULTS

The study included 4,602 participants (1,008, 1,067, and 2,527 children from the 1993–2001, 1996–2004, and 2003–2012 cohorts respectively) who had data from two or more annual follow-up questionnaires and after excluding 297 participants who were newly diagnosed with asthma during the follow-up period. There were similar numbers of girls and boys overall (49% vs. 51%) and across all cohorts (Table 1). The proportion of Hispanic children increased from 29% for the 1993–2001 cohort to 35% for the 1996–2004 cohort and to 56% for the 2003–2012 cohort. The 2003–2012 cohort had significantly lower proportion of exposure to SHS or history of in-utero exposure to maternal smoking and lower prevalence of ownership of any pets including cats and dogs as well as higher

prevalence of asthma at age 10 (23% vs. 15%). Additionally, the 2003–2012 cohort had larger proportions of children with health insurance, living in homes with gas stoves, and who were obese or overweight at age 10 as well as lower proportion of children who had carpet in the house and who had parents with a high school diploma. A higher proportion of the 2003–2012 cohort participants completed a Spanish language questionnaire. Prevalence of bronchitic symptoms decreased across the 1993–2012 study period, but the reduction was larger between the 1996–2004 and the 2003–2012 cohorts compared to that between the two earlier cohorts which showed modest change or even slight increase at times. Levels were slightly higher at age 15 compared to age 10 within each cohort. Children with asthma had a significantly higher overall prevalence of bronchitic symptoms (Table 1, eTable 1 and eFigure 1).[20]

Overall, air pollution levels declined (especially after 2001) across the three cohorts as can be seen in Figure 1.[21] For NO_2 and O_3, pollution levels in all eight communities declined with the lowest average levels observed for the 2003–2012 cohort, with the exception of Long Beach and Santa Maria where O3 levels were higher in the 2003–2012 cohort (eTable 2 and eFigure 2). The decreases were larger in communities with the highest levels of pollutants. Similar declines were observed for $PM_{2.5}$, with the exception of Alpine. Changes in levels of PM_{10} were relatively smaller in most communities with modestly increased levels in some communities (eTable 2 and eFigure 2).

Decreases in ambient air pollutant levels of NO_2, O_3, PM_{10}, and $PM_{2.5}$ were associated with reductions in bronchitic symptoms at ages 10 and 15 with and without asthma (Table 2). Among children with asthma, bronchitic symptoms at age 10 were significantly associated with NO_2 (odds ratio [OR], 0.79; 95% CI, 0.67–0.94) for a median reduction of 4.9 ppb with corresponding absolute decrease in prevalence of 10.1% (95% CI, 15.8-2.9). For O_3, the OR was 0.66 (95% CI, 0.50–0.86) for a median reduction of 3.6 ppb with corresponding absolute decrease in prevalence of 16.3% (95% CI, 24.0-6.7). For PM_{10}, the OR was 0.61 (95% CI, 0.48–0.78) for a median reduction of 5.8 $\mu g/m^3$ with corresponding absolute decrease in prevalence of 18.7% (95% CI, 25.0-10.6). For $PM_{2.5}$, the OR was 0.68 (95% CI, 0.53–0.86) for a median reduction of 6.8 $\mu g/m^3$ with corresponding absolute decrease in prevalence of 15.4% (95% CI, 22.6–6.7). In the above calculations, the median reductions were based on the eight community-level changes in mean pollution levels during the 1992–2000, 1995–2003 and the 2002–2011 averaging periods for the three cohorts. The absolute differences in prevalence were calculated relative to the adjusted baseline prevalence of 48% for the 1993–2001 cohort. Among children without asthma, the corresponding associations with prevalence of bronchitic symptoms were relatively smaller: NO_2 (OR, 0.84; 95% CI, 0.76–0.92) with corresponding absolute decrease in prevalence of 1.8% (95% CI, 2.7-0.9), O_3 (OR, 0.85; 95% CI, 0.74–0.97) with corresponding absolute decrease in prevalence of 1.7% (95% CI, 2.9-0.3), PM_{10} (OR, 0.80; 95% CI, 0.70–0.92) with corresponding absolute decrease in prevalence of 2.2% (95% CI, 3.3-0.9), and PM2.5 (OR, 0.79; 95% CI, 0.69–0.91) with corresponding absolute decrease in prevalence of 2.3% (95% CI, 3.4-1.0) (Table 2). The absolute differences in prevalence were calculated relative to adjusted baseline prevalence of 11.1% for the 1993–2001 cohort. Corresponding results at age 15 were either similar or slightly larger (Table 2). In post hoc analyses, areas with increased concentrations of regulated regional air pollution levels generally had increased prevalence of bronchitis

within any given cohort (eFigure 3). Similar associations were seen in graphs of unprocessed data, focusing on prevalences at age 10 (eFigure 4). Due to high multi-collinearity between NO_2, PM_{10}, and $PM_{2.5}$ (see eTable 3), two-pollutant models were only possible with O_3. Based on these two-pollutant models, the associations with O_3 became non-significant (except for the O_3 + NO_2 model in the asthma group) while the estimates for each of the other pollutants remained significant (see eTable 4).

Based on models with random effects for the air pollution estimates, there was no heterogeneity of model estimates by community of residence. Plots of the predicted changes in prevalence of bronchitic symptoms by changes in air pollution levels across the study period showed that relatively larger changes in prevalence of bronchitic symptoms were observed in communities with larger changes in air pollutant levels (Figure 2), indicating that decreases in symptoms were not an artifact of temporal confounding acting across communities. For example, in the asthma group, a 12 $\mu g/m^2$ decline in $PM_{2.5}$ for children in Riverside was associated with a 20% reduction in bronchitic symptom prevalence while in Alpine, a decline of 0.5 $\mu g/m^2$ was associated with a negligible change in the prevalence of bronchitic symptoms.

Sensitivity analyses were conducted to test the robustness of study findings by limiting the analysis to important subgroups (see eMethods). The estimated reductions in bronchitic symptoms were robust to any of these restrictions (see eTable 5) and remained similar when examined at ages 10, 13 and 15 (Table 2 and eTable 6). Results from models limited to data with overlapping ages for all three cohorts (i.e., between ages of 10 and 15 years) were similar to those based on the whole age range (Table 2 and eTable 7). The results presented in eTable 7 were based on exposure averaging periods that were relevant to the overlapping age periods. Specifically, we used 1992–1997, 1995–2000, and 2006–2011 respectively for the three successive cohorts.

In the asthma group, the associations with NO_2 and $PM_{2.5}$ were significantly larger in boys and among children with family dog ownership (Table 3). Reductions in bronchitic symptoms as a function of improvement in air quality were qualitatively similar for ages 10 and 15, or slightly larger for age 15 in some cases. None of the other interaction tests by parental level of education, race/ethnicity, cat ownership, or exposure to SHS were found to be statistically significant. Models that tested for effect modification by cat or dog ownership used data from 4,523 children, due to missing relevant questionnaire data.

DISCUSSION

The findings from this study demonstrate that reductions in levels of ambient air pollution over the past 20 years in Southern California were associated with significant reductions in bronchitic symptoms in children with and without asthma. The reductions were proportionally larger in children with asthma and remained similar when examined at 10, 13 and 15 years of age during the follow-up period (Table 2 and eTable 6). Among asthmatics, the reductions in bronchitic symptoms tended to be larger in boys and those from households with dogs.[9]

The reductions in bronchitic symptoms were larger in communities that showed higher improvements in air quality levels (Figure 2) indicating that the findings were robust to temporal confounding.[22] The findings remained robust during subgroup analysis by several factors that could contribute to differential biases and/or potential over- or under-estimation of study findings (eTable 5). Any temporal trends in asthma diagnosis, prevalence, severity or medication use are unlikely to account for these findings as our models also included spline terms for age to account for any secular trends in bronchitic symptoms. The linear relationship between change in air quality and changes in prevalence across all communities is consistent with an effect of air pollution reduction and also suggests that the results are not explained by a secular temporal trend (Figure 2).

Our results are consistent with findings from a large multi-community Swiss study of 9,591 children which showed that moderate improvements in air quality were associated with significant reductions in respiratory symptoms, based on cross-sectional health assessments between 1992 and 2001.[23] Several studies have shown that areas with increased concentrations of regulated regional air pollution levels have increased prevalence of bronchitis [4, 7, 24], a finding that has also been confirmed in this study (eFigure 3). Some studies have shown that yearly variations in pollutant concentrations are positively associated with bronchitis prevalence, especially among children with asthma [1, 9]. Few previous studies have evaluated whether trends in reductions in air pollution levels over decades have led to reductions in bronchitic symptoms. Results from two repeated surveys in former East Germany showed that within-community reductions in total suspended particulates and SO_2 levels following reunification were associated with substantial reductions in total bronchitis prevalence and other nonallergic respiratory symptoms. [25, 26] It is possible that confounding by other temporal community characteristics or trends in respiratory outcomes across cohorts could explain these results. However, the consistency of associations in diverse populations and study designs, and biological patterns of susceptibility observed in studies of air pollution and bronchitis, suggest that the associations and the benefits observed in our study are causally related to air pollution reductions. Larger reductions in prevalence of bronchitic symptoms in children with asthma and with dogs as pets have been observed in previous analyses of the *within*-cohort variability in pollution concentrations across years in the CHS [1, 9]. These differences were predicted based on the known susceptibility of children with asthma to the pollutants studied and the higher levels of endotoxin, which has been shown to potentiate pollutant exposures, in the homes of children with dogs.

Our study has several strengths, including the prospective study design enabling evaluation of associations related to temporal trends in air pollution across several large ethnically diverse cohorts of children from the same communities on trends in bronchitic symptoms, substantial range in exposures to the spectrum of complex multi-pollutant mixtures available in Southern California representing the full national range in the United States, and the opportunity to test whether the associations varied by patterns in susceptibility factors. A major strength of the study was the consistency of protocols in collecting bronchitic symptoms, covariate information, and air pollution monitoring throughout the long study period.

The findings should also be interpreted in light of some limitations. The outcome measure is based on relatively imprecise assessment of health outcomes defined using questionnaire-based reporting of symptoms. However, these outcomes have been widely used in previous epidemiological studies and have shown robust associations with regional pollutants. [1, 4, 7, 9, 24, 25] The components of the bronchitic symptom outcomes used in this study are suggestive of chronic, indolent symptoms that may follow an illness, acute exacerbation of asthma or chronic inflammation which would likely be remembered well. Questionnaire based report of respiratory symptoms might also reflect repeated acute exacerbation, but acute bronchitis has been reported to have a marked influence on quality of life, in adults and in children, and to persist for several weeks, so such episodes also would be likely to be remembered well. [11, 27]

It is possible that false positive misclassification of asthma might have resulted in an under-estimation of the true effect of air pollution in children with asthma, given that asthmatic children were more sensitive than non-asthmatics. The misclassification of personal exposure based on community monitors may also have resulted in some under-estimation of the magnitude of associations. However, because concentrations of $PM_{2.5}$ and PM_{10} vary gradually with geographic distance in Southern California, exposure misclassification for children who attend school in their communities is unlikely to produce a large attenuation of associations. Ozone showed limited gradient across our communities, but has large indoor outdoor concentration differences that depend on housing characteristics and operation. The resulting exposure misclassification would likely result in artificially low model estimates for ozone. Reporting bias is an unlikely explanation for the observed within–community between-cohorts associations because any awareness of long-term trends in air pollution within any community is unlikely to have been a determinant of reporting of bronchitis. The shift in ethnic composition across the three cohorts towards more Hispanicity and lower SES is a potential source of bias. However, bias in our estimates from this change in ethnic distribution is not likely to have a major impact as sensitivity analyses based on models that only considered Hispanic children gave results that were similar to those that included all children. Our findings should be interpreted in the context of the observational design of the study and limitations associated with the use of ecologic community-level ambient (and personal level) exposure estimates in investigating the statistical associations. However, our study design with individual level longitudinal data on bronchitic outcomes and adjustment factors may help to reduce some of the limitations that occur in studies with purely ecologic design, such as aggregation bias, ecologic bias or both.[17, 28]

CONCLUSIONS

Decreases in ambient concentrations of NO_2, O_3, PM_{10} and $PM_{2.5}$ were associated with statistically significant decreases in bronchitic symptoms in children with and without asthma. While the study design does not establish causality, the findings support potential benefit of air pollution reduction on asthma control.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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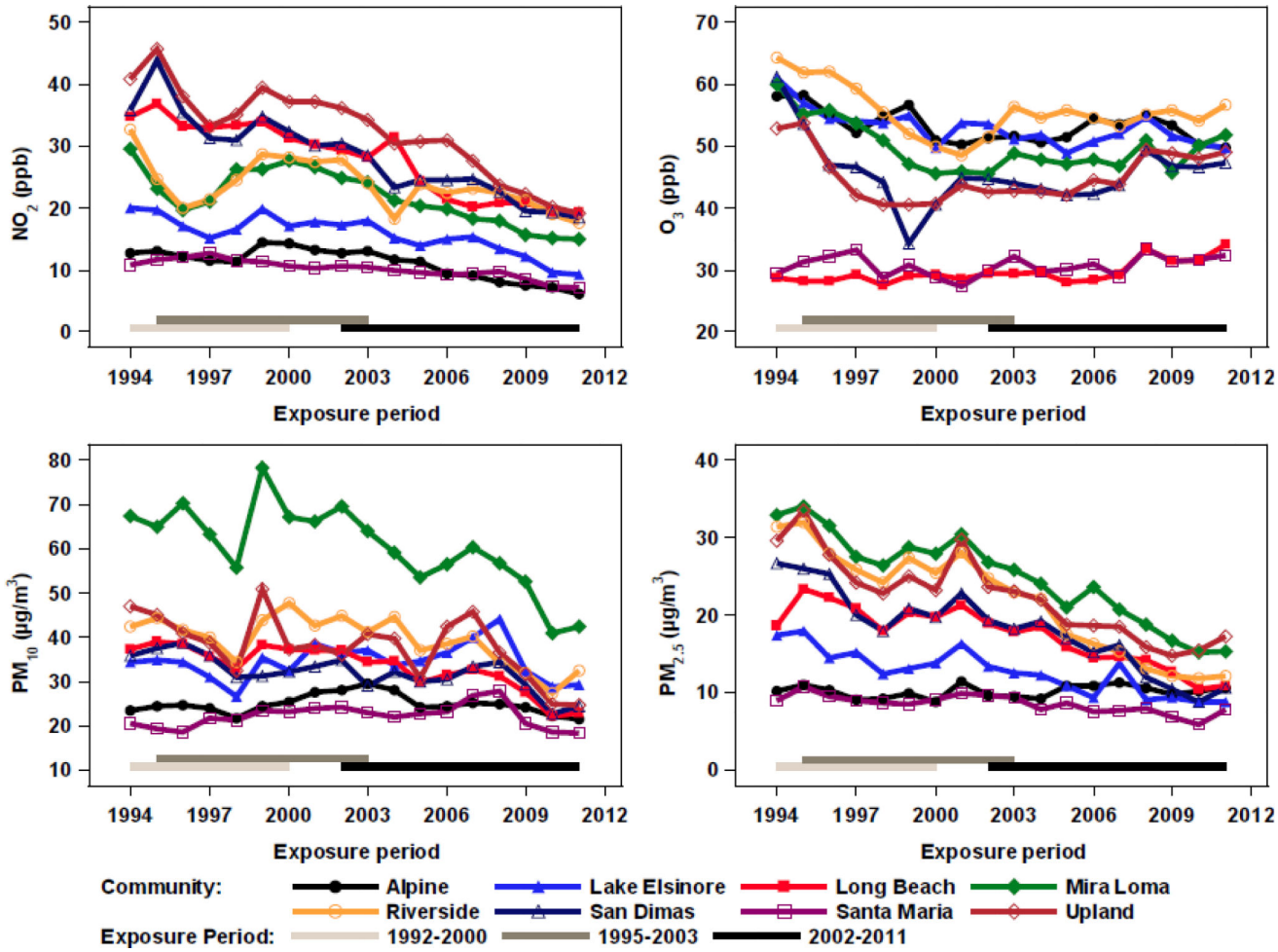

Figure 1. Annual mean air pollutant levels during the follow-up period of the CHS study (1994–2011) by community[a]

a. Plots depict data for 1994–2011, even though the models use 1992–2011 exposure data to examine associations with 1993–2012 data on bronchitic symptoms. This is because data for 1992 and 1993 were not complete and had to be substituted with 1994 data in some cases. For PM10 mean pollutant concentrations from 1994 were used for Alpine, Riverside and Upland for 1992 and 1993 due to missing data. Similarly, PM2.5 mean pollutant concentrations from 1994 were used for 1992 and 1993, for all eight communities, due to missing data.

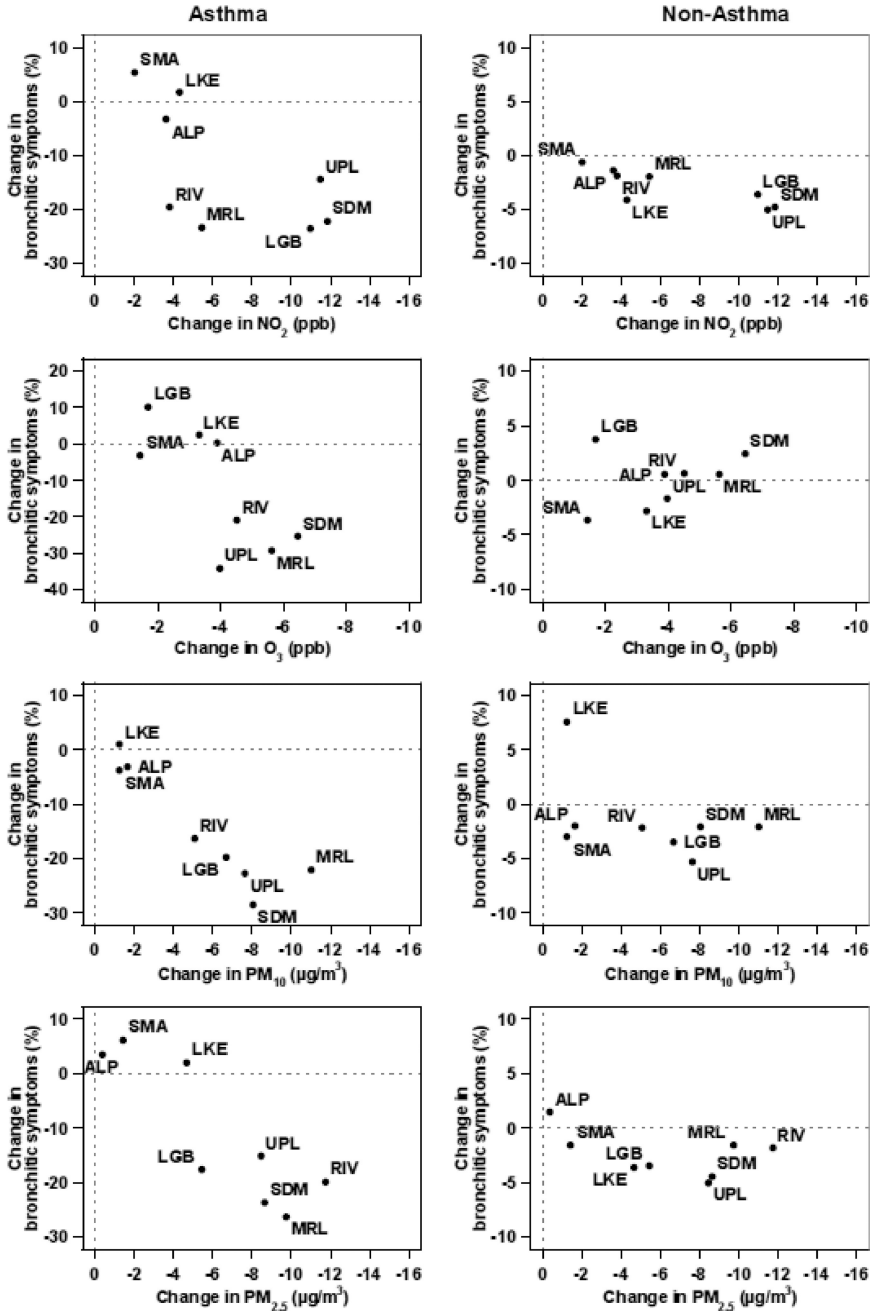

Figure 2. Predicted change in bronchitic symptom prevalence at age 10 versus the change in mean air pollutants over the study period by community[a,b]

a. ALP = Alpine, LKE= Lake Elsinore, LGB=Long Beach, MRL=Mira Loma, RIV=Riverside, SDM=San Dimas, SMA = Santa Maria, UPL=Upland

b. Plots depict (along with y=0 and x=0 line for reference) the predicted changes from the longitudinal model in prevalence of bronchitic symptoms at age 10 (across the 1993–2001 and 2003–2012 cohorts) as functions of the changes in mean exposures levels, comparing high to low mean pollution levels for the 1992–2000, 1995–2003 and the 2002–2011 averaging periods. The estimates used in the plots are based on longitudinal models with

adjustments for gender, race/ethnicity, and a spline function of age with knots (breakpoints) at 10 and 15 years of age.

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Table 1

Distribution of demographic and other baseline characteristics of participants in three CHS[a] cohorts[b]

Characteristic		All (N=4602)	Cohort Follow-Up Period			P-value[c]
			1993 – 2001 (N=1008)	1996 – 2004 (N=1067)	2003 – 2012 (N=2527)	
Age at baseline (yrs)		8.0 (1.7)	9.9 (0.6)	9.7 (0.6)	6.6 (0.7)	<0.001
Gender	Girls	2268 (49.3)	493 (48.9)	530 (49.7)	1245 (49.3)	0.94
	Boys	2334 (50.7)	515 (51.1)	537 (50.3)	1282 (50.7)	
Race/Ethnicity	Asian	198 (4.3)	56 (5.6)	59 (5.5)	83 (3.3)	<0.001
	Black	172 (3.7)	48 (4.8)	53 (5.0)	71 (2.8)	
	Hispanic White	2081 (45.2)	296 (29.4)	377 (35.3)	1408 (55.7)	
	Non-Hispanic white	1883 (40.9)	550 (54.6)	518 (48.5)	815 (32.3)	
	Other	268 (5.8)	58 (5.8)	60 (5.6)	150 (5.9)	
Dog ownership	No	2676 (59.2)	479 (47.5)	481 (45.1)	1716 (70.1)	<0.001
	Yes	1847 (40.8)	529 (52.5)	586 (54.9)	732 (29.9)	
Cat ownership	No	3318 (73.4)	640 (63.5)	684 (64.1)	1994 (81.5)	<0.001
	Yes	1205 (26.6)	368 (36.5)	383 (35.9)	454 (18.5)	
Any pets at home	No	1631 (36.1)	262 (26.0)	236 (22.1)	1133 (46.3)	<0.001
	Yes	2892 (63.9)	746 (74.0)	831 (77.9)	1315 (53.7)	
Spanish questionnaire	No	3870 (84.1)	931 (92.4)	930 (87.2)	2009 (79.5)	<0.001
	Yes	732 (15.9)	77 (7.6)	137 (12.8)	518 (20.5)	
Parental high school graduation	No	754 (17.1)	144 (14.6)	136 (13.4)	474 (19.6)	<0.001
	Yes	3663 (82.9)	842 (85.4)	880 (86.6)	1941 (80.4)	
Health insurance	No	599 (13.3)	163 (16.6)	162 (15.4)	274 (11.1)	<0.001
	Yes	3909 (86.7)	821 (83.4)	889 (84.6)	2199 (88.9)	
Exposure to smoke in-utero	No	3963 (88.7)	807 (82.1)	890 (85.3)	2266 (92.9)	<0.001
	Yes	503 (11.3)	176 (17.9)	153 (14.7)	174 (7.1)	
Exposure to second hand smoke	No	3831 (85.1)	738 (74.5)	803 (76.4)	2290 (93)	<0.001
	Yes	672 (14.9)	252 (25.5)	248 (23.6)	172 (7)	
Any pests at home	No	1145 (27.2)	194 (20.9)	189 (19.6)	762 (32.9)	<0.001
	Yes	3070 (72.8)	736 (79.1)	777 (80.4)	1557 (67.1)	

Characteristic		All (N=4602)	Cohort Follow-Up Period			P-value[c]
			1993 – 2001 (N=1008)	1996 – 2004 (N=1067)	2003 – 2012 (N=2527)	
Roaches at home	No	3709 (88)	769 (82.7)	817 (84.6)	2123 (91.5)	<0.001
	Yes	506 (12)	161 (17.3)	149 (15.4)	196 (8.5)	
Carpet at home	No	216 (4.8)	32 (3.2)	43 (4.1)	141 (5.8)	0.003
	Yes	4261 (95.2)	959 (96.8)	1004 (95.9)	2298 (94.2)	
Mildew at home	No	3294 (76.4)	714 (73.8)	789 (76.8)	1791 (77.4)	0.08
	Yes	1016 (23.6)	254 (26.2)	238 (23.2)	524 (22.6)	
Water damage at home	No	3813 (85.7)	828 (84.1)	920 (87.4)	2065 (85.6)	0.11
	Yes	636 (14.3)	156 (15.9)	133 (12.6)	347 (14.4)	
Gas stove at home	No	916 (20.6)	252 (25.6)	282 (27)	382 (15.7)	<0.001
	Yes	3539 (79.4)	733 (74.4)	762 (73)	2044 (84.3)	
Asthma medication use	No	3671 (79.8)	865 (85.8)	918 (86.0)	1888 (74.7)	<0.001
	Yes	931 (20.2)	143 (14.2)	149 (14.0)	639 (25.3)	
Categorized BMI at Age 10	BMI %ile < 85	2356 (67.4)	669 (73.1)	684 (72.1)	1003 (61.4)	<0.001
	85 ≤ BMI %ile<95	534 (15.2)	132 (14.4)	131 (13.8)	271 (16.6)	
	95 ≤ BMI %ile	608 (17.4)	114 (12.5)	134 (14.1)	360 (22.0)	
BMI (kg/m2) at Age 10		18.7 (3.7)	18.4 (3.3)	18.2 (3.5)	19.1 (3.9)	<0.001
Asthma Status at Age 10	Asthma	892 (19.4)	150 (14.9)	164 (15.4)	578 (22.9)	<0.001
	Non-asthma	3710 (80.6)	858 (85.1)	903 (84.6)	1949 (77.1)	
BCP[d] at Age 10 (Asthma Group)	No	400 (60.4)	68 (47.2)	78 (51.3)	254 (69.4)	<0.001
	Yes	262 (39.6)	76 (52.8)	74 (48.7)	112 (30.6)	
BCP[d] at Age 10 (Non-asthma Group)	No	2519 (88.8)	714 (86.2)	719 (85.4)	1086 (93.0)	<0.001
	Yes	319 (11.2)	114 (13.8)	123 (14.6)	82 (7.0)	
BCP[d] at Age 15 (Asthma Group)	No	313 (67.6)	69 (61.6)	81 (67.5)	163 (70.6)	0.25
	Yes	150 (32.4)	43 (38.4)	39 (32.5)	68 (29.4)	
BCP[d] at Age 15 (Non-asthma Group)	No	1535 (81.9)	456 (79.7)	495 (78.9)	584 (86.4)	<0.001
	Yes	340 (18.1)	116 (20.3)	132 (21.1)	92 (13.6)	

[a] CHS = Children's Health Study

[b] Entries are n(%) and mean (SD) for categorical and continuous (age and BMI) variables, respectively. Numbers may not always add up to overall total of 4,602 participants due to missing data.

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[c] Examining differences between cohorts based on Chi-square test (for categorical variables) and F-test (for the continuous variables).

[d] BCP = bronchitis, cough or phlegm

Table 2

Relative changes in bronchitic symptoms (1993–2012) associated with reductions in air pollution by asthma status

			NO_2[b]			O_3[c]			PM_{10}[c]			$PM_{2.5}$[c]	
Asthma Status	**Age**	**OR[a] (95% CI)**	**Absolute Prevalence Differences (%)[d] (95% CI)**	**p-value**	**OR[a] (95% CI)**	**Absolute Prevalence Differences (%)[d] (95% CI)**	**p-value**	**OR[a] (95% CI)**	**Absolute Prevalence Differences (%)[d] (95% CI)**	**p-value**	**OR[a] (95% CI)**	**Absolute Differences In Prevalence (%)[d] (95% CI)**	**p-value**
Asthma	10	0.79 (0.67, 0.94)	−10.1 (−15.8,−2.9)	0.007	0.66 (0.50, 0.86)	−16.3 (−24.0, −6.7)	0.002	0.61 (0.48, 0.78)	−18.7 (−25.0, −10.6)	<0.001	0.68 (0.53, 0.86)	−15.4 (−22.6, −6.7)	0.002
Non-asthma	10	0.84 (0.76, 0.92)	−1.8 (−2.7, −0.9)	<0.001	0.85 (0.74, 0.97)	−1.7 (−2.9, −0.3)	0.02	0.80 (0.70, 0.92)	−2.2 (−3.3, −0.9)	0.001	0.79 (0.69, 0.91)	−2.3 (−3.4, −1.0)	<0.001
Asthma	15	0.76 (0.64, 0.89)	−8.3 (−12.4, −3.8)	<0.001	0.66 (0.50, 0.86)	−11.7 (−17.2, −4.8)	0.002	0.61 (0.48, 0.77)	−13.4 (−17.9, −7.9)	<0.001	0.64 (0.50, 0.82)	−12.4 (−17.2, −6.2)	<0.001
Non-asthma	15	0.78 (0.71, 0.86)	−3.3 (−4.3, −2.1)	<0.001	0.85 (0.75, 0.98)	−2.2 (−3.7, −0.3)	0.02	0.78 (0.68, 0.89)	−3.3 (−4.7, −1.6)	<0.001	0.71 (0.61, 0.81)	−4.3 (−5.8, −2.8)	<0.001

[a]Odds Ratios (ORs) are per median decreases in pollution levels based on the eight community-level average changes during the period between the 1993-2001 and the 2003-2012 cohorts (4.9, and 3.6 ppb for NO2, O3, and 5.8 and 6.8 μg/m^3 for PM10, and PM2.5, respectively). 95% CI entries refer to 95% Confidence Intervals.

[b]Odds Ratio (OR), by asthma status, adjusted for age, gender, race/ethnicity, longitudinal exposure to second hand tobacco smoke, and roaches at baseline.

[c]Odds Ratio (OR), by asthma status, adjusted for age, gender, race/ethnicity and longitudinal exposure to second hand tobacco smoke.

[d]The absolute differences in prevalence were calculated relative to the adjusted baseline prevalence for the 1993-2001 cohort (48% for the asthma group and 11.1% for the non-asthma group).

Table 3

Relative changes in bronchitic symptoms (1993–2012) associated with reductions in air pollution by age, gender, dog ownership and asthma status

Asthma Status	Age	Effect Modifier	NO_2[b]		O_3[c]		PM_{10}[c]		$PM_{2.5}$[c]	
			OR[a] (95% CI) p-value	Interaction p-value[d]	OR[a] (95% CI) p-value	Interaction p-value[d]	OR[a] (95% CI) p-value	Interaction p-value[d]	OR[a] (95% CI) p-value	Interaction p-value[d]
Asthma	10	Boys	0.72 (0.60, 0.86)		0.66 (0.50, 0.86)		0.59 (0.46, 0.76)		0.55 (0.42, 0.72)	
			<0.001	0.01	0.002	0.61	<0.001	0.27	<0.001	0.02
		Girls	0.86 (0.71, 1.03)		0.64 (0.49, 0.85)		0.64 (0.50, 0.82)		0.82 (0.62, 1.09)	
			0.09		0.002		<0.001		0.16	
		Had Dog	0.71 (0.6, 0.85)		0.70 (0.54, 0.91)		0.60 (0.47, 0.77)		0.57 (0.43, 0.74)	
			<0.001	0.01	0.009	0.18	<0.001	0.06	<0.001	0.03
		No Dog	0.85 (0.7, 1.02)		0.65 (0.49, 0.86)		0.67 (0.51, 0.88)		0.79 (0.59, 1.06)	
			0.08		0.002		0.003		0.12	
Non-asthma	10	Boys	0.82 (0.74, 0.91)		0.85 (0.74, 0.98)		0.80 (0.70, 0.92)		0.78 (0.67, 0.92)	
			<0.001	0.18	0.02	1.00	0.002	0.71	0.002	0.20
		Girls	0.84 (0.76, 0.93)		0.83 (0.73, 0.96)		0.81 (0.71, 0.93)		0.79 (0.68, 0.92)	
			0.001		0.01		0.002		0.002	
		Had Dog	0.83 (0.74, 0.92)		0.84 (0.74, 0.97)		0.83 (0.72, 0.95)		0.79 (0.67, 0.92)	
			<0.001	0.20	0.01	0.28	0.006	0.34	0.002	0.44
		No Dog	0.85 (0.77, 0.95)		0.88 (0.77, 1.02)		0.80 (0.70, 0.94)		0.81 (0.69, 0.96)	
			0.003		0.09		0.006		0.01	
Asthma	15	Boys	0.70 (0.59, 0.84)		0.69 (0.53, 0.91)		0.59 (0.46, 0.76)		0.56 (0.43, 0.73)	
			<0.001	0.02	0.008	0.16	<0.001	0.14	<0.001	0.03
		Girls	0.83 (0.69, 1.00)		0.67 (0.50, 0.88)		0.63 (0.49, 0.81)		0.75 (0.56, 0.99)	
			0.048		0.005		<0.001		0.04	
		Had Dog	0.70 (0.59, 0.84)	0.03	0.68 (0.52, 0.88)	0.15	0.60 (0.47, 0.76)	0.06	0.54 (0.41, 0.71)	0.03
			<0.001		0.004		<0.001		<0.001	
		No Dog	0.82 (0.68, 0.99)		0.65 (0.49, 0.85)		0.67 (0.51, 0.88)		0.72 (0.54, 0.96)	
			0.04		0.002		0.004		0.03	
Non-asthma	15	Boys	0.78 (0.71, 0.87)		0.85 (0.74, 0.98)		0.77 (0.68, 0.89)		0.72 (0.61, 0.84)	

Asthma Status	Age	Effect Modifier	NO_2[b]		O_3[c]		PM_{10}[c]		$PM_{2.5}$[c]	
			OR[a] (95% CI) p-value	Interaction p-value[d]	OR[a] (95% CI) p-value	Interaction p-value[d]	OR[a] (95% CI) p-value	Interaction p-value[d]	OR[a] (95% CI) p-value	Interaction p-value[d]
	15		<0.001	0.99	0.02	0.99	<0.001	0.49	<0.001	0.34
		Girls	0.78 (0.71, 0.87)		0.84 (0.73, 0.96)		0.78 (0.68, 0.90)		0.69 (0.60, 0.81)	
			<0.001		0.01		<0.001		<0.001	
		Had Dog	0.80 (0.72, 0.89)		0.85 (0.74, 0.97)		0.80 (0.70, 0.92)		0.74 (0.63, 0.86)	
			<0.001	0.58	0.02	0.99	0.001	0.38	<0.001	0.68
			0.80 (0.72, 0.89)		0.87 (0.75, 1.00)		0.78 (0.68, 0.91)		0.73 (0.62, 0.86)	
		No Dog	<0.001		0.048		0.002		<0.001	

[a] Odds Ratios (ORs) are per median decreases in pollution levels based on the eight community-level average changes during the period between the 1993–2001 and the 2003-2012 cohorts (4.9, and 3.6 ppb for NO2, O3, and 5.8 and 6.8 μg/m^3 for PM10, and PM2.5, respectively). 95% CI entries refer to 95% Confidence Intervals.

[b] Odds Ratio (OR) adjusted for age, gender, race/ethnicity, longitudinal second hand smoke, and roaches at baseline.

[c] Odds Ratio (OR) adjusted for age, gender, race/ethnicity and longitudinal second hand smoke.

[d] p-values for tests of interaction effects between air pollutants and effect modifiers