HHS Public Access

Author manuscript

*Epidemiology*. Author manuscript; available in PMC 2015 July 28.

Published in final edited form as:

*Epidemiology*. 2009 May ; 20(3): 451–459. doi:10.1097/EDE.0b013e31819d128d.

# Respiratory Symptoms Following Wildfire Smoke Exposure:

## Airway Size as a Susceptibility Factor

**Maria C. Mirabelli**[a,b,c], **Nino Künzli**[a,b,d], **Edward Avol**[e], **Frank D. Gilliland**[e], **W. James Gauderman**[e], **Rob McConnell**[e], and **John M. Peters**[e]

[a]Centre for Research in Environmental Epidemiology, Barcelona, Spain

[b]Municipal Institute of Medical Research (IMIM-Hospital del Mar), Barcelona, Spain

[c]CIBER Epidemiología y Salud Pública, Spain

[d]Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain

[e]Department of Preventive Medicine, Keck School of Medicine, University of Southern California, Los Angeles, California

## Abstract

**Background—**Associations between exposure to smoke during wild-fire events and respiratory symptoms are well documented, but the role of airway size remains unclear. We conducted this analysis to assess whether small airway size modifies these relationships.

**Methods—**We analyzed data from 465 nonasthmatic 16- to 19-year-old participants in the Children's Health Study. Following an outbreak of wildfires in 2003, each student completed a questionnaire about smoke exposure, dry and wet cough, wheezing, and eye symptoms. We used log-binomial regression to evaluate associations between smoke exposure and fire-related health symptoms, and to assess modification of the associations by airway size. As a marker of airway size, we used the ratio of maximum midexpiratory flow to forced vital capacity.

**Results—**Forty percent (186 of 465) of this population (including students from 11 of 12 surveyed communities) reported the odor of wildfire smoke at home. We observed increased respiratory and eye symptoms with increasing frequency of wildfire smoke exposure. Associations between smoke exposure and having any of 4 respiratory symptoms were stronger in the lowest quartile of the lung function ratio (eg, fire smoke 6+ days: prevalence ratio: 3.8; 95% confidence interval (CI = 2.0 –7.2), compared with the remaining quartiles (fire smoke 6+ days: prevalence ratio = 2.0; 1.2–3.2). Analysis of individual symptoms suggests that this interaction may be strongest for effects on wheezing.

**Conclusions—**Small airways may serve as a marker of susceptibility to effects of wildfire smoke. Future studies should investigate the role of airway size for more common exposures and should include persons with asthma.

Correspondence: Maria C. Mirabelli, Centre for Research in Environmental Epidemiology, Barcelona Biomedical Research Park, c/Dr. Aiguader, 88, 08003 Barcelona, Spain. mmirabelli@creal.cat.

The contents of this manuscript are solely the responsibility of the authors and do not necessarily represent the official views of the funding agencies.

Combustion-related ambient air pollution is a well-documented cause of respiratory symptoms among children.[1,2] However, aside from a history of asthma, specific phenotypes determining individual susceptibility have not been well characterized. A more complete understanding of susceptibility factors may have implications for clinical management of respiratory symptoms and the development of prevention strategies for protecting susceptible individuals from hazardous inhalation exposures.

Previous analyses of data from the University of Southern California Children's Health Study (CHS), a longitudinal study designed to evaluate the health effects of chronic air pollution exposure among children living in 12 southern California communities,[3,4] found negative associations between ambient air pollutant concentrations and measurements of lung function development.[5–7] During October and November 2003, 14 wildfires spread across southern California and affected the communities from which participants were recruited. The health effects of exposure to smoke from the intense and, in some communities, long-lasting wildfires were not limited to persons with asthma.[8] Indeed, the responses observed among nonasthmatic children were more consistent than those among asthmatic children, who were far more likely to take preventive actions and medications that may have attenuated the effects of smoke exposure.[8]

Among asthmatic and nonasthmatic children alike, small airways relative to lung size are an anatomic feature of the lung with functional implications. Airway size relative to lung size is smaller, on average, for young boys than young girls; however, throughout childhood and adolescence, boys' airways grow relatively more in size compared with the lung parenchyma, resulting in larger relative airway size in young men.[9,10] This pattern of development and the resulting differences in airway size compared with lung size have been suggested as 1 of the reasons for the difference in respiratory health symptoms observed in girls and boys.[9,11] Although direct measurements of airway size are not readily available, the ratio between measures of midexpiratory flow and lung capacity has been shown to be correlated with airway size.[12]

We hypothesized that among teenagers without asthma, airway size may affect susceptibility to the acute effects of wildfire smoke. Using the results of pulmonary function assessments completed 5–10 months before the wildfires began and data collected before and after the 2003 wildfire episode, we investigated the effect of the ratio of maximum midexpiratory flow (MMEF) to forced vital capacity (FVC), used here as a measure of airway size, on the positive associations reported previously between wildfire smoke and symptoms.[8]

## METHODS

We conducted an epidemiologic analysis using data collected from study participants regarding their health symptoms and exposures to wildfire smoke. Methods have been described previously[3,4]; briefly, this longitudinal study was designed to evaluate the health effects of chronic air pollution exposures among children living in 12 southern California communities. Following the wildfires, members of elementary school– and high school–aged cohorts provided additional data about their wildfire exposures and health symptoms. For this analysis, we used data from the high school–aged cohort, whose 834 members were initially enrolled in 1996 as fourth-grade students and for whom pulmonary function testing was included in the last CHS survey performed before the wildfires. When the survey was conducted following the wildfires, these students were 16- to 19-year-old 12th graders. We further limited our analyses to include only those students without a history of asthma (n = 550, 66%), which was determined using responses about an asthma diagnosis reported at the time of the baseline survey or at the time of the prefire pulmonary function testing. Specifically, participants were classified as having asthma at baseline based on parents' responses to the question "Has a doctor ever diagnosed this child as having asthma?" Participants were categorized as having prefire asthma diagnosis if, at the time of the last pulmonary function test before the wildfires, they gave a positive response to the question "Has a doctor ever said you had asthma?" This exclusion was applied to reduce the likelihood of including persons for whom the measurements of lung capacity may have been affected by asthma. Finally, we excluded 85 of the 550 members (15%) of the cohort due to missing data for any of the following: pulmonary function (n = 6), respiratory symptom or eye symptoms (n = 39), or fire exposure (n = 17). Our final study population included 465 students from 12 southern California communities.

Following the wildfires, each respondent completed a self-administered questionnaire. Questionnaires were completed an average of 65 days after November 3, 2003, the last day of the wildfires (median: 37 days; range: 15–380 days); 95% of all questionnaires were completed before April 5, 2004, 154 days after the fires ended. To assess exposure to smoke from the wildfires, we used the following postfire questionnaire item: "On how many days during the time of the fires could you smell smoke inside the home where you were staying during the fires?" The time of the fires was specified as "the last 2 weeks of October 2003," and respondents were asked to circle a response from the following options: not at all, 1–2 days, 3–5 days, 6 –10 days, all days, and do not know. As with previous analysis of these data, we categorized the frequency of having smelled smoke indoors as none, 1–5 days, and 6+ days.[8]

Respiratory and eye symptoms were assessed using responses to the self-administered fire questionnaire described previously.[8] Symptom questions were posed using the following phrasing: "During the time of the fires (the last 2 weeks of October 2003), did you have any of the following:" The question was followed by a list of symptoms, including those assessed as outcomes in this analysis: (1) dry cough first thing in the morning, (2) dry cough at night, (3) wet cough (congestion in the chest or phlegm production), (4) wheezing or whistling in the chest, (5) itchy or watery eyes, and (6) irritated eyes. As a proxy for allergy status, we created a single variable to indicate whether each respondent experienced any of the following allergy-related symptoms: allergies, hay fever, or runny nose, as reported by parents in the baseline questionnaire. We also categorized individuals as having a history of wheezing based on a question from the baseline questionnaire about ever having whistling in the chest or wheezing, including when he or she had a cold.

The ratio of MMEF to FVC has been used as an indicator of airway size in previous epidemiologic research.[13] In our analyses, we used measurements of lung function obtained from January through May 2003—that is, the last pulmonary function testing that participants completed before the wildfires began. Because of the sex-related differences observed in pulmonary function measurements, we created separate sex-specific quartiles for girls and boys. In this analysis, we compared the exposure–symptom associations among participants in the lowest sex-specific ratio quartile to those generated by participants in the remaining upper 3 ratio quartiles.

We estimated associations between exposure to fire smoke and respiratory and eye symptoms by using log-binomial regression analysis. Associations between exposure to fire smoke and each of the respiratory and eye symptoms were assessed in separate models, each specified with a binomial error distribution and a log link. Included in each of the final models are indicator variables for the frequency of fire smoke exposure (1–5 days, 6+ days), an indicator variable for the airway quartile and 2 terms for the interaction of airway quartile and fire smoke exposure. To account for prefire, background air pollutant exposure levels, all models were also adjusted for community-level measurements of particles with aerodynamic diameter less than 10 $\mu$g ($PM_{10}$), included as the community-specific annual average of the 24-hour average concentration (micrograms/square meter). $PM_{10}$ collection methods have been described in previous publications.[4,5] In these analyses, associations are reported as prevalence ratios (PRs) with 95% confidence intervals (95% CIs). For all analyses, associations are reported separately for airway size quartiles 1 and 2–4.

In addition, we conducted a sensitivity analysis to assess the influence on our estimates of adjustment for additional covariates, namely sex, race (white/nonwhite), Hispanic ethnicity, parental education level (high school or less than high school/completed some college or technical school 4 or more years of college), allergy symptoms, and community of residence. We also assessed whether the results generated in our analyses were different for the populations with and without a history of allergies and without a history of wheezing. Due to small numbers in the exposure and outcome categories when stratified by allergy or wheezing history, the statistical models failed to converge. We therefore grouped the 4 respiratory outcome variables to assess the associations between the fire smoke exposure variables and any versus none of the 4 respiratory symptoms (morning dry cough, night-time dry cough, wet cough, and wheezing) and any versus none of the eye symptoms (irritated, itchy, and watery eyes). We performed all analyses using SAS version 9.1 (SAS Institute Inc., Cary, NC, USA).

## RESULTS

Forty percent of participants (186 of 465) reported the smell of smoke from the wildfires inside the home, with notable variation in the percentages among communities (range: 0%–72%, median: 40%). Fire smoke for 6+ days was reported in 10 of the 12 communities, and in only 1 community did no participant report the smell of fire smoke inside their homes. Overall, our final study population consisted of predominantly white, non-Hispanic students aged 16 to 17 years. The population excluded due to missing data (15%, 85 of 550) had a slightly higher percentage of female, nonwhite, and Hispanic respondents (Table 1).

At the time of the baseline questionnaire, the percentage of participants for whom any of the 3 allergy-related symptoms were reported was similar among boys and girls (Table 2). On average, the magnitudes of the spirometric measurements taken at the time of the last prefire pulmonary function examination were higher among boys. In the questionnaire completed following the wildfires, dry cough in the morning, wet cough, and both eye symptoms were reported among a slightly higher percentage of girls than boys (Table 2), and all of the respiratory and eye symptoms were more common among participants in the lowest quartile of lung function ratio than among participants in the remaining quartiles (Table 3).

Table 4 shows consistently positive associations between the duration of exposure to wildfire smoke and self-reported respiratory and eye symptoms following the fires. Elevated associations were observed in both categories of lung function ratio, with higher prevalence and $PM_{10}$-adjusted PRs generated in the lowest ratio quartile compared with the upper quartiles. This suggests a stronger effect of wildfire smoke exposure and duration of exposure in the lowest airway size quartile. For these models, tests for statistical interaction between airway size and wildfire smoke exposures generated $P$-values larger than 0.10 for all symptom models except for the effect of wildfire smoke exposure on wheezing ($P <$ 0.01). Also, although the percentages of respondents reporting eye symptoms are generally higher with presumed smaller airway size, the similarity of the PRs suggest smaller differences across airway-size groups than were observed for respiratory symptoms.

Assessing the association between wildfire smoke and any of the respiratory symptoms shows a monotonic duration response in both groups of lung function ratio (Table 4). This pattern appears to be driven by the associations among a sub-population of 357 participants without asthma or any history of wheezing (quartile 1: fire smoke for 1–5 days: PR = 2.2; CI = 0.96–5.1; fire smoke for 6+ days: 4.2; 2.1–8.4; quartiles 2–4: fire smoke for 1–5 days: 1.6; 1.0 –2.7; fire smoke for 6+ days: 2.3; 1.3–4.0) and by those generated in a population of participants without allergies (Fig.). Furthermore, with the exception of the effect of fire smoke exposure for 1–5 days in the lowest quartile of lung function ratio, the associations between wildfire smoke and any of the respiratory symptoms were not notably affected by simultaneous adjustment for sex, white race, Hispanic ethnicity, parental education, allergy symptoms, $PM_{10}$, and community of residence (quartile 1: fire smoke for 1–5 days: 2.3; 1.1–4.7; fire smoke for 6+ days: 3.4; 1.7–7.0; quartiles 2–4: fire smoke for 1–5 days: 1.8; 1.2–2.8; fire smoke for 6+ days: 1.7; 1.0–2.9).

## DISCUSSION

We observed elevated associations between wildfire smoke and the prevalence of respiratory symptoms among 16- to 19-year-olds living in southern California communities affected by the 2003 wildfires. When we evaluated each of 4 respiratory symptoms individually and all 4 symptoms combined, we observed increasing symptom prevalence with increasing duration of wildfire smoke exposure. These associations were higher among individuals in the lowest quartile of lung function ratio, suggesting that among teenagers without asthma, airway size may serve as a marker of susceptibility to acute effects of wildfire smoke. Specifically, these data provide evidence that small airway size may enhance susceptibility to exposures lasting 6 or more days. The associations appear to be driven largely by the effects observed among nonasthmatic individuals without a history of allergies.

We conducted this analysis to evaluate whether airway size may influence susceptibility to the effects of fire smoke. Thus far, this hypothesis has not been investigated in detail; therefore there are few published studies with which our findings may be compared. There are, however, pathophysiologic grounds as well as some empirical evidence in support of our hypothesis. For example, previous research has used the ratio between midexpiratory flow and vital capacity as an indicator of disproportionately small airways relative to lung size[12]; a low ratio was thought to identify individuals with smaller airways relative to lung size and to be associated with bronchial hyperreactivity. Petty et al proposed that relatively small airways may indicate a mechanism for hyperreactivity that is independent of airway obstruction, the most common cause of bronchial hyperreactivity.[13] Moreover, it has been suggested that airway size modifies local particle deposition patterns in the lung, with deposition increasing as airway size decreases,[14] and there can be large differences in local deposition.[15]

DeMeo et al observed smaller airways among first-degree relatives of individuals with early onset of chronic obstructive pulmonary disease than among individuals in a comparison population. The observed difference was further amplified among smokers.[16] Tager et al reported the effect of chronic exposure to ambient ozone on measures of pulmonary function to be present only among nonasthmatic teenagers with relatively small airways.[17] If individuals with small airways are more susceptible to repeated and acute ozone exposures, and if such exposures affect development of the lungs during childhood and adolescence, then airway size may modify the effects of both acute and long-term air pollutant exposures. In our data, we also observed a higher crude prevalence of symptoms among students in the lowest sex-specific of lung function ration quartile than in the remaining quartiles, irrespective of fire smoke exposure. This observation further supports the notion of small airways as a marker for increased susceptibility.

Our conclusions are limited by the methods used to measure and define airway size. As a marker of airway size, the flow-capacity ratio should ideally be based on spirometric measures obtained during nonforced expiratory maneuvers rather than during forced exhalation because the process of forced exhalation may affect measurements, especially among individuals with reactive airways. To avoid this non-differential measurement effect we excluded respondents with asthma; such an exclusion also eliminates additional heterogeneity due to the actions that participants with asthma reported taking during the time of the fires to avoid smoke exposure and to prevent exacerbation of their asthma-related symptoms.[8] Furthermore, limiting our analysis to individuals without preexisting asthma allowed us to create sex-specific ratio quartiles rather than quartiles created by both sex and asthma history. Inclusion of individuals with a history of asthma, a range of severity of current asthma, or persons with asthma controlled by medication might also improve our understanding of the importance of this measure of airway size. The lung function ratio we used may be a marker of both airway size and bronchial hyperreactivity, and therefore direct measures of airway size would be preferable. Direct measurement may be difficult, however, and here we show the potential utility of a marker based on spirometric measurement of lung function—a rather simple procedure. Because of the differences observed in measures of pulmonary function between boys and girls, we categorized the lung-function ratio into sex-specific ratio quartiles. The small numbers of participants in our analysis prohibited extensive analysis of modification of the exposure—symptom relationships by sex. Estimates generated from models that included sex as a covariate were not notably different from those presented in Table 4. Nonetheless, we cannot rule out the possibility that other sex-related factors may be important and not fully accounted for in our analyses. Additional investigation of the role of sex and sex-related factors may further our understanding of the relationships among airway size, sex, air pollutant exposures, and respiratory symptoms. Interpretation of our findings is also limited by our dichotomous categorization of small airway size. Observable trends within our airway size quartile categories or across smaller ratio categories would provide more convincing evidence of modification; larger datasets with higher numbers of exposed and symptomatic individuals could provide additional evidence to support or refute this hypothesis.

It is not clear to what extent the effects we observed in the lowest quartile of the lung function ratio reflects acute bronchial hyperreactivity, rather than a structural feature of the lung, namely airway size. One possibility is that individuals with hyperreactive airways suffer from undiagnosed asthma. When we conducted these analyses in a population restricted to 357 participants without asthma or any history of wheezing, we observed similar patterns suggestive of interaction between fire smoke exposure and airway size in the 4 respiratory symptom models. In alternate models constructed to maximize the statistical power of our analyses, we assessed the interaction between the sex-specific lung function ratio and fire smoke exposure. Broadly, these models generated results similar to those presented in Table 4; the evidence of interaction that emerged was consistent with our hypothesis. Finally, due to the statistical correlation between forced expiratory volume in 1 second ($FEV_1$), MMEF, $FEV_1$/FVC, and MMEF/FVC, the findings we present here were similar to analyses conducted using the sex-specific quartiles of each of these other metrics (not shown). We present the results for the ratio of MMEF to FVC because of evidence that this ratio may be used as an indicator of airway size and because our a priori primary hypothesis was that airway size may modify the effect of fire smoke exposure. Due to the small number of persons in our study population, our analyses lack the statistical power to investigate thoroughly the added value of using this ratio as an effect modifier, compared with the more traditional measures of lung function. Use of this ratio as an indicator of airway size and the finding of susceptibility based on this factor should be assessed in larger studies.

The effect of fire smoke exposure on irritated and itchy/watery eye symptoms needs further consideration. In both airway-size groups, we observed a duration—response trend for eye symptoms. This finding is not surprising given the density of the smoke in the southern California region[8]; also not surprising is the lack of a clear difference between these PRs generated across strata. Of note, however, are the across-strata differences in the prevalence of both eye symptoms in the highest exposure category. When we assessed the prevalence of any of the eye symptoms (ie, irritated, itchy, or watery eyes), we observed a higher percentage of respondents with any eye symptoms in the lowest quartile (no fire smoke exposure: 42%; fire smoke for 1–5 days: 62%; and fire smoke for 6+ days: 94%) compared with the remaining quartiles (no fire smoke exposure: 37%; fire smoke for 1–5 days: 56%; and fire smoke for 6+ days: 64%), with the largest difference observed in the highest exposure group. The prevalence differences observed may be due to random error. However, that the trend persisted when the population was restricted to the nonallergic participants (not shown) raises the possibility that this metric of airway size correlates with a genetic characteristic or with behaviors and other exogenous factors that are collinear with eye symptoms.

The analyses we present here have other important limitations that should be considered when interpreting our findings. We identified individuals' allergy status by using questionnaire data provided by parents at the time of the baseline survey. We used parent- and self-reported diagnosis of asthma to indicate a history of asthma. Improvements in classification of allergies and asthma history would reduce misclassification of individuals' health histories. The exposure and symptom information is based completely on self-report; we have no validated or objective measurements of wildfire exposures in the home or of symptoms that occurred during the time of the fires. Our analyses are based on small numbers, which limit our ability to assess thoroughly whether individual subpopulations or specific symptoms are particularly affected by airway size. Perhaps most importantly, our analyses are an extension of findings published in 2006 showing evidence of a strong association between exposure to wildfire smoke and acute health symptoms.[8] Here, we hypothesized that these risks could be modified by airway size and thus our analyses differed from those of Kunzli et al[8] in several ways. First, the previous analysis included an elementary-school cohort that we have excluded because the members of the elementary-school cohort, aged 6 –7 years, did not complete pulmonary function testing prior to the 2003 wildfires. Second, these analyses do not partition the effects of within-community and between-community response, and we used log-binomial regression methods. Despite these differences, our results are similar to those first presented by Kunzli et al and were robust to such minor modifications to the statistical approaches applied to the data. In addition, Kunzli et al noted that recall and reporting biases might have explained associations of wildfire smoke exposure with respiratory outcomes.[8] Unless individuals with symptoms associated with small airway size are more likely to recall or report their symptoms or exposures, these biases are unlikely to explain the pattern we observed across strata of airway size. When we assessed the interval of time between the end of the fires and completion of the fire questionnaire as a potential confounder of the exposure–symptom associations, the point estimates and precision of these estimates were largely unchanged. Nonetheless, in future studies of this type, a shorter duration of time between the exposure and symptoms of interest and the survey could reduce the potential for self-reported data to be affected by poor recall.

The identification of susceptible subpopulations is an area of clinical and public health relevance. To target most efficiently medical therapies and preventive measures, health care and public health personnel need easily measured or observed markers of susceptibility, such as those based on health status, sex, or age. The results of our study suggest that the adverse effects of fire smoke are not necessarily restricted to individuals with preexisting respiratory diseases who might otherwise be considered to be at highest risk for exacerbation of their respiratory symptoms. Additional research is needed to elucidate the role of airway size relative to lung size in modifying acute and chronic effects of combustion-related air pollutants.

## Acknowledgments

Supported by the California Air Resources Board (A033-186), the US National Institutes of Health (NIH) (1P01ES009581, 5P30ES007048, 1R01HL061768), the US Environmental Protection Agency (R826708, R831845) and the Hastings Foundation. Maria Mirabelli received funding from the National Institute of Environmental Health Sciences, NIH (1F32ES014142).

We thank Ed Rappaport for his review and comments.

## References

1. Brunekreef B, Holgate ST. Air pollution and health. Lancet. 2002; 360:1233–1242. [PubMed: 12401268]
2. Katsouyanni K. Ambient air pollution and health. Br Med Bull. 2003; 68:143–156. [PubMed: 14757714]
3. Peters JM, Avol E, Gauderman WJ, et al. A study of twelve Southern California communities with differing levels and types of air pollution. II. Effects on pulmonary function. Am J Respir Crit Care Med. 1999; 159:768–775. [PubMed: 10051249]
4. Peters JM, Avol E, Navidi W, et al. A study of twelve Southern California communities with differing levels and types of air pollution. I. Prevalence of respiratory morbidity. Am J Respir Crit Care Med. 1999; 159:760–767. [PubMed: 10051248]
5. Gauderman WJ, McConnell R, Gilliland F, et al. Association between air pollution and lung function growth in southern California children. Am J Respir Crit Care Med. 2000; 162(4 pt 1): 1383–1390. [PubMed: 11029349]
6. Gauderman WJ, Avol E, Gilliland F, et al. The effect of air pollution on lung development from 10 to 18 years of age. N Engl J Med. 2004; 351:1057–1067. [PubMed: 15356303]
7. Gauderman WJ, Vora H, McConnell R, et al. Effect of exposure to traffic on lung development from 10 to 18 years of age: a cohort study. Lancet. 2007; 369:571–577. [PubMed: 17307103]
8. Kunzli N, Avol E, Wu J, et al. Health effects of the 2003 Southern California wildfires on children. Am J Respir Crit Care Med. 2006; 174:1221–1228. [PubMed: 16946126]
9. Becklake MR, Kauffmann F. Gender differences in airway behaviour over the human life span. Thorax. 1999; 54:1119–1138. [PubMed: 10567633]
10. Mead J. Dysanapsis in normal lungs assessed by the relationship between maximal flow, static recoil, and vital capacity. Am Rev Respir Dis. 1980; 121:339–342. [PubMed: 7362140]
11. Merkus PJ, ten Have-Opbroek AA, Quanjer PH. Human lung growth: a review. Pediatr Pulmonol. 1996; 21:383–397. [PubMed: 8927465]
12. Tager IB, Weiss ST, Munoz A, Welty C, Speizer FE. Determinants of response to eucapneic hyperventilation with cold air in a population-based study. Am Rev Respir Dis. 1986; 134:502–508. [PubMed: 3092709]
13. Petty TL. Simple office spirometry. Clin Chest Med. 2001; 22:845–859. [PubMed: 11787669]
14. Balashazy I, Hofmann W, Heistracher T. Local particle deposition patterns may play a key role in the development of lung cancer. J Appl Physiol. 2003; 94:1719–1725. [PubMed: 12533493]
15. Phalen RF, Oldham MJ, Nel AE. Tracheobronchial particle dose considerations for in vitro toxicology studies. Toxicol Sci. 2006; 92:126–132. [PubMed: 16597657]
16. DeMeo DL, Carey VJ, Chapman HA, et al. Familial aggregation of FEF(25–75) and FEF(25–75)/FVC in families with severe, early onset COPD. Thorax. 2004; 59:396–400. [PubMed: 15115866]
17. Tager IB, Balmes J, Lurmann F, Ngo L, Alcorn S, Kunzli N. Chronic exposure to ambient ozone and lung function in young adults. Epidemiology. 2005; 16:751–759. [PubMed: 16222164]

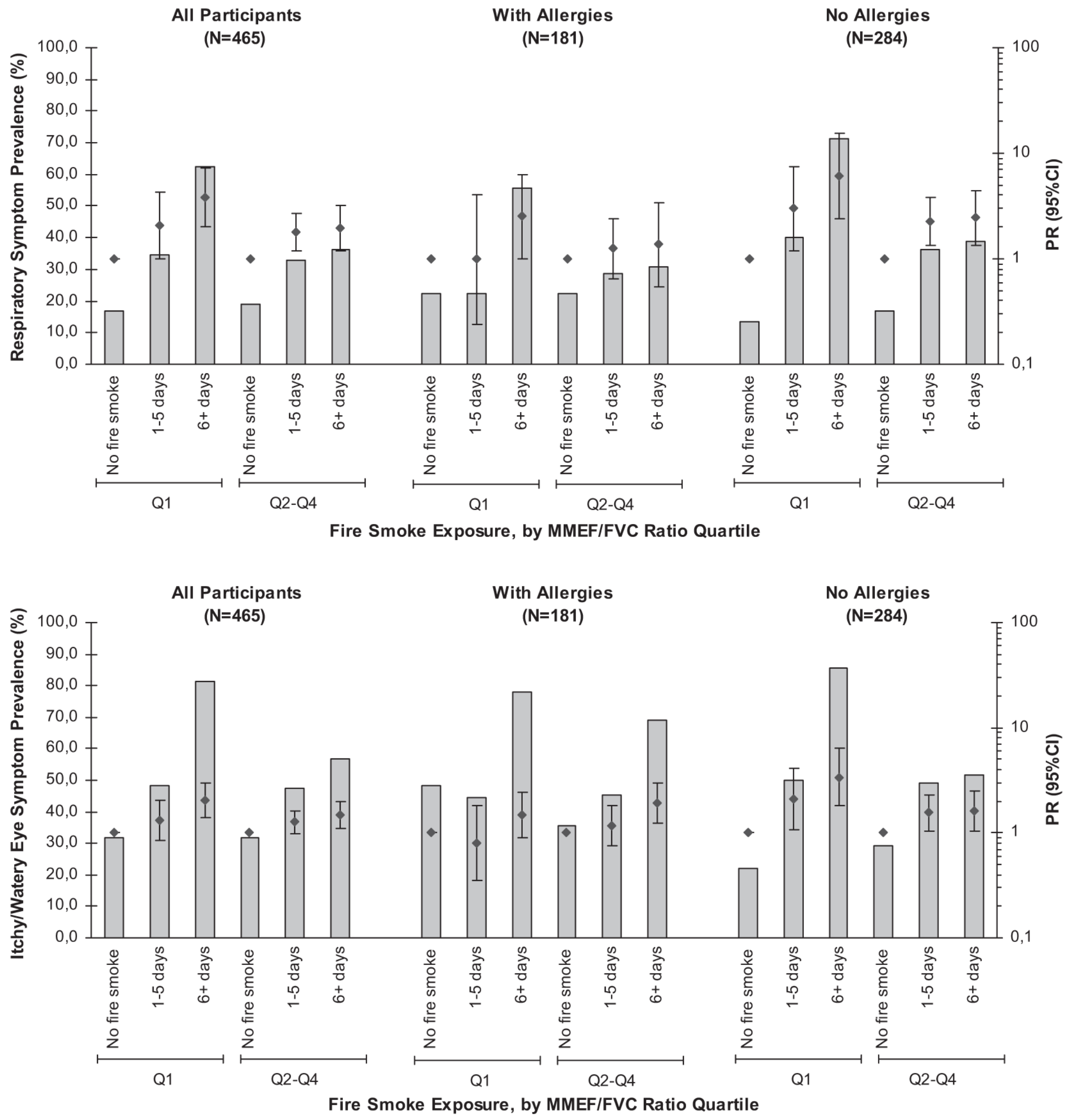


**FIGURE.**

Prevalence of any of 4 respiratory symptoms (morning dry cough, nighttime dry cough, wet cough, or wheezing) (top) and of watery, itchy eye symptoms (bottom) (left axis, ▩;) and PRs, with 95% confidence intervals, of the associations with duration of fire smoke exposure (right axis, ◆). Associations stratified by lung function ratio quartile and presented for all nonasthmatic survey participants and by allergy symptom status.

**TABLE 1**

Demographic Characteristics of the Final Study Population and Population Excluded due to Missing Data

| | Final Study Population | | Excluded Population | |
|---|---|---|---|---|
| **Characteristics** | **No.** | **%** | **No.** | **%** |
| Total | 465 | | 85 | |
| Age | | | | |
| 16–17 | 363 | 78 | 63 | 74 |
| 18–19 | 102 | 22 | 22 | 26 |
| Sex | | | | |
| Girl | 239 | 51 | 57 | 67 |
| Boy | 226 | 49 | 28 | 33 |
| Race | | | | |
| Nonwhite | 160 | 34 | 38 | 45 |
| White | 305 | 66 | 47 | 55 |
| Hispanic | | | | |
| No | 334 | 72 | 53 | 62 |
| Yes | 131 | 28 | 32 | 38 |
| Parental education[a] | | | | |
| High school, <high school | 130 | 28 | 15 | 18 |
| Some college/technical school | 201 | 43 | 29 | 34 |
| ≥4 y of college | 134 | 29 | 13 | 15 |

[a]Level of parental education is unknown for 28 of the 85 participants (33%) in the population excluded from our analysis.

## TABLE 2

Health-related Characteristics based on the CHS Baseline Survey, Prefire Pulmonary Function Testing and Fire Questionnaire

| Characteristics | Total (n = 465) | Girls (n = 239) | Boys (n = 226) |
|---|---|---|---|
| CHS baseline survey | | | |
| Allergy symptoms[a]; no. (%) | 181 (39) | 95 (40) | 86 (38) |
| History of wheezing; no. (%) | 86 (19) | 44 (18) | 42 (19) |
| Pulmonary function testing | | | |
| MMEF, in L/s | | | |
| Mean (SD) | 4.34 (1.08) | 3.86 (0.92) | 4.84 (1.00) |
| Median | 4.32 | 3.79 | 4.78 |
| Minimum, maximum | 1.09, 8.40 | 1.09, 6.14 | 2.54, 8.40 |
| FVC, in L | | | |
| Mean (SD) | 4.35 (0.95) | 3.71 (0.60) | 5.02 (0.77) |
| Median | 4.23 | 3.67 | 5.03 |
| Minimum, maximum | 2.31, 7.11 | 2.31, 5.64 | 3.06, 7.11 |
| MMEF/FVC ratio | | | |
| Mean (SD) | 1.02 (0.25) | 1.06 (0.26) | 0.98 (0.22) |
| Median | 0.98 | 1.02 | 0.94 |
| Minimum, maximum | 0.33, 1.92 | 0.33, 1.92 | 0.48, 1.78 |
| MMEF/FVC ratio quartiles[b] | | | |
| Quartile 1 | — | 0.3267, 0.8770 | 0.4805, 0.8329 |
| Quartile 2 | — | 0.8771, 1.0201 | 0.8330, 0.9429 |
| Quartile 3 | — | 1.0203, 1.2183 | 0.9432, 1.0963 |
| Quartile 4 | — | 1.2184, 1.9198 | 1.0867, 1.7229 |
| Fire questionnaire | | | |
| Respiratory symptoms; no. (%) | | | |
| Morning dry cough | 58 (13) | 34 (14) | 24 (11) |
| Nighttime dry cough | 70 (15) | 36 (15) | 34 (15) |
| Wet cough | 62 (13) | 37 (16) | 25 (11) |
| Wheezing | 33 (7) | 16 (7) | 17 (8) |
| Any respiratory symptom[c] | 119 (26) | 66 (28) | 53 (24) |
| Eye symptoms; no. (%) | | | |
| Irritated eyes | 193 (42) | 116 (49) | 77 (34) |
| Itchy/watery eyes | 187 (40) | 113 (47) | 74 (33) |
| Any eye symptom[d] | 221 (48) | 134 (56) | 87 (39) |

[a] Allergy symptoms are indicated by a positive response to any of the following baseline survey questions: ever had hay fever, doctor or other health care practitioner ever said child has allergies, in past 12 mo, runny nose for 3 or more days/wk for 3 or more months in a row.

[b] Minimum and maximum ratio values.

[c] Any of the 4 respiratory symptoms: morning dry cough, nighttime dry cough, wet cough, or wheezing.

[d] Any of the eye symptoms: irritated, itchy, or watery eyes.

## TABLE 3

Number and Percentage of Respondents with Preexisting Allergy Symptoms and With Respiratory and Eye Symptoms Reported After the 2003 Southern California Wildfires, Across Quartiles of MMEF/FVC Ratio

| Symptoms | MMEF/FVC Quartile 1 (n = 117) No. (%) | MMEF/FVC Quartiles 2–4 (n = 348) No. (%) | MMEF/FVC Quartiles 2–4 | | |
|---|---|---|---|---|---|
| | | | Quartile 2 (n = 115) No. (%) | Quartile 3 (n = 118) No. (%) | Quartile 4 (n = 115) No. (%) |
| CHS baseline survey | | | | | |
| Allergy symptoms[a] | 45 (39) | 136 (39) | 51 (44) | 44 (37) | 41 (36) |
| Fire questionnaire | | | | | |
| Respiratory symptoms | | | | | |
| Morning dry cough | 19 (16) | 39 (11) | 16 (14) | 14 (12) | 9 (8) |
| Nighttime dry cough | 20 (17) | 50 (14) | 15 (13) | 18 (15) | 17 (15) |
| Wet cough | 16 (14) | 46 (13) | 17 (15) | 13 (11) | 16 (14) |
| Wheezing | 10 (9) | 23 (7) | 10 (9) | 8 (7) | 5 (4) |
| Any respiratory symptom[b] | 32 (27) | 87 (25) | 31 (27) | 29 (25) | 27 (24) |
| Eye symptoms | | | | | |
| Irritated eyes | 60 (51) | 133 (38) | 46 (40) | 50 (42) | 37 (32) |
| Itchy/watery eyes | 50 (43) | 137 (39) | 47 (41) | 50 (42) | 40 (35) |
| Any eye symptom[c] | 63 (54) | 158 (45) | 55 (48) | 58 (49) | 45 (39) |

[a] Allergy symptoms are indicated by a positive response to any of the following baseline survey questions: ever had hay fever, doctor or other health care practitioner ever said child has allergies, in past 12 mo, runny nose for 3 or more days/wk for 3 or more months in a row.

[b] Any of the 4 respiratory symptoms: morning dry cough, nighttime dry cough, wet cough, or wheezing.

[c] Any of the eye symptoms: irritated, itchy, or watery eyes.

### TABLE 4

Estimates of the Associations of Exposure to Smoke From the 2003 Southern California Wildfires With Respiratory and Eye Symptoms, by MMEF/FVC Ratio Quartile

| | MMEF/FVC Ratio Quartile 1 | | | MMEF/FVC Ratio Quartiles 2–4 | | |
|---|---|---|---|---|---|---|
| | Total | Symptomatic No. (%) | PR (95% CI)[a] | Total | Symptomatic No. (%) | PR (95% CI)[a] |
| Respiratory symptoms | | | | | | |
| Morning dry cough | | | | | | |
| No fire smoke | 72 | 7 (10) | 1.00 | 207 | 17 (8) | 1.00 |
| Fire smoke 1–5 days | 29 | 5 (17) | 1.79 (0.62–5.20) | 97 | 15 (16) | 1.98 (1.01–3.87) |
| Fire smoke 6+ days | 16 | 7 (44) | 4.49 (1.83–11.0) | 44 | 7 (16) | 2.03 (0.88–4.68) |
| Nighttime dry cough | | | | | | |
| No fire smoke | 72 | 7 (10) | 1.00 | 207 | 17 (8) | 1.00 |
| Fire smoke 1–5 days | 29 | 6 (21) | 2.17 (0.80–5.92) | 97 | 20 (21) | 2.74 (1.47–5.08) |
| Fire smoke 6+ days | 16 | 7 (44) | 4.55 (1.86–11.1) | 44 | 13 (30) | 3.88 (2.01–7.49) |
| Wet cough | | | | | | |
| No fire smoke | 72 | 7 (10) | 1.00 | 207 | 23 (11) | 1.00 |
| Fire smoke 1–5 days | 29 | 5 (17) | 1.80 (0.62–5.20) | 97 | 16 (17) | 1.60 (0.86–2.96) |
| Fire smoke 6+ days | 16 | 4 (25) | 2.66 (0.88–8.02) | 44 | 7 (16) | 1.52 (0.69–3.37) |
| Wheezing | | | | | | |
| No fire smoke | 72 | 1 (1) | 1.00 | 207 | 10 (5) | 1.00 |
| Fire smoke 1–5 days | 29 | 2 (7) | 4.97 (0.47–52.7) | 97 | 9 (9) | 1.92 (0.79–4.65) |
| Fire smoke 6+ days | 16 | 7 (44) | 31.5 (4.14–239.) | 44 | 4 (9) | 1.88 (0.61–5.80) |
| Any respiratory symptom[b] | | | | | | |
| No fire smoke | 72 | 12 (17) | 1.00 | 207 | 39 (19) | 1.00 |
| Fire smoke 1–5 days | 29 | 10 (35) | 2.07 (1.01–4.26) | 97 | 32 (33) | 1.78 (1.18–2.68) |
| Fire smoke 6+ days | 16 | 10 (63) | 3.78 (1.99–7.19) | 44 | 16 (36) | 1.96 (1.20–3.20) |
| Eye symptoms | | | | | | |
| Irritated eyes | | | | | | |
| No fire smoke | 72 | 28 (39) | 1.00 | 207 | 59 (29) | 1.00 |
| Fire smoke 1–5 days | 29 | 17 (59) | 1.28 (0.93–1.77) | 97 | 46 (47) | 1.30 (1.04–1.62) |
| Fire smoke 6+ days | 16 | 15 (94) | 1.81 (1.39–2.34) | 44 | 28 (64) | 1.60 (1.26–2.02) |

| | MMEF/FVC Ratio Quartile 1 | | | MMEF/FVC Ratio Quartiles 2–4 | | |
|---|---|---|---|---|---|---|
| | Total | Symptomatic No. (%) | PR (95% CI)[a] | Total | Symptomatic No. (%) | PR (95% CI)[a] |
| Itchy/watery eyes | | | | | | |
| No fire smoke | 72 | 23 (32) | 1.00 | 207 | 66 (32) | 1.00 |
| Fire smoke 1–5 days | 29 | 14 (48) | 1.32 (0.85–2.04) | 97 | 46 (47) | 1.26 (0.98–1.63) |
| Fire smoke 6+ days | 16 | 13 (81) | 2.02 (1.38–2.94) | 44 | 25 (57) | 1.47 (1.09–1.97) |
| Any eye symptom[c] | | | | | | |
| No fire smoke | 72 | 30 (42) | 1.00 | 207 | 76 (37) | 1.00 |
| Fire smoke 1–5 days | 29 | 18 (62) | 1.18 (0.93–1.51) | 97 | 54 (56) | 1.16 (1.00–1.35) |
| Fire smoke 6+ days | 16 | 15 (94) | 1.47 (1.17–1.86) | 44 | 28 (64) | 1.25 (1.04–1.50) |

[a] Adjusted for community-level mean annual $PM_{10}$.

[b] Any of the 4 respiratory symptoms: morning dry cough, nighttime dry cough, wet cough, or wheezing.

[c] Any of the eye symptoms: irritated, itchy, or watery eyes.