Pulmonary Function and Respiratory Symptoms in Wildland Firefighters

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We studied cross-seasonal changes in pulmonary function and respiratory symptoms in 52 wildland firefighters in Northern California. The mean cross-seasonal change in forced expiratory volume in 1 second (FEV_1) was −1.2% (95% confidence interval [CI] −0.5%, −2.0%) with a corresponding mean change in forced expiratory volume (FVC) of −0.3% (95% CI 0.4%, −1.0%). Decreases in FEV_1 and FVC were most strongly associated with hours of recent fire-fighting activity (P = .002 and .01, respectively). When the study group was divided into three categories based on recent fire-fighting activity, firefighters in the high activity category (mean ± SE, 73 ± 7 hours of fire-fighting in previous week) had a −2.9% (130 mL) change in FEV_1 and a −1.9% (102 mL) change in forced vital capacity (FVC). There was a significant cross-seasonal increase in most respiratory symptoms evaluated. Several symptoms (eye irritation, nose irritation, and wheezing) were associated with recent fire-fighting. These findings suggest that wildland firefighters experience a small cross-seasonal decline in pulmonary function and an increase in several respiratory symptoms. Research is under way to identify the fire conditions and specific components of exposure that produce pulmonary irritants, and to examine the potential reversibility of acute pulmonary change.

There are approximately 80,000 full-time and seasonal wildland (forest or wilderness) firefighters in the United States.[1] At wildland fires, the concentrations of a variety of pulmonary irritants, including respirable particulates, acrolein and formaldehyde, may exceed Occupational Safety and Health Administration 8-hour permissible exposure limits or 15-minute short-term exposure limits.[2–4]

Exposures of firefighters are affected by ground fuel type, prevailing meteorologic conditions, terrain, and fire-suppression techniques[5] including spraying water from pump engines, constructing containment lines by hand or heavy machinery, and setting backfires that consume fuel in the path of the wildfire. The heavy physical demands of this work produce elevated pulmonary minute ventilation rates, increasing delivery of pulmonary irritants to the airways.

A striking feature of wildland fire-fighting is the potential for long, uninterrupted periods of exposure to smoke. During the initial phase of fire suppression, local crews may work for 48 or more hours until additional crews arrive. After this period, work shifts typically range from 12 to 18 hours per day. At large fires, firefighters may be on duty for 2 or more weeks at a time. Fire base camps, where firefighters eat and sleep, may be situated close to the fire, resulting in continuous exposure to fire smoke. At present, the only form of respiratory protection offered to wildland firefighters is a cotton bandanna.

The acute and chronic pulmonary effects of wildland fire-fighting have not been previously reported. We evaluated the cross-seasonal effects of wildland fire-fighting on forced expiratory flow and respiratory symptoms.

Methods

The study population included firefighters in six of the most active wildland fire stations in Region 2 of the

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California Department of Forestry and Fire Protection, located in the foothills of the Sierra Nevada mountains in Northern California. Crews from surrounding districts who were temporarily stationed at a fire station under study also were included. The participants were firefighters aged 18 to 45 who never smoked or former smokers who had not smoked for at least 6 months before the study. Sixty-nine participants (85% of eligibles) were enrolled.

Data Collection

Baseline measurements were made in July 1988, early in the fire season. Informed consent was obtained from all participants. A questionnaire including information on demographics, smoking history, occupational history, and work practices was self-administered and reviewed with an investigator. A modified Epidemiology Standardization Project respiratory symptoms questionnaire elicited the number of days in the previous week the participant had experienced eye irritation or upper or lower respiratory symptoms.[6] Daily fire-fighting activity on the actual fire line during the 4 weeks before the beginning of the study was recorded retrospectively by each participant with the help of fire station log records and diaries of fire crew captains. During the 8-week study, each participant prospectively recorded daily hours of fire-fighting activity. Self-reported hours of fire-fighting could not be independently validated because the available records did not break down work hours into hours on the fire line. Hours of self-reported fire-fighting activity were used as a surrogate for fire smoke exposure.

Spirometry was performed and interpreted by trained personnel using American Thoracic Society procedures.[7] A Collins I Survey Spirometer (Warren E. Collins, Braintree, MA) was calibrated with a 3-liter syringe before each testing session. Up to six tracings were recorded with the subject standing and wearing a nose clip. Spirograms were considered reproducible when the two largest values for forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC) were within 5% of each other. All measurements were corrected for body temperature and pressure, saturated with water. The largest FEV_1 and FVC were used for analysis, and predicted values were calculated from the equations of Crapo et al.[8] Five percent of tracings did not meet American Thoracic Society acceptability criteria for effort lasting 6 seconds; however, all these spirograms had reached a plateau for greater than 2 seconds by the end of effort and were included in the analysis.

The work practices and respiratory symptoms questionnaire was readministered 8 weeks after baseline to 52 firefighters, representing 75% of the original study population. Fifty of these individuals were retested with spirometry. The same personnel and spirometers were used for each subject's baseline and follow-up testing. Firefighters were restudied either at their fire stations or in a fire base camp 24 hours after a wildfire had ended, and after all smoke exposure had ceased. Work diaries were collected from all of these persons. None of the 17 firefighters who were unavailable for late season testing were on leave for pulmonary complaints; they were on duty in another part of the state, had left the fire service to attend school, or were physically injured.

Statistical Analysis

Data analyses were performed using SAS for PC Version 6.03 (SAS Institute Inc., Cary, NC).[9] Summary values were calculated as means ± standard error of the mean (SEM) or as 95% confidence intervals (CI). Nonparametric techniques were used for respiratory symptom data.[10] Two-tailed P values $< .05$ were considered statistically significant.

The relationship between symptoms and fire-fighting activity was tested by Spearman rank-order correlation.[10] The relationship between change in pulmonary function and fire-fighting activity was tested by linear regression and a test for trend using linear contrasts.[11] Potential confounders of that association (including age, race, sex, passive exposure to cigarette smoke, exposure to diesel exhaust, smoking status [never vs former], history of asthma, history of hay fever, previous number of years as a firefighter, hours of fire-fighting occurring before baseline measurements, and use of a bandanna for respiratory protection were assessed by multiple linear regression and analysis of covariance.[11]

RESULTS

Demographics

There were no significant differences in demographic, health, and work history characteristics between the 52 subjects with both early and late season data and the 17 subjects with early season data only (Table 1). The following analyses concern only the 52 participants with both early and late season data. Eighty-one percent of the participants were men, and 77% were Caucasian. The mean age of the participants was 26 ± 1 years, with 6 ± 1 seasons of fire-fighting experience. The 10 former smokers (19% of the study group) had 3 ± 1 lifetime pack-years; with 8 ± 2 years since quitting. Eighty-seven percent of the study group worked on engine crews, and the remainder worked as helicopter and truck-transported fire crews. All three job categories had potential for direct exposure to fire smoke.

Fire-Fighting Activity Patterns

There was little reported fire-fighting during the early part of the fire season, before baseline measurements made at the beginning of the 8-week study. Fire-fighting activity averaged 18 ± 3 hours in the 4 weeks before baseline, compared with 98 ± 14 hrs during the last 4 weeks of the study. Almost half (45%) the fire-

TABLE 1
Demographic Characteristics of Wildland Firefighters, by Follow-up Status

Demographic Characteristic	Follow-up Status*			
	Early Season Only		Early and Late Season	
	Number	(%)	Number	(%)
Total number	17	(100)	52	(100)
Sex				
Male	14	(82)	42	(81)
Female	3	(18)	10	(19)
Race				
Caucasian	15	(88)	40	(77)
Hispanic	0	(0)	5	(10)
Other	2	(12)	7	(13)
Age (y)				
19–29	13	(76)	38	(73)
30–39	3	(18)	11	(21)
40–49	1	(6)	3	(6)
Seasons fire-fighting				
0–5	8	(47)	32	(62)
6–10	5	(29)	10	(19)
11–15	3	(18)	8	(15)
16+	1	(6)	2	(4)
History of hay fever	3	(18)	12	(23)
History of asthma	0		3	(6)
Smoking status				
Never	14	(82)	42	(81)
Former	3	(18)	10	(19)

* There were no significant differences in any demographic characteristic by follow-up status (Fisher's exact test; two-tailed).

fighting activity occurred during the last 2 weeks of the study.

Several exposure variables were generated for each firefighter to assess the importance of proximity in time and magnitude of exposure on pulmonary function and symptoms. Exposure variables created were cumulative hours of fire-fighting in weeks 1 through 8, weeks 5 through 8, weeks 6 through 8, weeks 7 and 8, and week 8 only (the final week of the study).

Respiratory Symptoms

There was a significant cross-seasonal increase in reported eye irritation, nose irritation, cough, phlegm production, and wheezing (Table 2). When this increase was tested for an association with each fire-fighting exposure variable by Spearman rank-order correlation, eye irritation ($r = .48$, $P < .001$) and wheezing ($r = .25$, $P = .07$) were most strongly associated with fire-fighting activity during weeks 7 and 8, although nose irritation was most strongly associated with fire-fighting activity during week 8 ($r = .24$, $P = .08$). None of the other symptoms were associated with any fire-fighting variable tested. Hay fever, history of asthma, passive exposure to cigarette smoke, former smoking, and exposure to diesel exhaust were not associated with any of the symptom changes.

Pulmonary Function

Mean baseline spirometry for the study group were close to predicted values: FEV_1 % predicted = 100 ± 1%, FVC % predicted = 101 ± 1%, and FEV_1/FVC % predicted = 98 ± 1%. Baseline spirometry was not associated with previous number of fire-fighting seasons.

The mean cross-seasonal change in FEV_1 for the entire study population was −1.2% (95% CI −0.5%, −2.0%) with a corresponding mean change in FVC of −0.3% (95% CI 0.4%, −1.0%), the change in FEV_1/FVC was −.006 (95% CI −.001, −.01.), and the change in FEV_3/FEV_6 was −.005 (95% CI .003, −.013).

Cumulative hours of fire-fighting during week 8 were most strongly associated with a decline in FEV_1 ($r^2 = .15$, $P = .006$) (Figure). Cumulative hours of fire-fighting during weeks 7 and 8 were less strongly associated with a decline in FEV_1 ($r^2 = .11$, $P = .019$). The association between fire-fighting activity and decline in FEV_1 weakened as more distant exposure was included in the exposure variable (weeks 6 through 8, $r^2 = .07$, $P = .06$, weeks 5 through 8, $r^2 = .04$, $P = .12$, weeks 1 through 8, $r^2 = .02$, $P = .28$). Similar results were obtained in the analysis of hours of fire-fighting versus decline in FVC, with the strongest association seen for week 8 alone ($r^2 = .11$, $P = .02$). The association between hours of recent fire-fighting and decline in either FEV_1 or FVC was not altered after adjustment for potential confounders in a multiple regression model. Change in FEV_1/FVC or FEV_3/FEV_6 was not associated with any fire-fighting exposure variable.

Fire-fighting activity within the study population was highly variable during week 8 (median = 4.5 hours, range: 0–125 hours). To portray the mean change in pulmonary function for groups of firefighters with relatively homogeneous activity during that period, three exposure categories based on hours of fire-fighting with roughly equal numbers of persons in each group were created (none: 0 hours, low: 1–20 hours, and high: >20 hours) (Table 3). The 16 firefighters in the "none" category had a mean decrease in FEV_1 of 21 mL, the 19 persons in the low activity category had a mean decrease of 23 mL, and the 15 firefighters in the high activity category had a mean decrease of 130 mL (test for trend, $P < .005$) (Table 3). Adjustment for potential confounding variables by analysis of covariance did not alter this association. Similar results were obtained in the analysis of FVC by exposure category (Table 3).

TABLE 2
Cross-Seasonal Changes in Upper and Lower Respiratory Tract Symptoms

Symptom	Number of Days in Previous Week with Symptom (Mean ± SEM)		P Value* of Difference
	Early Season	Late Season	
Eye irritation	0.8 ± 0.2	1.7 ± 0.3	<.0001
Nose irritation	1.2 ± 0.2	2.3 ± 0.3	.009
Throat irritation	0.5 ± 0.2	1.0 ± 0.2	.081
Cough	0.6 ± 0.2	1.5 ± 0.3	.032
Phlegm	0.4 ± 0.2	1.6 ± 0.4	<.0001
Wheezing	0.0	0.6 ± 0.2	.023
Chest discomfort	0.1 ± 0.0	0.3 ± 0.1	.078
Shortness of breath	0.0	0.0	

* Wilcoxon matched pairs signed rank test, two-sided P value.

DISCUSSION

In this study, wildland firefighters had a cross-seasonal increase in the prevalence of eye and nose irritation, cough, phlegm production, and wheezing. Moreover, the increase in the prevalence of several of these symptoms was associated with recent fire-fighting activity.

Firefighters had a small cross-seasonal decline in both FEV_1 and FVC, which was associated with recent fire-fighting activity. This relationship was unchanged after adjustment for potential confounding variables. The magnitude of these changes is of particular interest for the 15 firefighters in the highest exposure category who averaged 73 hours of fire-fighting during week 8, the final week of the study. This group had a 2.9% decline in FEV_1, corresponding to a 130-mL decline, and a 1.9% decline in FVC, corresponding to a 101-mL decline.

It is likely that the exposure variable used in this study, self-reported hours of fire-fighting activity, is only crudely associated with actual exposure to pulmonary irritants. Industrial hygiene studies have demonstrated wide variations in smoke intensity at a wildland fire.[2] Treating all self-reported hours of fire-fighting as equal may have introduced nondifferential misclassification of actual exposure, biasing our findings toward the null hypothesis.

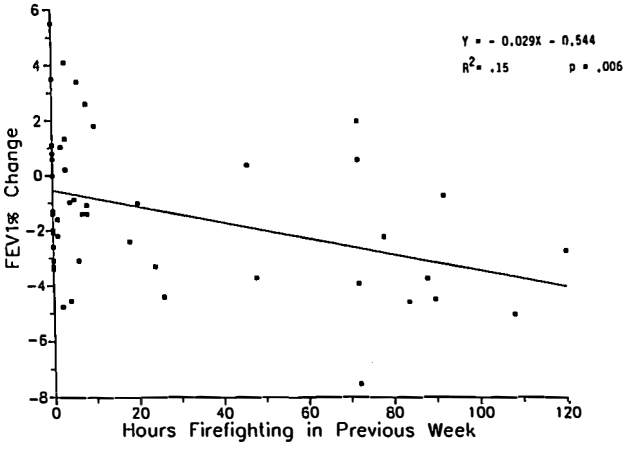

Figure. Cross-seasonal change in FEV_1 vs hours of fire-fighting in previous week, N = 50.

Because self-reported hours of fire-fighting activity could not be independently validated, differential misclassification of exposure also could have occurred (ie, individuals with respiratory symptoms may have tended to overreport hours of fire-fighting activity).[13] However, the marked difference between fire-fighting activity in the "none" (mean, 0 hours) and "low" (mean, 6 hours) categories versus the "high" (mean, 73 hours) exposure category minimizes the possibility that persons who truly had little or no fire-fighting activity would have been misclassified into the high category.

The association between hours of fire-fighting and decline in pulmonary function was most strongly associated with recent exposure and became progressively weaker as more distant fire-fighting activity was included in the exposure variable. This may reflect the fact that almost half the total exposure during the 8-week study was concentrated toward the end of the study. Alternatively, decreases in pulmonary function may have reversed after a relatively short period subsequent to cessation of exposure to irritants. There were not enough firefighters who were highly exposed early in the season and unexposed later in the season to differentiate between these two hypotheses. It should be noted that this study was not designed to evaluate the reversibility of acute pulmonary changes.

Previous studies of cross-shift changes in pulmonary function in structural firefighters have reported declines in FEV_1 similar to this study.[14–17] However, health outcomes in structural and wildland fire-fighting are only partially comparable because exposure patterns and work practices differ.

Although structural and wildland fires produce many similar compounds including particulates, acids, aldehydes, carbon monoxide, and free oxygen radicals, concentrations in structural fires generally are much higher and potentially asphyxiating.[2,18,19] In addition,

TABLE 3
Cross-Seasonal Change in Pulmonary Function, by Exposure Category

Exposure* Category	Difference between Late and Early Season Pulmonary Function (Mean ± SEM)				
	FEV_1 (mL)	FVC (mL)	FEV_1%†	FVC%‡	FEV/FVC
None (0 hours) (n = 16)	−21 ± 27	21 ± 30	−0.5 ± 0.6	0.7 ± 0.5	−.94 ± .6
Low (1–20 hours) (n = 19)	−23 ± 25	5 ± 32	−0.6 ± 0.6	0.1 ± 0.4	−.36 ± .41
High (>20 hours) (n = 15)	−130 ± 30	−102 ± 38	−2.9 ± 0.6	−1.9 ± 0.7	−.65 ± .32
F test§	10.06	9.39	9.31	10.76	.00
df 2/49					
P value for F test	.003	.004	.004	.002	.955

* Based on hours of firefighting activity in week 8, n = number of firefighters, mean ± SEM hours of fire-fighting by category: None (0), Low (6 ± 1), and High (73 ± 6).

† FEV_1% Change = $[(FEV1_l - FEV1_e)/(FEV1_l + FEV1_e)/2] \times 100$.[12] l, late season measurement; e, early season measurement.

‡ FVC% Change = $[(FVC_l - FVC_e)/(FVC_l + FVC_e)/2] \times 100$.[12]

§ F test for trend using linear contrasts, with contrasts chosen to reflect mean hours of fire-fighting in each exposure category.[11]

there are exposures unique to each type of fire such as synthetic compound combustion products in structural fires and vegetative resinous combustion products in wildland fires.[20] Finally, structural fires are usually fought over a period of hours, but wildland fires may be fought over a period of days to weeks.

Wildland fire-fighting is a unique occupation whose health effects require further study. Research is under way to confirm these findings in a larger population and to determine if airways reactivity increases with wildland fire-fighting, as it does following structural firefighting.[15,17] Attempts are being made to perform cross-shift measurements of pulmonary function at fire base camps and to retest study participants in the off season to determine the reversibility of acute pulmonary changes. In addition, researchers are trying to describe the wildland fire conditions that produce hazardous exposures and to measure the range and types of exposures present.[1]

Final recommendations for maintaining the health and safety of wildland firefighters must include an assessment of all potential risks including injuries, heat stress, acute and chronic effects of carbon monoxide inhalation[2] and prolonged exposure to carcinogenic agents.[20,21] Based on available information,[2,3] however, it is very likely that some form of effective respiratory protection will be necessary in certain situations, particularly during prolonged fire campaigns. Protective measures for wildland firefighters could consist of more frequent rotation of fire-fighting crews and the provision of effective and acceptable personal protective devices. A cotton bandanna, the only form of respiratory protection regularly available to workers, does not offer protection against the major classes of pulmonary irritants detected in wildland fire smoke.[2,3] In this study, cotton bandanna use was not associated with a protective effect for either respiratory symptoms or pulmonary function.

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