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RESEARCH ARTICLE

Lung function changes in wildland firefighters working at prescribed burns

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Abstract

Context: Although decline in lung function across workshift has been observed in wildland firefighters, measurements have been restricted to days when they worked at fires. Consequently, such results could have been confounded by normal circadian variation associated with lung function.

Objectives: We investigated the across-shift changes in lung function of wildland firefighters, and the effect of cumulative exposure on lung function during the burn season.

Materials and Methods: We measured forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), forced expiratory flow from 25% to 75% of FVC (FEF_{25-75}), and peak expiratory flow (PEF) of wildland firefighters before and after their workshifts. In all, 501 pre-shift and 488 post-shift measurements were collected over 22 prescribed burn days and 43 non-burn days from 24 non-smoking wildland firefighters during the dormant winter burn seasons of 2003 and 2004. We compared changes in the spirometry measures across the workshift on burn days to those observed on non-burn days. We also assessed the effect of cumulative exposure during the burn season on the spirometry measures.

Results: There were no significant differences in the across workshift changes on burn days compared to those on non-burn days for all the spirometry measures. However, for a given point in time during the season, each additional day of exposure was estimated to be associated with declines of 24 ml in pre-shift FVC and 24 ml in pre-shift FEV_1 ($p < 0.01$).

Discussion and Conclusion: Cumulative exposure to woodsmoke was associated with slight decrements in lung function among the wildland firefighters.

Keywords: Wildland firefighters, prescribed burns, spirometry, forced vital capacity, forced expiratory volume in 1 second

Introduction

Wildland firefighters work to suppress wildfires, and apply prescribed burns to wildlands in order to achieve desirable land management goals. However, they could be exposed to elevated levels of woodsmoke, while carrying out their duties. Woodsmoke contains many air pollutants including particulate matter, carbon monoxide (CO), aldehydes, volatile organic compounds, and polycyclic aromatic hydrocarbons (Naeher et al., 2007). Occupational exposure to fine/respirable particles and CO among wildland firefighters sometimes exceeds the relevant occupational exposure standards (Reinhardt and Ottmar, 2000; Reinhardt and Ottmar, 2004).

Woodsmoke exposure is linked with various adverse health effects, and exposure due to wildfires has been associated with acute health effects measurable by increases in hospital and emergency room visits (Duclos et al., 1990; Mott et al., 2002; Moore et al., 2006). Residential combustion of wood has also been linked with respiratory diseases, especially among women and children (Collings et al., 1990; Triche et al., 2005; Orozco-Levi et al., 2006). Furthermore, biomarker studies show that woodsmoke exposure could induce inflammation (Tan et al., 2000, van Eeden et al., 2001). Elevations in serum levels of pro-inflammatory cytokines from pre- to post-workshift have been observed in wildland firefighters (Swiston et al., 2008).

The focus of most health studies conducted among wildland firefighters has been largely limited to lung

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function and respiratory symptoms, and declines in lung function across workshifts and across burn seasons have been reported (Betchley et al., 1997; Letts et al., 1991; Liu et al., 1992). Previous lung function studies of wildland firefighters were conducted mainly at wildland fires or prescribed burns in the Western United States. In the current study, we examined whether exposure to woodsmoke induces lung function changes in non-smoking wildland firefighters working at prescribed burns in a forest in the Southeastern United States.

Results of studies of acute effect of occupational exposure on lung function in terms of across workshift changes could be confounded by circadian variation in lung function (Hetzel, 1981; Barnes, 1985; Troyanov et al., 1994). Consequently, it is important that the design of such studies allow for the separation of the effect of exposure from the changes that may have otherwise occurred during non-burn days (Gaughan et al., 2008) or the changes that occur due to the diurnal nature of lung function. However, previous studies investigating across workshift lung function changes among wildlland firefighters were not effectively designed to account for such confounding, as changes in lung function across workshifts were only measured on burn days (Gaughan et al., 2008; Betchley et al., 1997). Therefore, pre- and post-workshift spirometry measures were collected from the wildlland firefighters on burn and non-burn days in the current study; across workshift changes (from pre- to post-shift) in lung function on burn days were then compared to changes observed on non-burn days. Additionally, the effect of cumulative occupational exposure to woodsmoke on lung function was investigated since spirometry measurements were collected on multiple days during the burn season.

Methods

Study location and population

This study was conducted at the Savannah River Site (SRS), SC, which is a 198,000 acre Department of Energy industrial complex. The United States Forest Service (USFS) manages the complex's forest which is composed of 31% hardwood or mixed pine hardwood and 69% pine (USFS, 2005). Twenty-four non-smoking USFS firefighters were recruited to participate in the study during the dormant winter burn seasons of 2003 and 2004. Two current smokers also elected to and were allowed to participate in the study. Participation in the study was voluntary. Each subject had the study explained to them, and signed a consent form when they agreed to participate. The study protocol was reviewed and approved by the University of Georgia Institutional Review Board for the inclusion of human subjects.

Lung function measurements

Spirometry was performed using a Sensormedics OMI spirometer (Houston, TX) before and after workshifts. Each subject was coached on how to use the spirometer by the research staff before any measurement was taken. Measurements of forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), forced expiratory flow from 25% to 75% of FVC (FEF_{25-75}), peak expiratory flow (PEF), and FEV_1/FVC were done according to the American Thoracic Society (ATS) requirements.(ATS, 1995) At least, 3 acceptable and 2 reproducible forced expiratory maneuvers were required for analyses. A maximum of 8 maneuvers per session were allowed. The curve with the highest FVC+FEV_1 value was selected for analysis. Measurements were collected on multiple days, both when there was a prescribed burn (burn day) and when there was none (non-burn day).

Questionnaire

A baseline questionnaire was administered at the start of the burn seasons in 2003 and 2004 to obtain baseline information regarding the smoking status of subjects and pre-existing respiratory illnesses. A daily questionnaire was also administered to the subjects, and was used to obtain information regarding the use of prescription medication, visit to the physician, and exposure to second hand smoke (SHS).

Statistical analysis

Linear mixed effect models were used to test whether there were across (pre to post) shift changes in spirometry measures in non-smoking wildland firefighters. Terms in the models included race, gender, dummy variables representing whether a subject had respiratory allergies or not (allergy status), whether a measurement was taken pre- or post-shift (pre-post) and whether it was collected on a burn or non-burn day (fire-activity) and, interactions between "pre-post" and "fire-activity", and between "pre-post" and "allergy status". The interaction term between "pre-post" and "fire-activity" was used to assess differences in across-shift changes in lung function between burn and non-burn days, while the interaction term between "pre-post" and "allergy status" was used to assess whether across-shift differences in lung function depended on the allergy status of the subject. Interaction between "pre-post", "allergy status", and "fire-activity" was not significant and did not improve model fit for any of the spirometry measures, and so was dropped. Subject and date of spirometry were controlled as random variables due to multiple measurements on each firefighter. The random subject effect in the models induces correlation among all measurements collected from the same subjects, while a random subject within day-term induced additional correlation between the two (pre- and post-shift) measurements taken from a subject within a given day. Other within-subject correlation structures were attempted with some of them not converging, while those that converged gave the same qualitative and very similar quantitative results to those reported in this paper.

Linear mixed effect models were also used to analyze the effect of cumulative exposure (cumulative number of burn days) on pre-shift spirometry measures in non-smoking wildland firefighters. Parameter estimates changed substantially depending on whether subjects who reported having allergies were included or excluded from analyses. Therefore, terms representing allergy status, and the interaction between the "cumulative number of burn days" and "allergy status" were also included in the models. This interaction term was used to determine whether the effect of cumulative exposure on lung function depended on the allergy status of the subject. The other terms included in the models were gender, race, and the number of days since measurements started in each season (worktime). This last variable was included in the model in order to control for probable seasonal effect due to environmental exposures.

The two current smokers that elected to participate in the study were subsequently included in the analyses in order to determine the sensitivity of the results to their inclusion. All analyses were done in SAS version 9.1 (Cary, NC).

Results

The initial study subjects included 23 men (3 African American) and 1 woman, between the ages of 22 and 44 years at the time of recruitment (average = 29; SD = 6.7). The two current smokers who participated in the study were both women. Nine subjects reported having various allergies. Seven of these subjects reported being allergic to tree/grass pollen, while the remaining two reported having unspecified respiratory related allergies. None reported having a pre-existing lung illness at baseline. None of the subjects reported using prescription medication or visiting the physician during the duration of the study, and these were not considered as factors in any of the data analyses. Exposure to SHS was minimal (>/ = 15 minutes or "few minutes") and only reported during 16 person-workshifts, and the variable was similarly not included in any of the statistical analyses. On the average, workshifts were longer on burn days (average = 596 minutes; SD = 97 minutes) than on non-burn days (average = 508 minutes; SD = 52 minutes). Pre-shift spirometry measurements were more likely to have been collected from the subjects between 8 am and 9 am, while post-shift measurements were more likely to have been collected between 4 pm and 5 pm on non-burn days compared to burn days. Most of the pre-shift samples were collected between 7 am and 9 am for both non-burn (89%) and burn days (88%), while most of the post-shift samples were collected between 4 pm and 8 pm for both non-burn (96%) and burn days (86%).

Spirometry measurements that were collected from the wildland firefighters included FVC, FEV_1, FEF_{25-75}, PEF and FEV_1/FVC. FVC is the volume of air that can forcibly be blown out after maximal inspiration. FEV_1 is the volume of air that is expired during the first one second of a maximal expiratory effort undertaken after maximal inspiration. FEV_1/FCV is the percentage of the vital capacity that is expired during the first one second of a maximal expiratory effort undertaken after maximal inspiration. FEF_{25-75} is the average rate of flow of expired air during the mid-point of FVC. PEF is the maximal flow of exhaled air during maximal forced expiration undertaken after maximal inspiration. These measures indicate how well the lung functions and are used as a diagnostic tool for obstructive and restrictive respiratory diseases. Forced expiratory maneuvers selected for analyses included 501 pre- and 488 post-workshift measurements collected over 22 burn days and 43 non-burn days during the two burn seasons. Averages of 21 pre- (range: 1–47) and 20 (range: 1–49) post-shift measurements per subject were collected from each subject. Nineteen out of the 24 subjects had at least 14 pre- and 14 post-shift measurements. A total of 462 complete pre-/post-shift pair measurements were collected; 175 complete pairs on burn days and 287 complete pairs on non-burn days.

Changes across workshift

Declines across workshift on burn days were observed for mean individual FVC and FEV_1, but not for FEF_{25-75}, PEF and FEV_1/FVC. However, the interaction terms between cross-shift changes in lung function and type of work day were not significant, and therefore, changes in both FVC and FEV_1 on burn days were not significantly different from those on non-burn days. Box plots of the changes in the spirometry measures according to burn vs. non-burn days are presented in Figure 1. Results were similar when current smokers were included. Results were also similar with or without the inclusion of subjects with allergies, and changes in spirometry measures across the workshift did not depend on the allergy status of the subject.

Effect of cumulative exposure

The effect of cumulative exposure on lung function during the burn season depended on the allergy status of the subject. Each additional day of working at a prescribed burn, at any given point during the burn season, was associated with declines of 24 ml (p <0.01) in pre-shift FVC and 24 ml in pre-shift FEV_1 (p <0.01) in non-allergic firefighters, and 8 ml in FVC (p <0.01) and 4 ml in FEV_1 (p <0.01) in allergic firefighters (Table 1). Results did not change appreciably when data from the two smokers who participated in the study were included in the analyses. Subjects with allergies had non-significant lower baseline pre-shift FVC and FEV_1. Changes in pre- and post-shift FVC through the study period for 2003 and 2004 are presented for two subjects in Figure 2. The figure illustrates the decline in FVC and FEV1 as the seasons progressed, the number of burns conducted by the subjects rose, and cumulative exposure to woodsmoke increased.

Discussion

The current study followed a group of non-smoking wildland firefighters working at prescribed burns during the dormant winter burn seasons of 2003 and 2004 in a Southeastern United States forest. Lung function measurements were collected from the firefighters during the study. To our knowledge, this is the first study among wildland firefighters that compares changes in lung function across workshift on burn and non-burn days. Gaughan et al. (Gaughan et al., 2008) had suggested that such comparison would strengthen the inference about cross-shift changes in FEV_1 in their study of wildland firefighters at wildfires.Although, declines across the workshift were observed for FVC and FEV_1, changes on burn and non-burn days were similar. Betchley et al. (Betchley et al., 1997), reported significant cross-shift declines from pre- to mid-shift and from pre- to post-shift in FVC, FEV_1, and FEF_{25-75} among firefighters working at forest fires in Washington and Oregon States. However, comparisons were not made against non-burn days. Swiston et al. (Swiston et al., 2008) reported no difference in changes in FEV_1 after bronchodilation at baseline and after a forest firefighting workshift. Together, these results suggest that

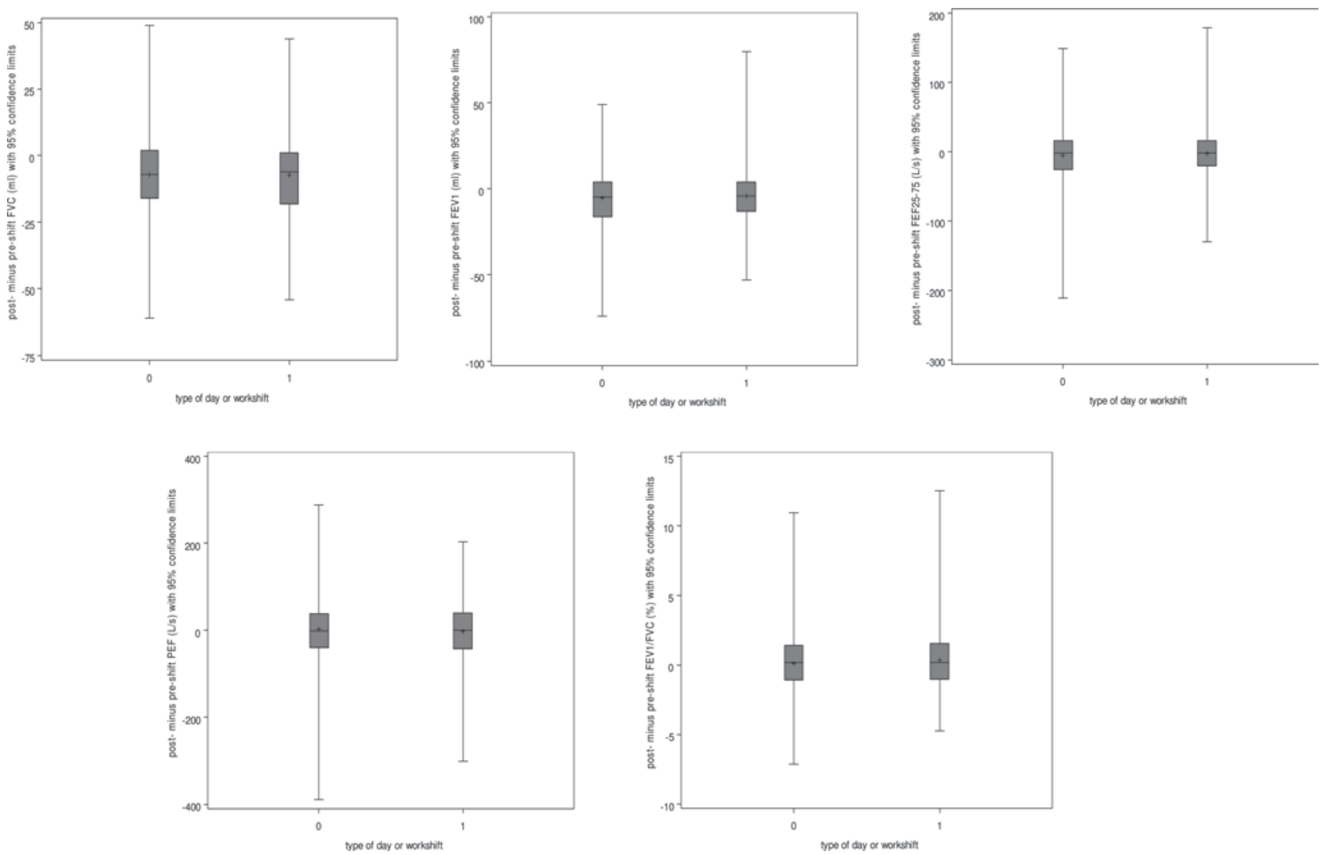

Figure 1. Post- minus pre-shift changes in FVC, FEV_1, FEF_{25-75}, PEF and FEV_1/FVC plotted against burn activity for non-smokers. 0 = represents non-burn days (n = 287). 1 = represents burn days (n = 175).

Table 1. Parameter estimates from linear mixed effect models.

	Estimate (ml)	
	FVC (p)	FEV_1 (p)
Subjects – non-smokers only (n = 24)		
Gender (if subject is female)	–2877 (<0.01)	–2272 (<0.03)
Race (if subject is Caucasian)	393 (0.47)	–152 (0.80)
Worktime*	0.8 (0.56)	–0.03 (<0.03)
Cumulative burn days**	–24 (<0.01)	–24 (<0.01)
Allergies (yes)	–280 (0.62)	–303 (0.1)
Cumulative burn days × allergies (yes)	16 (<0.01)	20 (<0.01)
Subjects with smokers included (n = 26)		
Gender (if subject is female)	–1840 (<0.01)	–1376 (<0.01)
Race (if subject is Caucasian)	390 (0.47)	–156 (0.78)
Worktime*	1.2 (0.35)	0.8 (<0.01)
Cumulative burn days**	–25 (<0.01)	–27 (<0.01)
Allergies (yes)	–176 (0.62)	–154 (0.68)
Cumulative burn days × allergies (yes)	15 (<0.01)	19 (<0.01)

*Worktime – the number of work days since study began for each burn season.
**Cumulative Burn Days – number of burn days since study began for each burn season.

Figure 2. Profile of pre-shift FVC across 2003 and 2004 burn seasons for two subjects. *The dates that have asterisks are for days when there were burns and dates without asterisks are for days when there was no burn. (See colour version of this figure online at www.informahealthcare.com/iht)

lung function may be insensitive for assessing cross-shift effect of woodsmoke exposure among wildland firefighters. It is possible that observed cross-shift changes may not be different from changes that would otherwise have been observed during workshifts when the firefighters did not work at prescribed burns or wildfires (Gaughan et al., 2008), or that the changes were confounded by the normal circadian variation in lung function. Circadian variation in lung function has been demonstrated in healthy subjects and patients of respiratory diseases (Barnes, 1985; Hetzel, 1981). For instance, diurnal variations (amplitude about the daily mean) of 2.8%, and 1.9% in FEV_1 have been reported for two Dutch communities and in non-asthmatics in a controlled study respectively (Troyanov et al., 1994; Borsboom et al., 1999), while the difference in FEV_1 between the one-hour period with the lowest mean value and the period with the highest mean value was 17.6% among a set of hospital-based subjects in the United States (Medarov et al., 2008). Although, there were variations between burn and non-burn days with regards to the length of workshift and the times pre- and post-shift spirometry measurements were collected, it is not expected that this would have diminished the ability to detect differences in declines in lung function measurements between burn and non-burn days. On the other hand, the longer workshifts would have been expected to contribute to more pronounced declines on burn days. In the Dutch community study, FVC remained flat during the period when 86% of the burn and 96% of the non-burn day post-shift measurements were collected in the current study (4 pm to 8 pm), while FEV_1 and PEF tended to decline (Borsboom et al., 1999). A further 11% of the burn day post-shift spirometry measurements were collected at later times. Close to 90% of both the burn and non-burn day pre-shift samples were collected within a two-hour window (7 am to 9 am).

Although our study was not specifically designed for the purpose, we observed significant associations between cumulative exposure, defined as cumulative number of firefighting days during a burn season, and decrements in pre-shift FVC and FEV_1 (Table 1). Similar effects were observed when the post-shift measures were analyzed instead of the pre-shift values. Declines in FVC, FEV_1 and FEF_{25-75} from pre- to post-season have also been reported in previous cross-seasonal studies (Rothman et al., 1991; Letts et al., 1991; Liu et al., 1992; Betchley et al., 1997). The effect of cumulative exposure on lung function during the burn season depended on the allergy status of the subject with less pronounced declines in FVC and FEV_1 being associated with each additional day of working at a prescribed burn in subjects who reported having allergies. This implies less sensitivity in lung function changes in response to cumulative exposure to woodsmoke during the burn season in subjects with allergies. It is not clear why there was a decreased sensitivity in subjects with allergies. Studies of lung function changes in cotton mill workers show that atopy (including to pollen) was a factor in acute lung function decline, with larger declines in spirometry measures observed for atopic workers (Sepulvelda et al., 1984; Wang et al., 2003a; Wang et al., 2003b), but declines in FEV_1 were similar for both atopic and non-atopic subjects over a one-year period. The use of medication by allergic subjects could have modified their response to cumulative woodsmoke exposure. However, none of the subjects reported using any medication during the study period. The seven subjects who specified the type of respiratory allergies, had reported being allergic to tree/grass pollen. Our study was conducted during the winter burn season, whereas pollen allergy typically starts during the spring season. Therefore, the use of medication is unlikely to be a reason for the decreased sensitivity of subjects with allergies to the effect of cumulative exposure on lung function observed in this study. However, this result may have been due to a small number of subjects and/or unaccounted for confounders. Furthermore, a few large burns had already been conducted (seven in 2003, four in 2004) before spirometry measurements started.

We did not collect lung function measures beyond eight days of the last burn, and did not assess whether lung function improved during the off-season. Therefore, we could only explore whether the observed declines were sustained beyond the burn season by comparing spirometry measures at the start of the study periods in the two consecutive dormant winter burn seasons. There was no difference in FVC and FEV_1 between the start of measurements in 2003 and 2004 in nine subjects who participated in both years. Thus, the results suggest that there was no permanent effect of woodland smoke on lung function. Betchley et al. (Betchley et al., 1997) reported that declines in FVC, FEV_1 and FEF_{25-75} during the burn season tended to resolve after a considerable number of days (average = 257; SD = 53.3 days) away from firefighting. However, they reported that significant decrements in FEV_1 and FEF_{25-75} compared to baseline remained 2.5 months after the last firefighting activity.

Gravimetric measurements of personal exposure to $PM_{2.5}$ were collected alongside spirometry measurements during the study (Adetona et al., 2011). However, spirometry measurements and exposure monitoring were missed for several days for some subjects. There was no exposure data for 89 person-days out of the total of 203 person-days of spirometry measurements collected on burn days. Consequently, a more accurate measure of cumulative exposure could not be determined from personal monitoring, and we used cumulative number of firefighting days to estimate this measure. Nevertheless, we observed a significant effect of cumulative exposure on lung function through one-month periods with 11 days of exposure each in our study group with or without the inclusion of current smokers. We also relied on questionnaire information for the allergy status of the subjects. Furthermore, our study was specifically designed to assess across workshift changes and not the effect of cumulative exposure on within-season lung function changes. A study designed to measure declines in firefighters against those of control subjects as has been done for other groups of workers (Beeckman et al., 2001; Christiani et al., 1999; Senthilselvan et al., 1997; Ulvestad et al., 2001) would more definitively answer questions regarding within-season or longer term effects of cumulative exposure. Excess annual declines in FEV_1 were observed in non-smoking tunnel workers (Ulvestad et al., 2001) and confinement swine workers (Senthilselvan et al., 1997) relative to non-exposed referent groups over follow-up periods of eight and four years respectively, while observed declines were similar for both cotton and silk textile mills workers over an 11-year period (Christiani et al., 1999). Subsequent development of chronic respiratory diseases including bronchitis, asthma and emphysema was more likely in coal miners who had more rapid declines in FEV_1 (>60 ml/year) than in a referent group of coal miners with less rapid declines in FEV_1. The possibility that within-season declines in wildland firefighters such as those observed in this study could persist in the longer term, and that such declines could be consequential for future development of chronic respiratory diseases could be determined through the conduct of longitudinal studies similar to the ones referenced above.

The sample in this study was small. However, we collected measurements over multiple days across two burn seasons (2003 and 2004) from the subjects. Therefore, we were able to investigate the effect of cumulative exposure on lung function, in addition to determining whether there were across-shift changes in lung function by comparing responses on burn days to those measured on non-burn days. We did not have exposure data for about 45% of the total number of burn-day spirometry measurements, and so relied on the cumulative number of burn days as a measure of cumulative exposure. Nevertheless, we expect that the cumulative number of burn days is an adequate measure since exposure to $PM_{2.5}$ on burn days was about 15 times of what was measured on non-burn days during the study (Adetona et al., 2011).

Conclusions

The results in our study indicate that across shift changes in lung function on burn days were not different from those on non-burn days at the levels of woodsmoke exposure experienced by the wildland firefighters. However, a small cumulative effect was seen with multiple days of exposure. Therefore, the results indicate that measurements should span a longer period of time in order to investigate the effect of occupational woodsmoke exposure on wildland firefighters. It would also be advisable to collect the pre- and post-exposure measurements during the same period of the day if the study design does not incorporate control non-exposure (non-burn days) in order to avoid confounding with diurnal effects. Alternatively, comparison of changes in lung function should be made between burn and non-burn days as was done in the current study.

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Declaration of interest

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