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Characterization of inhalation exposures at a wildfire incident during the Wildland Firefighter Exposure and Health Effects (WFFEHE) Study

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Abstract

Wildland firefighters (WFFs) are exposed to many inhalation hazards working in the wildland fire environment. To assess occupational exposures and acute and subacute health effects among WFFs, the wildland firefighter exposure and health effects study collected data for a 2-year repeated measures study. This manuscript describes the exposure assessment from one Interagency Hotshot Crew (*N* = 19) conducted at a wildfire incident. Exposures to benzene, toluene, ethylbenzene, xylene isomers, formaldehyde, acetaldehyde, and naphthalene were measured through personal air sampling each work shift. Biological monitoring was done for creatinine-adjusted levoglucosan in urine pre- and post-shift. For 3 days sampling at the wildfire incident, benzene, toluene, ethylbenzene, xylene isomers (m and p, and o) exposure was highest on day 1 (geometric mean [GM] = 0.015, 0.042, 0.10, 0.42, and 0.15 ppm, respectively) when WFFs were not exposed to smoke but used chainsaws to remove vegetation and prepare fire suppression breaks. Exposure to formaldehyde and acetaldehyde was highest on day 2 (GM = 0.03 and 0.036 ppm, respectively) when the WFFs conducted a firing operation and were directly exposed to

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Supplementary data
Supplementary data are available at *Annals of Work Exposures and Health* online.

Conflict of interest statement. The authors declare no conflict of interest relating to the material presented in this Article. Its contents, including any opinions and/or conclusions expressed, are solely those of the authors.

wildfire smoke. The greatest difference of pre- and post-shift levoglucosan concentrations were observed on day 3 (pre-shift: 9.7 and post-shift: 47 µg/mg creatinine) after WFFs conducted mop up (returned to partially burned area to extinguish any smoldering vegetation). Overall, 65% of paired samples (across all sample days) showed a post-shift increase in urinary levoglucosan and 5 firefighters were exposed to benzene at concentrations at or above the National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit. Our findings further demonstrate that exposure to inhalation hazards is one of many risks that wildland firefighters experience while suppressing wildfires.

Keywords

chainsaw exhaust; firefighter; wildfire; wood smoke

Introduction

Through 2018–2019, wildland firefighters (WFFs) suppressed over 108,000 wildfires that burned over 13 million acres in the United States (NIFC 2020). WFFs work long shifts under arduous conditions. Wildfire smoke is a common workplace exposure and no respiratory protection designed and approved for wildfire conditions is currently available (Domitrovich et al. 2017). Previous smoke exposure assessments of WFFs have measured acrolein, benzene, carbon monoxide (CO), formaldehyde, polycyclic aromatic hydrocarbons (PAHs), and fine (aerodynamic diameters <2.5 micrometers [µm]) and respirable (aerodynamic diameters <4 µm) particulate matter (PM) (Adetona et al. 2016). WFF exposure to smoke has been associated with acute health effects, such as declines in lung function and increases in inflammation, and possible chronic health effects, such as lung cancer and cardiovascular disease (Liu et al. 1992; Gaughan et al. 2014; Adetona et al. 2019; Navarro et al. 2019; Main et al. 2020).

The objective of the National Institute for Occupational Safety and Health (NIOSH) Wildland Firefighter Exposure and Health Effects (WFFEHE) Study was to examine the associations between occupational exposures and risk of adverse health outcomes among federally employed WFFs across 2 wildfire seasons (2018–2019). Here, we describe a mid-season exposure assessment that was conducted during a wildfire incident to characterize WFFs' exposure to air contaminants at this wildfire incident by conducting personal air sampling and biological monitoring of various compounds.

Methods

This exposure assessment was conducted at a wildfire incident near Salmon, Idaho in 2019 as part of the WFFEHE study. An Interagency Hotshot Crew (IHC) of 19 WFFs participated in the study. A detailed description of the entire study rationale, design, and methods for the repeated-measures study were reported previously (Navarro, Butler, et al. 2021).

Personal air sampling was conducted to characterize WFFs' exposures to benzene, toluene, ethylbenzene, xylene isomers (m, p, and o-), formaldehyde, acetaldehyde, and naphthalene. At the beginning of the shift, passive volatile organic compound (VOC) (Tenax TA thermal desorption tubes with passive caps) and aldehyde (UMEX-100 passive badges) samplers were attached to the shoulder strap of each firefighter's gear pack, as close to the breathing zone as possible. To assess the biological uptake of levoglucosan (a combustion breakdown product of cellulose and marker for wood smoke exposure), firefighters provided pre- and post-shift urine samples (Naeher et al. 2013). Two NIOSH industrial hygienists accompanied the IHC into the field to observe and document environmental conditions, work activities, and use of tools, equipment, and personal protective equipment.

When the WFFs returned to base camp at shift's end, the passive VOC and aldehyde air sampling media were collected, capped and/or bagged, and stored in a refrigerator prior to shipment to the laboratory. The Tenax tubes were analyzed for BTEX and naphthalene following EPA method TO-17 (US EPA 1999a). The aldehyde samplers were subsequently analyzed for formaldehyde and acetaldehyde using EPA method TO-11 (US EPA 1999b). Following urine collection, 1–2 mL urine aliquots were made and frozen at −20 °C before being shipped to the lab on dry ice. Urine samples were stored frozen until analysis. To adjust for hydration status, all levoglucosan concentrations were normalized by creatinine. See Supplementary Material for a full description of creatinine, levoglucosan analysis methods, and unadjusted levoglucosan concentrations.

Summary statistics are presented as geometric mean (GM), geometric standard deviation, and range. Box and whisker plots with minimum, 25th percentile, median, 75th percentile, and maximum were generated by sampling day for all personal air sampling results and pre- and post-shift for levoglucosan urinary results. Limits of detection (LOD) were 0.004, 0.001, 0.008, and 0.009 ppm for benzene, toluene, ethylbenzene, and xylenes, respectively. The LOD for both formaldehyde and acetaldehyde was 0.009 ppb, naphthalene was 5.23 ng/m^3 and levoglucosan was 0.1 μg/mL of sample. In calculating the descriptive statistics, sample concentrations below the LOD were assigned values equal to one half the LOD to prevent skewing the data (Hornung et al. 1990).

Results

Samples for this exposure assessment were collected over 3 days (August 2019) during the Cove Creek Fire at the Salmon Challis National Forest. At the time of the assessment, the wildfire had burned 2,258 acres of grass, brush, and mixed conifer. Firefighters on the IHC operated in 3 different roles: crew member (N = 9), saw team (N = 8), and overhead (N = 2). Crew members performed ground level fire management tasks as described below, firefighters on a saw team (2 individuals/team) used chainsaws to fell trees and remove brush, and individuals in overhead positions such as squad leaders, captains, or superintendents directed and oversaw firefighters performing operational tasks in addition to performing operational tasks as well. In general, these firefighters performed these roles and positions throughout the sampling event, but saw teams may have engaged in other fire management tasks as described below when there was not a need for saw work to be completed. Because of their similar job duties and proximity to the rest of the crew, we presented crew members and overheard results together.

During day 1 and most of day 2, the IHC prepped firelines by using chainsaws to remove hazard trees and flammable brush and vegetation to reduce fire behavior near control lines and structures. Firefighters also used hand tools to dig firelines, clearing all flammable material down to mineral soil. On day 2, the crew conducted a firing operation where crewmembers carried drip torches to ignite fuels and the remainder of the crew performed “holding” by monitoring fire behavior and watching for embers to cross the control line and ignite unburned fuels. This firing operation was completed to actively slow and stop the progression of the Cove Creek Fire itself by creating a fuel break through the burning of available fuel between the main fire and the control lines. On day 3, the crew returned to the site of their firing operation and extinguished smoldering material (known as mop up) and walked in coordinated progression looking and feeling with their bare hands for areas of heat to extinguish (known as cold trailing).

Based on field observations collected during the work tasks and the expert judgement of our firefighter partners, the most visible smoke was observed on day 2 during the firing operation, followed by day 3 while firefighters were performing mop-up. Little smoke was observed on day 1, but firefighters were exposed to chainsaw exhaust. In addition, there was little to no additional smoke exposure observed from regional smoke from the Cove Creek Fire at the work site or while off-duty at fire camp.

Full-shift personal air contaminants and pre- and post-shift levoglucosan concentrations, presented across all study participants and stratified by day and crew assignment, are provided in Table 1. We collected 56 VOC samples and 55 paired urine samples with over 84% of samples above the LOD. GMs across all sampling days for benzene, toluene, ethylbenzene, m,p- xylene, and o-xylene were 0.013, 0.032, 0.074, 0.32, and 0.11 ppm, respectively. The GM for naphthalene across all sampling days was 7.2 μg/m^3. For formaldehyde and acetaldehyde, the GMs were 0.019 and 0.024 ppb, respectively. The GM for pre-shift levoglucosan was 7.2 μg/mg creatinine, while post-shift was 14 μg/mg creatinine. The average difference between pre- and post-shift levoglucosan was 26.9 μg/mg creatinine.

Exploring differences in exposures by day (Fig. 1) and job activities, the GMs of benzene, toluene, ethylbenzene, and xylene isomers (BTEX) were highest on day 1 compared to day 2 and 3 and were higher for saw team members. Naphthalene concentrations were similar on day 1 and 3 and for all crew members and slightly higher on those days compared to day 2. In contrast, both formaldehyde and acetaldehyde GM concentrations were higher on day 2 compared to day 1 and 3. Overall, creatinine-adjusted levoglucosan concentrations were higher post-shift compared to preshift, with the largest difference measured on day 3. The average difference between pre- and post-shift levoglucosan was 1.84, 4.6, 74.4 μg/mg creatinine for day 1, 2, and 3, respectively.

Discussion

Our objective of this exposure assessment was to assess WFFs’ exposure to air contaminants at a wildfire incident. Our results demonstrate that not only are WFFs exposed to air contaminants from smoke during a firing operation and mop-up, but they can also be exposed to air contaminants from chainsaw exhaust. We observed higher concentrations of BTEX on day 1 and for WFFs that were part of a saw team (compared to other days and job activities), indicating that exposure to chain saw exhaust likely contributes to higher BTEX exposures.

Five full-shift exposures to benzene were equal to or exceeded the NIOSH Recommended Exposure Limit (REL; 0.1 ppm). A 2004 study by Reinhardt and Ottmar measured wildland firefighter exposures to VOCs at project fires and found averages of 0.004 ppm and 13 ppb for benzene and formaldehyde, respectively, which is lower than our findings for benzene, but higher for formaldehyde. Compared to exposures estimated by Navarro et al. (2021), the GM for benzene was higher in this study (0.013 ppm compared to 0.003 ppm), while the GM for formaldehyde was lower (0.019 ppb compared to 31.2 ppb). Reinhart and Ottmar (2004) and Navarro et al. (2021), included data from many wildfires and WFFs performing a greater variety of tasks. In addition, differences compared to Navarro et al. (2021) could also be due to using emission ratios from PM to calculate the exposures, which had limitations.

Similar to Naeher et al. (2013), we observed that 65% of urine samples had higher creatinine-adjusted levoglucosan concentrations post-shift compared to pre-shift. However, their reported pre-shift (16 µg/mg creatinine) and post-shift (21 µg/mg creatinine) levoglucosan concentrations were higher compared to our overall geometric means. This difference could be due to exposures differences at the prescribed fires that were evaluated compared to our wildfire incident. The greatest difference was observed on Day 3. Since the half-life of levoglucosan is short (4.5 h), the increase in urinary levoglucosan may be attributed to WFFs performing mop-up and exposure to smoldering vegetation for much of their shift (Moshammer et al. 2012).

Our results contribute to the literature examining WFF exposure to air contaminants on wildfires and can be paired with many of the health measurements collected during this wildfire assignment. Although this assessment only included 3 d on one wildfire incident, and has a limited sample size, which limits our ability to generalize these exposures to all wildland firefighters. However, crewmembers sampled performed variety of tasks and roles, which provided insight into specific activities that contributed to firefighters' exposure. More comprehensive exposure monitoring over a longer duration (e.g. air and biological monitoring of other combustion products, multiple campaign fires) is needed to better characterize WFF exposures, but these assessments are challenging under the extreme and remote conditions that WFFs operate.

Conclusion

Exposure to inhalation hazards will continue to be a risk for WFFs, as there is currently no respirator that can both provide protection to particles and gases from wildfire smoke and perform in the extreme and complex environment of wildfire (Reinhardt and Broyles 2019). In this study, we found that a few WFFs were overexposed to benzene (based on the NIOSH REL). In addition, based on observations by the field team research within exposures for structural firefighters, and some initial intervention research on wildland firefighters conducted by Nicola Cherry and others (2021), there should be further investigation of all routes of exposure to contaminants including dermal exposures (Fent et al. 2020). It is important for all fire personnel to understand the hazards of exposures from their occupation. Wildland fire managers should continue to develop and promote feasible mitigation strategies for inhalation hazards that can be flexible and adaptable to a changing fire environment.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data availability

The data underlying this article cannot be shared publicly due to the privacy of individuals that participated in the study. The data will be shared on reasonable request to the corresponding author.

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What's Important About This Paper?

There is increased awareness about the hazards of wildland firefighting, and this study increases this knowledge base by describing inhalation exposures and total wood smoke exposure, indicated by lavoglucosan in urine among one crew responding to an incident over 3 days. There remains a need to develop interventions that reduce inhalation exposures among these workers.

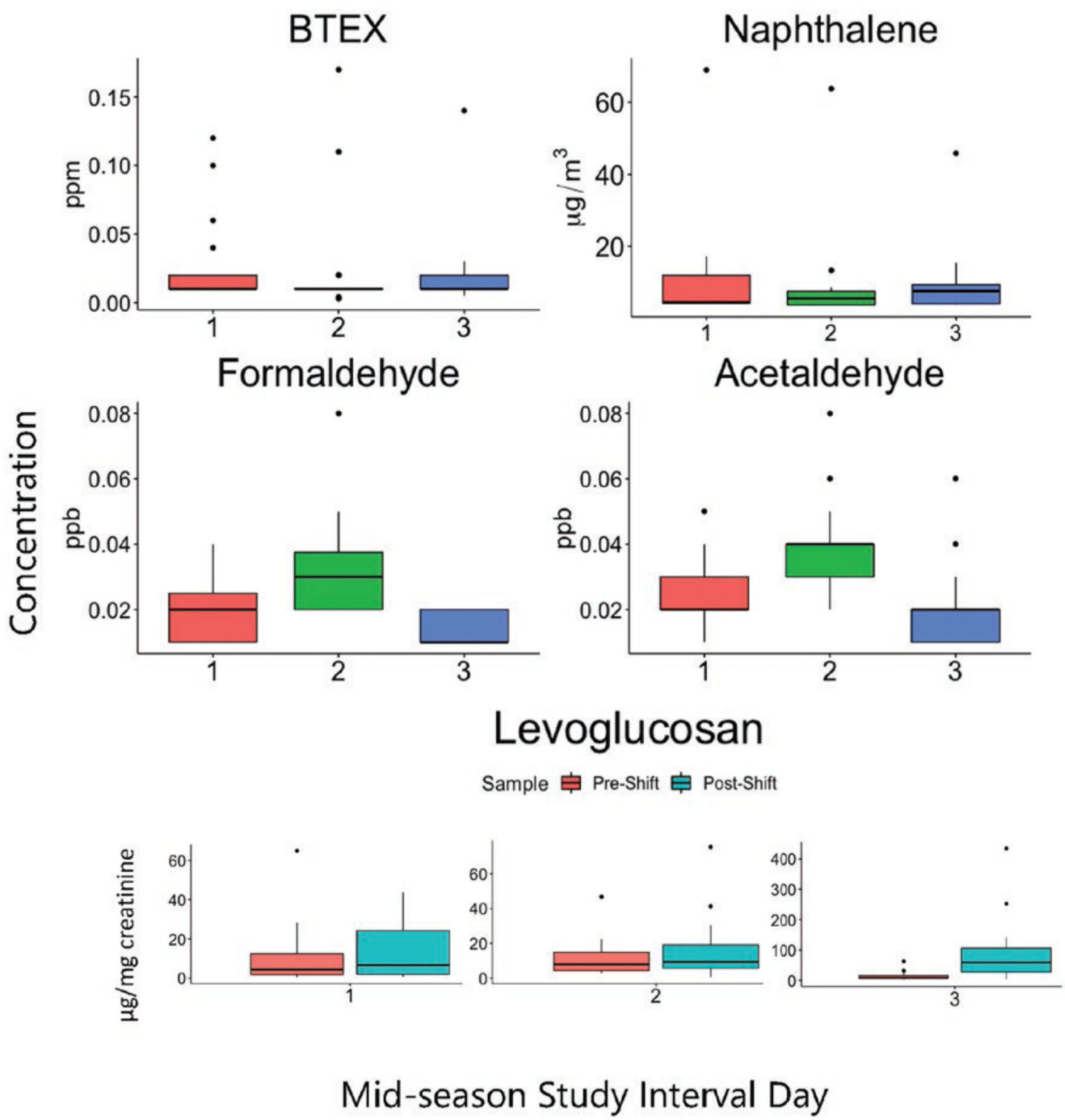

Fig. 1.

Concentrations of benzene, toluene, ethylbenzene and xylenes isomers (BTEX), naphthalene, formaldehyde, acetaldehyde, and levoglucosan across mid-season study interval days.

Table 1.

Work-shift concentrations of air contaminants across all study participants, mid-season study interval day and crew assignment

Air contaminants measured											
Summary statistics		**Benzene (ppm)**	**Toluene (ppm)**	**Ethylbenzene(ppm)**	**m-Xylene p-Xylene (ppm)**	**o-Xylene (ppm)**	**Naphthalene (μg/m3)**	**Formaldehyde (ppb)**	**Acetaldehyde (ppb)**	**Pre-Shift Levoglucosan (μg/mg creatinine)**	**P Le cr**
All Days	*N*	56	56	56	56	56	56	56	56	57	55
	% above LOD	96%	98%	98%	98%	98%	57%	100%	96%	100%	96
	GM	0.013	0.032	0.074	0.32	0.11	7.2	0.019	0.024	7.2	14
	GSD	2.5	3.9	3.8	3.8	3.8	2.0	1.7	1.7	3.0	4.8
	Min	0.0030	0.00037	0.0059	0.015	0.0066	3.7	0.0080	0.0064	0.50	0.6
	Max	0.17	0.77	2.0	8.1	2.8	69	0.079	0.082	65	43
Mid-Season Study Interval Day											
Day 1	*N*	19	19	19	19	19	19	19	19	19	17
	GM	0.015	0.042	0.10	0.42	0.15	7.8	0.017	0.023	4.6	6.3
	GSD	2.5	3.3	3.5	3.4	3.4	2.1	1.7	1.4	4.0	4.3
	Min	0.0050	0.0065	0.012	0.056	0.021	4.2	0.0080	0.012	0.50	0.6
	Max	0.12	0.56	1.5	5.7	2.1	69	0.042	0.051	65	44
Day 2	*N*	18	18	18	18	18	18	18	18	19	19
	GM	0.011	0.028	0.073	0.31	0.11	6.2	0.030	0.036	8.2	9.1
	GSD	2.9	4.8	3.8	4.0	3.9	2.0	1.5	1.4	2.2	3.2
	Min	0.0030	0.00037	0.0059	0.015	0.0066	3.7	0.016	0.019	2.7	0.6
	Max	0.17	0.43	1.2	5.2	1.9	64	0.079	0.082	47	75
Day 3	*N*	19	19	19	19	19	19	19	19	19	19
	GM	0.013	0.027	0.058	0.25	0.088	7.7	0.014	0.017	9.7	47
	GSD	2.2	3.9	4.2	4.1	4.1	1.8	1.3	1.7	2.5	3.7
	Min	0.0047	0.0070	0.011	0.058	0.019	4.0	0.0087	0.0064	1.4	2.9
	Max	0.14	0.77	2.0	8.1	2.8	45.8	0.022	0.057	63	43
Crew Assignment											
Crew	*N*	32	32	32	32	32	32	33	33	33	32
Member\Overhead[a]	GM	0.012	0.025	0.058	0.24	0.086	7.0	0.019	0.025	7.05	14
	GSD	2.3	4.7	4.3	4.4	4.3	2.2	1.7	1.8	3.3	5.9
	Min	0.0041	0.00037	0.0059	0.015	0.0066	3.7	0.009	0.01	0.59	0.6
	Max	0.14	0.77	2.0	8.06	2.8	69	0.079	0.082	65	43
Saw Team	*N*	24	24	24	24	24	24	23	23	24	23
	GM	0.015	0.046	0.10	0.46	0.16	7.5	0.020	0.023	7.3	15
	GSD	2.8	2.8	2.9	2.9	2.9	1.7	1.7	1.5	2.6	3.4
	Min	0.00	0.01	0.02	0.09	0.03	3.73	0.01	0.01	0.50	0.7
	Max	0.17	0.56	1.13	4.84	1.58	17.3	0.05	0.05	46.74	14

N = number of samples that were collected; GM = Geometric mean; GSD = geometric standard deviation.

[a]Due to small sample size and similar job tasks overhead was combined with crew member.