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The Wildland Firefighter Exposure and Health Effect (WFFEHE) Study: Rationale, Design, and Methods of a Repeated-Measures Study

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Abstract

The wildland firefighter exposure and health effect (WFFEHE) study was a 2-year repeated-measures study to investigate occupational exposures and acute and subacute health effects among wildland firefighters. This manuscript describes study rationale, design, methods, limitations, challenges, and lessons learned. The WFFEHE cohort included fire personnel ages 18–57 from six federal wildland firefighting crews in Colorado and Idaho during the 2018 and 2019 fire seasons. All wildland firefighters employed by the recruited crews were invited to participate in

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

the study at preseason and postseason study intervals. In 2019, one of the crews also participated in a 3-day midseason study interval where workplace exposures and pre/postshift measurements were collected while at a wildland fire incident. Study components assessed cardiovascular health, pulmonary function and inflammation, kidney function, workplace exposures, and noise-induced hearing loss. Measurements included self-reported risk factors and symptoms collected through questionnaires; serum and urine biomarkers of exposure, effect, and inflammation; pulmonary function; platelet function and arterial stiffness; and audiometric testing. Throughout the study, 154 wildland firefighters participated in at least one study interval, while 144 participated in two or more study interval. This study was completed by the Centers for Disease Control and Prevention's National Institute for Occupational Safety and Health through a collaborative effort with the U.S. Department of Agriculture Forest Service, Department of the Interior National Park Service, and Skidmore College. Conducting research in the wildfire environment came with many challenges including collecting study data with study participants with changing work schedules and conducting study protocols safely and operating laboratory equipment in remote field locations. Forthcoming WFFEHE study results will contribute to the scientific evidence regarding occupational risk factors and exposures that can impact wildland firefighter health over a season and across two wildland fire seasons. This research is anticipated to lead to the development of preventive measures and policies aimed at reducing risk for wildland firefighters and aid in identifying future research needs for the wildland fire community.

Keywords

cardiovascular; hearing; kidney; pulmonary; wildfire

Introduction

In the USA, the National Interagency Fire Center (NIFC) reported over 65 000 wildfires that burned an average of 7.6 million acres between 2014 and 2019 (NIFC, 2020). In the past decade, the annual acreage burned was often double or triple the annual average of 3.3 million acres burned in the 1990s. Data also suggest that climate change, along with human behaviors and increased housing in the wildland urban interface, have increased the length of fire season. This has extended burning from early spring through summer and late fall or even winter seasons (Westerling *et al.*, 2006; Westerling, 2016; Balch *et al.*, 2017). As the length and severity of the fire season increases, the number of wildland firefighters (WFFs) needed to manage these fires and days spent working to suppress these fires is expected to increase (Westerling *et al.*, 2006; Stephens *et al.*, 2013; Navarro *et al.*, 2019).

WFFs work to actively suppress wildfires (unplanned ignitions) and conduct prescribed burns on wildland fire incidents (includes wildfires and prescribed fires). Prescribed fires (also called prescribed or controlled burns) are a form of land management in which fire is intentionally applied to vegetation for resource benefit such as reducing available burnable material (fuel) for future fires (Ryan *et al.*, 2013). To work on a wildfire or prescribed fire incident, WFFs are employed on different types of crews that can range both in size (3–25 people) and in function (e.g. helitack crews, engine crews, and handcrews) (US Forest Service, 2021a, 2021b). Helitack crews use helicopters to travel to and complete operational missions, whereas engine crews use varying types of fire engines to deliver and apply water or foam as suppression resources. Handcrews are generally tasked with constructing firelines (described below) with hand tools. Each handcrew is categorized into one of several types, such as Type 1 Interagency Hot Shots (IHCs) and Type 2 Initial Attack (T2IA) (US Forest Service, 2021a). Within the Incident Command System, both crew types maintain national training, qualifications standards, experience, supervisory capabilities and are available to be deployed nationally to a wildfire incident. IHC crewmembers are typically more experienced and must meet higher fire qualification standards (including additional training, experience, and physical fitness requirements), allowing the crew to perform more complex tasks on the fireline. T2IA crews may perform similar but less complex operations, have less rigorous qualification standards for their overhead positions, and can have more first-season (rookie) crewmembers (NIFC, 2021). Both crews can perform initial attack on a fire, which means, that they are the initial resource responding to the wildfire incident while trying to suppress and contain the fire quickly.

To suppress and contain wildland fires, WFFs perform common job tasks across their work shift under varying fire environment conditions. To create a break in available fuel, WFFs construct firelines by clearing brush (often with a chainsaw) and digging down to bare mineral soil. WFFs engage in "holding" by walking along a fireline to observe and ensure that the fire has not crossed the fireline and that the fire stays contained. After a fire has finished actively burning and is smoldering, WFFs 'mop-up' by digging out any hot, smoldering, or smoking burnt material or ash, moving around burnt and unburnt materials, or applying water to extinguish any smoldering material that has the potential to re-ignite the fire. To conduct a prescribed fire or a firing operation on a wildfire to remove unburnt fuel, WFFs apply fire to a specific area generally using torches filled with a mixture of diesel and gasoline or other incendiary devices.

In addition to workplace risks and hazards such as burnovers/entrapments, heat-related illnesses and injuries, equipment (i.e. chainsaws) and vehicle-related injuries (including aircraft), slips, trips, and falls, and falling trees and rocks, WFFs are exposed to smoke and ash (Britton *et al.*, 2013). Wildfire smoke and ash may contain toxic contaminants such as fine particulate matter (PM; ≤ 2.5 μm in aerodynamic diameter), and respirable PM (≤4 μm in aerodynamic diameter), acrolein, benzene, carbon dioxide, carbon monoxide (CO), formaldehyde, and polycyclic aromatic hydrocarbons (PAHs) (Adetona *et al.*, 2016). The composition and concentration of exposures of wildland fire smoke and ash varies greatly from fire to fire and even day to day within the same fire and for individual WFFs performing various job tasks (Adetona *et al.*, 2017; Navarro *et al.*, 2017; Reinhardt and Broyles, 2019).

While studies investigating sudden cardiac events, respiratory health decline, rhabdomyolysis (muscle damage and breakdown), and risk factors for these conditions have been documented among structural firefighters, less research to understand and report these conditions has been conducted among WFFs (Scannell and Balmes, 1995; Burgess *et al.*, 2001; Kales *et al.*, 2003; Soteriades *et al.*, 2011; Eisenberg *et al.*, 2015; Smith *et al.*, 2018; Eisenberg *et al.*, 2019; Smith *et al.*, 2019; Mathias *et al.*, 2020). Some physiologic and workplace factors (e.g. stress, exposure to contaminants and heat, intense physical workload) are shared between structural firefighters and WFFs (Ruby *et al.*, 2002; Gainey *et al.*, 2018; Wong and Swanson, 2019; West *et al.*, 2020). However, several environmental and occupational factors differ between these two groups including environmental conditions, duration of and specific composition of smoke and combustion product exposures, respiratory protection and other personal protective equipment (PPE) use, metabolic and physiologic demand (intensity and duration of work), access to medical care and treatment during fire responses, workforce demographics, and work shift duration and schedule (Austin *et al.*, 2001; Ruby *et al.*, 2002; Cuddy *et al.*, 2015; Adetona *et al.*, 2016; Fent *et al.*, 2018; Sol *et al.*, 2018). WFFs typically work 12–16 h per day for 14 days with 2 days off between each fire assignment, whereas structural firefighters typically have a work schedule of 24 h on and 48–72 h off or 48 h on with 72–96 h off (Mims, 1999; Choi *et al.*, 2014; NIFC, 2021). Since structural firefighters are often on-duty to provide protection in case a fire is reported they can experience long periods of relative inactivity punctuated by strenuous firefighting work. In contrast, WFFs are often engaged in arduous work for much of their shift. Another major difference between structural firefighters and WFFs is that structural firefighters wear a self-contained breathing apparatus to protect their airways when they are in smoke-filled environments, whereas WFFs have no respiratory protection (Domitrovich *et al.*, 2017). These important differences limit the ability to extrapolate research and occupational safety and health recommendations from structural firefighters to WFFs.

Study Rationale

Most wildland fire research studies consist of short-term measurements, often across individual work shifts and single fire seasons, with data reported for only a single factor, health outcome or exposure of interest, such as, smoke, noise, or heat-stress (Adetona *et al.*, 2016, 2019; Broyles *et al.*, 2017; Henn *et al.*, 2019; Reinhardt and Broyles, 2019; West *et al.*, 2020). These studies and others report that WFFs can be exposed to hazardous concentrations of specific compounds in smoke (such as carbon monoxide and PM), and in some cases, occupational exposure limits (OELs) may be exceeded during 1–28% of the work shift (Miranda *et al.*, 2010; McCleery *et al.*, 2011; Adetona, Simpson, *et al.*, 2013a, 2013b; Reinhardt and Broyles, 2019). In addition, a recent study reported that WFFs were exposed to PAHs across their work shift not only through inhalation of smoke but also dermally by absorption through their skin across their work shift (Cherry *et al.*, 2021).

Research also indicates that some WFFs experience negative acute health effects, such as increases respiratory symptoms, decreases in lung function, oxidative stress, and inflammatory responses due to their occupational exposures (Gaughan *et al.*, 2008; Gaughan *et al.*, 2014a; Gaughan *et al.*, 2014b; Adetona *et al.*, 2016, 2017; Main *et al.*, 2020). Across single fire seasons, WFFs in the USA experienced significant declines in lung function [forced vital capacity (FVC), forced exhalation at 1 s (FEV_1), and forced vital capacity at 25–75%], an increase in airway responsiveness and inflammation, and increases in mean upper and lower respiratory symptom scores measured through questionnaires (Liu *et al.*, 1992; Gaughan *et al.*, 2008). Increases in oxidate stress markers (formamidopyrimidine DNA glycosylase and malondialdehyde) were reported for WFFs in Portugal after suppressing wildfires (2–12 h) and for WFFs in USA across work shifts after conducting prescribed burns (Adetona *et al.*, 2019; Oliveira *et al.*, 2020). Across individual 12-h work shifts, Main *et al.* (2020) reported a significant increase in inflammation markers measured by interleukin (IL) 6 and IL 8 among WFFs working in Australia a week after a wildfire outbreak.

Inconsistent and varying study results reported in previous research could be due to differences in duration and types of exposures and environmental conditions, study participant work tasks and physical activity levels, general challenges with conducting research among WFF populations, and issues related to self-reporting among study participants. As a result, many questions still exist regarding the severity of WFFs' health effects when exposed to physical and chemical stressors during extreme fire seasons or over a whole career. Information about baseline health status of WFFs at the start of and across each fire season, along with research about underlying health conditions is needed, especially since medical standards and surveillance programs vary greatly (and do not exist for some worker populations). Additionally, the synergistic effects of repeated exposures to multiple chemical and physical hazards are not well understood.

This repeated-measures study was designed to investigate the associations between occupational exposures and risk of and changes in cardiovascular, pulmonary, kidney, and hearing function among federally employed WFFs. This manuscript describes the study design and methods for a WFF exposure and health effect (WFFEHE) cohort study and discusses potential limitations, study challenges, and lessons learned.

Methods

Study background

In 2016, the National Institute for Occupational Safety and Health (NIOSH), an Institute within the Centers for Disease Control and Prevention (CDC), received funding through a competitive internal funding process to conduct a 3-year prospective cohort study to follow groups of WFFs employed by federal land management agencies. CDC/NIOSH collaborated with fire managers and researchers from the U.S. Department of Agriculture Forest Service (USFS), Department of the Interior National Park Service (DOI/NPS), and Skidmore College. This study was designed to investigate potential associations between occupational exposures and risk of acute and subacute health outcomes. Over the course of the study, researchers assessed WFFs' exposures and tracked changes for a variety of health measures. While originally designed as a 3-year study to assess chronic health outcomes as well, the study was shortened to 2 years due to safety and health concerns for researchers and study participants during the coronavirus disease 2019 (COVID-19) pandemic.

The NIOSH Institutional Review Board approved all study procedures and provided oversight for human subject protection. WFFs employed by federal land management agencies, USFS and DOI/NPS, were recruited for this study. Inclusion criteria included both males and females (self-reported as 'not pregnant' during the informed consent) employed on an IHC or T2IA as a crewmember, squad leader, or crew supervisor.

Study population

The USFS and DOI/NPS identified and recruited six wildland firefighting crews in March 2018. Five of these crews were IHC crews, three with a duty station in Colorado, and two in Idaho. One crew was a T2IA crew with a duty station in Idaho. This was not a randomly selected study population. Due to past anecdotal experience, researchers, USFS, and DOI/NPS suspected that IHCs would have lower crew turnover, were more likely to stay together throughout the entire wildland fire season and would have higher and longer exposures in the wildland fire environment due to their land management responsibilities. Additionally, to maximize study funds and limit researcher travel, these crews were selected based on their proximity to each other and to centralized locations to perform sample collection.

Eligible WFFs on these crews included seasonal part-time (employed 3–9 months each year with no guarantee of rehire), permanent seasonal (employed 3–9 months each year with a guarantee of rehire), and permanent full-time (employed 10–12 months) WFFs. As a condition of federal WFF employment, all study participants completed a work capacity test (also known as a pack test) to ensure the WFFs are physically capable of meeting the minimum fitness requirement associated with job duties. In addition, they completed required annual safety training. This annual fitness test and safety training is typically completed within the first 2 weeks after the entire crew is assembled for the fire season.

Study design

Within the identified crews, individual participant recruitment occurred within two weeks of when the seasonal WFFs reported to their duty stations (in mid- to late April and early May). Prior to participation at all study intervals, the researchers met with the eligible WFFs from each crew to explain the study, review the informed consent, and answer questions. Eligible participants could elect to participate in the study in its entirety or for only certain tests within the study. For some study components, participants could opt out entirely, but they could not opt out of specific measurements within a study component (i.e., they could opt out of blood draw entirely but not out of individual tests or measure for which the blood draw was used). WFF management personnel or supervisors were not provided any individual crewmember information about participation or results. In addition, a Certificate of Confidentially was granted by CDC to protect the privacy of research participants by prohibiting disclosure of identifiable or sensitive research information for non-research purposes without the participant’s permission.

Data collection was organized into following components: questionnaires, cardiovascular function and effects, pulmonary function and inflammation, kidney function, noise-induced hearing loss, exposure monitoring, and job task assessment. In 2018 and 2019, measurements were collected at pre- and postseason study intervals for all six wildland firefighting crews. One crew per year was randomly selected each year to participate in additional study measurements. In 2018, the randomly selected crew (IHC 4) was asked to have additional biomarkers analyzed for kidney function. In 2019, additional, pre- and postshift measurements were also obtained from the randomly selected crew (IHC 5, hereafter referred to as the “midseason crew”) on three consecutive days at a wildland fire base camp (midseason). At midseason, collection of blood and urine samples were limited to pre- and postshift days 1–3 (urine only at pre shift on days 2 and 3), to minimize participant time and risk. The researchers were unable to collect data at a wildfire incident during the 2018 midseason while responding to NIOSH Institutional Review Board concerns about participant safety after the 2018 preseason study interval. The researchers were able to adequately address and mitigate these concerns to continue data collection in postseason 2018.

At each testing location, participants rotated through various stations that collected samples or took measurements for the study components. Sample collection was performed in locations that were conducive to collecting study data, such as locations with minimal air flow within a specific temperature range for spirometry, were quiet or in a sound-treated booth for audiometry, or a clean environment for biologic sample collection and blood processing. Sampling protocols required that participants' personal information and data collected be protected during all data collection.

Study Components

Below, we summarize each study component used to assess health outcomes and occupational exposures. Detailed data collection methods and analysis plans including how missing data will be managed will be presented in future manuscripts. Supplementary Table 1 (available at *Annals of Work Exposures and Health* online) provides additional information about the specific measurements offered to participants.

Questionnaires

Participants completed questionnaires at pre- and postseason, in both 2018 and 2019, to capture information on personal and occupational risk factors for the exposures and health effects of concern. Participants from IHC 5 completed a preshift survey 1 day during the 2019 midseason. The questionnaires were based on existing validated questions from previous studies of structural and WFFs, the Behavior Risk Factor Surveillance System (BRFSS), and the National Health and Nutrition Examination Survey (NHANES) (CDC, 2017a, 2017b). The questionnaires were designed to provide information about participant demographics; employment history; noise, chemical, biological, and physical agent exposure history; chronic cardiovascular and pulmonary conditions; kidney disease; rhabdomyolysis; heat-related illnesses; tobacco history; alcohol use; symptom and medication history; and dietary intake. Participants had the option to complete the questionnaire manually with pen and paper or digitally on a tablet loaded with the Qualtrics platform tablet (Version May 2018-October 2019, Qualtrics, Provo, UT). Qualtrics was used as the data collection tool to administer the digital version of the survey. If the questionnaire was taken on paper, CDC/NIOSH researchers later manually entered the data into Qualtrics. Once all questionnaire data for all study intervals was uploaded, it was exported from Qualtrics for further analysis.

Cardiovascular function and effects

Venous blood was collected and analyzed to assess cardiovascular risk and vascular damage, hemostatic balance, platelet count and function, coagulation and fibrinolysis, inflammation, and oxidative stress. Blood was submitted to a clinical laboratory for measurement of cardiovascular and inflammatory markers (Supplementary Table 1, available at *Annals of Work Exposures and Health* online). Pulse wave velocity, a measure of the speed in which blood travels, assessed arterial stiffness, a loss of elasticity or hardening of the blood vessels, and examined acute changes in atherosclerotic progression. Blood pressure was measured by an automated blood pressure cuff and central blood pressure and pulse wave velocity were calculated using proprietary algorithms (Mobil-O-Graph, IEM GmbH). A better understanding of hemostasis and vascular stiffness after arduous work is important, and both measures are involved in the progression of atherosclerosis and the triggering of an acute cardiac event. Platelet function assessment, completed onsite, using the PFA-100 System (Siemens Healthcare Diagnostics, Inc), allowed for automated assessment of platelet dysfunction and an examination of clotting time, which can be an important predictor of sudden cardiac events. In addition, the questionnaire component at each study interval included questions about symptoms and cardiovascular outcomes.

Pulmonary function and inflammation

WFFEHE participant lung health was determined through pulmonary function and serum biomarker measures. Prior to spirometry testing and fractional exhaled nitric oxide measurement (FeNO), participants were asked standardized prescreening, exclusionary questions, and blood pressure assessment designed to identify any relative contraindications to testing (Dweik *et al.*, 2011; Redlich *et al.*, 2014). Based on each participant's pretest responses, participants performed spirometry and FeNO testing. Spirometry test procedures followed current American Thoracic Society guidelines and measured: FEV_1, FVC, peak expiratory flowrate, and the FEV_1/FVC ratio (Graham *et al.*, 2019). These measures detect lung function impairment by measuring the maximal speed and volume of air that can be forcibly exhaled after taking a maximal inspiration (deep breath). FeNO is used to assess airway inflammation through nitric oxide fractional concentrations present in an exhaled breath (Dweik *et al.*, 2011). Nitric oxide is produced within the respiratory system, exhaled in the breath, and is a marker for eosinophilic airway inflammation. Additionally, blood samples were collected for an exploratory serum biomarker investigation regarding potential pulmonary inflammation, acute lung injury, or airway remodeling. Serum biomarkers of interest were surfactant protein-D, tumor necrosis factor alpha, receptor for advanced glycation end-products, IL 8, IL 6, matrix metalloproteinase 9, Club cell protein-16, angiopoietin-2, and monocyte chemoattractant protein 1 (Barnes, 2009; Deshmane *et al.*, 2009; Kurowski *et al.*, 2014; Naik *et al.*, 2017; Machahua *et al.*, 2018; Tong *et al.*, 2021).

Kidney function

This study component focused on serum and urinary biomarkers of kidney function and injury, dehydration, and rhabdomyolysis (see Supplementary Table 1, available at *Annals of Work Exposures and Health* online). The primary aim was to measure serum creatinine, sodium, potassium, blood urea nitrogen (BUN), glucose, and creatine kinase. These measures were obtained to assess kidney function based on estimated glomerular filtration rate, dehydration based on calculated serum osmolality, and the BUN to creatinine ratio. Rhabdomyolysis can be directly assessed by creatine kinase levels and its end organ effects may be reflected in BUN and creatinine levels for kidney damage and elevated serum potassium levels, which can induce cardiac arrythmias and/or seizures. However, these biomarkers, measured by a Piccolo Xpress™ Chemistry Analyzer, were not obtained for all participants at each study interval due to administrative barriers, sample shipments, and equipment malfunctions. Additional biomarkers in urine (e.g. cystatin C in serum and albumin to creatinine ratio, neutrophil gelatinase-associated lipocalin, and kidney injury molecule-1) were measured to further evaluate kidney function and injury and potential mechanisms for kidney effects. Due to resource limitations, these additional biomarkers were assessed only from urine samples among participants from one preselected crew in 2018 (IHC 4) and the midseason crew in 2019.

Noise-induced hearing loss

This study component consisted of otoscopy, tympanometry, and pure tone (i.e. single frequency) air conduction audiometry. Otoscopy is a visual inspection of the ear canal to identify any abnormalities and/or ear wax obstruction. Tympanometry is a measure of middle ear function; it looks at the response of the eardrum to changing air pressure, which indicates how effectively sound is transmitted to the middle ear. Abnormal results may be caused by fluid in the middle ear, a perforated eardrum, excessive earwax buildup, or other conditions not directly related to hazardous noise exposure. These measurements are useful in interpreting the audiometric results. Audiometric testing was then conducted by presenting pure tone signals to each ear through headphones and varying the intensity of the signals to identify the threshold at which the participant was just able to hear the sound. Thresholds were obtained at frequencies across the range of human hearing for all study participants pre- and postseason in 2018 and 2019 and every pre- and postshift for one crew at midseason in 2019. Lifetime and occupational exposures to noise were included in the questionnaire component at each study interval.

Exposure monitoring and job task assessment

Exposure monitoring on the midseason crew consisted of air and biological monitoring over three consecutive days at a wildland fire in 2019. Personal air sampling was performed for volatile organic compounds (e.g., benzene, toluene, xylenes), aldehydes, and carbon monoxide. During each shift, two industrial hygienists, along with USFS personnel, followed the crew to record tasks performed and ensure proper functioning of the sampling equipment attached to the firefighters' protective clothing or packs. Pre- and postshift urine samples were also collected to assess biological uptake of PAHs and levoglucosan (marker of wood smoke) by measuring metabolites of these chemicals. In addition, crewmembers of IHC 5 collected dry and wet bulb ambient temperatures approximately every hour per their standard procedures, which was shared with the research team.

Over the entire fire season, each fire crew provided self-reported daily shift and task information for the entire crew. Administered through the USFS, each crew entered data into daily surveys in ArcGIS Survey 123 (Version 3.5, ESRI, Redlands, CA). These data were not unique to each study participant; however, it provided information about the crew's location, fire assignments, and activities throughout the fire season. Researchers were also given access to copies of each fire crews' time report and logbook to determine each crews' employment duration for the season, work shift lengths, tasks, and time assigned to perform wildland fire management duties at both wildland and prescribed fires. In addition, participants voluntarily granted researchers permission to their individual timesheets and Incident Qualification Command System (IQCS) Records that documented each participant's work history, experience, fires attended (both wildfire and prescribed), and assigned roles for the 2018 and 2019 fire season.

Results

Figure 1 provides an overview of the general study design and identifies the study intervals during the 2018–2019 fire seasons. Preseason testing occurred in mid-April to mid-May and postseason testing occurred in late September to early October. For a full list of measurements and study components collected at each study interval, see Supplementary Table 1 (available at *Annals of Work Exposures and Health* online).

Eligible participants had varying levels of firefighting experience and were males or females between the ages of 18 and 57. Biological and physiological measurements were obtained from 154 study participants across the entire study period. Table 1 provides the number of total and newly enrolled participants by crew for each study interval across the 2018 and 2019 fire season. The number of participants from crew ranged from 10 to 20 WFFs and a total of 103–109 WFFs during each study interval. During the midseason study interval, a total of 19 WFFs participated from IHC 5. During the initial study enrollment at preseason 2018, 15–20 WFFs per crew enrolled in the study. An additional 38 WFFs enrolled in the beginning of the second year of the study. Due to confidentially and reducing coercion to participation in the study, CDC/NIOSH researchers were 'blinded' from the number of crewmembers that did not participate from each crew, so crew participation rates could not be determined.

Of the 154 total participants, 144 elected to participate in more than one study interval over the entire study period (Table 2). Fifty-six WFFs participated in all four of the study intervals, this included 13 WFFs from IHC 5 that also participated in the midseason study interval. Most of the participants, 75 WFFs, only participated in 2 of the 4 study intervals.

Table 3 provides an overview and summary of the types of measurements, samples collected at each study interval. In addition, it provides the number of participants that provided samples or measurements at each study interval. In general, study participants opted to participate in many of the study components and provided samples for many of various study measurements, including ones that involved giving biological samples or maybe burdensome, such as spirometry. Many of the WFF participants gave blood samples, with participation rates ranging from 88 to 96% across the study intervals. Urine samples were only collected from the preselected crews (IHC 4 and 5) for 19–20 participants per study interval. Of the exposure samples collected during the midseason study interval, aldehydes and BTEX samples were collected on almost all study participants. While CO exposures were collected on 11–16 participants per shift. Fewer WFFs complete many of the study components in postseason year 2, compared with preseason year 1.

Discussion

The WFFEHE study is the first repeated-measures study that includes multiple wildland firefighting crews across different geographic areas and over multiple fire seasons. This large-scale, multidisciplinary project generated a broad range of relevant health data along with detailed records about the work that WFFs performed, leaving researchers well positioned to investigate the possible associations between occupational risk factors, exposures, and acute and subacute health outcomes associated with wildland firefighting. Researchers gathered important shift and exposure information from six different WFF crews, each performing different tasks for varying numbers of days and locations throughout the USA. This enables the researchers to study the relationships between occupational factors and health outcomes in detail. In addition, health, demographic, and other factors collected through the questionnaires and clinical test measurements provides important information about this unique cohort that is important in determining how wildland fire conditions and other confounding factors impact WFF health status.

Study strengths and limitations

The main strength of this repeated-measures study was its ability to follow over 150 WFFs across two consecutive fire seasons (although three seasons were planned). This type of research assessing health changes and exposures across multiple fires seasons has been recommended since the 1990s (Reh and Deitchman, 1992). Another strength of this study was the comprehensive design to assess multiple exposures and health outcomes. This project was designed and conducted by numerous subject matter experts (SMEs) from different disciplines and fields of expertise including occupational medicine, industrial hygiene, epidemiology, audiology, human physiology, cardiovascular health, kidney health, respiratory health, and wildland firefighting. This study team collaborated to provide insight into the study design, methods, and field research elements to ensure the project's scientific validity and accuracy. Each SME was also responsible for determining inclusion or exclusion criteria and validity of sample they collected for their study component. All clinically relevant decisions were made by the five physicians on the study team. This included determining critical risk test result values that would require immediate action and notifying study participants of any critical risk test results from laboratory tests that signified the participant was at an immediate risk of major adverse health outcomes. The list of critical risk test results for this study was based on existing criteria used by a range of laboratories, other institutions, and from the literature. In addition, researchers worked closely with CDC/NIOSH administrative personnel to support the challenges associated with coordinating researcher travel and shipping large amounts of testing equipment and supplies on short notice due to the transitory deployment of the WFF crews.

The USFS and DOI/NPS provided support and personnel to act as liaisons to overcome the inherent difficulty of obtaining data from study participants that have been previously hesitant to participating in research studies. In addition, they also aided in facilitating research in this challenging work environment that includes, remote locations, a transient workforce, and unknown work schedules and locations. The participating crews accommodated the researchers within their work environment to provide adequate space, resources to conduct sample collection, and flexibility within their work schedules. Through this coordinated effort, the data collected provides meaningful information that will improve our understanding on potential chemical and physical hazards associated with wildland firefighting and their possible effect on WFFs' health, especially after multiple fire seasons.

Although this study provides robust information on health measures and exposures for WFFs, there were several limitations. First, the preseason measurements in 2018 do not reflect a true baseline prior to employment as a WFF. All the study participants were employed for several days and had completed conditional employment physical tests and training prior to participation in the study in 2018 and 2019. In addition, since having previous fire experience is typically a condition of the crew qualification standards, most WFFs participating in this study had previous wildland firefighting experience. To better understand and account for this, information about occupational and non-occupational exposures, health conditions, and risk factors prior to enrollment were obtained from the questionnaire. Some of this information was verified through the IQCS records.

Similarly, postseason testing could not be completed immediately following each crews' last exposure to the chemical and physical hazards of wildland firefighting as the employing agencies required travel and mandatory rest and relaxation (R&R) days after each crew returned from their deployments. Thus, postseason testing was completed 1–5 days following actual wildland fire suppression work and chemical and physical exposure to the hazards associated with fighting fires. Additionally, non-occupational exposures (i.e., campfires, grilled meats, power tool use) could have occurred during the R&R days and were not captured on the postseason questionnaire. Postseason measurements were collected on or close to the study participant's very last day of employment each year. The timing of this study interval may limit our ability to interpret acute chemical and physical exposure to the hazards associated with fighting fires and is a limitation for this study interval.

An additional limitation was that some data (e.g., demographic, previous exposures, health history) was obtained by self-reporting as is common with studies that have a questionnaire component. While health information was not verified using medical records, employment information was verified through ICQS (for those who consented to ICQS access). Our Certificate of Confidentiality, which was thoroughly explained to the study participants in the informed consent process, was an additional step implemented to encourage accuracy in self-reporting.

Lastly, reliable data do not exist to determine if the demographics information, employment history, and occupational exposures of our cohort are similar to those of other WFFs. However, the study focuses on the type of WFFs expected to have the highest exposures to the physical and chemical hazards associated with wildland firefighting. Five of the six fire crews in the study were IHCs. Yet, only 10–20% of the total federal wildland firefighting workforce is employed on an IHC, and the primary duties differ between IHCs and some other federally employed WFFs such as those employed on engine or helitack (helicopter) crews, as smokejumpers, or in management positions. Similar research with WFFs who are not federally employed on IHCs is also critical to better understand how WFFs with different risk factors, baseline characteristics, occupational tasks and shift types, and occupational exposures are impacted by chemical and physical hazards of this occupation. Additionally, the study population was not a random selection of WFFs. The representativeness or generalizability of this data for non-IHC and other IHC WFFs is unknown. For this reason, these findings should be further explored in future studies with firefighters from other resource types.

Study challenges and lessons learned

Other investigators planning to conduct large prospective occupational cohort studies of WFFs may encounter similar challenges as those encountered during this study. The challenges encountered during the study included:

1. Recruiting study participants and getting access to wildfire incidents to conduct research. CDC/NIOSH, USFS, DOI/NPS started discussing and coordinating project details in 2016 even before the study was funded in 2017. Study participants were recruited after obtaining IRB approval and shortly before the first sample collection in March 2018. Although the process to develop the project and obtain funding took multiple years, these initial conversations during the proposal development allowed for refinement of the study aims and identification of achievable research methodology for this dynamic environment.
2. The complexity of conducting comprehensive longitudinal repeat measurements with WFFs with little to no advanced notice of the dates and location for the field research. This required extensive collaboration between researchers and our study partners to quickly adapt to changing work schedules and locations. The data collection required a minimum of 10–15 researchers. The logistics of assembling schedules of the crews along with researchers from different locations was a complex operation. This required careful coordination between CDC/NIOSH and the USFS (including the participating crews).
3. Operating laboratory equipment in a remote field location with minimal services (electricity, internet, and delivery services). The space available for data collection, especially biologic and physiologic testing, vastly varied for each site. These sites ranged from conference rooms to living quarters to tents. Most of the sample collection instruments required some form of electricity for charging or operating. Electrical, internet, and delivery service needs were discussed well in advance of each site visit. For midseason testing, generators and internet hot spots were needed as research personnel were housed onsite at the fire base camp.
4. Conducting research safely at a wildfire incident. All research staff completed basic wildland fire safety training. The industrial hygienists who went on the fireline completed additional training and obtained fire boots and other required PPE before being allowed to accompany and observe the crew during midseason work shifts. Furthermore, due to the tight timeframes and remote testing locations, any equipment malfunctions typically resulted in a loss of data as there was neither time nor resources for repairs.

5. The abrupt end of the study. This study was originally planned as a 3-year study. However, due to the unprecedented COVID-19 pandemic, the study ended as a two-year study since (i) it was not possible to continue the study safely during the COVID-19 pandemic, (ii) researchers would be unable to control for confounding factors associated with COVID-19, and (iii) the participant return rate to each crew was anticipated to be adversely impacted in both 2020 and 2021, affecting the repeated-measures design and statistical power.

Study challenges are listed here, in hopes of contributing to successful design and implementation of future studies on the potential health effects among WFFs. Future studies that follow WFFs over more than two fire seasons and track a variety of health outcomes are certainly warranted but would require careful planning and coordination.

Conclusions

With the continued yearly average increase in wildland fires across the USA, the number of WFFs responding to and the total time spent responding to these fires are projected to increase (Abatzoglou and Williams, 2016). While personnel who respond to these fires have historically done so on a ‘seasonal’ basis, the season is becoming longer, and in many parts of the country, wildland firefighting is now a year-round occupation (US Forest Service, 2021b). Despite the obvious challenges that these workers face, very little is known about the exposures and health outcomes associated with wildland firefighting. This paper is the first of a series of manuscripts detailing the findings from the WFFEHE study. In addition, the extensive set of data acquired increases knowledge regarding demographics, health status, and certain potential health effects related to arduous duty shift work and workplace exposures, including wildfire smoke. Finally, it is anticipated that by partnering with wildland management agencies, specific and evidence-based recommendations can be developed to prevent exposures and negative health outcomes related to wildland firefighting.

It is expected that the findings from this study may prompt further research questions and inform the direction of future research with this critically important emergency response population and with other outdoor workers who may be exposed to wildfire smoke. As the specific findings from this study are published, there may be a need for further research exploring risk factors and the resulting biological and physiological responses.

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?

The Wildland Firefighter Exposure and Health Effects study is the first study involving multiple wildland firefighting crews across two wildfire fire seasons, and over 150 wildland firefighters participated. This work reports the approach and challenges to collecting comprehensive measurements that will be used to examine health effects and exposures from many risks in the wildfire environment and across multiple health outcomes.

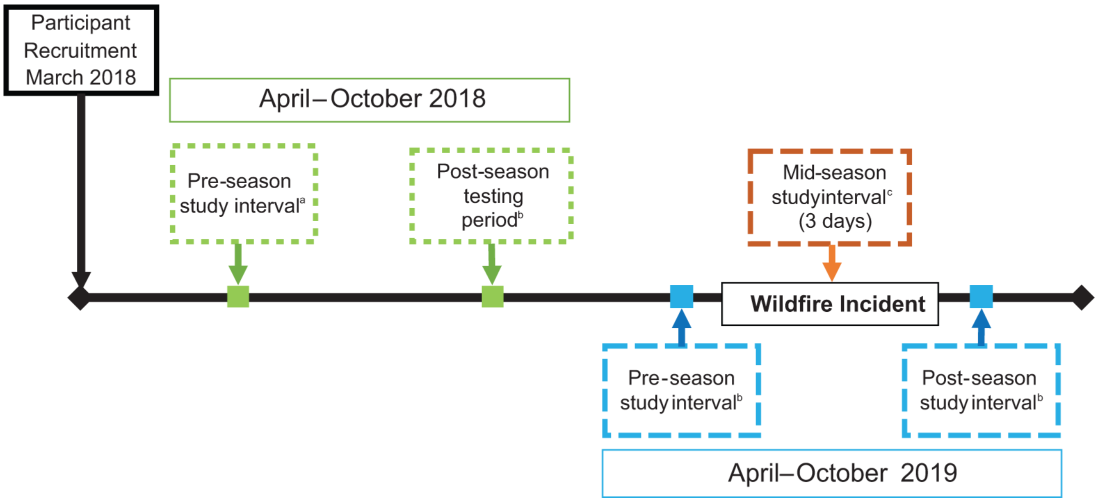

Figure 1.

Overview of study timeline and intervals during fire season 2018 and 2019. Participant recruitment occurred in March 2018, initial study enrollment in April/May 2018, and a postseason in September/October 2018. In 2019, preseason and postseason study intervals occurred at the same time as 2018 with the addition of a midseason study interval for 3 days at a wildfire incident.

A - Initial study enrollment

B - Additional study participants were enrolled at these study intervals, See Table 1 for number of newly enrolled participants

C - Mid-season testing interval was conducted with one- preselected Interagency Hotshot Crew (IHC 5)

Table 1.

Number of total and newly enrolled participants by crew for each study interval, 2018–2019 fire seasons.

	2018		2019			
Crew	Preseason	Postseason	Preseason	Midseason	Postseason	Total participants
IHC 1	17	18 (3)	19 (6)	—	19 (0)	26
IHC 2	20	18 (0)	19 (3)	—	16 (0)	23
IHC 3	18	18 (1)	16 (9)	—	19 (1)	29
IHC 4	19	20 (1)	20 (5)[a]	—	20 (1)[a]	27
IHC 5	20	20 (0)	21 (7)	19	20 (0)	26
T2IA Crew 1	15	10 (0)	15 (6)	—	9 (1)	23
Total	109	104 (5)	110 (38)	19	103	154

Numbers provided in parentheses indicate newly enrolled participants at each study interval past the initial study enrollment in preseason 2018. IHC, Interagency Hotshot Crew; T2IA, Type 2 Initial Attack.

[a]One crewmember from the Type 2 Initial Attack Crew from 2018 transferred to IHC 4 in 2019 and was not considered a newly enrolled participant thus, the total number of participants is 154.

Table 2.

Frequency of participants that participated in each study interval, 2018–2019.

Crew	Number of study intervals participated				
	Four	Three	Two	One	Four plus midseason[a]
IHC 1	10	4	9	3	NA
IHC 2	13	1	9	0	NA
IHC 3	6	3	18	2	NA
IHC 4[a]	11	2	14[a]	1	NA
IHC 5	14	1	11	0	13
T2IA Crew	2	3	14[a]	4	NA
Total	56	14	75	10	13

IHC, Interagency Hotshot Crew; T2IA, Type 2 Initial Attack.

[a]Four study intervals completed plus the midseason study interval.

Table 3.

Overview of samples and measurements and number of participants across study intervals.

Description of measurement or sample collected	Year 1		Year 2							
	Preseason	Postseason	Preseason	Midseason (IHC 5)						Postseason
				Day 1		Day 2		Day 3		
				AM	PM	AM	PM	AM	PM	
Height and weight	108	104	105	19	19	19	19	19	19	103
Questionnaire responses	108	104	104	19						98
Blood samples	105	93	99	19	19	—	19	—	19	91
Urine samples	19	20	21	19	19	19	19	19	19	20
Spirometry	105	98	93	19	19	—	—	—	—	91
Fractional exhaled nitric oxide	91	97	99		19	19	19	19	19	95
Hearing tests performed	109	93	108	19	19	19	19	19	19	102
Platelet function assessment	105	93	99	19	19		19		19	91
Pulse wave velocity	109	102	106	—	19	—	—	—	—	103
IQCS records access (Consented)	108	104	105	19						103
Carbon monoxide[a]	—	—	—	16		16		11		—
BTEX[a]	—	—	—	19		18		19		—
Aldehydes[a]	—	—	—	19		19		19		—
Total participants	109	104	110			19				103

[a] Collected as a full-shift exposure sample.