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Risk factors for injury among federal wildland firefighters in the United States

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RISK FACTORS FOR INJURY AMONG FEDERAL WILDLAND FIREFIGHTERS IN THE UNITED STATES

by

Carla Lea Britton

An Abstract

Of a thesis submitted in partial fulfillment
of the requirements for the Doctor of
Philosophy degree in Epidemiology
in the Graduate College of
The University of Iowa

May 2010

Thesis Supervisor: Professor Corinne Peek-Asa

ABSTRACT

This research project focused on estimating the burden of injury on large federal wildland fires and describing the injury characteristics and risk factors for severity of injury in a sample of injured federal wildland firefighters.

Chapter 2 “Peak incident management level affects rates of injury on large federal wildland fires” reports estimates of rates of injury for large federal wildland fires and assesses the effect of peak incident management level (PIML) as a predictor of rate of injury. After adjusting for seasonal factors and fire characteristics, PIML was a predictor of both rate of injury and odds of any injury occurrence, but the effect was opposite. Fires with higher PIML demonstrated lower incidence rate ratios, but the odds of injury were increased.

Chapter 3 “Wildland fire job assignment and burden of injury” describes the injury characteristics and severity associated with the firefighter’s job assignment in fire-related injuries reported to the United States Department of Interior. Job assignment was significantly associated with cause and nature of injury, but not with the severity of injury as defined by days off work or job transfer.

Chapter 4 “Cause, characteristics and severity of injuries in wildland firefighters” examines the relationship between the cause of injury and type of injury and the severity of injury. Injuries caused by slips, trips or falls were most frequently reported. Injuries caused by bites or stings and plants were less likely to be severe relative to injuries caused by slips, trips or falls.

Together, these studies provide evidence that injuries may significantly impact the wildland fire community, but that better information is needed to fully evaluate risk factors and develop evidence-based interventions.

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CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

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has been approved by the Examining Committee
for the thesis requirement for the Doctor of Philosophy
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Christopher Buresh

To my parents

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CHAPTER 1

INTRODUCTION

Wildfire, uncontrolled or unwanted fire burning in rural or wilderness areas, annually costs governments, insurers and private individuals billions of dollars. Every year an average of 80,000 wildfires will burn 6.5 million acres on public and private lands in the United States.[1] The majority of these fires will remain small and be suppressed by local firefighters. The small minority, 1-2% that defies early suppression efforts will demand the attention of thousands of firefighters over days to weeks. These fires will cost millions of dollars each to control, result in the loss of homes, businesses and wilderness resources and put both firefighters and civilians at risk for death or serious injury.

Although the number of fires reported each year has remained relatively flat, the number of acres burned has steadily increased over the last fifteen years.[1] To put it in perspective, nationally, nine of the ten largest fires in recorded history have occurred within the last ten years. The largest fire burned 1.3 million acres in Alaska in 2004. The largest fire in the continental United States charred 907,000 acres in Texas in 2006. In California, a state with a tradition of long and intense fire seasons, four of the five largest fires were reported in 2003 or later. Almost 4500 structures were lost in those four fires. Nineteen people, civilians and firefighters, lost their lives.[2]

Several factors account for the changing character of wildfires and the hazards associated with them. The first is the general trend toward warmer temperatures leading to earlier springs and increased spring and summer temperatures.[3-6] The second factor is significant drought events causing decreased snowpack, earlier drying of fuels, and decreased overall precipitation. The other factor responsible for changing wildfire character is sociological. As population has increased in the United States, development has spread beyond the boundaries of cities and into areas traditionally thought of as wildland.[7] This is both due to the extension of city edges into wildlands and to the development of primary and second homes in rural and wilderness areas.

The increased number of structures in wildland areas has changed the hazards associated with fighting wildfires. When wildfires primarily burned in wilderness areas with few structures, the job hazards were mainly natural or associated with the tools and equipment used in firefighting. The addition of structures changes the firefighting dynamic and expectations. The equipment and techniques used for structure protection are different than those used for strictly wildland fire. The involvement of structures and associated value we put on them also increases the exposure of civilians to wildfire hazards and encourages fire managers to engage in direct attacks on the fire rather than moving back to safer areas when structures may be lost.

The cost of wildfires is not measured just in dollars or structures. There is a well-documented cost in human life as well. Three hundred eighty-nine wildland firefighters died of injury-related causes between 1979 and 2008. Still others died of non-traumatic causes related to fire suppression activities.[8] These fatalities are investigated exhaustively and documented extensively.

While much is known about fatal injuries, the little we know about the burden of non-fatal injuries in wildland firefighters is based on scant literature describing injuries treated at fires and summary reports.[9-13] An injury pyramid based on H.W. Heinrich's industrial safety work in the 1930s would depict a few fatalities at the top of a pyramid resting on a base of serious injuries, minor injuries and near-miss events that had the potential to result in injury. Heinrich found that for every serious injury, there were 29 minor injuries and 300 near misses.[14] These injuries come with substantial costs for treatment and in lost workplace productivity and thus deserve closer examination.

The wildland fire community developed a particular interest in firefighter safety after the 1994 fire season. That season 34 firefighters died, 14 of them on a single fire in Colorado. The deaths prompted the National Wildfire Coordinating Group (NWCG), a consortium of federal and state agencies and organizations that provides oversight and management direction for wildland fire, to charter a study examining the culture of safety within the wildland fire arena, specifically among the five federal land management agencies. These agencies, the United States Forest Service (USFS), Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), Fish and Wildlife Service (FWS) and National Park Service (NPS) have management responsibility for approximately 60 % of the annual acres burned.

The *Wildland Firefighter Safety Awareness Study* (WFSAS) was charged with identifying aspects of the agencies' organizational cultures that negatively impacted firefighter safety and recommending changes. The study was completed in three phases: identifying problems and solutions, developing goals and making specific recommendations. In the Phase III report, *Wildland Firefighter Safety Awareness Study – Implementing Cultural Changes for Safety,* it was specifically noted that the need existed for reliable safety data in order to target, develop and evaluate programs. The need for comprehensive data collection for injury and near-miss events across all agencies was also noted.[15]

The WFSAS recommendations were addressed in a number of ways within the fire organization. To address the need for more comprehensive injury surveillance, the United States Department of Interior, home to the BLM, BIA, FWS and NPS, added a component to the departmental occupational illness and injury reporting system to collect additional information about fire-related illnesses and injuries.[16] An annual descriptive summary is presented to fire managers. The USFS has an analogous system. No comprehensive injury surveillance database that covers all injuries, whether incurred by contract, local, state or federal employees, exists to date.

This project was developed to expand the knowledge about the burden of injury on federal wildland fires and the risk factors for injury among wildland firefighters from the United States Department of the Interior.

The specific aims for the project are as follows:

Specific aim 1: Quantify injury occurrence and evaluate risk factors for rate of injury on large wildland fires occurring on federal land within the United States using data from the National Interagency Coordination Center's Incident Management Situation Report dataset for the years 2003 through 2007.

Specific aim 2: Describe risk factors associated with injury characteristics and severity in a sample of injured firefighters from the U.S. Department of Interior.

Specific aim 2a: Describe the associations between the fire job assignment and injury mechanism, type of injury, body part and severity of injury among injured Department of Interior firefighters.

Specific aim 2b: Describe the associations between the mechanism of injury and injury characteristics and severity among injured Department of Interior firefighters.

CHAPTER 2

PEAK INCIDENT MANAGEMENT LEVEL AFFECTS RATES OF INJURY ON LARGE FEDERAL WILDLAND FIRES

Abstract

Objective: To estimate rates of injury and identify associated risk factors on wildland fires in the United States.

Methods: Data were used on number of injuries, person-days worked and fire characteristics (year, region, season, cause, fuel type, resistance to control and structures destroyed) for federal fires reported through the Incident Management Situation Report system of the National Interagency Fire Center from 2003-2007. Logistic regression was used to assess fire-level risk factors for the odds of any injury. Negative binomial regression was used to examine incidence rate ratios associated with fire-level risk-factors. 95% confidence levels were calculated for both statistical methods.

Results: After adjustment for season and fire characteristics, odds ratios for the odds of any injury reported versus no injury were 1.34 (95% CI 0.65 – 2.81) for Type I Peak Incident Management Level (PIML) and 1.91 (95% CI 1.40 – 3.22) for Type II PIML fires as compared to Type III PIML fires. Person-days of exposures and the fire's resistance to control were also significantly predictive of injury occurrence. After adjustment for season and fire characteristics and compared to Type III PIML fires, the adjusted injury incident rate ratio for fires with a Type I PIML was 0.36 (95% CI 0.25 – 0.53) and for fires with a Type II PIML was 0.74 (95% CI 0.56 – 0.99). PIML was the only risk factor significantly predictive of rate of injury.

<u>Conclusions:</u> Incident-level risk factor data for wildland fire injury are sparse. Epidemiological methods are a useful tool for evaluating these risk factors, but more risk factor variables and higher quality data are needed.

Introduction

Wildfires across the United States cost governments, insurers and private individuals billions of dollars per year and char millions of acres. Changes in fire suppression tactics, climate change and increasing incursion of housing into rural and wilderness areas have caused fires to burn more intensely, to grow larger, and to threaten more residential areas escalating costs and increasing risks to firefighters.

Each year in the United States approximately 100 firefighters die in the line-of-duty. [12] From 1997 through 2007, excluding 2001, about 17% of the deaths occurred during wildland firefighting activities. During the same period, the National Fire Protection Association estimated that 370,000 injuries occurred to firefighters on the scene at fires.[11] If the proportion of injuries occurring to wildland firefighters in comparison to all firefighters mirrors the proportion of fatalities then over the same ten-year period an estimated 60,000 injuries would have occurred to firefighters involved in wildland fire activities. Despite the potential for a significant number of injuries, we know little about them.

The majority of research to date regarding occupational hazards to wildland firefighters assesses exposures to smoke or other related toxics, or examines physiological responses to firefighting activities.[17-27] Information about injuries in firefighters is derived from summary reports and limited research describing the distribution of injuries at wildfire events.[9, 10, 13] No previous literature evaluating personal or fire-level risk for injuries on wildfires was identified. One study examined incident-level risk for injury on structure fires.[28] Structure fires, however, use different equipment and techniques than used on most wildland fires.

To address this critical information gap, we used epidemiologic methods to expand on previous descriptive studies. We estimated rates of injury and evaluated fire-level risk factors for rate of injury and injury occurrence on large wildfires burning in federal jurisdiction that were reported to the National Interagency Coordination Center in the years 2003 – 2007. We hypothesized that fire-level characteristics are predictive of both injury occurrence and rate of injury.

Methods

Data Source: Analysis data were obtained from the Incident Management Situation Reporting (IMSR) system maintained by the National Interagency Coordination Center in Boise, ID. This information is freely available for download via the National Fire and Aviation Management website.[29] Information about wildfire and other all-risk management incidents (e.g. hurricanes, earthquakes, and search and rescue operations) are reported electronically through this system. Incidents coded as "wildfires" from January 1, 2003 through December 31, 2007 were included. A wildfire is defined as an unplanned or unwanted wildland fire with a goal of full suppression.

A report summarizing fire characteristics, committed personnel, injuries and significant events is submitted daily for all wildfires meeting size or complexity criteria. Reports are submitted daily until the fire is contained and the majority of personnel are dismissed. A final report is submitted when a fire is essentially suppressed completely. Federal fire management agencies are required to report fires to the IMSR. The federal wildland fire management agencies are the United States Forest Service and the Department of the Interior agencies the Bureau of Land Management, Bureau of Indian Affairs, Fish and Wildlife Service and National Park Service. Non-federal entities such as states may also report in this manner, but it is not required and consequently these fires were excluded from analysis.

This study uses only information submitted about wildfires in federal jurisdiction and on Indian reservations. Although these fires represent a very small percentage of the total number of wildfires reported to the IMSR these fires were chosen for analysis based on homogeneity of reporting requirements and management. Fires occurring in federal jurisdiction were excluded from analysis if they were missing the total number of injuries, information about the number of personnel assigned to the fire, or both. They were also excluded if the number of personnel assigned was reported to be zero. (Figure 1)

<u>Main Outcome:</u> Two outcomes were considered. The first outcome was simply whether or not any injuries were reported on a fire. The second outcome considered was the rate of injury. Rate of injury for each fire was calculated by dividing the number of injuries by the number of person-days worked over the course of the fire.

The "injuries- to- date" reported on the last daily summary submitted for a fire was used as this number represents the total number of injuries reported in which the firefighter was unable to return to his or her fire assignment.

The number of person-days for each fire was estimated by adding the total number of personnel reported on each summary report for each day of the fire. For analysis purposes, this variable was either continuous or divided into quartiles.

Main Exposure: The main exposure was the highest level of Incident Management Team (IMT) assigned at any point to the fire. IMTs are groups of specially trained firefighters brought in by agencies to provide fire management expertise beyond the scope of locally available personnel. IMTs function as part of the Incident Command System, a flexible, standardized management structure consistent across local, state and federal agencies. Each IMT is assigned an incident management level (IML) based on the training and experience of the personnel. IML Type I teams are the most experienced, IML Type III the least.

The IML assigned to a fire is based on the complexity of the fire as determined by staff of the agency having jurisdiction of the fire. Factors involved in determining incident complexity include threats to life or property, current and predicted weather, environmental influences like topography and fuels, political sensitivity, jurisdictional boundaries, availability of resources and safety of both firefighters and the surrounding communities. The IML assigned to the fire changes as evaluation of the incident complexity changes. Thus a fire may start out with a Type III IML, be assigned a Type I or II IML later and end with another Type III IML. Only fires with a peak IML (PIML) of Type I, II or III were included in this analysis. These fires represent the full spectrum of fires from smaller, relatively uncomplicated fires of short duration to large and complex fires lasting multiple weeks. Fires reporting a PIML of Type IV or greater were reported only during 2007 and thus were excluded.

Confounders: Confounders considered in the analysis were year of occurrence, seasonality, geographic region, cause, fire fuels, resistance to control and destruction of structures.

Year of occurrence served as an indicator of overall fire severity for that particular year and was used to account for time trends.

Season of fire occurrence was defined as either “summer season”, (months of June, July and August), which coincide with highest fire incidence or as “off-season” (months of September through May).

Geographic region was described as either “western” or “eastern”. The western region included the states of Alaska and Hawaii and the states from the west coast of the United States east to the Rocky Mountains. Also included in the western region were the states of South Dakota, North Dakota, Nebraska and Kansas. These states were included with the western states because the fire activities in these states are coordinated with those of Colorado and Wyoming and the type and amount of fire activity are similar.

Fire cause is defined as human, lightning or under investigation. Cause is determined by the responding firefighters and is either essentially apparent immediately or requires investigation. In some cases, there is insufficient evidence to determine cause with certainty.

Fuel is the vegetation, both living and dead, which feeds the fire. [30] The most commonly used fuel description in the United States, and the one reported on the fire summary report, has 13 categories. A simplified categorization of fire fuels was used in this analysis where the 13 groups were categorized into three basic fuel types: 1) Grass and grass dominated, 2) chaparral and shrub fields and 3) timber litter and slash. Grass and grass dominated fuel types include grasslands and savannas of annual and perennial grasses, open shrub lands where fire is carried mainly through fine herbaceous fuels, tall-grass prairies and marshland grasses. Chaparral and shrub field fuel types include fuels along a spectrum from young, immature shrub types to mature stands of shrubs greater than 6 feet high exemplified by much of the California mixed chaparral or the pine barrens of New Jersey. Timber and slash fuel types include heavier fuels with various amounts of leaf litter and logging remnants, either piles or widely distributed downed woody fuel. Examples of this fuel type include oak-hickory stands and stands of long-needle pines like ponderosa.[31]

Fire resistance to control is a composite rating that combines and summarizes the contributing effects of three primary factors that influence fire spread: fuel type and fuel moisture, topography of the area in which the fire is burning, and air mass. Topography includes both the slope and the elevation of the area. Air mass takes into account such factors as the temperature, relative humidity, wind speed and direction, and precipitation. It also may include forecasted weather events. Resistance to control is rated on a four-point scale from low to extremely resistant. Depending on the fire size and complexity, this value may be assigned by a firefighter, the incident commander, or the fire behavior analyst assigned to the fire. Peak resistance to control, the most extreme value reported at any time during the fire, was chosen for this analysis.

Destruction of structures is defined as whether any structures were reported lost at any time on the fire.

<u>Analysis:</u> Descriptive statistics were calculated for the main effect of peak incident management level and for year, season of fire occurrence, region of occurrence, cause, fuel type, resistance to control and any structure loss. Pearson chi-square tests of association were used to assess relationships between variables.

Mean rates of injury per 10,000 person-days of exposure were calculated for both main effect and for potentially confounding variables. Due to the violations of assumptions of normality, a non-parametric Kruskal-Wallis test was used to compare the medians. Multiple Wilcoxon rank-sum comparisons were used to determine the locations of the differences. Multiple comparisons were considered significant at $p \leq 0.01$.

Logistic regression was used to assess the association of fire-level risk factors and the dichotomous variable of no injury versus one or more injuries occurring on a fire. The main effect, peak incident management type, was modeled alone, adjusted for seasonal factors (year of occurrence and season) and in a full model adjusted for all risk-factors, excluding vegetation based on missing data. A Hosmer and Lemeshow goodness-of-fit test was conducted to assess model fit and the three models were compared using likelihood ratio tests for nested models.[32, 33]

Negative binomial regression[34-36] was used to test the association of the main effect variable and potential confounders on the rate of injury. The effect of PIML was examined alone, adjusted for seasonal factors, and adjusted for seasonal and fire characteristics. A negative binomial model was chosen over a Poisson model based on the over-dispersion in the data. Likelihood-ratio testing of whether the dispersion parameter was zero was used to assess model fit. A zero-inflated negative binomial model was considered based on the excessive zeros within the data, however Vuong test [37] results comparing the zero-inflated model with the negative binomial model suggested that there was no explanatory improvement in the zero-inflated negative binomial model over the standard negative binomial model given the available variables. The three models were compared using likelihood ratio tests for nested models.

All statistical analysis used SAS v 9.1 (SAS Institute, Inc., Cary, NC) and Stata 10 (StataCorp, LP, College Station, TX). Statistical significance was set at alpha = 0.05.

Results

8,105 wildfires were reported through the IMSR from January 1, 2003 through December 31, 2007. Of these fires, 2,881 (35.5%) occurred on lands in federal jurisdiction. 867 fires reported a Type I, II or III PIML and had information about both the number injuries and the number of personnel on the fire. (Figure 1.1)

In this sample the most fires were reported in 2006 (29%) with the fewest in 2004 (15%). Seventy percent occurred during the summer season and over 80% occurred in the western United States. Lightning was the cause of ignition for over half the fires. Timber was the most common fuel type at almost 40% followed closely by the grass and shrub types. Thirty-five percent of fires were rated as having “high” resistance to control and 30% were described as having “low” resistance to control. Only 15% of the fires reported destruction of any structures.

Type I PIMLs were proportionately the greatest in 2007 and Type II and Type III PIMLs were proportionately greatest in 2006. The western region accounted for greater than 90% of all Type I and II PIMLs, but only 75% of Type III PIMLs. Although most fires reporting a PIML of Type I, II or III occurred during the summer season, a larger proportion of Type III assignments occurred during the off-season. Lightning was the most common cause regardless of PIML. Timber was the most common fuel type for Type I and II PIMLs, grass the most common for Type III. Almost 50% of fires with Type I PIMLs reported “extreme” resistance to control whereas only 6% of fires with Type III PIMLs reported “extreme” resistance. About 50% of fires with Type II PIMLs reported “high” resistance to control. Destruction of structures was proportionately most likely to be reported among fires with Type I PIMLs and least likely to be reported among those with Type III PIMLs. (Table 2.1)

The overall mean rate of injury per 10,000 person-days of observation for all fires was 13.20. (SD = 48.62). The mean rate of injury per 10,000 person-days for fires with a Type I PIML was 3.61 (SD = 5.35), for those with a Type II 11.69 (SD = 30.06) and for those with a Type III 15.15 (SD = 56.85). A significant difference in distribution was demonstrated across all PIMLs ($p < 0.001$). Pair-wise comparisons demonstrated differences between levels I and II, I and III and II and III ($p < 0.01$).

The lowest reported mean injury rate of 2.28 injuries (SD = 3.91)/10,000 person-days was on Type I fires in the year 2006. The highest observed mean injury rate of 31.99 injuries (SD = 55.74) /10,000 person-days was seen on Type II fires categorized as having low resistance to control. (Table 2.2)

Table 2.3 summarizes the logistic regression models assessing the effect of fire-level risk factors on whether or not any injury was reported on a fire. After adjusting for person-days of exposure, seasonal and fire characteristics, the odds ratio for the odds of any injury reported versus no injury was 1.64 (95% CI 0.65 – 2.81) for Type I PIML fires and 1.91 (95% CI 1.40 – 3.22) for Type II PIML fires as compared to Type III PIML fires. In this fully adjusted model both PIML, person-days of exposure and the fire’s resistance to control were significantly predictive of injury occurrence. There was no evidence of lack of fit of the data to the model using Hosmer and Lemeshow goodness-of-fit testing ($X^2 \leq 0.00$, $p = 0.99$, main effect model; X^2=2.62, p=0.96, main effect and season; $X^2 = 4.75$, $p = 0.78$, saturated model). Likelihood ratio testing comparing the main effects model and the model including person-days and seasonal characteristics suggested that the adjusted model was improved over the main effects model ($X^2 = 95.30$, df = 3, $p < 0.05$). Comparing the saturated model to the model including only person-days and seasonal characteristics suggested that the additional variables in the saturated model contributed significant explanatory improvement ($X^2 = 48.36$, df = 4, $p < 0.05$).

Table 2.4 describes the results of the negative binomial regression models examining the association between PIML and rate of injury. After adjustment for time and fire and compared to Type III PIML fires, the adjusted incident rate ratio for fires with a Type I PIML was 0.36 (95% CI 0.25 – 0.53) and for fires with a Type II PIML was 0.74 (95% CI 0.56 – 0.99). PIML was the only risk factor significantly predictive of rate of injury. A likelihood-ratio chi-square test that the dispersion parameter was equal to zero suggested that the response variable was over-dispersed and would not be adequately described by a Poisson distribution ($p = 0.00$). A likelihood ratio test comparing the main effects model with the model including seasonal characteristics suggested that the adjusted model was improved over the main effects model ($X^2 = 6.62$, df = 2, $p < 0.05$). The fully saturated model was significantly improved over the model including only seasonal characteristics ($X^2 = 56.36$, df = 4, $p<0.05$).

Discussion

The PIML of large federal wildland fires is associated both with any reported injury and the rate of injury. However, the effect is different. The odds of any injury being reported on a fire are significantly greater in Type II fires as compared to Type III fires after controlling for the number of person-days of exposure. The opposite effect is seen with regard to the rate of injury. Type I and Type II fires have significantly lower rates of injury than do Type III fires. Type II fires are often incidents where fire managers have a concern about a particular resource or weather condition, but don't believe that the fire will be especially complex or large. The fires to which Type II teams are assigned vary to a much greater degree than the fires to which Type I teams are assigned. This variation may result in more injury.

The single factor most predictive of whether or not any injuries were reported on a fire after controlling for other variables was the number of person-days. Fires in the quartile with the highest number of person-days had 20 time the odds of reported injury relative to fires in the lowest quartile. Fires in the highest quartile were complex Type I and Type II fires. In general, Type I fires occur later in the season, often burning until snowfall in the Pacific Northwest and northern Rocky Mountain areas. Because these fires are long and late, firefighter assignments are often the maximum 14 to 21 days allowed. Many firefighters will also have had multiple assignments over the course of the season by the time these fires occur, so fatigue may be a factor.

Both PIML and the fire's resistance to control were predictive of any injury after controlling for person-days of exposure. A fire's resistance to control may be indicative of the hazards firefighters' encounter that could lead to injury. It might be instructive to collect data on the individual fire characteristics that contribute to this overall rating and determine their effects on both injury occurrence and rate. The current reporting format includes some of the data, but much of it is reported only sporadically or is of poor quality. For example, the difficulty of the terrain in which the fire is burning is rated on the same four-point scale as the resistance to control, but over 90% of fires reported the terrain to be extreme. It may be that specific terrain features, for example steep or rocky, are predictive of injury occurrence, not a global subjective assessment of terrain difficulty.

Fires with a Type I PIML had a significantly lower rate of injury than fires with a Type II or Type III PIML and this pattern was maintained after adjustment for other fire-level risk factors. This may reflect the fact that Type I PIML fires are more likely to be a higher priority for resource assignment at both the regional and national level. Type I fires are generally well-established and firefighting tactics used may be more deliberate and less hurried. Type II fires may fall between Type I and Type III fires in terms of priority for resource assignments and firefighting tactics.

Rates of injury on large fires vary across many factors. This reflects the complexity of the wildfire environment and may result from a combination of environmental and human factors. For example, only 15% of fires were reported in 2004, but the mean rate of injury was highest in 2004, attributable to a very high rate of injury among Type III fires that year. The 2004 fire season was unusual in that Alaska had a severe fire season with many more fires located near developed areas than during a typical Alaskan season. These fires required more active fire suppression than usual, exposing firefighters to greater risk of injury.

While only 15% of fires overall reported that any structures were destroyed, almost 40% of Type I fires reported destroyed structures. This reflects the management decision making process for fires. Structure loss is politically sensitive. The presence of structures also adds additional complexity to the tactics necessary for fire suppression. These two factors encourage fire managers to transition a fire to a Type I fire, in some cases even though the fire may be less complex than other fires managed at a lower level. This same process is observed in the presence of a fatality as well.

Our mean rate for Type I fires at 3.61 injuries/10,000 person-days was lower than the rates determined by Keifer and Mangan [10] on the two large fires they evaluated from the 2000 fire season. This is not surprising considering the difference in methodology. Keiffer and Mangan obtained documents, including the daily summaries, for two of the largest fires of 2000 fire season and collected information on all injuries that were reported from a variety of sources including the logs from the medical unit. The number of injuries reported on the daily summary is a small subset of all injuries as they represent only the injuries where the injured person could not return to his or her fire assignment. Injuries reported on medical logs include everything from minor injuries requiring only minimal first aid to significant injuries and illnesses requiring more advanced medical care. It isn't clear from the Keifer and Mangan report which injuries were included in the final injury counts. They noted that the information quality was highly variable. In line with that observation, it is likely that the quality of reporting of injuries on daily summary reports varies significantly among fires as well.

Wildfire is a dynamic process and one of the significant limitations to this study was our inability to account for transitions in fire management team level over time. In the life of a fire, initial management may be at a Type III level. If the fire exhibits behavior that will require more time, resources or experience to fight then it may transition to a Type II or Type I level. As conditions change and the fire reaches containment or complete suppression, then management responsibility may transition back to a team of lesser experience, or management responsibility may be returned to the local agency on whose land the fire occurred. This means that PIML, which we used to describe a fire's overall management level, may represent only a small proportion of a fire's management over the course of the entire fire life cycle.

As with PIML, the resistance to control a fire exhibits changes over time with changing weather, fuel and topography. We used the most extreme resistance to control reported to summarize the fire's overall resistance to control. We were not able to examine how the rate of injury might change as the resistance to control varies over the life of the fire.

Another important limitation was our inability to determine when injuries occurred over the time course of the fire. When the daily report is submitted, both injuries occurring during the reporting period and the running total of all injuries should be reported. In practice, however, reporting variability exists between management teams of the same level and between management teams of different levels in terms of how the information is transmitted to the person submitting the report. Also, neither of the injury fields is required. As a result, injury numbers are often recorded as missing and it is not possible to determine whether a number just wasn't entered or if it was actually intended to be zero. The data used here was intended to inform fire managers about the most recent events on the fire in order to help plan and prioritize resource needs for the next few days. It was not intended as a method for injury surveillance. The injuries-to-date on the last submitted report is the best summary of injuries on a fire, but provides no information about timing. Thus we were unable to evaluate changing level of injury risk associated with changing fire and management dynamics.

We were limited in the fire-level characteristics that could be evaluated. Although the terrain and altitude in which firefighters must work may have a significant impact on the injury rate for a particular fire, terrain was described as "extreme" in almost every case when reported on the daily summary. Other fire characteristics that may be of interest must be abstracted from narrative fields describing significant events on the daily summary or may be recorded on other documentation produced by the fire management team.

An important caveat is that the results discussed here are only generalizable to a small percentage of the largest wildfires that occur each year. Most wildfires occur on non-federal lands, remain small and are extinguished by local firefighters, many of whom are volunteers also responsible for structural fire.

Future research should focus on establishing better surveillance for injuries on wildfires at all levels. Better surveillance would provide the opportunity to study the "natural history" of injury on fire, over the course of an individual fire and also over the course of a season. Information could be developed to evaluate at what stage of fire suppression injuries occur and what types of injury are experienced, information not available to us with these data, and about other fire and managerial characteristics associated with injuries. This would provide a basis for injury prevention strategies and for the evaluation of injury prevention efforts.

Despite the data limitations, we provide important new knowledge about risk factors for occurrence of injury and quantity of occupational injury on wildfires. We also suggest that epidemiological methods are a valuable tool in assessing injury in this high-risk occupational group about which relatively little is known.

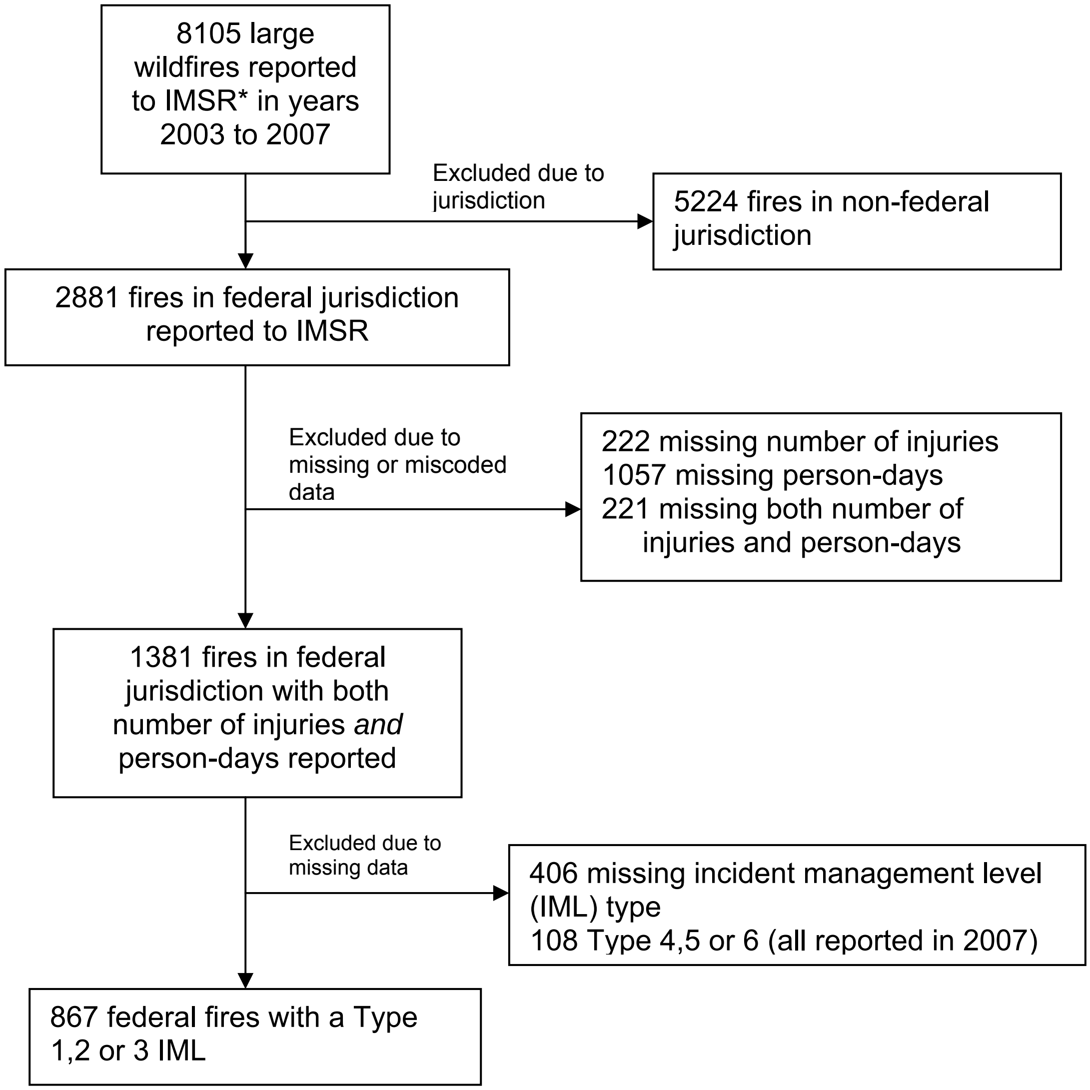

Figure 2.1. Data flowchart for inclusion in analysis sample.

*IMSR, Incident Management Situation Report system of the National Interagency Coordination Center

Table 2.1. Selected characteristics of wildfires in federal jurisdiction reported to the Incident Management Situation Report system from 2003 – 2007.

	Peak Incident Management Level			
	Type I	Type II	Type III	Total
	N	N	N	N
Total	82	214	571	867
Fire Characteristic	n (%)	n (%)	n (%)	n (%)
Person-days				
< 71	1 (1.2)	2 (0.93)	217 (38.0)	220 (25.4)
> 71 and ≤ 309	2 (2.4)	7 (3.3)	205 (35.9)	214 (24.7)
> 309 and ≤ 1647	12 (14.6)	66 (30.8)	139 (24.3)	217 (25.0)
> 1647	67 (81.7)	139 (65.0)	10 (1.8)	216 (24.9)
Year				
2003	14 (17.1)	49 (22.9)	106 (18.6)	169 (19.5)
2004	12 (14.6)	21 (9.8)	97 (17.0)	130 (15.0)
2005	7 (8.5)	40 (18.7)	134 (23.5)	181 (20.9)
2006	23 (28.1)	61 (28.5)	167 (29.2)	251 (28.9)
2007	26 (31.7)	43 (20.1)	67 (11.7)	136 (15.7)
Region				
Western	75 (91.5)	209 (97.7)	434 (76.0)	718 (82.8)
Eastern	7 (8.5)	5 (2.3)	137 (24.0)	149 (17.2)
Season				
Summer (Jun Jul Aug)	64 (78.1)	178 (83.2)	361 (63.3)	603 (69.6)
Off-season	18 (21.9)	36 (16.8)	209 (36.7)	263 (30.4)
Cause				
Human	16 (19.8)	43 (20.1)	189 (33.1)	248 (28.6)
Lightning	55 (67.9)	144 (67.3)	276 (48.3)	475 (54.9)
Under Inv	10 (12.3)	27 (12.6)	106 (18.6)	143 (16.5)
Fuel Type				
Grass	5 (6.7)	51 (27.1)	193 (45.5)	249 (36.2)
Shrub	25 (33.3)	36 (19.2)	101 (23.8)	162 (23.6)
Timber	45 (60.0)	101 (53.7)	130 (30.7)	276 (40.2)
Resistance to Control				
Low	0 (0.0)	17 (8.0)	234 (43.6)	251 (30.2)
Moderate	4 (4.9)	33 (15.4)	128 (23.9)	165 (19.8)
High	38 (46.3)	110 (51.4)	144 (26.9)	292 (35.1)
Extreme	40 (48.8)	54 (25.2)	30 (5.6)	124 (14.9)
Structures Destroyed				
Yes	32 (39.0)	40 (18.7)	59 (10.3)	131 (15.1)
No	50 (61.0)	174 (81.3)	512 (89.7)	736 (84.9)

Note: Frequency counts do not always sum to total because of missing data.

Table 2.2. Mean rates of injury per 10,000 person-days for large wildfires in federal jurisdiction reported to the Incident Management Situation Report system from 2003 – 2007.

	Peak Incident Management Level			
	Type I	Type II	Type III	Total
	injuries per 10000 person-days mean(sd)	injuries per 10000 person-days mean(sd)	injuries per 10000 person-days mean(sd)	injuries per 10000 person-days mean(sd)
Fire Characteristic				
Year				
2003	5.84 (7.9)	8.04 (11.7)	10.91 (41.6)	9.66 (33.6)
2004	4.04 (6.7)	4.45 (5.2)	24.00 (84.7)	19.00 (73.6)
2005	3.98 (5.9)	8.07 (8.9)	16.55 (60.3)	14.19 (52.1)
2006	2.28 (3.9)	17.93 (34.3)	13.39 (49.6)	13.48 (44.0)
2007	3.29 (3.8)	13.92 (50.4)	10.59 (32.4)	10.25 (36.3)
Region				
Western	3.48 (5.3)	11.30 (29.4)	15.69 (56.6)	13.14 (46.9)
Eastern	5.06 (6.3)	28.00 (53.8)	13.43 (57.9)	13.52 (56.3)
Season				
Summer (Jun Jul Aug)	3.92 (5.7)	11.19 (27.8)	13.50 (43.9)	11.80 (37.3)
Off-season	2.51 (3.7)	14.19 (39.9)	18.06 (74.2)	16.46 (67.8)
Cause				
Human	6.26 (8.1)	6.22 (18.8)	21.26 (74.7)	17.68 (66.0)
Lightning	2.78 (4.2)	14.57 (34.8)	11.36 (46.6)	11.34 (40.5)
Under Inv	4.32 (4.6)	5.09 (5.6)	14.11 (41.7)	11.72 (36.2)
Fuel Type				
Grass	3.31 (3.2)	17.02 (34.4)	13.36 (52.5)	13.90 (48.8)
Shrub	3.42 (6.5)	8.69 (14.8)	17.38 (52.1)	13.29 (42.0)
Timber	3.83 (5.2)	11.53 (34.9)	17.10 (60.7)	12.90 (46.9)

Table 2.2. continued.

Resistance to Control				
Low	0 (0.0)	31.99 (55.7)	11.87 (53.1)	13.23 (53.4)
Moderate	3.32 (3.4)	16.64 (57.6)	23.44 (78.1)	21.59 (73.4)
High	4.52 (7.0)	8.51 (14.2)	9.61 (24.6)	8.53 (19.5)
Extreme	2.78 (3.2)	8.77 (10.1)	14.10 (23.8)	8.12 (14.1)
Structures Destroyed				
Yes	3.41 (5.2)	11.02 (16.4)	27.67 (92.8)	16.66 (63.6)
No	3.74 (5.5)	11.85 (32.5)	13.70 (51.1)	12.59 (45.5)

Note: Percentages do not always sum to 100% due to rounding.

Table 2.3. Factors associated with odds of any reported injury occurrence on large federal wildland fires, 2003 - 2007.

			Logistic Regression					
			Model 1 - Unadjusted		Model 2 – Season and P-days		Model 3 – All Variables	
	Injury	No Injury	N = 867		N = 866		N = 830	
	N (%)	N (%)	OR	95% CI	OR	95% CI	OR	95% CI
PIML								
IMT Type I	55 (67.1)	27 (32.9)	9.15	5.51 – 15.19	1.35	0.66 – 2.71	1.34	0.65 – 2.81
IMT Type II	147 (68.7)	67 (31.3)	9.85	6.88 – 14.10	1.83	1.10 – 3.05	1.91	1.40 – 3.22
IMT Type III	104 (18.2)	467 (81.8)	1.00		1.00		1.00	
Person-days								
≤ 71	14 (6.4)	206 (93.6)			1.00		1.00	
>71 to ≤ 309	36 (16.8)	178 (83.2)			2.71	1.40 – 5.24	2.31	1.11 – 4.80
>309 to ≤ 1647	89 (41.0)	128 (59.0)			7.87	4.13 – 14.99	6.59	3.15 – 13.79
> 1647	167 (77.3)	49 (22.7)			29.06	12.94 – 65.24	22.02	8.81 – 55.05
Year								
2003	71 (42.0)	98 (58.0)			1.00		1.00	
2004	37 (28.5)	93 (71.5)			0.90	0.49 – 1.63	0.87	0.47 – 1.63
2005	54 (29.8)	127 (70.2)			1.08	0.62 – 1.87	1.05	0.59 – 1.85
2006	83 (33.1)	168 (66.9)			1.05	0.64 – 1.74	1.01	0.60 – 1.70
2007	61 (44.9)	75 (55.2)			0.92	0.53 – 1.62	0.88	0.49 – 1.58
Season								
Summer	249 (41.3)	354 (58.7)			1.00		1.00	
Off-season	57 (21.7)	206 (78.3)			0.73	0.48 – 1.10	0.66	0.39 – 1.09
Region								
Eastern	17 (11.4)	132 (88.6)					1.00	
Western	289 (40.2)	429 (59.8)					1.21	0.56 – 2.62
Cause								
Human	63 (25.4)	185 (74.6)					1.00	
Lightning	192 (40.4)	283 (59.6)					1.03	0.64 – 1.67
Under Inv.	51 (35.7)	92 (64.3)					1.38	0.77 – 2.45

Table 2.3. continued.

Resistance to Control				
Low	31 (12.4)	220 (87.6)	1.00	
Moderate	55 (33.3)	110 (66.7)	1.64	0.93 – 2.91
High	128 (43.8)	164 (56.2)	1.06	0.60 – 1.86
Extreme	87 (70.2)	37 (29.8)	2.12	1.06 – 4.24
Structures				
No	240 (32.6)	496 (67.4)	1.00	
Yes	66 (50.4)	65 (49.6)	1.14	0.69 – 1.88

Note: PIML, peak incident management level assigned to a fire; P-days, person-days. Hosmer and Lemeshow goodness-of-fit statistics: Model 1 (X^2=0.00, p=0.99), Model 2 (X^2=2.62,p=0.96), Model 3 (X^2=4.75, p=0.78). Likelihood ratio tests: Model 2 vs. Model 1: (X^2=95.30, df=3, $p<0.05$); Model 3 vs. Model 2: (X^2=48.36, df=4, $p<0.05$).

Table 2.4. Injury incident rate ratios and association with reported risk factors on large federal wildland fires.

	Negative Binomial Regression					
	Model 1 - Unadjusted		Model 2 - Season		Model 3 – Season and Fire	
	N = 867		N = 866		N = 831	
	IRR	95% CI	IRR	95% CI	IRR	95% CI
PIML						
IMT Type I	0.28	0.20 – 0.40	0.30	0.21 – 0.42	0.36	0.25 – 0.53
IMT Type II	0.62	0.47 – 0.80	0.65	0.49 – 0.85	0.74	0.56 – 0.99
IMT Type III	1.00		1.00		1.00	
Year						
2003			1.00		1.00	
2004			1.40	0.95 – 2.09	1.25	0.845 – 1.86
2005			1.16	0.80 – 1.69	1.16	0.80 – 1.67
2006			1.15	0.81 – 1.62	1.11	0.79 – 1.55
2007			0.91	0.64 – 1.30	0.91	0.64 – 1.30
Season						
Summer			1.00		1.00	
Off-season			1.06	0.78 – 1.45	0.86	0.61 – 1.21
Region						
Eastern					1.00	
Western					0.87	0.49 – 1.55
Cause						
Human					1.00	
Lightning					1.14	0.83 – 1.56
Under Inv.					1.18	0.80 – 1.74
Resistance to Control						
Low					1.00	
Moderate					0.73	0.47 – 1.13
High					0.66	0.45 – 0.98
Extreme					0.66	0.43 – 1.02
Structures						
No					1.00	
Yes					1.03	0.76 – 1.40

Note: PIML, Peak incident management level assigned to a fire. Likelihood ratio test of whether the dispersion parameter $\alpha=0$: ($X^2 \geq 382.21$, $p=0.00$ for all models). Likelihood ratio tests for model comparisons: Model 2 vs. Model 1: ($X^2=6.62$, df=2, $p<0.05$), Model 3 vs. Model 2: ($X^2=56.36$, df=4, $p<0.05$).

CHAPTER 3

WILDLAND FIRE JOB ASSIGNMENT AND BURDEN OF INJURY

Abstract

Introduction: Wildland fire costs billions of dollars annually and exposes thousands of firefighters to a variety of occupational hazards. Little is known about the burden of injury among wildland firefighters. We hypothesized that fire job assignment would predict the cause, nature, injured body part and severity of fire-related injuries.

Methods: We examined firefighter injuries reported to the U.S. Department of the Interior for the years 2003 – 2007. Associations between the job assignments of Engine crew, Type 1 or Type 2 handcrew, Overhead and Camp crew, Smokejumper and Helitack crew and Other/Unspecified and cause, nature and injured body part were assessed. A logistic regression model was used to evaluate the risk of disabling injury associated with job assignment after controlling for demographic and temporal variables.

Results: 1301 non-fatal injuries to wildland firefighters were reported during the five-year period. Fire job assignment was significantly associated with the cause and nature of injury of injury ($p \leq 0.001$). The most common injury cause was a slip, trip or fall and the most common type of injury was a sprain or strain. No association was identified between fire job assignment and risk of disabling injury after controlling for age, year of fire occurrence and season.

Conclusions: Understanding the job assignment and its relationship to injury characteristics provides a basis for developing injury prevention strategies in order to reduce the cost of injury and work-related disability in this high-risk occupational cohort.

Introduction

Wildland fires affect wilderness areas, rural communities and urban areas in the "rural-urban interface" in the United States. On average in the United States, 80,000 fires burn 4.5 million acres each year costing taxpayers, insurers and private individuals billions of dollars. Fighting these fires requires the combined resources of local, state and federal agencies as well as volunteers and contractors.

At the heart of the firefighting effort are tens of thousands of firefighters. In 2003, the National Interagency Coordination Center, a clearinghouse operated jointly by several federal agencies that provides coordination and logistical support to fire management operations in the United States, filled requests to deploy over 53,000 firefighters to fires throughout the U.S. These firefighters supplemented the far greater number of local firefighters.

Despite the number of personnel involved in wildland firefighting efforts, and the hazards to which they are exposed, relatively little is known about non-fatal injury in this occupational group. The majority of research has focused on exposure to respiratory hazards and physiological response to training and environmental conditions.[17-23, 25-27, 38] To date, information about injuries suffered by wildland firefighters comes from fatality investigations conducted by the involved agency and the National Institute for Occupational Safety and Health and limited publications in peer-reviewed literature.[9] Additional information is provided in descriptive summaries published by the United States Fire Administration and in unpublished project reports. [10, 12, 13, 39-41]

Wildland firefighters engage in a range of varied tasks including clearing brush with hand tools, parachuting to fires, operating bulldozers, ordering supplies and managing food service operations. We expect that injury profiles will vary according to exposures associated with these jobs. To date, no study examined fire jobs and the injuries associated with them. To bridge this critical information gap, we examined fire-related injuries reported to the United States Department of Interior over a five-year period to evaluate how the job a firefighter was assigned affects the cause and type of injury, body part injured and severity of injury reported on wildland fires.

Methods

Source of data: Information for this analysis was from the United States Department of Interior (DOI) Safety Management Information System (SMIS). The SMIS is the web-based automated reporting system used by DOI employees to record occupational illness, injury or "accidents" involving DOI employees, volunteers, contractors and visitors to DOI facilities. Incidents are reported by the involved employee or by a supervisor and include job-related illness or injury involving a worker's compensation claim, minor injuries not involving a compensation claim, property damage only events and near-miss events. In late 2002, the Fire Management Accident Report (FMAR) module was implemented to capture fire specific information for incidents occurring during any fire management activity. [16] Using a Freedom of Information Act request, we obtained records for all incidents reported using the FMAR from 2003 through 2007. This study was considered exempt by the University of Iowa Institutional Review Board.

Exposure variables: The main exposure variable was the job to which the injured firefighter was assigned on the fire. Firefighters were categorized in the SMIS into one of eight job assignments: Handcrews (subcategorized into Type 1 and 2), engine crews, smokejumpers, helitack crews, overhead personnel, camp crews, and other jobs not consistent with the previous categories. After combining smokejumpers and helitack and overhead and camp crews due to small samples and shared exposures, we had six categories for analysis.

Handcrews are groups of approximately 20 firefighters who primarily use hand tools (e.g. shovels, rakes, saws) to construct a line clear of vegetation around a fire as a means of controlling fire spread. Type 1 handcrews ("hotshots") are crews available full-time for deployment to a fire throughout the fire season. These crews are limited in number and are the most experienced and thus are often assigned the most challenging duties. There are approximately 95 Type 1 crews nationwide of which approximately 20 are housed within the DOI. Injuries from these Type 1 crews are reported through the SMIS. Non-DOI Type 1 crews report injuries through their home reporting systems.

Type 2 crews are composed of regular agency employees temporarily assigned to a fire, firefighters hired for one assignment only, or contract employees. Type 2 crews have widely varied experience and their numbers are limited by the number of trained firefighters and sponsors. Injuries from these crews are reported through the SMIS if the crew was sponsored by a DOI agency or if the injury occurred on a fire under DOI jurisdiction. Because Type 1 and 2 crews are significantly different in experience and employment, they are considered separately.

Engines provide water, hoses and pumping capability to a fire. Each engine has several crewmembers to run the pump and manage the hoses. Engines are used in areas of fires that are accessible by road. Many DOI units (national parks, wildlife refuges, resource areas) have one or more engines available for fire suppression on the local unit which may also be available for off unit assignment. Engines and their crews also work on contract. Engine crewmember experience is highly variable, but they all must meet minimum national training requirements. Injuries to DOI employees and to contractors engaged on fires within DOI jurisdiction are reported through the SMIS.

Smokejumpers and helitack personnel were combined into one category due to shared exposure to hazards associated with arriving at a fire by air and because the numbers of injuries reported and number of personnel assigned to these jobs is small relative to the other categories. Smokejumpers are experienced firefighters who are trained to parachute to fires in inaccessible locations. They then use hand tools to suppress the fire. The DOI employs approximately 150 smokejumpers who report injuries through the SMIS. Helitack personnel are assigned to managing helicopter operations. These personnel also rappel from helicopters to inaccessible fires and, like smokejumpers, use hand tools to suppress them.

Overhead personnel are individuals assigned to supervisory positions on fires. These positions include the incident commander who has overall responsibility for the conduct of the fire operation as well as personnel who are responsible for managing specific aspects of the fire that may range from ensuring that firefighters have adequate food and water to supervising groups of engines during fire suppression activities. Overhead jobs may be conducted from a camp that is several miles from the fire or they may be directly involved in firefighting. Camp crews, groups of 10 people who mainly perform general upkeep chores around a fire camp, were included with overhead in this analysis due to their small numbers and their general lack of direct involvement in firefighting activities.

The category "other" combined the records where "other" was selected and the records where the job assignment was missing. Approximately 8.5% of the records were missing job assignment. Examples of personnel who might be included in this category are heavy equipment operators (e.g. bulldozers, semi-tractors), caterer and shower operators, airplane and helicopter pilots and tree fallers.

Available potential confounding variables that could be associated with fire job assignment and severity of injury were age at injury (17-24 years, 25-32 years and 33 - 65 years), the year of injury, the season (Early season: January - June, Peak season: July – September, Late season: October – December) and the time of day of occurrence (Day: 6 am – 6 pm, Night: 6pm – 6 am). Age categories were defined to create a relatively even distribution across categories and to describe firefighter career progression with the youngest firefighters having fewer seasons of experience and working shorter seasons, the middle group encompassing firefighters with multiple seasons of fire experience who work longer seasons or are permanent employees and the oldest group encompassing experienced firefighters with multiple years of experience. Categories for time of occurrence were based on the standard 12 hour wildland firefighting shifts.

Outcome variables: The outcome variables assessed were the cause of injury, the nature of the injury, the body part injured and the severity of injury based on whether the injury was reported as disabling (permanent or temporary) or not. Disabling injuries were injuries defined by the Bureau of Labor Statistics as involving days away from work, or days of restricted work activity or job transfer or both [42] and were reported using this definition consistently throughout the study period. Other variables that could serve as proxy measures for severity, such as length of time off from work, were not consistently available throughout the study period. Injuries that required physician treatment only, first aid or no treatment were considered non-disabling.

The cause of injury was collapsed from the original 62 categories into eight general categories based on frequency and similarity based on the CDC WISQARS^{tm} *Proposed Matrix of E-Code Groupings*.[43] The eight categories were 1) equipment, tools and machinery, 2) bites and stings, 3) burns and smoke, 4)transportation (of any type, includes aircraft), 5) poisoning and natural or environmental exposure, 6) slips, trips and falls, 7) struck by or against and 8) not otherwise classified. Poisonings and natural or environmental injuries were combined to reflect the possible classification of exposure to toxic plants as poisonings. The ten records with missing cause data were combined with the records coded as “not otherwise classified”.

The nature of injury was grouped into six categories from the original 36 categories based on the *Barell Injury Diagnosis Matrix Classification by Body Region and Nature of Injury*.[44] The categories were 1) burns and heat-related, 2) contusions and wounds, 3) fractures and dislocations, 4) sprains and strains, 5) poisoning and environmentally-related and 6) other injuries or not elsewhere classified. Poisoning and environmental injury, although not included in the matrix, was added as a category because it was a frequently selected option within the SMIS. Ten records where the nature of injury was missing were included in the ‘other or not elsewhere classified’ category.

Body part injured was collapsed into six categories from the original 88 based on the *Barell Injury Diagnosis Matrix Classification by Body Region and Nature of Injury*.[44] These categories were used based on frequency of injury and included 1) lower extremity, 2) upper extremity, 3) abdominal/thoracic, 4) back, 5) any head or neck and 6) injuries that were not otherwise classified. None were missing.

Analysis: Pearson chi-square tests of independence were used to test the null hypothesis that the main effect of fire job assignment was independent of the outcome variables and potential confounders.

Prevalence odds ratios were calculated to describe the distribution of the cause of injury, injury type and body region among injury cases.

A logistic regression model was developed to evaluate the effect of job assignment on the odds of reporting a disabling injury after controlling for confounding variables. A logistic model was chosen to use the best reported data and because it models an outcome that will significantly impact the workplace. A manual backwards elimination strategy was used to develop a final model using the previously identified potential confounders. Significance was set at $p \geq 0.1$ for elimination from the model. Hosmer and Lemeshow goodness-of-fit tests were conducted to assess the adequacy of model fit and likelihood ratio tests were conducted to compare the full model with the main effects only model.[33]

Results were considered significant at $p \leq 0.05$. All analyses were completed using SAS v 9.1 (SAS Institute, Inc., Cary, NC) and Stata 10 (Stata Corp, LP, College Station, TX).

Results

A Safety Management Information System query for Fire Management Accident Report incidents for the years 2003 -2007 yielded 2245 records. Of those, 575 records were classified as structural fire, training or work-capacity testing incidents and were excluded from this analysis. 366 of the remaining records were classified as occupational illness, leaving a total of 1304 records coded as "injury (not occupational illness)" that occurred on either a prescribed fire or wildfire. After the three fatalities were excluded, 1301 records remained for analysis.

Table 3.1 summarizes the time and demographic characteristics of the sample. The distribution of fire job assignment for injuries varied significantly by age at injury, year and season ($p < 0.001$). This variation was not observed for the time of day ($p = 0.46$). Age at injury ranged from 17 years to 65 years of age. Engine crews and Type 1 crews had the largest proportions of injuries to young firefighters; overhead and camp crews the largest proportion of injuries to older firefighters.

Almost one-third of smokejumper/helitack (32.5%) injuries and "other" (31.1%) injuries were reported in 2003. One-quarter (25.4%) of engine crew injuries were reported in 2006. Over half (54%) of Type 1 crew injuries were reported in 2003 and 2004. Type 2 crews reported over one-quarter (28.9%) of injuries in 2006 while one quarter (26.6%) of overhead/camp crew injuries was reported in 2007.

The majority of injuries across all jobs were reported July-September consistent with the peak of fire season. However, for engine crews and those with an unspecified job assignment, one-third of injuries occurred during the first six months of the year consistent with the types of resources available and firefighting tactics used in early season fires.

The distribution of cause, nature and injured body part by job assignment is summarized in Table 3.2. Both cause and nature of injury were significantly associated with job assignment ($p < 0.001$); body part was not ($p = 0.07$). Accounting for approximately 40% of the injuries, the two most common causes were slips/trips/falls and equipment/tools/machinery. Transportation was the least commonly reported cause of injury for all job assignments.

Overall, sprains and strains were the most often specified nature of injury. Slightly less than half of all injuries suffered by engine crewmembers (45.0%) and by smokejumpers/helitack crews (45.0%) were sprains and strains. For all job assignments, fractures and dislocations (3.9%) and burns and other heat-related injuries (6.9%) were least frequently specified. Poisoning and environmental exposure type injuries accounted for about one-fifth (21.6%) of all injuries, but was the nature of injury reported in over one-third (36.4%) of injuries to Type 1 crews.

The lower extremity (35.2%) was the most frequently injured body part, followed by the upper extremity (22.5%). Sixteen percent of overhead and camp crew injuries were back injuries. Almost one-quarter (23.8%) of smokejumper and helitack injuries were to the head or neck. For injuries where the body part was specified, abdominal/thoracic injuries were least common.

The prevalence odds ratios for specific causes and types of injury and body part as compared to all other cause, types and body parts by job are reported in Table 3.3. Significant differences in the prevalence odds were noted particularly for injuries caused by burns and smoke where, with the exception of overhead and camp crews, the odds of this type of injury were significantly reduced for all jobs relative to engine crews. An increase in the prevalence odds was observed for Type 2 crews (OR 1.42, 95% CI 1.01 – 1.99) and smokejumpers and helitack crews (OR 2.24, 95% CI 1.37 – 3.65) relative to engine crews for sprains and strains. Overhead and camp crews (OR 0.44. 95% CI 0.21 –

0.92) and smokejumpers /helitack crews (OR 0.33, 95% CI 0.15 – 0.74) had significantly decreased prevalence odds for poisoning and environmental exposure type injuries as compared to engine crews whereas an increase in odds relative to engine crews was observed for Type 1 crews for both the cause (OR 2.32, 95% CI 1.49 – 3.60) and nature (OR 1.98, 95% CI 1.39 – 2.82) of injury. In cases where the job was unspecified, significantly increased odds of bites and stings (OR 1.77, 95% CI 1.04 – 3.01) and transportation-related (OR 2.23, 95% CI 1.02 – 4.91) injuries were observed relative to engine crews.

Table 3.4 summarizes the logistic model for disabling injuries. A total of 180 (13.8%) of the injuries were reported as either permanently or temporarily disabling. Seventeen percent of injuries reported by Type 2 crews and those classified as "other" were disabling. Overhead and camp crews reported the smallest proportion of disabling injuries at 8.9%. The largest proportion of disabling injuries was reported in 2006 (22.8%) and in the late fire season (21.6%).

A Hosmer and Lemeshow goodness-of-fit test suggested that the model using three levels of season might be a poor fit for the data ($X^2 = 16.91$, p = 0.03) likely as a result of the small number of injuries reported in the late season. Thus we report the complete logistic model using only two levels of season (early and peak/late season) which exhibited no lack of fit ($X^2 = 6.97$, p = 0.54). Logistic regression modeling showed that the job to which an employee was assigned on a fire was not associated with injury severity as measured by whether or not the injury was reported as permanently or partially disabling after controlling for age at injury, year and season of occurrence. However, the odds of severe injury were elevated in 2004 relative to 2003 (OR 2.14, 95%

CI 1.32 – 3.45). The odds of severe injury were elevated for combined peak and late season injuries relative to early season injuries (OR 1.53, 95% CI 1.03 – 2.26). A likelihood ratio test comparing the full model with the main effects only model showed that the full model had significant explanatory improvement over the simpler model (X^2 = 16.05, df = 3, $p<0.05$).

Discussion

Wildfire suppression utilizes varied personnel assigned to tasks as diverse as building firelines with a shovel to food preparation. These jobs assignments lead to exposure to different job hazards. This is the first assessment of the effect of the type of fire job assignment on the cause, nature and severity of injuries reported by firefighters.

The most common specified cause of injury involved equipment, tools or machinery. Equipment used in fire suppression ranges from simple hand tools like shovels and rakes to chainsaws to heavy equipment like bulldozers. Equipment hazards to which firefighters are exposed vary by the type of job to which they are assigned. For example, Type 1 and Type 2 crewmembers will all use shovel and rakes, but Type 1 crewmembers use more chainsaws. Bulldozer operators will be exposed to hazards associated with operating and maintaining heavy equipment in harsh environments.

Slips, trips and falls were also frequently reported and were seen equally among all job assignments. Keifer and Mangan[10] also noted that falls were a common cause of injury on the two large fires from the 2002 fire season that they described in their study. The terrain in which firefighters work is often steep and unstable increasing the possibility of trips and falls.

Injuries caused by contact with heat or smoke were reported less than 10% of the time, and, in comparison to engine crews, Type 1 and Type 2 crews, and those whose job assignment was not classified, were significantly less likely to report this as the cause of injury. Engines are generally the first resources to be assigned to a fire. As a result, engine crews may be exposed to fire activity that is highly unpredictable. Every year engine crews are involved in incidents where fires overrun engines. This leads to injuries and substantial equipment loss. In the five-year period covered by our analysis, 15 burnover incidents were recorded in the multi-agency Wildland Fire Lessons Learned Center database.[45] These incidents involved agencies from local volunteer fire departments to federal land management agencies. A 2006 burnover incident involving a United States Forest Service engine resulted in five firefighter fatalities.[45]

The increased prevalence of transportation-related injuries in the "other" job type may be due to the types of duties other personnel are assigned. This group includes heavy equipment operators of bulldozers and semi-tractor transporters, water tender operators and airplane and helicopter pilots. These are all occupations that are more likely to be involved in the transport of equipment or personnel.

Sprains and strains were the most frequently reported type of injury. Both Type 2 crewmembers and smokejumper/helitack crews exhibited elevated odds for these types of injuries relative to engine crews. Type 2 crews spend up to 12 hours per day on the fireline using hand tools such as shovels and rakes to create a line bare of vegetation to contain a fire. They often will hike to the fire carrying heavy, awkward equipment. The terrain in which they work is likely to be uneven, unstable and steep. All these factors elevate the risk of a sprain or strain.

Injuries related to environmental exposures were common among this group of firefighters. Type 1 crewmembers exhibited an elevated risk for this type of injury whereas overhead and camp crews exhibited a reduced odds compared to engine crews. Many of these injuries are likely related to exposure to toxic plants, particularly poison oak. Although toxic plants are encountered throughout the United States, they are especially prevalent on the west coast in fire-prone chaparral where fire activity is also high. In a previous study it was estimated that one-third of forestry workers in the west coast states were disabled by poison oak at some point during a fire season.[46] Most Type 1 crews will participate in multiple western fire assignments each season. Since Type 1 crews are considered national resources, they travel outside their home geographic areas more often than do engines and are more likely to be assigned to large western fires, regardless of home base. The reduced risk for poisoning and natural or environmental exposure is likely attributable to the activities in which overhead/camp crew personnel are engaged. Overhead are responsible for the management of the fire including planning of fire suppression activities and the logistics associated with providing support to, in some cases, thousands of firefighters. These activities are generally accomplished in a fire camp removed from the active fire. Fire camps may be located at local schools or fairgrounds, areas with less possibility of toxic plant exposure.

We did not find any association between the type of job assignment as recorded in these data and the severity of the injury after controlling for age at injury and the year of occurrence. The jobs as characterized in this dataset are based on the way that personnel resources are requested for fires. Although these groups may be considered distinct occupation groups by fire managers, the occupational activities and the hazards to which they are exposed on the fireline may actually be quite similar. A more productive approach to evaluating risk might involve developing classifications of general job duties encountered on fires such as, for example, fireline construction, logistical support or helicopter operations and comparing outcomes among these groups.

Although there was no association with job assignment, we did observe significant variations in injury severity in the year of occurrence and in the season. After controlling for job, age and season, injuries reported in 2004 had significantly increased odds for disabling injury than those in 2003. Of note, the 2004 fire season was unusual in that much of the activity occurred in Alaska. The 6.5 million acres burned in Alaska was 82% of the total acreage burned in the United States in 2004 and was more than eight times Alaska's 10-year average acreage. During a two-day period in mid-June, Alaska received 17,000 lightning strikes.[47] We weren't able to identify how many of the 2004 injuries occurred in Alaska, but firefighters regularly assigned to Alaska would have worked long hours over many days increasing both their overall risk of injury and of severe injury.

A 50% increase (OR 1.53, 95% CI 1.03 – 2.26) in the odds of severe injury after controlling for job, age and injury year, was noted for peak and late season injuries relative to early season injuries. Firefighting tactics and terrain vary over fire seasons. Early fires are more likely to be in the southeast and engines and mechanized equipment are frequently used to fight these fires. Temperatures and humidity are generally more moderate and fires are of shorter duration. Peak season fires tend to occur in the western United States. The terrain is often mountainous and the temperatures can be high and the humidity low. Access is frequently difficult and may involve travel on narrow mountain roads, hiking several miles, or flying in by helicopter. Much of the fire suppression is accomplished through the use of hand tools. Some of these fires burn for months. The relative severity of peak and late season injuries is concerning. A closer examination of the circumstances surrounding them is needed to identify the risk factors associated with these injuries.

Limitations in this study include biases associated with reporting and misclassification. Differential reporting of injuries by severity and job occurs primarily based on type of employment status which is related to job assignment. There was evidence that more severe injuries were more often reported in Type 2 crews and for injuries with no job specified, but the difference did not reach statistical significance. In both cases, personnel are less likely to be regular agency employees meaning that a supervisor would need to enter the incident information. This would be more likely to occur in cases severe enough to trigger a workmen's compensation claim.

Misclassification in these data could occur due to incomplete information about the details of an incident or because, for some variables, there were several similar choices. The results of this bias can be seen in the elevated risk for Type 2 crews in the "other" category of cause of injury. Type 2 crewmembers are often hired for one assignment only. Any injuries for this type of employee would be entered by a supervisor whose knowledge of the injury details may be limited. How the "true" distribution of cause affects the risk cannot be estimated.

There are several limitations associated with database attributes. The data discussed here were limited to injured firefighters only. We had no access to information about firefighters who were not injured. As a result we were not able to estimate the overall burden of injury or to examine possible risk factors for the injury itself, only the severity of the injury after it had occurred. Because the dataset lacked personal identifiers, we also could not identify cases in which a firefighter reported multiple injuries during the study period. These injuries have important implications for prevention as there may be modifiable risk factors for multiple injuries over time that should be identified. We also could not identify specific injury events that led to multiple firefighter injuries. Injuries suffered in events where multiple firefighters are injured violate assumptions of independence and may affect results.

The results of this study are generalizable to wildland firefighters who are employed by federal agencies involved in fire suppression. Although many firefighters employed by state and local agencies will face similar hazards and will work alongside their federal counterparts, state and local firefighters may be subject to different training standards and use equipment and tactics suitable for the types of fires most prevalent in their area and thus be exposed to additional hazards.

This study, the first to examine specific firefighter and injury characteristics and severity associated with wildland firefighter injuries, reinforces the need for further investigation into the burden of and risk factors for, injury in this occupational group about which little is known. Focusing on injury to wildland firefighters will increase awareness of the daily hazards faced during wildfire suppression and provide for the development of evidence-based injury prevention strategies in order to reduce the cost of injury and work-related disability in this high-risk occupational cohort.

Table 3.1. Demographic and temporal characteristics of Department of Interior wildland firefighter injuries by fire job assignment.

	Fire Job Assignment						
Characteristic	Engine Crew N (%)	Type 1 Handcrew N (%)	Type 2 Handcrew N (%)	Overhead Camp Crew N (%)	Smokejumper Helitack N (%)	Other Unspecified N (%)	All Injuries N (%)
Number of Injuries (%)	437 (33.6)	220 (16.9)	249 (19.1)	79 (6.1)	80 (6.2)	236 (18.1)	1301 (100.0)
Age at Injury							*P = <0.001*
17 – 24 years	195 (44.6)	99 (45.0)	87 (34.9)	11 (13.9)	17 (21.3)	68 (28.8)	477 (36.7)
25 – 32 years	149 (34.1)	104 (47.3)	118 (47.4)	14 (17.7)	24 (30.0)	95 (40.3)	504 (38.7)
33 – 65 years	93 (21.3)	17 (7.7)	44 (17.7)	54 (68.4)	39 (48.8)	73 (30.9)	320 (24.6)
Year							*P = <0.001*
2003	85 (19.5)	61 (27.7)	54 (21.7)	20 (25.3)	26 (32.5)	71 (31.1)	317 (24.4)
2004	75 (17.2)	58 (26.4)	29 (11.7)	13 (16.5)	17 (21.3)	46 (19.5)	238 (18.3)
2005	86 (19.7)	23 (10.5)	40 (16.1)	14 (17.7)	14 (17.5)	31 (13.1)	208 (16.0)
2006	111 (25.4)	36 (16.4)	72 (28.9)	11 (13.9)	12 (15.0)	45 (19.1)	287 (22.1)
2007	80 (18.3)	42 (19.1)	54 (21.7)	21 (26.6)	11 (13.8)	43 (18.2)	251 (19.3)
Season							*P = <0.001*
Early (January – June)	148 (33.9)	52 (23.6)	38 (15.3)	21 (26.6)	22 (27.5)	74 (31.4)	355 (27.3)
Peak (July – September)	251 (57.4)	159 (72.3)	194 (77.9)	53 (67.1)	57 (71.3)	130 (55.1)	844 (64.9)
Late (October – December)	38 (8.7)	9 (4.1)	17 (6.8)	5 (6.3)	1 (1.3)	32 (13.4)	102 (7.8)
Shift							*P = 0.4649*
Day Shift (0600 – 1800)	332 (76.0)	167 (75.9)	174 (69.9)	57 (72.2)	60 (75.0)	182 (77.1)	972 (74.7)
Night Shift (0600 – 1800)	105 (24.0)	53 (24.1)	75 (30.1)	22 (27.9)	20 (25.0)	54 (22.9)	329 (25.3)

Note: P-values are for Pearson chi-square tests of independence, testing the null hypothesis that the main effect and predictors are independent.

Table 3.2. Cause of injury, nature of injury and injured body part for Department of Interior wildland firefighters by fire job assignment.

	Fire Job Assignment						
Characteristic	Engine Crew N (%)	Type 1 Handcrew N (%)	Type 2 Handcrew N (%)	Overhead Camp Crew N (%)	Smokejumper Helitack N (%)	Other Unspecified N (%)	All Injuries N (%)
Number of Injuries (%)	437 (33.6)	220 (16.9)	249 (19.1)	79 (6.1)	80 (6.2)	236 (18.1)	1301 (100.0)
Cause of Injury							*P = <0.001*
Bites/Stings	32 (7.3)	18 (8.2)	16 (6.4)	3 (3.8)	4 (5.0)	29 (12.3)	102 (7.8)
Burns and Smoke	66 (15.1)	9 (4.1)	16 (6.4)	9 (11.4)	4 (5.0)	12 (5.1)	116 (8.9)
Equipment, Tools and Machinery	96 (22.0)	32 (14.6)	51 (20.5)	17 (21.5)	19 (23.8)	57 (24.2)	272 (20.9)
Poisoning/Environmental Exposure	47 (10.8)	48 (21.8)	27 (10.8)	3 (3.8)	3 (3.8)	20 (8.5)	148 (11.4)
Slips, Trips and Falls	111 (25.4)	59 (26.8)	79 (31.7)	26 (32.9)	26 (32.5)	64 (27.1)	365 (28.1)
Struck by, Against	28 (6.4)	14 (6.4)	16 (6.4)	6 (7.6)	7 (8.8)	15 (6.4)	86 (6.6)
Transportation	12 (2.8)	3 (1.4)	2 (0.8)	4 (5.1)	3 (3.8)	14 (5.9)	38 (3.0)
Other/Unspecified	45 (10.3)	37 (16.8)	42 (16.9)	11 (13.9)	14 (17.5)	25 (10.6)	174 (13.4)
Nature of Injury							*P = <0.001*
Burns and Heat-related	36 (8.2)	9 (4.1)	18 (7.2)	6 (7.6)	8 (10.0)	13 (5.5)	90 (6.9)
Contusions and Wounds	96 (22.0)	43 (19.6)	43 (17.3)	22(27.8)	15 (18.8)	54 (22.9)	273 (21.0)
Fractures and Dislocations	18 (4.1)	7 (3.2)	6 (2.4)	5 (6.3)	3 (3.8)	12 (5.1)	51 (3.9)
Sprains and Strains	117 (26.8)	55 (25.0)	85 (34.1)	22 (27.9)	36 (45.0)	67 (28.4)	382 (29.4)
Poisoning/Environ. Exposure	98 (22.4)	80 (36.4)	42 (16.9)	9 (11.4)	7 (8.8)	45 (19.1)	281 (21.6)
Other/Unspecified	72 (16.5)	26 (11.8)	55 (22.1)	15 (19.0)	11 (13.8)	45 (19.1)	224 (17.2)
Injured Body Part							*P = .067*
Abdominal/Thoracic	35 (8.0)	24 (10.9)	24 (9.6)	3 (3.8)	3 (3.8)	19 (8.1)	108 (8.3)
Back	37 (8.5)	17 (7.7)	23 (9.2)	13 (16.5)	8 (10.0)	23 (9.8)	121 (9.3)
Head/Neck	95 (21.7)	32 (14.6)	41 (16.5)	16 (20.3)	19 (23.8)	40 (17.0)	243 (18.7)
Lower Extremity	154 (35.2)	69 (31.4)	102 (41.0)	26 (32.9)	28 (35.0)	79 (33.5)	458 (35.2)
Upper Extremity	90 (20.6)	57 (25.9)	45 (18.1)	16 (20.3)	20 (25.0)	65 (27.5)	293 (22.5)
Other/Unspecified	26 (6.0)	21 (9.6)	14 (5.6)	5 (6.3)	2 (2.5)	10 (4.2)	78 (6.0)

Note: P-values are for Pearson chi-square tests of independence, testing the null hypothesis that the main effect is independent of outcome.

Table 3.3. Prevalence odds ratios (OR) for cause and nature of injury and body part injured by job assignment for injuries reported by DOI wildland firefighters, 2003 - 2007.

	Fire Job Assignment (Engine is reference)				
Characteristic	Type 1 Handcrew	Type 2 Handcrew	Overhead Camp Crew	Smokejumper Helitack	Other Unspecified
Cause of Injury					
Bites/Stings	1.13 (0.62 – 2.06)	0.87 (0.47 – 1.62)	--	--	**1.77 (1.04 – 3.01)**
Burns and Smoke	**0.24 (0.12 – 0.49)**	**0.39 (0.22 – 0.68)**	0.72 (0.34 – 1.52)	--	**0.30 (0.16 – 0.57)**
Equipment, Tools and Machinery	**0.61 (0.39 – 0.94)**	0.92 (0.62 – 1.34)	0.97 (0.54 – 1.74)	1.11 (0.63 – 1.94)	1.13 (0.78 – 1.65)
Poisoning/Environmental Exposure	**2.32 (1.49 – 3.60)**	1.01 (0.61 – 1.67)	--	--	0.77 (0.44 – 1.33)
Slips, Trips and Falls	1.08 (0.75 – 1.56)	1.37 (0.97 – 1.92)	1.44 (0.86 – 2.42)	1.41 (0.84 – 2.37)	1.09 (0.76 – 1.57)
Struck by, Against	0.99 (0.51 – 1.93)	1.00 (0.53 – 1.89)	1.20 (0.48 – 3.00)	1.40 (0.59 – 3.33)	0.99 (0.52 – 1.90)
Transportation	--	--	--	--	**2.23 (1.02 – 4.91)**
Other/Unspecified	**1.76 (1.10 – 2.81)**	**1.77 (1.12 – 2.78)**	1.41 (0.69 – 2.86)	1.85 (0.96 – 3.55)	1.03 (0.62 – 1.73)
Nature of Injury					
Burns and Heat-related	0.48 (0.23 – 1.01)	0.87 (0.48 – 1.56)	0.92 (0.37 – 2.25)	1.24 (0.55 – 2.77)	0.65 (0.34 – 1.25)
Contusions and Wounds	0.86 (0.58 – 1.29)	0.74 (0.50 – 1.11)	1.37 (0.80 – 2.36)	0.82 (0.45 – 1.50)	1.05 (0.72 – 1.54)
Fractures and Dislocations	0.77 (0.32 – 1.86)	0.58 (0.23 – 1.47)	1.57 (0.57 – 4.37)	--	1.25 (0.59 – 2.64)
Sprains and Strains	0.91 (0.63 – 1.32)	**1.42 (1.01 – 1.99)**	1.06 (0.62 – 1.80)	**2.24 (1.37 – 3.65)**	1.08 (0.76 – 1.54)
Poisoning/Environ. Exposure	**1.98 (1.39 – 2.82)**	0.70 (0.47 – 1.05)	**0.44 (0.21 – 0.92)**	**0.33 (0.15 – 0.74)**	0.82 (0.55 – 1.21)
Other/Unspecified	0.68 (0.42 – 1.10)	1.44 (0.97 – 2.13)	1.19 (0.64 – 2.20)	0.81 (0.41 – 1.60)	1.19 (0.79 – 1.80)
Injured Body Part					
Abdominal/Thoracic	1.41 (0.81 – 2.43)	1.23 (0.71 – 2.11)	0.45 (0.14 – 1.51)	0.45 (0.13 – 1.49)	1.01 (0.56 – 1.80)
Back	0.91 (0.50 – 1.65)	1.10 (0.64 – 1.90)	--	--	1.17 (0.68 – 2.02)
Head/Neck	**0.61 (0.40 – 0.95)**	0.71 (0.47 – 1.06)	0.91 (0.51 – 1.66)	1.12 (0.64 – 1.97)	0.74 (0.49 – 1.11)
Lower Extremity	0.84 (0.59 – 1.89)	1.28 (0.93 – 1.76)	0.90 (0.54 – 1.50)	0.99 (0.60 – 1.63)	0.93 (0.66 – 1.29)
Upper Extremity	1.35 (0.92 – 1.97)	0.85 (0.57 – 1.27)	0.98 (0.54 – 1.78)	1.29 (0.74 – 2.24)	**1.47 (1.02 – 2.12)**
Other/Unspecified	1.67 (0.92 – 3.04)	0.94 (0.48 – 1.84)	1.07 (0.40 – 2.87)	--	0.70 (0.33 – 1.48)

Table 3.3. continued.

Note: ORs are calculated as the odds of the specific cause, nature or body part versus all other causes, natures or body parts. ORs significant at $p = \leq 0.05$ are in bold type; results for cells with < 5 injuries are not reported.

Table 3.4. Adjusted odds of disabling injury (permanent or temporary) for DOI wildland firefighters.

Characteristic	Disabling Injuries N (%)	Non-disabling Injuries N (%)	Odds Ratio (95% CI)
Number of Injuries	180 (13.8)	1121 (86.2)	
Job Assignment			
Engines	53 (12.1)	384 (87.9)	Reference
Handcrew – Type 1	28 (12.7)	192 (87.3)	1.00 (0.61 – 1.65)
Handcrew – Type 2	42 (16.9)	207 (83.1)	1.46 (0.93 – 2.28)
Overhead/Camp Crew	7 (8.9)	72 (91.1)	0.71 (0.30 – 1.66)
Smokejumper/Helitack	10 (12.5)	70 (87.5)	1.03 (0.49 – 2.16)
Other/NEC	40 (17.0)	196 (83.0)	1.52 (0.97 – 2.40)
Age Group			
17 – 24 Years	71 (14.9)	406 (85.1)	Reference
25 – 32 Years	66 (13.1)	438 (86.9)	0.81 (0.56 – 1.17)
33 + Years	43 (13.4)	277 (86.6)	0.93 (0.60 – 1.43)
Injury Year			
2003	35 (11.0)	282 (89.0)	Reference
2004	47 (19.8)	191 (80.2)	2.14 (1.32 – 3.45)
2005	25 (12.0)	183 (88.0)	1.19 (0.68 – 2.07)
2006	41 (14.3)	246 (85.7)	1.40 (0.85 – 2.27)
2007	32 (12.7)	219 (87.2)	1.25 (0.746 – 2.09)
Season			
Early (January – June)	37 (10.4)	318 (89.6)	Reference
Peak and Late (July – December)	143 (15.1)	803 (84.9)	1.53 (1.03 – 2.26)

Note: Odds ratios reported are adjusted for all other variables in the model. Hosmer and Lemeshow goodness-of-fit statistics: $X^2 = 6.97$, $p = 0.54$. Likelihood ratio test comparing full model to main effects only model: $X^2 = 16.05$, df = 3, $p<0.05$.

CHAPTER 4

CAUSE, CHARACTERISTICS AND SEVERITY OF INJURIES IN WILDLAND FIREFIGHTERS

Abstract

Introduction: Wildland fires have significant ecologic and economic impact in the United States. Despite the number of firefighters involved in controlling them, little is known about injuries in this occupational group. We hypothesized that mechanism of injury would predict injury characteristics and severity of fire-related injuries.

Methods: We examined firefighter injuries reported to the U.S. Department of the Interior from the years 2003 – 2007. Associations between the injury mechanism and the type of injury and body part injured were assessed. A logistic regression model was used to evaluate the odds of disabling injury associated with mechanism of injury after controlling for demographic and temporal variables.

Results: 1301 non-fatal injuries to wildland firefighters were reported during the five year period. Mechanism of injury was significantly associated with the type of injury and body part ($p \leq 0.001$). The most common injury mechanism was slips/trips/falls followed by equipment/tools/machinery. Reduced odds for severe injury relative to slips/trips/falls were observed for injuries caused by bites/stings (OR 0.10, 95% CI 0.02 – 0.41) and plants (OR 0.45, 95% CI 0.21 – 0.95). Back injuries (OR 2.18, 95% CI 1.39 – 3.42) and fractures and dislocations (OR 7.39, 95% CI 4.16 – 13.12) were more likely to be severe relative to other injuries.

Conclusions: This study contributes important knowledge for implementing evidence-based injury prevention programs, for planning emergency medical responses

on fire incidents and for provoking further inquiry into work-related risk factors affecting this high-risk occupational group.

Introduction

Wildland fires burning in areas of limited development with widely scattered structures are common and are an important ecologic and economic force in the United States. On average, 80,000 wildland fires burning over 6.5 million acres are reported in the U.S. annually.[48] Most of these fires occur within state jurisdiction, remain small and are suppressed with local resources. About 20% of these fires and 60% of the acres burned are within the jurisdiction of United States Forest Service (USFS), the Bureau of Land Management (BLM), the Bureau of Indian Affairs (BIA), the Fish and Wildlife Service (FWS) and the National Park Service (NPS). Each of these federal land management agencies maintains a significant firefighting workforce of employees who are dedicated firefighters or for whom firefighting is a partial job responsibility.

Over the five-year period 2003-2007, the National Interagency Coordination Center (NICC), a national clearinghouse for fire resources within the National Interagency Fire Center in Boise, ID, mobilized over 200,000 firefighters to wildland fires.[1] Despite the significant number of resources employed to fight these fires, little is known about the illnesses and injuries affecting this occupational group. To date, much of the research pertaining to wildland firefighters has focused on monitoring the effects of chronic or acute smoke exposure and measuring the physiological responses to the work.[17-27, 38] With little exception, research on injury in this occupation has focused on firefighters from community fire departments rather than firefighters whose main responsibility is wildland fire suppression.[10-13, 39-41, 49-54] Only one published study has specifically addressed injuries in wildland firefighters.[9]

Although wildland fire suppression is a duty performed by most firefighters, regardless of the type of fire department, firefighters from land management agencies are responsible for suppression of large fires burning in remote areas where access may be difficult. And where most firefighters from fire departments will be on the fire scene for a matter of hours, federal wildland firefighters may regularly be assigned to a fire for days or weeks. These differences mean that federal wildland firefighters experience different stressors and different hazards and may experience different injuries from their rural, suburban and urban counterparts. To date, there is no description of the specific causes that lead to injury in wildland firefighters, their extent, and how they affect injury characteristics and severity.

In order to address this paucity of information, we investigated non-fatal wildland firefighter injuries reported to the United States Department of Interior from 2003 through 2007. We hypothesized that injury mechanism would be associated with injury characteristics and severity.

Methods

Data source: Information for this analysis was from the United States Department of Interior (DOI) Safety Management Information System (SMIS). The SMIS is the web-based automated reporting system used by DOI employees to record occupational illness, injury or "accidents" involving DOI employees, volunteers, contractors and visitors to DOI facilities. Incidents are reported by the involved employee or by a supervisor. Incidents may include job-related illness or injury involving a worker's compensation claim, minor injuries not involving a compensation claim and property damage only or near-miss events. In late 2002, the Fire Management Accident Report (FMAR) module was implemented to capture fire specific information for incidents occurring during any fire management activity.[16] Through a Freedom of Information Act request, we obtained records for all incidents reported using the FMAR from 2003 through 2007. Records included in this analysis were those attributed to wildfire or prescribed fire in the FMAR. Records attributed to structural fire, training, or work capacity testing were excluded. "Injury" was defined as a record coded as "Injury (not occupational illness)" at the time of entry. This study was considered exempt by the university Institutional Review Board.

Variable descriptions: Our primary exposure was the mechanism of injury. We used the CDC WISQARS[tm] *Proposed Matrix of E-Code Groupings* as a framework for reducing the original 62 causes reported in the dataset to nine categories based on frequency and similarity.[43] The nine categories were 1) bites and stings, 2) fire/smoke and flash burn 3) equipment, tools and machinery 4) slips, trips and falls, 5) struck by or against, 6) motor vehicles, 7) plants and 8) weather. Fire/smoke/flash burn represents an exposure experienced by all firefighters, regardless of type of fire department. Bites (insect), plants (specifically poison oak, ivy or sumac) and weather are exposures more likely to be encountered by wildland firefighters than by firefighters from traditional departments.

We identified three potential confounding variables that could be associated with the mechanism of injury and that could predict severity of injury that were present in these data. These were age at injury (17-24 years, 25-32 years and 33-65 years), the year of injury, the time of year (Early season: January - June, Peak season: July – September, Late season: October – December) and the time of day of occurrence (Day: 6 am – 6 pm, Night: 6pm – 6 am). Missing age values were imputed using the mean age stratified by fire job assignment. Age categories were created to provide a relatively even distribution across categories and to reflect the general career progression of firefighters with the youngest group being mainly summer seasonal employees with less experience, the middle group encompassing employees who work longer seasons or are permanent employees and the oldest group encompassing experienced firefighters with multiple seasons of experience. Day and night times were based on the standard 12 hour wildland firefighting shifts.

Three outcomes were evaluated. These were the type of injury, the body part injured and the severity of injury. From the original 36 categories of nature of injury reported in the data, we developed six categories using the *Barell Injury Diagnosis Matrix Classification by Body Region and Nature of Injury* as a framework.[44] These categories were 1) burns and heat-related, 2) contusions and wounds, 3) fractures and dislocations 4) sprains and strains, 5) poisoning and environmentally-related and 6) other injuries not elsewhere classified (including missing data). We added poisoning/environmental injuries as an additional classification because it was a frequently selected option in the SMIS.

Based on the *Barell Injury Diagnosis Matrix Classification by Body Region and Nature of Injury*.[44], we collapsed the 88 originally reported body parts into six main categories chosen based on the frequency of injury. These categories were 1) lower extremity, 2) upper extremity, 3) abdominal/thoracic, 4) back, 5) any head or neck and 6) injuries that were not otherwise classified.

In addition to the general categories of injured body part, we also examined three specific injuries that are associated with significant work-related disability and cost. These injuries were back injuries reported as any injury to the back region, fractures and dislocations, and knee injuries. Knee injuries included in this analysis were any injury that was coded as being specifically to a single knee or both knees.

We defined a severe injury as any injury requiring days away from work, or days of restricted work activity or job transfer or both consistent with the Bureau of Labor Statistics definition.[42] Of the possible measures describing injury severity within these data, this metric was the only one that was reported consistently using the same definition throughout the study period.

Analysis: Pearson chi-square tests of independence were used to test the null hypothesis that the main effect of mechanism of injury was independent of the outcome variables and potential confounders.

A logistic regression model was developed to evaluate the effect of mechanism of injury on the odds of reporting a severe injury after controlling for confounding variables. This model was chosen because the best-reported variable describing severity was logically dichotomized into whether or not the injury reported days of lost work or job transfer. A manual backwards elimination strategy was used to develop a final model using the previously identified potential confounders. Significance was set at $p \geq 0.1$ for elimination from the model. A similar logistic regression model was used to evaluate the relationship of back injuries, fractures and dislocations, and knee injuries to injury severity, controlling for age at injury. Hosmer-Lemeshow goodness-of-fit statistics were calculated to assess model fit and a likelihood ratio test was used to compare the full model with the main effects model for injury severity.[33]

Results were considered significant at $p \leq 0.05$. All analyses were completed using SAS v 9.1 (SAS Institute, Inc., Cary, NC) and Stata 10 (Stata Corp, LP, College Station, TX).

Results

A SMIS database query for the years 2003-2007 yielded 2245 records that were recorded as fire-related using the FMAR. 1670 records specified that the incident occurred on a wildland or prescribed fire; 545 records that specified structure fire, training, or work capacity testing were excluded. Of the 1670 incidents from wildland and prescribed fires, 366 records were recorded as "occupational illness, not injury", leaving 1304 records. After excluding three fatalities, we had 1301 records for analysis.

Table 4.1 summarizes the demographic and temporal characteristics of the sample by mechanism of injury. Significant associations were observed between mechanism of injury and age, year and season ($p < 0.001$) but not between injury mechanism and time of day ($p = 0.071$) suggesting that mechanism of injury and age, year and season are not independent of one another. The most commonly specified injury mechanisms were slips/trips/falls (28.1%) followed by equipment/tools/machinery (22.1%). Weather was least often specified (2.6%). Young firefighters reported more injuries associated with animal and plant hazards, accounting for over half of all injuries caused by plants (52.0%) and weather (55.9%) than did older fighters. The oldest firefighters had greater proportions of fire/smoke/flash burn injuries (36.2%) and slips/trips/falls (33.3%) than did the youngest firefighters.

Over half (55.2%) of the fire/smoke/flash burn injuries that were reported were in the early season. Injury mechanisms associated specifically with outdoor hazards such as bites, plants and weather were reported all year but were predominantly reported during the peak fire season.

The distributions of the nature of injury and the body part injured are described in Table 4.2. Both nature of injury and injured body part were significantly associated with mechanism of injury (p = <0.001). Fire/smoke/flash burn predominantly resulted in burn/heat-related injuries and exposure-type injuries (66.4%). Slips/trips/falls was the mechanism for almost half of all sprains and strains (48.7%) and fractures and dislocations (43.1%). Contusions and wounds were the leading injury (46.5%) for stuck by/against. 62% of weather-related injuries were classified as burns or heat-related.

Injuries caused by fire/smoke/flash burn and struck by/against were to the head/neck region in over half the cases whereas injuries caused by slips/trips/falls were mainly to the lower extremity (71.2%). Equipment/tools/machinery-caused injuries were most often reported to the upper extremity (39.4%).

Back injuries represented slightly less than 10% of all injuries reported, but comprised 21% of all injuries caused by equipment/tools/machinery. Of the 121 back injuries reported, 29 (16.1%) were considered severe. Fractures and dislocations were rare injuries (51, 3.9%), but were seven times more likely to be severe relative to other injuries (OR 7.39, 95% CI 4.16 – 13.12). Overall, 168 (12.9%) injuries specifically referenced the knee. Among slip/trips/falls, there were 123 (33.6%) knee injuries, making knee injuries the most common injury resulting from this mechanism. In terms of injury severity, back injuries had twice the odds of being reported as disabling relative to all other injuries after adjusting for age at injury (OR 2.17, 95% CI 1.39 – 3.42). There was no significant difference in severity for knee injuries relative to any other injury.

Table 4.3 describes the odds of severe injury by mechanism. One hundred eighty injuries (13.8%) in this sample were reported as either temporarily or permanently disabling and thus were considered severe. One-fifth of severe injuries were reported as being caused by equipment/tools or machinery (19.5%). Only 1% of injuries caused by bites/stings were severe. Almost one-quarter (23.5%) of weather-related injuries was severe.

Logistic regression modeling showed that the odds of severe injury were significantly reduced for injuries caused by bites/stings (OR 0.10, 95% CI 0.02 – 0.41) and plants (OR 0.45, 95% CI 0.21 – 0.95) relative to injuries caused by slips/trips/falls after adjusting for age at injury, year and season. After adjusting for the other variables in the model, the odds of severe injury in 2004 were twice those of an injury reported in 2003 (OR 2.10, 95% CI 1.29 – 3.42). The odds of severe injury in the late season were twice those of early season injury (OR 2.24, 95% CI 1.23 – 4.10). Hosmer and Lemeshow goodness-of-fit tests exhibited no lack of fit of the model to the data ($X^2 = 7.72$, $p = 0.46$). A likelihood ratio test of the full model compared to the main effects only model suggested that the additional variables had significant explanatory improvement ($X^2 = 19.34$, $df = 3$, $p < 0.05$).

Discussion

This is the first published study to examine how mechanism of injury affects injury characteristics and severity in wildland firefighters. We found that injury mechanism was predictive of both the type of injury reported and of the severity of the injury.

Other studies have examined injuries in structural firefighters using worker's compensation claims[55] or statistics gathered through the National Fire Information Reporting System (NFIRS) based at the United States Fire Administration.[13, 56] The NFIRS is used by a self-selected sample of U.S. fire departments to report incidents. Based on 2004 NFIRS non-fatal injury data, most firefighter injuries resulted in no lost time although a higher proportion of moderate severity lost time injuries was reported in NFIRS (29%) than was observed in our sample of injured firefighters.[13] The definitions used in NFIRS and our definition of severity based on the Bureau of Labor Statistics definition may not be completely consistent however.

The most frequently reported specific mechanism of injury in our sample was slips/trips/falls. Other studies and reports have attributed the majority of injuries to firefighters to overexertion.[13, 55, 56] Overexertion is a very general description of the inciting cause for an injury. We were interested in developing a more specific understanding of cause in order to identify potential intervention points for injury reduction. The predominance of slip/trip/fall injuries in our sample of injured wildland firefighters relative to structural firefighters may result from elevated exposure to hazards like walking on hills, steep slopes and uneven terrain. Within slip/trip/fall injuries in our study, almost one-third were specifically related to a fall from a hill or slope. Within a sample of worker's compensation (WC) claims for firefighters in suburban fire departments, injuries resulting from falls were among some of the most expensive.[55] In an ergonomics model of workplace slips/trips/falls, researchers listed natural factors as often relatively uncontrollable latent factors. However, these factors interact with individual factors.[57] This would suggest that interventions to reduce slips/trips/falls in this environment might need to focus on individual factors such as fatigue and on engineering technology in areas such as personal protective equipment design.

Sprains and strains were the most often reported nature of injury in our sample overall and specifically for injuries caused by both slips/trips/falls and equipment/tools/machinery. These injuries were the most costly type of injury among suburban structural firefighters based on WC claims.[55] Slips/trips/falls were also responsible for one third of all fractures and dislocations, injuries which were significantly more likely to lead to lost work time and hospital treatment than other injuries in our sample. One half of all back injuries reported were caused by equipment/tools/machinery and were classified as sprains or strains. These injuries, while twice as likely as other injuries to result in days off or job restriction, were not any more likely to result in hospitalization. However, back injuries represent a significant economic burden in the workplace.[58-60] This would suggest that a closer examination of the mechanism of these injuries could lead to valuable improvements in technology or policy that could reduce these injuries and the associated costs.

We looked at injuries caused by three mechanisms specific to outdoor environments: bites, plants and weather. While injuries associated with bites or plants were less likely to be severe than injuries caused by slips/trips/falls, weather-related injuries had the highest proportion of severe injuries of any cause. Peak wildland fire season occurs during the hottest months and ambient conditions on fires are likely to be both hot and dry, increasing the risk of heat-related injuries such as heat exhaustion and heat stroke in this active population. These conditions and the increased risk for heat injuries have implications for both planning for logistical support for firefighters and for planning emergency care. Plant exposure was specifically related to three toxic plants which are found throughout the U.S. Past studies suggest that exposure to these plants results in substantial disability in western firefighters.[46]

Limitations to this study are associated with misclassification of information. The proportion of unspecified injuries could affect the outcome if the true distributions were known, but there is no way to estimate the systematic nature, direction or magnitude of effect. In theory, all injuries to Department of Interior wildland firefighters from this time period were included in this sample, however injuries for certain groups within firefighters may be reported differentially although there is no reason to believe that this would be related to injury mechanism.

There are several additional limitations. This study was limited to injured wildland firefighters only thus we were unable to compare firefighters who sustain an injury with those who do not. We were also unable to assess the extent of overall injury and the relationship of fire-level characteristics to injury. The lack of personal identifiers and poor reporting of fire identifiers meant that we could not identify individual firefighters who sustained multiple injuries during the study period or injury events in which more than one firefighter was injured. Both have implications for the assumption of independence of events and for prevention efforts.

Our results are generalizable to federal wildland firefighters. Although wildland firefighters working in other situations may share exposure to many of the same hazards experienced by federal firefighters, training requirements and local fire suppression tactics and equipment differ across regions and by agency.

This study, the first to present information about the causes of injury and their consequences in a group of wildland firefighters, contributes important knowledge for implementing evidence-based injury prevention programs and for provoking further inquiry into work-related risk factors affecting this high-risk occupational group.

Table 4.1. Demographic and temporal characteristics of injuries reported to the U.S. Department of the Interior, 2003-2007, by mechanism of injury.

	BITES N (%)	SMOKE N (%)	EQUIPMENT N (%)	PLANTS N (%)	FALLS N (%)	STRUCK N (%)	MVEH N (%)	WX N (%)	Other N (%)	All Injuries N (%)
Number of Injuries (%)	102 (7.8)	116 (8.9)	287 (22.1)	99 (7.6)	365 (28.1)	86 (6.6)	38 (2.9)	34 (2.6)	174 (13.4)	1301 (100.0)
Age at Injury										*P < 0.001*
17 - 24	43 (42.2)	38 (32.8)	121 (42.2)	48 (48.5)	99 (27.1)	38 (44.2)	15 (39.5)	19 (55.9)	56 (32.2)	477 (36.7)
25 - 32	37 (36.3)	36 (31.0)	112 (39.0)	38 (38.4)	149 (40.8)	32 (37.2)	15 (39.5)	11 (32.4)	74 (42.5)	504 (38.7)
33 +	22 (21.6)	42 (36.2)	54 (18.8)	13(13.1)	117 (32.1)	16 (18.6)	8 (21.1)	4 (11.8)	44 (25.3)	320 (24.6)
Year										*P = < 0.001*
2003	37 (36.3)	14 (12.1)	53 (18.5)	25 (25.3)	86 (23.6)	20 (23.3)	12 (31.6)	9 (26.5)	61 (35.1)	317 (24.4)
2004	18 (17.7)	19 (16.4)	43 (15.0)	27 (27.3)	59 (16.2)	12 (14.0)	4 (10.5)	4 (11.8)	52 (30.0)	238 (18.3)
2005	11 (10.8)	32 (27.6)	43 (14.3)	16 (16.2)	51 (14.0)	18 (20.9)	8 (21.1)	10 (29.4)	19 (10.9)	208 (16.0)
2006	16 (15.7)	36 (31.0)	71 (24.7)	11 (11.1)	102 (28.0)	14 (16.3)	9 (23.7)	6 (17.7)	22 (12.6)	287 (22.1)
2007	20 (19.6)	15 (12.9)	77 (26.8)	20 (20.2)	67 (18.4)	22 (25.6)	5 (13.2)	5 (14.7)	20 (11.5)	251 (19.3)
Season										*P < 0.001*
Early	28 (27.5)	64 (55.2)	85 (29.6)	19 (19.2)	82 (22.5)	20 (23.3)	7 (18.0)	7 (20.6)	43 (24.7)	355 (27.3)
Peak	67 (65.7)	45 (38.8)	172 (59.9)	71 (71.7)	251 (68.8)	58 (67.4)	27 (71.1)	25 (73.5)	128 (73.6)	844 (64.9)
Late	7 (6.9)	7 (6.0)	30 (10.5)	9 (9.1)	32 (8.8)	8 (9.3)	4 (10.5)	2 (5.9)	3 (1.7)	102 (7.84)
Shift										*P = 0.0706*
Day	68 (66.7)	91 (78.5)	227 (79.1)	72 (72.7)	260 (71.2)	69 (80.2)	33 (86.8)	25 (73.5)	127 (73.0)	972 (74.7)
Night	34 (33.3)	25 (21.6)	60 (20.9)	27 (27.3)	105 (28.8)	17 (19.8)	5 (13.2)	9 (26.5)	47 (27.0)	329 (25.3)

Note: BITES, bites/stings; SMOKE, fire/smoke/flash burn; EQUIPMENT, equipment/tools/machinery; PLANTS, poison oak, ivy or sumac; FALLS, slips/trips/falls; STRUCK, struck by/against; MVEH, motor vehicles; WX, weather. P-values are for Pearson chi-square tests of independence testing the null hypothesis that the main effect is independent of the predictors.

Table 4.2. Type of injury and injured body part reported by wildland firefighters by mechanism of injury.

	BITES N (%)	SMOKE N (%)	EQUIPMENT N (%)	PLANTS N (%)	FALLS N (%)	STRUCK N (%)	MVEH N (%)	WX N (%)	Other N (%)	All Injuries N (%)
# of Injuries (%)	102 (7.8)	116 (8.9)	287 (22.1)	99 (7.6)	365 (28.1)	86 (6.6)	38 (2.9)	34 (2.6)	174 (13.4)	1301 (100.0)
Type of Injury										*P < 0.001*
Burn, Heat	--	46 (39.7)	6 (2.1)	--	6 (1.6)	2 (2.3)	--	21 (61.8)	9 (5.2)	90 (6.9)
Contusions, Wounds	3 (2.9)	7 (6.0)	81 (28.2)	2 (2.0)	83 (22.7)	40 (46.5)	22 (57.9)	4 (11.8)	31 (17.8)	273 (21.0)
Fractures, Dislocations	--	2 (1.7)	18 (6.3)	--	22 (6.0)	4 (4.7)	2 (5.3)	--	3 (1.7)	51 (3.9)
Poisoning, Env. Exp.	97 (95.1)	31 (26.7)	11 (3.8)	95 (96.0)	25 (6.9)	1 (1.2)	--	6 (17.7)	15 (8.6)	281 (21.6)
Sprains, Strains	2 (2.0)	1 (1.0)	126 (43.9)	--	186 (51.0)	9 (10.5)	12 (31.6)	--	46 (26.4)	382 (29.4)
Other, NEC	--	29 (25.0)	45 (15.7)	2 (2.0)	43 (11.8)	30 (34.9)	2 (5.3)	3 (8.8)	70 (40.2)	224 (17.2)
Body Part										*P = < 0.001*
Abdominal, Thoracic	7 (6.9)	13 (11.2)	15 (5.2)	23 (23.2)	7 (1.9)	--	5 (13.2)	14 (41.2)	24 (13.8)	108 (8.3)
Back	2 (2.0)	2 (1.7)	61 (21.3)	2 (2.0)	29 (8.0)	7 (8.1)	2 (5.3)	--	16 (9.2)	121 (9.3)
Head, Neck	28 (27.5)	60 (51.7)	37 (12.9)	8 (8.1)	9 (2.5)	47 (54.7)	6 (15.8)	6 (17.7)	42 (24.1)	243 (18.7)
Lower Extremity	31 (30.4)	14 (12.1)	58 (20.2)	10 (10.0)	260 (71.2)	17 (19.8)	9 (23.7)	3 (8.8)	56 (32.2)	458 (35.2)
Upper Extremity	29 (28.4)	21 (18.1)	113 (39.4)	26 (26.3)	54 (14.8)	14 (16.3)	12 (31.6)	1 (2.9)	23 (13.2)	293 (22.5)
Other, NEC	5 (4.9)	6 (5.2)	3 (1.1)	30 (30.3)	6 (1.6)	1 (1.2)	4 (10.5)	10 (29.4)	13 (7.5)	78 (6.0)

Note: BITES, bites/stings; SMOKE, fire/smoke/flash burn; EQUIPMENT, equipment/tools/machinery; PLANTS, poison oak, ivy or sumac; FALLS, slips/trips/falls; STRUCK, struck by/against; MVEH, motor vehicles; WX, weather. P-values are for Pearson chi-square tests of independence testing the null hypothesis that the main effect is independent of the outcome.

Table 4.3. Odds of disabling injury (permanent or temporary) for mechanism of injury for wildland firefighter injuries reported to the U.S. Department of Interior, 2003 - 2007.

	Disabling Injuries N (%)	Non-disabling Injuries N (%)	Adjusted Odds Ratio (95% CI)
Total Injuries	180 (13.8)	1121 (86.2)	
Mechanism of Injury			
Slips/Trips/Falls	61 (16.7)	304 (83.3)	Reference
Equipment/Tools/Machinery	56 (19.5)	231 (80.5)	1.21 (0.80 – 1.83)
Fire/Smoke/Flash Burn	11 (6.1)	105 (93.9)	0.57 (0.28 – 1.14)
Bites/Stings	2 (1.1)	100 (98.9)	0.10 (0.02 – 0.41)
Poison Oak/Ivy/Sumac	9 (10.0)	90 (90.0)	0.45 (0.21 – 0.95)
Struck By/Against	9 (10.5)	77 (89.5)	0.58 (0.27 – 1.23)
Motor Vehicle	5 (13.1)	33 (86.9)	0.77 (0.29 – 2.07)
Weather	8 (23.5)	26 (76.5)	1.59 (0.68 – 3.73)
Other	19 (10.9)	155 (89.1)	0.59 (0.33 – 1.03)
Age at Injury			
17 - 24	71 (14.9)	406 (85.1)	Reference
25 - 32	66 (13.1)	438 (86.9)	0.81 (0.55 – 1.17)
33 +	43 (13.4)	277 (86.6)	0.87 (0.57 – 1.34)
Year			
2003	35 (11.0)	282 (89.0)	Reference
2004	47 (19.8)	191 (80.2)	2.10 (1.29 – 3.42)
2005	25 (12.0)	183 (88.0)	1.04 (0.60 – 1.83)
2006	41 (14.3)	246 (85.7)	1.24 (0.75 – 2.03)
2007	32 (12.8)	219 (87.2)	1.12 (0.66 – 1.89)
Season			
Early (January – June)	37 (10.4)	318 (89.6)	Reference
Peak (July – September)	121 (14.3)	723 (85.7)	1.44 (0.96 – 2.16)
Late (October – December)	22 (21.6)	80 (78.4)	2.24 (1.23 – 4.10)

Note: Odds ratios reported are adjusted for all other variables in the model. Hosmer and Lemeshow goodness-of-fit statistics: $X^2 = 7.72$, $p = 0.46$. Likelihood ratio test of the full model compared to main effects only model: $X^2 = 19.34$, $df = 3$, $p<0.05$.

CHAPTER 5

CONCLUSIONS

Current Project

Wildland fire is a tremendously complex work environment that presents significant hazards to personnel from both extrinsic and intrinsic sources. Extrinsic sources include weather and topography which influence fire behavior, management strategies and fire suppression tactics. These in turn influence the type of firefighters and equipment used on the fire and the hazards firefighters will experience. Intrinsic influences include firefighter training, skill, fitness and fatigue. Obstacles to measuring these elements have limited objective estimation of both the overall extent of injury in this occupational group as well as identification and evaluation of possible influential factors on injury.

The purpose of this project was to contribute to the limited knowledge about non-fatal injury in federal wildland firefighters in the United States. We sought to estimate the burden of injury and identify fire-level risk factors associated with injury characteristics and to describe the types of injuries observed in firefighters and identify risk factors for severity and type of injury.

We investigated the effect of the fire's peak incident management level (PIML) on the rate of injury observed on large federal wildland fires reported to the National Interagency Fire Center from 2003 through 2007. PIML had differing effects on the rate of injury and the odds of any injury being reported on a fire. PIML I and PIML II both predicted lower rates of injury than PIML III. However, the odds of a fire reporting any injury were increased for PIML II fires over PIML III after controlling for person-days worked, year and season suggesting that this metric may depend on the length of time a fire burns and the amount of exposure the firefighters experience since PIML I and PIML II fires are more complex and generally burn longer.

To examine the effect of risk factors associated with the injuries that firefighters suffer, we evaluated the effect of the fire job assignment and the injury mechanism on the injury characteristics and severity in a group of injured firefighters from the U.S. Department of Interior from 2003 through 2007. In the first case, fire job assignment was associated with the injury mechanism and nature of injury, but not with injury severity after controlling for age at injury, year of occurrence and season. In the second instance, the mechanism of injury was associated with both the nature of injury and body part as well as severity of injury after controlling for age at injury and the temporal characteristics.

Injury risk factors exist at the level of the firefighter and at the level of the fire. To comprehensively describe when, where, how and why injuries occur, it is necessary to see the whole picture. In this project we were able to examine fire-level risk factors, but not in conjunction with any information about specific injuries. We were also able to look at specific injuries in a group of injured firefighters, but we could not link the injury to a fire or examine overall risk for injury. Regardless, it is clear based on both the rate of injury and the types and severity of injury, that non-fatal injuries represent an often overlooked human cost in wildland fire. The wildland fire community should expand its focus beyond the investigation of fatalities and embrace new methodologies to evaluate and mitigate the impact of non-fatal occupational injuries in wildland fire.

Future Directions

To better investigate the many influential factors associated with wildland firefighter injuries, fire managers should focus on three areas: 1) inventory and evaluation of existing data sources, 2) modification of existing sources to provide more comprehensive information and 3) development of partnerships with government agencies or educational institutions to assist with the design of new data sources and analysis.

Existing data: A number of data sources currently exist that may provide critical information to describe the burden of injury in wildland firefighters. Most agencies track all fires that burn within their jurisdiction including small fires that do not meet the mandatory reporting requirements for inclusion in the Incident Management Situation Report (ISMR) database. These data would provide important additional information as most wildfires are smaller than the 100-acre reporting minimum for the IMSR and may have inherent risks for firefighter injury that differ from large fires. These sources are maintained by both federal and non-federal agencies thus increasing the scope of any conclusions drawn.

Developing adequate exposure estimates for firefighters is challenging. The Resource Ordering and Status System (ROSS), a computer software program automating the resource ordering and reporting for wildfires that is used by roughly 400 interagency coordination and dispatch centers nation-wide[61], tracks the mobilization and demobilization dates by incident for tens of thousands of firefighters annually. The database is well-documented and could provide a base for estimating the number of person-days worked on incidents at all jurisdictional levels. ROSS could also provide information about the length of firefighter assignments and the number of assignments a firefighter works per season. ROSS is sponsored by the National Wildfire Coordinating Group (NWCG) as an interagency, national-level project.

The annual cost of wildland firefighter injuries has not been examined, however state and federal worker's compensation databases are possible sources of this information. Linking worker's compensation claim data to fire-level variables could identify fire-level predictors of high-cost injuries. Cost-of-injury estimates are important for identifying productive injury prevention intervention points in this population.

Other possible sources of data include databases maintained by agencies to track firefighters and their qualifications and incident business management databases used to document incident financial activities. Incident business management software is available but is used mainly on large fires. The software continues to undergo modifications to increase its usefulness across the broad spectrum of fire and non-fire incidents.

Modification of existing sources: Database documentation and consistency of data reporting are significant weaknesses in existing data sources. In some cases, for example the Department of Interior's Safety Management Information System database, no data dictionary or documentation is available. Agencies should take steps to remedy documentation deficits as they affect data value in all areas of use.

Existing sources of data have large amounts of missing data. To address this issue, managers should create simple, fire-relevant categories for fire-related variables and simplified classifications for other variables. These categories should be based on standard classification schemes used in other occupational areas. By simplifying data entry, the process should take less time and be more consistent. Increasing the numbers of mandatory variables in the databases will also reduce the quantity of missing data.

As fire managers consider data improvement, it would be helpful for them to integrate methods to link multiple data sources. To link data sources at the individual level and to allow access to interested researchers, a system of unique identifiers, separate from personal identifiers exempted from the Freedom of Information Act, should be developed.

Comprehensive surveillance: The resources currently available to estimate and evaluate the burden of injury in firefighters are found in a diversity of situations and are not, in many cases, suitable for linking. Fire managers should work toward developing a new comprehensive occupational injury surveillance system to capture fire-related injuries, illness and fatalities across the spectrum of wild- and prescribed fires, training activities and types of employment.

Information gathered through a comprehensive surveillance system could be used to identify modifiable risk factors and develop targeted interventions. It could be used to develop a multi-faceted approach to mitigating hazards through engineering, training and administrative changes. It could also be used to inform overall fire management policy to effectively reduce risk of injury or death among wildland firefighters and provide important baseline data against which to gauge the success of interventions.

Partnerships: Guidance on the safety and health of wildland firefighters is provided by the NWCG's Safety and Health Working Team (SHWT). The SHWT's mission is to improve health and safety through workforce development, leadership and the development of standards using data collection and analysis to validate and prioritize safety issues.[62] While the mission is commendable, the SHWT lacks both the resources and expertise to fully realize its goal. The SHWT is comprised of representatives from the NWCG member agencies. Most of the committee members are the national-level fire safety managers for the agencies they represent. While all have extensive backgrounds in fire suppression, few, if any, have any formal training in occupational health and safety. The SHWT should actively pursue partnerships with either the National Institute for Occupational Safety and Health or with university-based researchers to provide additional expertise, particularly in the area of injury epidemiology and prevention, topics on which there have been little research emphasis in the past.

Among the benefits of a partnership is the potential for improved access for researchers to existing data. Under the current arrangement, access is limited to data freely available on-line or by Freedom of Information Act (FOIA) request. The FOIA process is hampered by the poor documentation associated with much of the data, forcing interested researchers into making educated guesses about what is available. The FOIA process also creates a workload burden for the agency receiving the request that can result in the loss of valuable information, either through the redaction of information that is not specifically exempted by the FOIA law or through inadvertent exclusion of records.

A partnership would provide dedicated, expert resources with complete access to existing data to assist the SHWT in developing and testing injury and illness-related hypotheses relevant to firefighters and fire managers in order to move toward a truly evidence-based approach to injury reduction.

This project has shown that, even with sub-optimal data collected for other purposes, systematic evaluation of existing data can provide useful hints for prevention and point to areas where further inquiry is likely to be fertile. To move forward, the wildland fire community needs to commit to using existing data to the best advantage possible and to developing new surveillance methods to provide comprehensive information about all wildland firefighter injuries and their circumstances.

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