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Original Contribution

Epidemiology of injuries to wildland firefighters☆,☆☆,★

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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 the injuries that they sustain. We hypothesized that the mechanism of injury would predict injury characteristics and severity of fire-related injuries.

Methods: We examined firefighter injuries reported to the US Department of the Interior from the years 2003 to 2007. Associations between the injury mechanism and the injury diagnosis and body part 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: A total of 1301 nonfatal injuries to wildland firefighters were reported during the 5-year period. Mechanism of injury was significantly associated with the type of injury and injured body part ($P \leq .001$). The most common injury mechanism was slips/trips/falls followed by equipment/tools/machinery. Injuries from poisoning or environmental exposure were less likely to lead to severe injury than slips, trips, or falls (odds ratio, 0.45; 95% confidence interval, 0.21-0.95). Compared with injuries in the early and peak season, those in the late season had more than twice the odds of being severe (odds ratio, 2.24; 95% confidence interval, 1.23-4.10).

Discussion: 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 occupational risk factors affecting this high-risk occupational group.

1. Introduction

On average, 80 000 wildland fires burn more than 6.5 million acres annually in the United States, and the number of fires that threaten inhabited areas is increasing [1]. Most of these fires remain small and are suppressed with state and local resources [1,2]. However, approximately 20% of these fires and 60% of the acres burned are larger and fall within the jurisdiction of the United States Forest Service, the Bureau of Land Management, the Bureau of Indian Affairs,

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the Fish and Wildlife Service, and the National Park Service. Each of these federal land management agencies maintains a significant firefighting workforce composed of full- and part-time firefighters.

Although wildland fire suppression is a duty performed by most firefighters, regardless of the type of fire department, federal wildland firefighters are deployed to suppress large fires that pose increased injury risks. These fires often burn in remote areas, in hazardous terrain, where access may be difficult. Although 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.

Over the 5-year period from 2003 through 2007, the National Interagency Coordination Center, a national clearinghouse for fire resources within the National Interagency Fire Center in Boise, ID, mobilized more than 200 000 firefighters to suppress wildland fires [2]. Despite the significant number of resources deployed to fight these fires, little is known about the injuries affecting wildland firefighters. 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 physiologic responses to the work [3-14]. Previous studies have described traumatic injuries but have been limited to small populations or annual summaries with little injury detail [15-19].

To address this critical information gap, we examined nonfatal wildland firefighter injuries reported to the United States Department of Interior (DOI) from 2003 through 2007. We hypothesized that the mechanism of injury would be associated with the type of injury, body part injured, and severity of injury.

2. Methods

2.1. Data source

Information for this analysis was from the United States 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 (WC) 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 [20]. 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 and that were recorded as “Injury (not occupational illness).” Events attributed to structural fire, training, or work capacity testing were excluded. This study was considered exempt by the University of Iowa Institutional Review Board.

2.2. Variable descriptions

Our primary exposure was the mechanism of injury. We used the CDC WISQARS *Proposed Matrix of E-Code Groupings* as a framework to create 9 injury categories: bites and stings; fire/smoke and flash burn; equipment, tools, and machinery; slips, trips, and falls; struck by or against; motor vehicles; plants; weather; and other [21]. We identified 4 potential confounding variables that could be associated with the mechanism of injury and were likely predictors of injury severity. These were age at injury (17-24, 25-32, 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 (day: 6 AM-6 PM, night: 6 PM-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. Day and night shifts were based on the standard 12-hour wildland firefighting shifts.

Three outcomes were evaluated: 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 6 categories using the *Barell Injury Diagnosis Matrix Classification by Body Region and Nature of Injury* as a framework [22]. These categories were burns and heat related, contusions and wounds, fractures and dislocations, sprains and strains, poisoning and environmentally related, and other injuries not elsewhere classified (including missing data). Poisoning/environmental injuries were included as an additional category because they were a frequently selected option in the SMIS.

We defined a severe injury as any injury requiring days away from work, days of restricted work activity, or job transfer, consistent with the Bureau of Labor Statistics definition [23]. 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.

2.3. Analysis

Pearson χ^2 statistics were computed to test for differences in proportions and evaluate associations between mechanism of injury and type of injury and body part as well as between potential confounders and mechanism of injury and severity.

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. A manual backwards elimination strategy was used to develop a

Table 1 Demographic and temporal characteristics of injuries reported to the US DOI, 2003-2007, by mechanism of injury

	Bites/stings n (%)	Fire/smoke/flash burn n (%)	Equipment/tools/machinery n (%)	Poisoning/environmental n (%)	Slips/trips/falls n (%)	Struck by/against n (%)	Transport n (%)	Weather n (%)	Other n (%)	All injuries n (%)
No. 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)
Age at injury (y)										[a]*P* < .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* < .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 (15.0)	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* < .001
Early (January-June)	28 (27.5)	64 (55.2)	85 (29.6)	19 (19.2)	82 (22.5)	20 (23.3)	7 (18.4)	7 (20.6)	43 (24.7)	355 (27.3)
Peak (July-September)	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 (October-December)	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 (7.8)
Shift										*P* = .071
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)

[a] *P* values are for Pearson χ^2 tests of independence testing the null hypothesis that the main effect is independent of the predictors.

final model using the previously identified potential confounders. All confounders were entered into the model for the backwards elimination procedure with significance was set at $P \geq .1$ for elimination from the model. The likelihood ratio test was used to test the full model (with all confounding variables) compared with the main effects model (with retained variables after the elimination procedure). All analyses were completed using SAS v 9.1 (SAS Institute, Inc, Cary, NC) and Stata 10 (Stata Corp, LP, College Station, TX).

3. Results

A SMIS database query for the years 2003 to 2007 yielded 2245 records that were recorded as fire related using the FMAR. A total of 1670 records specified that the incident occurred on a wildland or prescribed fire; 575 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 3 fatalities, we had 1301 records for analysis.

Significant associations were observed between mechanism of injury and age, year, and season ($P < .001$) but not between injury mechanism and time of day ($P = .07$) suggesting that mechanism of injury and age, year, and season are not independent of one another (Table 1). The most commonly specified injury mechanisms were slips/trips/falls (28%) followed by equipment/tools/machinery (22%). Firefighters between the ages of 17 and 24 years had the highest proportion of bites/stings (42%) and poisoning/environmental injuries (49%), whereas firefighters 33 years or older had the highest proportion of injuries from fire/smoke (36%), but the lowest proportion of injuries from bites/stings (21.6%), equipment/tools/machinery (19%), poisoning/environment (13%), struck by objects (19%), and transport (21%).

Almost two-thirds of all injuries (65%) occurred during the peak season. More than half (55%) 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.

Both nature of injury and injured body part were significantly associated with mechanism of injury ($P = <.001$) (Table 2). Fire/smoke predominantly resulted in burn/heat-related injuries and exposure-type injuries (66%). Slips/trips/falls was the most common type of injury and the mechanism for almost half of all sprains and strains (49%) and fractures and dislocations (43%). Contusions and wounds were the leading injury (47%) for stuck by/against.

For all injuries, the lower extremity was the most common body part involved (35%). Injuries caused by fire/smoke/flash burn and struck by/against were to the head/neck region in more than half the cases, whereas injuries caused by slips/

Table 2 Type of injury and injured body part reported by wildland firefighters by mechanism of injury, 2003-2007

	Bites/stings n (%)	Fire/smoke/flash burn n (%)	Equipment/tools/machinery n (%)	Poisoning/environmental n (%)	Slips/trips/falls n (%)	Struck by/against n (%)	Transport n (%)	Weather n (%)	Other n (%)	All injuries n (%)
No. of injuries (row %)	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										[a]$P < .001$
Burn/scald	–	77 (66.4)	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/environmental	97 (95.1)	0 (0)	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										$P < .001$
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)

[a] P values are for Pearson χ^2 tests of independence testing the null hypothesis that the main effect is independent of the outcome.

trips/falls were mainly to the lower extremity (71%). Equipment/tools/machinery–caused injuries were most often reported to the upper extremity (39%). 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%) were considered severe (data not shown).

In this sample, 180 injuries (14%) were reported as requiring missed work days, restricted work activities, or a job transfer and thus met our operational definition for a severe injury (Table 3). Slips/trips/falls (34%) and equipment/tools/machinery (31%) were the most common mechanisms associated with severe injury. One-fifth of injuries reported as being caused by equipment/tools or machinery were severe. Almost one-quarter (24%) of weather-related injuries were severe; only 1% of injuries caused by bites/stings were severe. Logistic regression modeling showed that the odds of severe injury was significantly reduced for injuries caused by poisoning/environmental exposure (odds ratio [OR], 0.45; 95% confidence interval [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 indicate no lack of fit of the model to the data ($\chi^2 = 7.72$, $P = .46$). A likelihood ratio test of the full model compared with the main-effects-only model suggested that the additional variables had significant explanatory improvement ($\chi^2 = 19.34$, $df = 3$, $P < .05$).

4. Discussion

Previous studies have examined injuries in structural firefighters using WC claims [24] or statistics gathered through the National Fire Information Reporting System (NFIRS) based at the United States Fire Administration [18,19]. The NFIRS is used by a self-selected sample of US fire departments to report incidents. Based on 2004 NFIRS nonfatal injury data, most firefighter injuries resulted in no

Table 3 Odds of severe/disabling injury (permanent or temporary) by characteristic for wildland firefighter injuries reported to the US DOI, 2003-2007

Characteristic	Severe injuries n (row %)	Nonsevere injuries n (row %)	Adjusted OR for severe injury [a] (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)	N/A
Poisoning/environmental	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)

Likelihood ratio test of the full model (all confounders) compared with main-effects-only (variables retained after elimination procedure) model: $\chi^2 = 19.34$, $df = 3$, $P < .05$. Abbreviation: N/A, not applicable due to small cell size.

[a] Odds ratios reported are for the main effects model, which includes all variables retained after the selection procedure. Hosmer and Lemeshow goodness-of-fit statistics: $\chi^2 = 7.72$, $P = .46$.

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 (14%) [18]. These differences could be due to different definitions for severity used in NFIRS and our definition based on the Bureau of Labor Statistics.

The most frequently reported mechanism of injury in our sample was slips/trips/falls. Other studies and reports have attributed most injuries to firefighters to overexertion [18,25]. Overexertion is a very general description of the inciting cause for an injury. We were interested in developing a more specific understanding of cause 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 such as 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 WC claims for firefighters in suburban fire departments, injuries resulting from falls were among some of the most expensive [24]. 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 [25,26]. 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 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 [24]. Slips/trips/falls were also responsible for one-third of all fractures and dislocations. One-half of all back injuries reported were caused by equipment/tools/machinery and were classified as sprains or strains. These injuries, although 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 [27-30]. 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 3 mechanisms specific to outdoor environments: bites, plants, and weather. Although 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 of firefighters and for planning emergency care. Plant exposure was specifically related to 3 toxic plants (poison oak, ivy, or sumac), which are found throughout the United States. Past studies suggest that exposure to these plants results in substantial disability in western firefighters [30].

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 DOI wildland firefighters from this 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 injured with noninjured firefighters. 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 1 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.

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