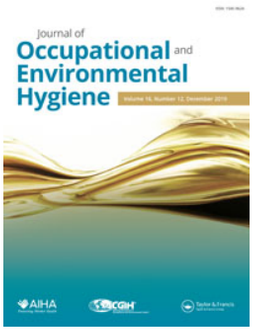

Journal of Occupational and Environmental Hygiene

ISSN: 1545-9624 (Print) 1545-9632 (Online) Journal homepage: https://www.tandfonline.com/loi/uoeh20

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To cite this article: George Broyles, Chucri A. Kardous, Peter B. Shaw & Edward F. Krieg (2019) Noise exposures and perceptions of hearing conservation programs among wildland firefighters , Journal of Occupational and Environmental Hygiene, 16:12, 775-784, DOI: 10.1080/15459624.2019.1668001

To link to this article: https://doi.org/10.1080/15459624.2019.1668001

Published online: 28 Oct 2019.

JOURNAL OF OCCUPATIONAL AND ENVIRONMENTAL HYGIENE
2019, VOL. 16, NO. 12, 775–784
https://doi.org/10.1080/15459624.2019.1668001

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Noise exposures and perceptions of hearing conservation programs among wildland firefighters

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ABSTRACT

Wildland firefighters are exposed to numerous noise sources that may be hazardous to their hearing. This study examined the noise exposure profiles for 264 wildland firefighters across 15 job categories. All 264 firefighters completed questionnaires to assess their use of hearing protection devices, enrollment in hearing conservation programs, and their overall perception of their noise exposure. Roughly 54% of firefighters' noise exposures exceeded the National Institute for Occupational Safety and Health recommended exposure limit of 85 decibels, A-weighted, over 8 hr, and 32% exceeded the Occupational Safety and Health Administration permissible exposure limit of 90 decibels, A-weighted, over 8 hr. Questionnaire results indicated good agreement between noise exposures and firefighters' perceptions of the noise hazard. Approximately 65% reported that they used some form of hearing protection; however, only 19% reported receiving any proper training regarding the use of hearing protection devices, with the majority of those firefighters relying on earplugs, including electronic and level-dependent earplugs, over earmuffs or other forms of hearing protectors. The results also suggest that improved communication and situational awareness play a greater role in the consistent use of hearing protection devices than other factors such as risk of developing noise-induced hearing loss. The study highlighted the challenges facing wildland firefighters and their management and the need for a comprehensive wildland fire agencies' hearing conservation program especially for firefighters who were exempt based on their occupational designations.

KEYWORDS

Firefighters; hearing conservation; hearing loss; noise exposure

Introduction

The National Institute for Occupational Safety and Health (NIOSH) estimates that 22 million workers are exposed to hazardous noise levels every year at work.[1] Occupational noise-induced hearing loss (NIHL) is one of the most common occupational illnesses in the U.S., carries a high economic burden to society, and can damage a worker's quality of life. The U.S. Department of Interior and the U.S. Department of Agriculture's Forest Service (USFS) estimate that there are 19,000 career and seasonal wildland firefighters. In addition, it is estimated that 86% of the 1.1 million firefighters from local fire departments have some wildland firefighting duties.[2] Wildland firefighters (WLFFs) are exposed to many sources of noise during their daily activities, including chainsaws, wood chipping equipment, aircraft, engine pumps, and earth-moving vehicles such as bulldozers and heavy trucks. In addition to noise, exposures to carbon monoxide and other combustion byproducts from equipment and fires have ototoxic effects that could exacerbate hearing loss and lead to other non-auditory effects, such as increased heart rate, hypertension, fatigue, reduced reaction time and concentration, and increased prevalence of injuries.[3–6]

Numerous studies have examined noise exposure and hearing risk among structural and urban firefighters[7–9] but WLFFs have received little attention, mainly because of their seasonal and transient work schedules and the hazardous conditions under which they often operate. A typical fire season runs from 49 days (short season) to as many as 98 fire days (long season).[10] A review of the literature on noise

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exposure among WLFFs revealed a single study conducted in 1985[11] that examined several groups of wildland firefighters including fire line, ground, and helitack (WLFFs transported by helicopters) crews. Researchers found that 100% of the helitack crews and 100% of the portable pump operators had noise exposures above the OSHA permissible exposure limit (PEL) of 90 dBA during work shifts that lasted up to 14 hr. Thirty percent of the WLFFs who used chain saws had exposures that exceeded the OSHA PEL as well. A recent study by USFS and NIOSH evaluated the noise exposure of 156 WLFFs at 26 different fire/training locations and found an elevated risk for hearing loss among a large subset of firefighters: time-weighted average (TWA) noise exposures and daily noise doses exceeded the NIOSH recommended exposure limit (REL) for several occupations and tasks. The loudest exposures were found amongst masticator/chipper operators (TWA: 94–105 dBA), sawing/swamping operations (91–106 dBA), helicopter pilots (92–94 dBA), and bulldozer operators (72–112 dBA). Daily noise dose for the bulldozer operators reached 2,000% using OSHA PEL and 51,804% using the NIOSH REL criteria, which was more than 20-fold and 500-fold greater than the OSHA PEL and NIOSH REL, respectively.[12]

Several agencies are involved in wildland fire suppression operations in the U.S.; however, each agency has its own policies and procedures to assess noise exposure and prevent hearing loss among its employees. The USFS, the largest employer of full-time WLFFs, has a hearing conservation program for its employees. However, WLFFs are exempt because their occupation is not included in the USFS hazardous noise occupational category.[13] Certain occupational categories that participate in wildland fire suppression activities (such as pilots and heavy equipment operators) are considered hazardous noise occupations and therefore included in the hearing conservation program. Although USFS WLFFs are not included in the hearing conservation program, the agency provides them with hearing protection that they are required to use when noise levels exceed 85 dBA.

This study was conducted to understand and characterize the WLFFs' noise exposures in the unique environmental and extreme work conditions under which most WLFFs operate and to evaluate the need to include them in the USFS hazardous noise occupational category. These aims were accomplished by examining noise exposures of WLFFs during fire suppression activities, and by administering a questionnaire to assess their perception of noise exposure, hearing protection, and training received. The questionnaire also determined whether the WLFFs received a baseline or annual audiogram, and what percentage of respondents were enrolled in or aware of hearing conservation programs.

Methods

Personal noise dosimetry was conducted with 3M Edge5 (3M Personal Safety Division, Oconomowoc, WI) data-logging noise dosimeters, which conformed to the American National Standards Institute (ANSI) S1.25-1991 Specification for Personal Noise Dosimeters (R2007). Dosimeter parameters were set to simultaneously measure noise according to the OSHA requirements for comparison with their PEL and to the NIOSH guidelines for comparison with their REL. The REL for noise is 85 decibels, using the A-weighting frequency response and a 3-dB exchange rate as an 8-hr TWA; exposures at or above this level are considered hazardous.[14] OSHA sets legally enforceable PELs that require employers to take actions to reduce worker exposures. The OSHA PEL for noise is 90 dBA as an 8-hr TWA based on a 5-dB exchange rate.[15] NIOSH uses the 80-dBA threshold level for calculating the REL. OSHA uses a 90-dBA threshold for calculating the PEL and an 80-dBA threshold for calculating the Action Level. The noise dosimeters were set to capture both OSHA PEL and AL (exchange rate set to 5-dB and thresholds are automatically set to 90-dBA and 80-dBA) as well as the NIOSH REL (exchange rate set to 3-dB and threshold set to 80 dBA). Because most of the WLFFs worked longer than the typical 8-hr shift, the average sound levels for which the NIOSH REL and OSHA Action Level are based upon were reduced according to Eqs. (1) and (2) to account for increased risk associated with increased noise exposure duration from longer work shifts. OSHA does not allow adjustment of its PEL for extended work shifts:

$$\text{Adjusted Sound Level for NIOSH REL} = 85 - 10 * \text{LOG}\ (T/8) \quad (1)$$

$$\text{Adjusted Sound Level for OSHA Action Level} = 85 - 16.61 * \text{LOG}\ (T/8). \quad (2)$$

Researchers attached dosimeters to the WLFFs' outer garments (within their hearing zones) and placed them in a way that did not interfere with their communication or exposure to other gear or equipment. Researchers instructed WLFFs to avoid contact with the dosimeters' microphone. Researchers observed WLFFs

throughout the assessment to ensure the dosimeters did not touch clothes or equipment in order to avoid extraneous noise data (artifacts). In addition, the dosimeters' microphones come equipped with windscreens to reduce the effects of wind and environmental conditions on the collected data. All dosimetry data were downloaded to a computer for analysis after each shift using the QuestSuite Professional II software (3M Personal Safety Division, Oconomowoc, WI) and inspected for any errors (for example, missing data points or unexplained spikes in sound levels) that could have been introduced during the noise assessments. The dosimeters were factory-calibrated within the previous year and field-calibrated before and after each work shift. Researchers conducted field calibrations on the survey date using a 3M AcoustiCAL AC300 calibrator (3M Personal Safety Division, Oconomowoc, WI). Researchers observed the firefighters during fire suppression and training exercises and documented the occupational and environmental variables that could have contributed to their overall noise exposure during the entire work shift

USFS researchers distributed and administered a questionnaire on-site to 264 WLFFs. Its purpose was to evaluate their overall perception of their noise environment during work, the type of hearing protection used, training on proper hearing protection use, whether the firefighter received an introductory baseline hearing test and annual audiograms, and whether the firefighter was enrolled in a comprehensive hearing conservation program. The questionnaire asked the following.

1. Describe your personal perception of your noise environment for the work shift: *very low* (whisper), *low* (normal conversation), *moderate* (busy office), *high/loud* (have to raise your voice to communicate in noisy situations), or *very high/very loud* (have to shout to communicate).
2. What type, brand, and model of hearing protection device did you use? What was the noise reduction rating (NRR) if known? How often did you use hearing protection? Did you like or dislike them? For those provided communication HPDs, do you think they improved communication and situational awareness?
3. Did you receive training on proper use of hearing protection devices?
4. Did you receive a baseline audiogram upon entering the service?
5. Do you receive an annual audiogram?
6. Are you enrolled in an OSHA hearing conservation program?

Other collected questions were related to age, gender, year of experience as a wildland firefighter, equipment used during the shift, and years of experience with the equipment.

Statistical analysis determined which of the explanatory variables had a significant impact on the outcome variables, the TWA for noise for OSHA's PEL and for NIOSH's REL. The explanatory variables were *noise perception* (*very low, low, moderate, high, and very high*) by the firefighter, *type of HPD (earplugs, earmuffs, double protection, or other forms of protection)*, received *training in HPD use (yes/no)*, *having a baseline test (yes/no)*, having a *yearly audiogram (yes/no)*, and participating in a *hearing conservation program (yes/no)*. Hearing protection devices were categorized based on the response of WLFFs into five different categories: insert earplugs; banded or canal earplugs; earmuffs; double hearing protection such as earmuffs worn over earplugs; and other for electronic or level-dependent hearing protectors). The data were modeled using SAS's PROC MIXED procedure (SAS Institute, Cary, NC). The reason for employing mixed models was that, in a number of instances, the same firefighter received repeated measurements. Restricted maximum likelihood (REML) estimation was used with the Kenward-Roger denominator degrees of freedom; the covariance structure was variance components. Initially researchers ran the full model with all six explanatory variables; then this model was reduced by eliminating terms for which $p > 0.10$ as judged by F-tests. The results were based on 134 observations; the rest were not used due to missing data. Mixed models were used for individual observations. However, for the box plots in Figure 1, with repeated noise exposure for an individual WLFF within the same work category, individual WLFF's exposure measurements were averaged so that there was only one data point for each individual in each separate work category.

Results

Researchers collected 324 noise dosimetry measurements on 264 WLFFs during a 2-year noise assessment period (2015 and 2016) for 15 wildland fire fighting job categories. Researchers collected repeat measurements on 60 firefighters conducting similar tasks on different days. Shift lengths ranged from 2.5–14 hr, but most work shifts exceeded 12 hr. A work shift included the entire period during a day that a firefighter was in paid status, including time on the fire line, morning briefings, traveling to/from a fire line, staging, and any breaks in between. Most of

the WLFFs had 6 or more years of firefighting experience; the average age was 33 years (range: 21–71 years). Ninety-three percent (n = 245) were male and 7% (n = 19) were female. The abbreviated job categories and their descriptions along with the number of measurements, age, and average work shift per job category are described in Table 1.

The results of the noise dosimetry are shown in Figure 1 as box plots of TWA and noise dose per OSHA PEL and NIOSH REL noise measurement criteria for all 15 job categories.

The medians of TWA dosimetry measurements using the OSHA's PEL criterion were lower than the medians computed using NIOSH's REL criterion. These differences are mainly due to the use of the different exchange rates (3-dB for NIOSH vs. 5-dB for OSHA) and the threshold levels (80 dBA for NIOSH vs. 90 dBA for OSHA). Overall, 54% of the TWAs and noise doses (n = 175) were above the NIOSH REL (80 dBA threshold and 3-dB exchange rate). Thirty-two percent (n = 100) were at or above the OSHA action limit of 85 dBA (80-dBA threshold and 5-dB exchange rate) and 15.5% (n = 50) were at or above the OSHA PEL of 90 dBA (90-dBA threshold and 5-dB exchange rate). Almost all bulldozer operators, masticators/chippers, pump operators, leaf blowers, sawyers/swampers, and helicopter pilots had exposures that exceeded the NIOSH REL. This compares to almost 90% of masticators/chippers, 73% of sawyer/swampers, and 50% of helicopter pilots and bulldozer operators who exceeded the OSHA PEL. The highest TWAs per NIOSH REL were recorded for bulldozer operators (112 dBA); chippers (109 dBA); and sawyers/swampers (105 dBA).

The *noise perception* and *having baseline testing* (yes/no) were retained as explanatory variables for linear mixed models of both OSHA's PEL and of NIOSH's REL. Tables 2–5 show the tests for explanatory variables for the reduced models and for the least squares means for different levels of noise perception. Least squares means are what the models predict for given levels of an explanatory variable.

For the TWA for OSHA's PEL, the *noise perception* was clearly significant. The values of the least squares means gradually increased as the qualitative judgement of noise intensity increased (though not perfectly, as with *low* and *moderate* levels). As evidenced by a contrast, the difference of the mean of the two highest levels (*very high* and *high*) and the mean of the two lowest levels (*low* and *very low*) was found to be significant (p = 0.0017). None of the levels of the least square means exceeded OSHA's PEL of 90 dBA.

In the case of the TWA for NIOSH REL, the *noise perception* was clearly significant (p = 0.0052) but the *baseline testing* only bordered on significance (p = 0.0573). The values of the least square means increased as the qualitative category increased. For the NIOSH REL, the contrast for the difference of the mean of the two highest and the two lowest categories was significant (p = 0.0006). The two highest qualitative responses for *noise perception* (*high* and *very high*) were associated with noise exceeding the NIOSH 85 dB REL. In fact, the confidence intervals for both the *high* and *very high* in Table 5 exceed the 85 dB of the NIOSH REL (C. I. for *high* is (86.9, 91.4) and for *very high* is (87.5, 97.3)).

The results of the questionnaire administered to the 264 WLFFs and corresponding to 324 noise dosimetry measurements are in Tables 6–8. Table 6 shows the relationship between actual noise exposures in term of TWA and noise dose (shown as simple arithmetic means) and the WLFFs' perception of their noise exposures ranking from *very high* to *very low*. One hundred sixty-two (61%) WLFFs did not submit a response even though their noise exposures could be classified between *moderate* and *high* (mean TWA of 87 dBA and NIOSH noise dose of 893%). Of these 162 WLFFs, 89 (55%) had noise exposure above the NIOSH REL and 27 (17%) exceeded the OSHA PEL. Five WLFFs reported having *very high* noise exposure and their perceptions of their noise exposure were confirmed by the mean TWA (95 dBA) and noise dose (1700%) based on the NIOSH REL. The five WLFFs were: a swamper, a pump operator, a heavy equipment boss, a chipper, and an airboat operator—all considered high noise exposure job categories. The mean TWA noise exposures for employees reporting their perceived noise exposure as '*moderate* (n = 49)' or '*low* (n = 12)' was 85 dBA for both categories. Only seven WLFFs reported having *very low* noise exposure that corresponded to personal dosimetry measurements below 85 dBA (mean TWA of 83 dBA and mean noise dose of 80%).

The responses regarding the type of hearing protection devices (HPDs) used are in Table 7. Most WLFFS, or 65% (n = 173), reported that they used some form of hearing protection. Of those 173 WLFFs, 60% (n = 104) reported using insert earplugs, but only 13% (n = 22) used earmuffs. Two people used double protection in the form of earmuffs over top of insert earplugs. Their noise exposures were substantially higher than WLFFs wearing single hearing protection (mean NIOSH TWA of 98 dBA and noise dose of 4,300%). Thirty-three WLFFs did not provide an answer, and 60 reported using no hearing

Table 1. Sampling and demographic breakdown of WLFFs per activity/task.

Job description activity/task	Typical work activities and tasks	Number of measurements	Age range	Average work shift (hrs:min)
Airboat	Airboat operator	4	30–46	2:36
All-terrain buggy (ATB) operator	Operates four-wheel drive ATBs to transport supplies or scout a fireline	14	20–64	12:00
Bulldozer operator	Operates a bulldozer typically used for cutting a fireline.	11	32–63	12:31
Engine operator (ENOP)	Firefighters who operate a pump on a fire engine.	59	24–57	12:58
Equipment operator	Operates any equipment other than dozers, masticators, chippers, and excavators.	36	26–77	11:49
Heavy equipment boss (HEQB)	Works with various types of heavy equipment (e.g., bulldozers, feller bunchers, excavator) and identifies the heavy equipment operator's route.	26	24–57	11:50
Helitack crew member	Works around helicopters performing a variety of tasks, such as marshalling the helicopter during takeoff or landing and loading passengers and supplies.	42	26–60	12:25
Helicopter pilot	Operates a helicopter performing a variety of different tasks including transporting passengers and supplies and dropping water or retardant on the fire.	5	34–65	13:05
Leaf blower operator	Operates leaf blowers to remove leaves to create a fireline/fuelbreak or clear out area around trees in advance of an approaching fire or before a prescribed burn.	9	23–46	7:30
Masticator/ chipper operator	Operates a masticator or chipper to grind up small trees and brush.	23	21–59	12:43
Pump operator	Operates a variety of pumps including portable pumps	30	20–39	14:00
Sawyer/swamper	Operates chainsaws during a variety of activities. A sawyer operates a chainsaw during fire suppression or prescribed fire preparation. The swamper works in conjunction with the sawyer, removing cut branches and brush, and acting as lookout. Sawyers/swampers often switch roles with each chainsaw fuel cycle.	28	25–62	11:48
(UTV)/buggy operator	Operates or rides on UTVs in wet, swampy, areas. UTVs typically transport crews, water, and supplies.	15	27–58	9:53
Water tender driver	Operates water tender vehicles to supply water to engines or stationary holding tanks.	10	21–71	11:37
Weed whip operator	Operates weed whip to clear grass from around trees and buildings.	12	19–46	6:15

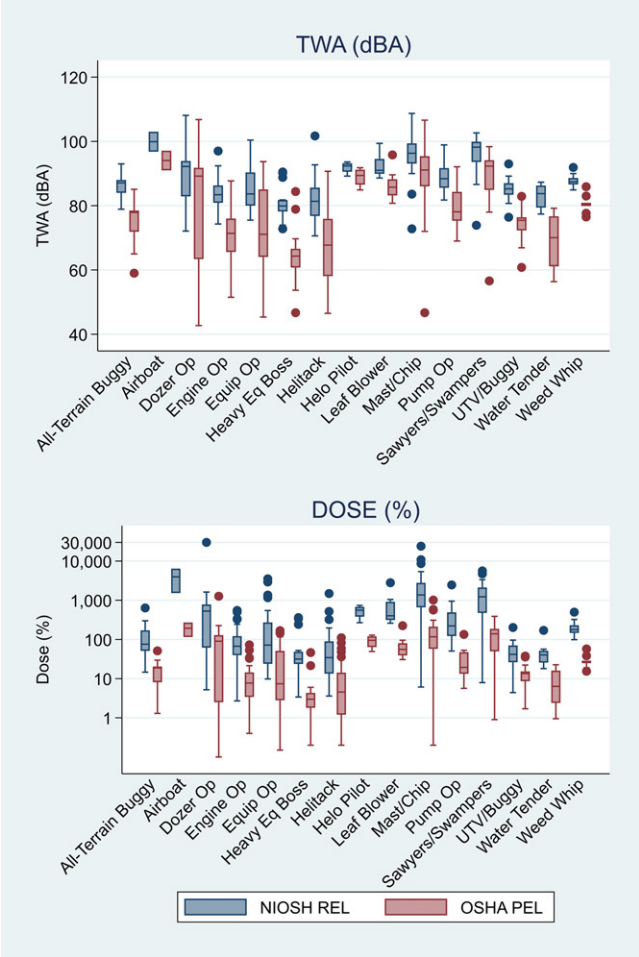

Figure 1. Time-weighted average and noise dose graphs for the OSHA's PEL and for NIOSH's REL. Mean of repeated measures for an individual was used for repeated measures for the same work category.

Table 2. Results of linear mixed model with TWA of OSHA PEL as the outcome variable and with the *participant noise perception* and *having a baseline test performed* as explanatory variables.

Effect	Numerator deg. freedom	Denominator deg. freedom	F	p
Participant noise perception	4	94.1	3.95	0.0052
Having baseline test performed	1	116	3.69	0.0573

Table 3. The least squares means for reported perceived *noise exposure* using the linear mixed model with TWA of OSHA PEL as the outcome variable.

Participant noise exposure perception	Estimate	Standard error	Lower 95% conf. lim.	Upper 95% conf. lim.
Very low	71.1	3.55	64.1	78.2
Low	73.2	2.48	68.3	78.1
Moderate	72.9	1.40	70.2	75.7
High	79.2	1.84	75.6	82.8
Very high	84.9	3.93	77	92.7

Table 4. Results of linear mixed model with TWA of NIOSH REL as the outcome variable and with the *participant noise perception* and *having a baseline test performed* as explanatory variables.

Effect	Numerator deg. freedom	Denominator deg. freedom	F	p
Participant noise perception	4	107	4.19	0.0034
Having baseline test performed	1	112	4.21	0.0425

protection at all. The 33 who did not provide an answer had a mean TWA of 90 dBA, and those who reported using none had a mean TWA of 86 dBA—both above the NIOSH REL. Of the 35 WLFFs who reported using "other" type of hearing protection, most used electronic level-dependent earplugs. Overall, more than 20 different

Table 5. The least squares means by response category of participant perceived *noise exposure,* from the linear mixed model, for TWA of NIOSH REL as the outcome variable.

Noise perception	Estimate	Standard error	Lower 95% conf. lim.	Upper 95% conf. lim.
Very low	83	2.14	78.8	87.2
Low	85.2	1.52	82.2	88.2
Moderate	85.3	0.84	83.7	87
High	89.2	1.12	86.9	91.4
Very high	92.4	2.48	87.5	97.3

Table 6. Noise exposures of WLFFs per NIOSH REL and their perception of their work noise environment.

Perception of noise exposure	Number of respondents (%)	Mean ± SD of TWA (dBA)	TWA range (dBA)	Mean ± SD of dose (%)
Very high	5 (2%)	95 ± 4	89–102	1712 ± 1470
High	29 (11%)	89 ± 5.5	73–109	1151 ± 1523
Moderate	49 (18.5%)	85 ± 5	73–103	470 ± 572
Low	12 (4.5%)	85 ± 6.5	74–99	451 ± 551
Very low	7 (3%)	83 ± 3	74–91	80 ± 57
No response	162 (61%)	87 ± 6.6	71–112	893 ± 1243

Table 7. Noise exposure summary by reported type of hearing protection device used.

		OSHA PEL measurement criterion		NIOSH REL measurement criterion	
Type of HPD	Number (%) of respondents	Mean ± SD of TWA (dBA)	Mean ± SD of dose (%)	Mean ± SD of TWA (dBA)	Mean ± SD of dose (%)
Insert earplugs	104 (39.3%)	76 ± 10.4	55 ± 61	87 ± 6.3	793 ± 1031
Banded earplugs	10 (4%)	76 ± 9.6	36 ± 31	88 ± 5.8	315 ± 310
Earmuffs	22 (8%)	79 ± 8.7	125 ± 143	88 ± 5	2539 ± 4284
Earmuffs + plugs	2 (0.7%)	96 ± 9	313 ± 315	97 ± 10	4348 ± 5402
Other	35 (13%)	83 ± 9.2	48 ± 45	88 ± 5.4	317 ± 604
None	60 (23%)	68 ± 8.6	15 ± 16	86 ± 4.4	175 ± 225
No response	33 (13%)	80 ± 11.5	104 ± 118	90 ± 8	1118 ± 1434

Table 8. Response count (and percentage) of WLFFs who use hearing protection, receive hearing tests, or are enrolled in hearing conservation programs.

Questionnaire	N	Yes (%)	No (%)	N/A or don't know
Received training on proper usage of HPD	264	50 (19%)	53 (20%)	161 (61%)
Received introductory audiogram	264	57 (22%)	46 (17%)	161 (61%)
Received annual audiogram	264	41 (16%)	62 (23%)	161 (61%)
Included in a hearing conservation program	264	19 (7%)	84 (32%)	161 (61%)

types of HPDs were used by WLFFs and most of those devices (n = 96) had a noise reduction rating (NRR) between 25–30 dB, 61 had NRRs above 30 dB, and 33 had an NRR between 20–25 dB.

Sixty-three WLFFs provided their own personal assessment of the HPDs they used. Of those, 28 (44%) WLFFs indicated they always used the provided hearing protection, 32 (51%) WLFFs indicated they used them "sometimes," and three indicated that they would not use the HPDs they were provided.

When asked about what they perceived as the most important features of the hearing protection devices they used, 43 (68%) WLFFs indicated that their HPDs were comfortable and they attenuated noise adequately. Six indicated that while their HPDs attenuated noise, they were uncomfortable to wear, and four indicated their HPDs did not attenuate noise adequately but were comfortable. Of the WLFFs who selected electronic or level-dependent HPDs or those who used built-in communication headsets, most (78% or 63/81) respondents indicated that their devices improved communication.

The responses on training for HPDs, whether WLFFs received baseline or annual hearing tests, and whether they were enrolled in hearing conservation programs are provided in Table 8. Most (61%, n = 161) gave no response. A similar number of WLFFs responded "yes" or "no" to the question about training on HPD use, receiving baseline audiograms, and receiving annual audiograms. Overall, out of the 264 WLFFs who were queried, only 16–22% responded affirmatively to these three questions, and even less (7%, n = 19) responded "yes" to the question about enrollment in a hearing conservation program.

Discussion

USFS and NIOSH are collaborating to document and examine any risk of hearing impairment among WLFFs. The initial efforts have focused on

documenting noise exposures through personal dosimetry and endeavored to examine WLFFS' perceptions, attitudes, and understanding of the hazardous noise, their use of hearing protection, training, and their current enrollment in a hearing conservation program.

The results of the personal noise dosimetry showed WLFFs are exposed to hazardous noise levels daily and can be at risk of developing NIHL. Sixteen percent of WLFFs exceeded the OSHA PEL and 32% exceeded the OSHA Action Level, while 54% exceeded the NIOSH REL. This difference in exceedance levels under the NIOSH and OSHA criteria is mainly due to the NIOSH REL being more protective than the OSHA PEL (the excess risk of developing NIHL over a 40-year working lifetime is 8% according to the NIOSH REL of 85 dBA vs. 25% excess risk at the OSHA PEL of 90 dBA). The differences in criteria should be considered when examining the issue of compliance versus protecting the hearing health of WLFFs, especially when it comes to enrollment in hearing conservation programs and requiring the use of hearing protection devices. Almost all WLFFs and personnel who operated bulldozers, along with masticators/chippers, pump operators, leaf blowers, sawyers/swampers, and helicopter pilots exceeded the NIOSH REL. The highest TWAs and noise dose, on the basis of NIOSH REL measurement criteria, were recorded for a bulldozer operator (TWA of 112 dBA and noise dose over 50,000%), a chipper (TWA of 109 dBA and noise dose of 24,000%), and a sawyer (105 dBA and noise dose of 9200%). To put these exposures in perspective, WLFFs exposed to 105 dBA without hearing protection would exceed their maximum daily limit in less than 4 min. According to the NIOSH noise exposure criteria, the bulldozer operator, at 112 dBA, would exceed his maximum daily limit in less than 1 min.[14] Interestingly, several bulldozer operators who operated in closed or environmental cabs had TWAs lower than the NIOSH and OSHA limits (20–30 dBA lower) because the cab enclosures isolated them from much of the noise. The common-sense approach to protect bulldozer operators from excessive noise is to use this simple noise control and equip the bulldozers with environmental cabs when possible. Use of such cabs removes the need to enroll the operators in hearing conservation programs and reduces the exposure of the bulldozer operator to dust and other particulates.

The results show that WLFFs noise exposures varied across job and job tasks. For some jobs, all WLFFs noise exposures were well above noise exposure limits. Whereas, for other jobs, some but not all exposures were above noise exposure limits. To reduce WLFFs risk of developing hearing loss and other hearing disorders, it is important to identify and characterize noise exposures across all jobs and job tasks. All WLFFs in jobs that have noise exposures or potential for noise exposures above occupational limits should enroll in a comprehensive hearing conservation program. A potential approach to reducing WLFFs risk of hearing loss is periodically rotating them from jobs or tasks with high noise exposures into jobs or tasks with lower noise exposures, if feasible.

WLFFs were asked to provide a subjective assessment of their perceived noise exposures from the various job tasks they are involved in on a daily basis during a fire season which can last from early spring until late fall. Those who responded as having *very high and high* noise exposures were above the NIOSH REL and OSHA Action Level of 85 dBA, confirming their self-assessment. Those who responded with *moderate* and *low*, were right around at the NIOSH REL of 85 dBA, while those who indicated they had *very low* noise exposures were below both the NIOSH REL and OSHA PEL. This suggests that WLFFs can accurately assess their noise environments and should trust their own instincts to avoid hazardous exposures, remove themselves away from such noise sources, or if not feasible, use proper hearing protection. It is worth noting that at least half of the WLFFs who reported having *low* or *moderate* noise exposure were not aware that they were in need of protection and being included in a hearing conservation program. Another interesting finding from the study concerns the 161 WLFFs who did not submit a response, yet, on average, their noise exposures (mean TWA of 87 dBA) exceeded the NIOSH REL. This specific finding is somewhat troubling because it suggests WLFFS are either disinterested in their own hearing health or they lack a level of awareness about the risk of noise exposure on their hearing and overall well-being.

Approximately 65% reported that they used some form of hearing protection, with the majority reporting using earplugs. Passive or electronic/level-dependent earplugs were the most commonly used hearing protection device. Both the 23% of WLFFs who reported not wearing HPDs and the 13% who did not provide a response on HPD use had mean TWA noise exposures greater than the NIOSH REL, but less than the OSHA PEL. Although OSHA would not require these WLFFs to use HPDs, NIOSH would consider them to be at risk of hearing impairment and would recommend they use HPD. No significant differences

were found in noise exposures between WLFFs who used earplugs, earmuffs, or banded earplugs. Most of the TWAs were in the high 70s dBA (per OSHA PEL) or mid-80s dBA (per NIOSH REL). Only two WLFFs wore double protection (both earplugs and earmuffs), and their noise exposures (mean TWA of 97 dBA and 98 dBA per OSHA and NIOSH respectively) ranged from 300% (per OSHA) to more than 4,000% (per NIOSH). These measurements show that double hearing protection is sometimes warranted for areas or tasks with such extreme noise levels. This also highlights the importance of matching noise dosimetry and exposure to HPD use.

The responses regarding HPD use and WLFFs' perception of the most important HPD features suggest that improved communication and situational awareness play a greater role in the consistent and regular use of hearing protection than any other factors. This confirms a similar finding by Hong et al. who reported that the ability to hear and communicate vital information was a very important factor in firefighters' decision not to wear hearing protection.[6] They also found that firefighters tended to ignore the risk of hearing loss when faced with hazardous and possibly life-threatening circumstances. The findings suggest that agencies and fire services should place more emphasis on the proper selection of HPDs that offer the greatest communication and situational awareness while still providing adequate hearing protection. Another important finding regarding proper training on HPD usage showed that only 19% of WLFFs ($n = 50$) reported receiving any training. This suggests that improvements in proper training on usage and fitting of HPDs are necessary to ensure greater adoption and acceptance among the various fire services and departments to help protect WLFFs hearing.

Current U.S. Forest Service policy does not require some WLFFs to be included in a hearing conservation program because their occupations are not included in the USFS hazardous noise occupational category. However, some occupations within the service, such as pilots and heavy equipment operators are included. This study identified that only 7% of the 264 WLFFs reported enrollment in a hearing conservation program, 22% receiving a baseline audiogram, and 16% reporting having regular annual audiograms, which is likely a reflection of the differences in fire service occupations included or not included in the hazardous noise occupational category. However, noise measurement results clearly show that almost all WLFFs occupations and job activities have noise exposures that may be considered hazardous to hearing. To reduce hearing loss risk, the USFS should include all WLFFs, as well as seasonal employees, in their hearing conservation programs. Hearing conservation programs should be tailored and developed for such a unique and transient working population. The programs should place greater emphasis on engineering and administrative controls to reduce noise exposure levels instead of solely relying on personal hearing protection devices. The programs should also include educational and training elements to improve WLFFs' understanding of the harmful effects of noise and the risk of developing NIHL, as well as the effect on their quality of life and employability prospects. Noise monitoring should continue to be a crucial element of any program, especially as new equipment and tasks are included. Finally, WLFFs should be fit-tested for proper hearing protection, and emphasis should focus on the selection of HPDs that offer greater communication and noise-limiting features.

Conclusions

This study evaluated the noise exposure of 264 wildland firefighters and collected 324 personal noise dosimetry measurements. The results showed that some or all WLFFs in all job titles had noise exposures above the NIOSH REL and were therefore at increased risk of developing noise-induced hearing loss. WLFFs perception of their noise environments were accurate and they should be trusted to make educated decisions to protect their hearing. The study also reported on WLFFs' use of hearing protection devices and showed that earplugs were the preferred device of choice. Firefighters reported that comfort and adequate attenuation were the most important features of HPDs. However, WLFFS also reported they would forgo use of HPD if they thought the devices would negatively affect their ability to communicate and maintain situational awareness. The lack of training and enrollment in hearing conservation programs can potentially have a detrimental effect on their overall hearing health. The next phase in the USFS and NIOSH collaboration aims to conduct hearing evaluations of select WLFFs crews and follow their progress over several years.

Acknowledgments

The authors would like to acknowledge each of the 264 tireless and dedicated wildland firefighters who participated in this study, who saw value in this research and in advancing the current state of science and hearing-loss prevention efforts, and without whom this publication would not have been possible. The findings and conclusions in this study are those of the authors and do not necessarily represent

the official position of the U.S. Forest Service or the National Institute for Occupational Safety and Health.

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