THESIS

NOISE EXPOSURES OF FIREFIGHTERS DURING TRAINING ACTIVITIES

Submitted by

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ABSTRACT

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Occupational hearing loss is the most common work-related injury in the United States according to the National Institute for Occupational Safety and Health (NIOSH). Consequently, NIOSH recommends that occupational noise exposure be among the top occupational hazard research areas of the next century. Firefighters represent a unique population in which noise exposure data are difficult to obtain. The unique settings in which firefighters perform their duties (e.g., inside burning structures) make it difficult to collect noise exposure data and quantify exposures due to environmental factors and unpredictability. Furthermore, firefighting requires that multiple tasks by each participant be accomplished during emergency responses.

In order to address the challenge of obtaining personal noise samples from firefighters during emergency situations, this study was conducted to gather firefighter personal noise samples during training exercises that simulated on-scene firefighting tasks. Noise exposure data were collected on five training days during the summers of 2010 and 2011. Two training exercises were executed each day, totaling ten training exercises. Each training exercise averaged 35 minutes in duration and included ten to eleven participants, resulting in ninety-three total personal noise exposure samples.

Noise monitoring results showed that none of the ninety-three (100%) firefighter samples were exposed to noise exceeding the Occupation Safety and Health

Administration (OSHA) permissible exposure limit (PEL) of an 8-hour time-weighted average (TWA) of 90 dBA. Nine of ninety-three (9.6%) exposures were above the OSHA action level (AL) of 50% dose when extrapolated across an 8-hour workday. Additional analysis was performed after dividing the noise exposure data into three groups consisting of *Interior*, *Exterior*, and *Engineering* categories. This division showed a statistically significant difference (alpha = 0.1) between the interior and engineer categories in relation to noise exposure.

ACKNKOWLEDGEMENTS

I would like to thank my family for all of their support while working towards the completion of this project. Additionally, my thanks go to my advisors for their time and expertise in completing this project. I would also like to thank the firefighters of the Poudre Fire Authority for their participation and support which made this project possible.

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LIST OF ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
ANOVA	Analysis of Variance
CFR	Code of Federal Regulations
CSU	Colorado State University
dB	Decibel
dBA	Decibel, A-weighted Scale
HCP	Hearing Conservation Program
HPD	Hearing Protection Device
ISO	International Standards Organization
Leq	Equivalent Continuous Sound Pressure Level
NFPA	National Fire Protection Association
NIHL	Noise-induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PFA	Poudre Fire Authority
StD	Standard Deviation
SLM	Sound Level Meter
TLV	Threshold Limit Value
TWA	Time Weighted Average

CHAPTER 1: INTRODUCTION

The formal definition of noise, as defined by the Merriam-Webster Dictionary, is any sound that is undesired or interferes with one's hearing of something.[1] Noise can be found in nearly every aspect of life; personal, social, and occupational. On any street corner one can experience what would be considered noise. Occupational noise is a direct concern to workers, as relatively high noise exposure has been correlated with hearing loss. Given the industrialization of the working environment, occupational noise exposure has steadily increased.

As occupational noise exposure has increased, concern regarding the hearing health of employees has increased. Many organizations have published standards or guidelines to help reduce the risk of noise-induced hearing loss (NIHL). The Occupational Safety and Health Administration (OSHA) serves as the governmental organization responsible for promulgating and enforcing occupational noise exposure regulations. OSHA specifies that occupational noise exposures be limited to a permissible exposure limit (PEL) of 90 decibels on an A-weighted scale (dBA) over an 8-hour TWA.[2] Furthermore, OSHA enforces an action limit (AL) of an 8-hour TWA of 85 dBA or 50 percent dose.[2] The AL is the threshold at which a hearing conservation program (HCP) must be implemented in order to protect employee hearing health. OSHA requires that noise exposure measurements be taken with a 5 dB exchange rate. The primary component of most HCPs is the use of hearing protection devices (HPD).

A second organization which recommends standards for occupational noise exposure is the American Conference of Governmental Industrial Hygienists (ACGIH). ACGIH specifies a threshold limit value (TLV) of 85 dBA over an 8-hour TWA.[3] The

TLV is considered to protect the median population from NIHL. ACGIH recommends that noise exposure measurements be taken with a 3 dB exchange rate. If noise levels exceed the TLV, workers are considered overexposed and the use of appropriate noise controls is recommended.

The National Fire Protection Association (NFPA) is responsible for providing recommendations and codes in order to ensure the welfare of firefighting personnel. NFPA 1500 7.16.1 insists that hearing protection should be provided for and used by all members subject to noise levels in excess of 90 dBA. [(4)] This guideline does not include the determination of an 8-hour TWA. Additionally, the NFPA classifies hearing loss as either a Category A medical condition or a Category B medical condition based on severity. [(5)] A Category A medical condition is defined as a medical condition which *would* preclude an individual from performing as a member in a training or emergency operational environment by presenting a significant risk to the safety and health of the individual or others. [(5)] A Category B medical condition is defined as a medical condition that, based on its severity or degree, *could* preclude an individual from performing as a member in a training or emergency operational environment by presenting a significant risk to the safety or health of the individual or others. [(5)] Hearing loss becomes a Category A condition when average hearing loss in the unaided better ear is greater than 40 dB at 500 Hz, 1000 Hz, 2000 Hz, and 3000 Hz. [(5)] A Category B medical condition exists when an average uncorrected hearing loss greater than 40 dB exists at the 500 Hz, 1000 Hz, 2000 Hz, and 3000 Hz in either ear. [(5)]

These standards show the potential severity of hearing loss when individuals become afflicted. Given the use of the Category A and Category B medical condition classifications, severe hearing loss can have a drastic effect on the professional firefighter. When hearing loss reaches the level at which it becomes classifiable, it can preclude a firefighter from continued duty.

Firefighters are a unique population of employees and present challenges for controlling occupational noise exposure. The nature of firefighting activities (e.g., intense heat, irregular exposures to noise, and long work-shifts) make it difficult to quantify personal noise exposures over the course of an entire shift. Research approaches that account for the limitations of dosimeters and other measurement equipment, as well as methodology for obtaining the best estimate of exposure, must be considered in order to accurately obtain data and protect the hearing of firefighters.

CHAPTER 2: LITERATURE REVIEW

Physiology of the Ear

The ear is an exceptional mechanism by which a person can discern sounds from the environment. This function allows for communication to be possible. For firefighters, one might argue that communication is especially important to perform effectively in the line of duty. Without the ability to hear, many every-day and fire suppression-specific tasks would become much more difficult. It is important that the ear and its function be protected from damaging noise.

The human ear can be divided into four distinct parts; the outer ear, the tympanic membrane (or ear drum), the middle ear, and the inner ear. All of these play a role in the process of hearing. First, sound is captured by the visible part of the ear, the auricle. Sound then travels through the external auditory canal. After passing through this canal, sound reaches the ear drum. Sound waves cause the eardrum to vibrate. The vibrations are carried across the eardrum and passed through three small bones, known as the malleus, incus and stapes. Collectively, these three bones are referred to as the ossicles, which serve to increase the strength of the vibrations thus amplifying the sound. The vibrations then pass into the cochlea of the inner ear and are translated into electrical signals by sterocilia that can be interpreted by the brain. [6] See figure 2.1.

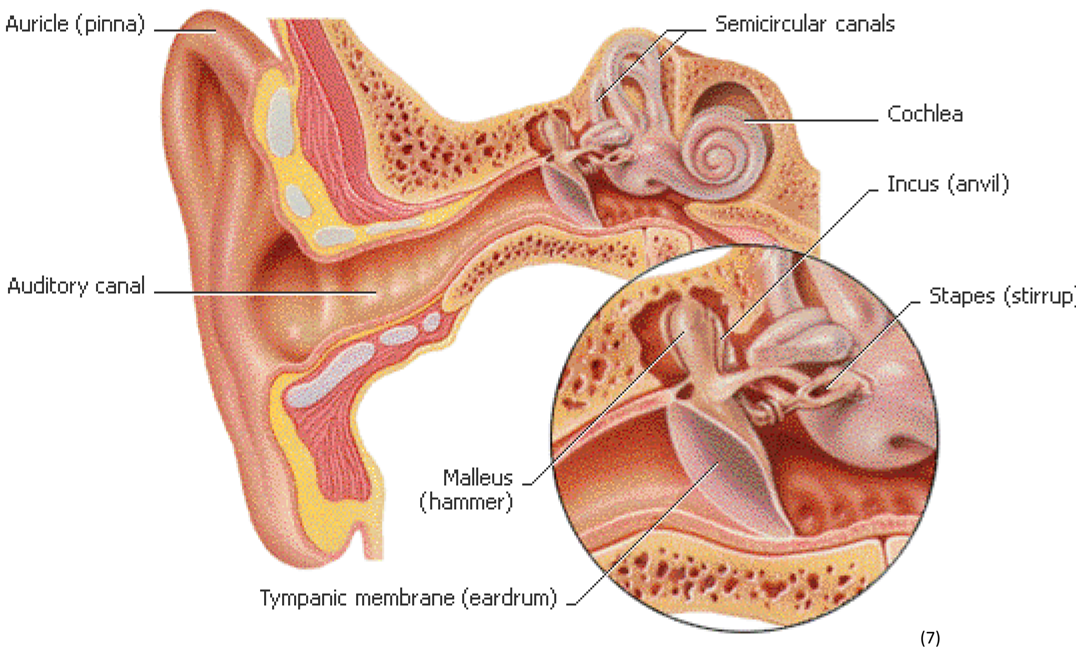

Figure 2.1: The Human Ear

Noise-Induced Hearing Loss

NIHL is characterized by a decrease in the hearing sensitivity in the human ear caused by excessive exposure to noise. This can be caused by a one-time, extremely loud noise or by long-term exposure to excessive noise over time. [8] Damage can occur to both the stereocilia within the cochlea and the nerve responsible for transferring electrical signals to the brain for interpretation. Changes to hearing capability can be short-term or long-term depending on the regularity of exposure.

There are three main types of hearing loss; conductive hearing loss, sensorineural hearing loss, and any combination of conductive and sensorineural. In conductive hearing loss, impedance occurs to decrease the transmission of sound to the cochlea. Some examples include blockage of the external auditory canal, perforation of the tympanum, or fluid build-up in the external auditory canal. Sensorineural hearing loss is attributed to damage of the stereocilia within the organ of corti or degeneration of the auditory nerve. This can occur for a variety of reasons. However, excessive noise exposure can damage the stereocilia thus leading to sensorineural hearing loss. Other causes include congenital defects, drug toxicity, and viruses. [9] NIHL is one form of sensorineural hearing loss.

It is estimated that 17% of adults suffer from some form of NIHL. [10] NIOSH proposes that twenty-two million workers are exposed to potentially damaging noise each year. In 2007, approximately 23,000 cases of occupational hearing loss great enough to cause hearing impairment were reported. [11] Amongst firefighters, NIHL has been shown to be 32.8% higher than data from the United States general population. [16] NIHL is dependent upon the surrounding environment. Environments possessing the potential for NIHL can be occupational or recreational (e.g., concerts or athletic games). Damage to the stereocilia is dependent upon the frequency of the noise exposure. Noises at higher frequencies cause greater damage due to sensitivities within the human ear. Frequencies of 3000, 4000, and 6000 Hz are the first frequencies to be observed during audiometric testing where hearing acuity is decreased. [12]

Two types of hearing threshold shifts or decrease in hearing acuity can be monitored in order to determine negative impact to hearing acuity. These include temporary threshold shifts (TTS) and permanent threshold shifts (PTS). A temporary threshold shift is a shift in hearing acuity that returns to standard hearing acuity after time. A permanent threshold shift is a shift in hearing acuity that is continuous and does not recover over time. [9] Threshold shifts can be easily avoided by following precautions and controlling the noise to which one is exposed. An individual should wear a HPD whenever she/he expects to be exposed to excessive noise. Regular hearing exams should be conducted to monitor changes in hearing acuity as age increases and are recommended by the NFPA. [12]

A hearing conservation program (HCP) should be put into place in order to protect the hearing health of employees if exposed to hazardous levels of noise. OSHA requires an HCP when exposure exceeds 85 dBA for an eight-hour TWA or 50% of the maximum dose. The functional components of a successful program include audiometric testing, continual monitoring, and HPDs where exposure exceeds the 85 dBA exposure limit. Multiple types of HPDs exist that can be successful in limiting noise exposure. The most common types include circumaural and aural inserts. Circumaural HPDs are more commonly known as earmuffs, and aural inserts are ear plugs. [13]

Relevant Studies

There are no current studies published regarding firefighter noise exposure during training exercises. Additionally, no studies have been published measuring noise exposures while actively participating in fire suppression largely due to the limitations of equipment and a desire to not hinder the process. However, there are studies that have been conducted in reference to sirens and overall noise exposure of firefighters.

A study was conducted in 1980 by NIOSH examining hearing loss due to noise exposure in firefighters. The researchers found that noise levels ranged from 99 dBA to 116 dBA. The associated 8-hour TWA ranged from 63 dBA to 85 dBA. [13, 14] Researchers found that exposure levels were correlated with hearing loss in the study population by performing audiometric testing. Audiometric testing showed that firefighters were experiencing permanent threshold shifts. This evidence suggested that a HCP should be put into place in order to protect hearing health.

Kales et al. found that firefighters experienced average accelerated hearing loss of 6 dB at the 90th percentile when compared to population databases from the International Standards Organization (ISO). [15] These researchers found that hearing loss associated with firefighting was strongly associated with age and the duration of time as a firefighter. Hearing loss was associated with the relative higher frequencies of sound perception.

Reischl et al. completed a study agreeing with the 1980 study performed by NIOSH. After surveying the hearing health of 750 Los Angeles City fire fighters, researchers found higher than average permanent threshold shifts at the 3000 Hz, 4000 Hz, and 6000 Hz frequencies. Additionally, researchers compared this finding with fire fighter medical histories and data about lifestyle and hobbies. They concluded that other factors would not have substantially contributed to hearing loss and subsequently recommended that a HCP be put into place. [16,17]

Randy L. Tubbs was a primary researcher of noise exposure and NIHL among firefighters. In one study, he found that TWAs ranged from 60-82 dBA amongst firefighters responding to emergent incidents. [18] Furthermore, Tubbs was able to show that the average firefighter in the Memphis area experienced a permanent threshold shift. After this study, a HCP for the Memphis fire department was implemented. Further studies confirmed that firefighters were experiencing hearing loss faster than the average population, and it became general knowledge that firefighters should participate in a HCP while on duty.

Since the promulgation of the OSHA noise standard in the 1970's, multiple firefighter noise exposure studies have been published. However, few of these studies took into account what the firefighters thought of hearing protection and their willingness to participate.

A study by Hong et al. found that while firefighters acknowledged the importance of hearing on the job, few were willing to use HPDs because they felt that they interfered with their ability to accomplish necessary tasks. [19] Firefighters perform a variety of tasks while performing their duties. These tasks can range from search and rescue within a burning structure, starting equipment that clears a structure of smoke, and running the pumps that supply water during fire suppression. In addition, these researchers found that the HCPs were not followed for this reason. This presents a serious problem for preserving the hearing of firefighters.

In a second study, Hong et al. found that HCPs and diligent use of HPDs could significantly reduce the risk and prevalence of NIHL among the firefighting population. [20] This showed that interventions could be successful if followed appropriately. The researchers also recommended that effective interventions are needed to educate firefighters about the hazardous effects of noise and the importance of HPDs.

CHAPTER 3: PURPOSE AND SCOPE

Purpose

The purpose of this research was to determine if firefighters at the Poudre Fire Authority (PFA) were overexposed to noise during routine training activities which simulated small house fires. Noise data were collected based on the OSHA noise standard. Additionally, data were stratified by activity type in order to better determine which tasks exposed firefighters to greater noise levels, and consequently higher doses. The job activities were then combined into three groups; exterior crew, interior crew, and engineers. Analysis of the noise exposure data by job type will benefit the PFA by providing them an analysis of different job types by which to determine what jobs pose a higher risk of NIHL. Using these data, firefighters can determine where HPDs can be most effectively used and what activities offer the highest exposure to noise.

Research Questions

The data were collected and analyzed to answer the following questions:

1. Do PFA firefighters have a potential for overexposure to noise during routine training activities?
2. Is there a significant difference in noise exposure between the different job types or activities?

Scope

This research included personal noise exposure monitoring for ten firefighter training events at two different training sites. Firefighters were fitted with dosimeters that measured their personal noise exposure level during each training event. The work tasks of each firefighter were divided into three job categories for statistical analysis: *Interior*, *Exterior*, and *Engineer*. Work tasks within each job category included: interior search, backup line, outside crew, second line out, attack line, technician, engineer, captain, battalion chief, exterior, search ladder, and ladder crew. The following noise exposure parameters were measured for each firefighter: time, OSHA dose percent, Leq, L_{max}, and the OSHA-projected eight hour dose. All data were collected during the summer months of 2010 and 2011.

CHAPTER 4: MATERIALS AND METHODS

A total of 93 personal noise exposure measurements were taken on fire fighters during routine training activities. The sampling occurred at two different training facilities. One location was located near a busy intersection and the other location was located at a rural training facility. All aspects of this study were conducted in compliance with the Research Integrity and Compliance Review Office at Colorado State University.

Data Collection

Personal noise samples were taken using Ametek MK-2 and MK-3 type II audio dosimeters. Each dosimeter was set to record on the A-weighted scale with slow response. Each dosimeter was pre- and post-calibrated for accuracy and was found to be within +/- 1 dB. An institutional review board (IRB) approved recruitment script was read to all subjects at the beginning of each sampling day and informed consent was obtained from each of the firefighters. Dosimeters were attached to firefighters using one of three different methods depending on their work tasks. In all three methods, the dosimeter microphone was located within the OSHA recommended 2 foot diameter surrounding the head on the shoulder of the subject. Additionally, microphones were placed on the shoulder opposite of the ear accommodating the radio ear bud. For firefighters using air packs, the dosimeter was attached to the hip strap of the air pack and the microphone wire and microphone were guided up to the location on the shoulder. For firefighters that did not use air packs but still wore overcoats, the dosimeter was attached to the belt and the microphone was guided underneath the overcoat and up to the location on the shoulder. Excess dosimeter microphone wires were wound up and tightened with a twisty-tie, rather than tape, to avoid equipment exposure to an adhesive. An adhesive could potentially compromise the integrity of the suit. The third method was used for firefighters in vehicles or those that did not wear overcoats. These dosimeters were placed in an inside garment pocket or on the inside of the pants with the microphone wire guided up and the microphone placed on the shoulder below the ear.

Two personal noise samples were taken on each firefighter for each data collection day; one sample for each of the two training events. Between 8 and 12 firefighters participated each day. Dosimeters were attached to the firefighters during the entire training exercise. Training exercises included all activities that are typically completed during an actual fire-fighting event, including the use of fans, chainsaws, and directed water disbursement. Generated heat was excluded for the purpose of the training exercises due to equipment limitations. Heat generated during the training exercises could exceed the level where equipment was effective, thus destroying the equipment. Data were collected after the first event and then the dosimeters were reset for the second event. Between the exercises, a break in activity occurred averaging ten to fifteen minutes after which the second event was executed.

The flow of activities was standard for a typical fire-fighting event, beginning with the arrival of the first-in crew. Approximately two minutes later, the second crew would enter the exercise. After another approximated two minutes, the third crew arrived. The outside crew would activate fans within four minutes of the start of the exercise when a crew would enter the structure, and chainsaws were used when two firefighters ascended the roof of the structure at approximately seven minutes after the beginning of the exercise. The average time of each training event was 35 minutes.

A Larson-Davis System 824 Sound Level Meter/octave band analyzer was used to obtain background noise levels at the site that was located near a busy intersection to evaluate the contribution of noise from traffic. The SLM was pre- and post-calibrated using a Larson-Davis Acoustic Calibrator Cal 200, 1000 Hz, and found to be within acceptable limits. Data were collected to the north, east, and south of the practice building in twelve foot increments with the final location at thirty-six feet from the building. The SLM was raised sixty inches high on a tripod while data were collected. The average background traffic noise was 65 dB L_{eq}. Background noise could potentially have contributed to exposure measurements at the first site.

Grouping by Job Task

Firefighters perform a multitude of tasks while on the job. For this reason, three job categories were identified and then each job task was assigned to a job category based on the relative location of the task. The three job categories were *Interior*, *Exterior*, and *Engineer*. The interior crew included the job tasks of: interior search, attack line, interior crew, search ladder, second interior engine, search and rescue, engine nozzle, and the captains of these respective groups. These tasks were all those individuals who were expected to be within the structure over the course of the exercise. The exterior crew included the job tasks of: second out line, backup line, outside crew, exterior, battalion chief, second interior hose line, second in, ladder out, outside crew truck, fans and chainsaw out, and the respective captains for each group. These individuals remained outside the structure as support, operating equipment such as chainsaws, fans, and ladders. Engineers included the job tasks of: technician, engineer, and pumping the engine. These individuals remained near the fire engine, ensuring that water supply was constant.

Analysis of Data

Data from the Ametek MK-2 and MK-3 dosimeters were manually recorded following each training exercise on a data sheet. Analysis included descriptive statistics for the entire group, each job task, and the three job categories (interior, exterior, and engineer) using the dose percent and predicted 8 hour dose percent for OSHA and the average noise level (L_{avg}). All measurements were measured in the A-weighted scale. Tests for normality were performed on the total data sets and on each activity data set. Student's T-tests were used to assess the validity of the data against the 85 dBA OSHA action limit. A generalized linear model was used to compare the mean of each activity group and to determine the presence of any statistical difference. Microsoft Excel and Statistical Analysis System (SAS) statistical software were used to perform the calculations and analysis of all data. Statistical methods were verified using the Colorado State University Statistics Consultant Office.

CHAPTER 5: RESULTS AND DISCUSSION

Results of the L_{avg}

Ninety-three total firefighter personal noise exposure samples were taken during ten training events on five separate occasions at two locations during the course of this study. The L_{avg} and dose percent data were analyzed in order to determine compliance with recommended protective standards. Table 5.1 shows descriptive statistics for the L_{avg} for all data and each of the activity categories.

Table 5.1: Descriptive Statistics for the L_{avg}

Category	N (number of samples)	Mean (dBA)	Standard Deviation (dBA)	Standard Error
All L_{avg} Data	93	78	6	0.6
L_{avg} Interior	41	77	5	0.8
L_{avg} Exterior	41	78	6	0.9
L_{avg} Engineer	11	81	6	1.8

Data were analyzed for normal distribution and then a student's t-test was used to determine the validity of the findings (See Figure 5.1). Additional analysis was performed on each of the activity categories in order to determine the validity of the mean in each group against the 85 dBA AL. See Figures 5.3-5.5 for tests for normality. See Table 5.2 for t-test statistics. Each test performed had a total power of 1 with the exception of the t-test for the engineering category which had a power of 0.79. The p-values show that there was no statistically significant overexposure when compared to the standard of 85 dBA.

The mean values for each group appear to be relatively low when considering the equipment used by firefighters. However, firefighters are not continuously exposed to maximum L_{avg} decibels. Given the short time period that monitoring occurred, and the intermittent exposure, the means were offset by the higher number of low exposures.

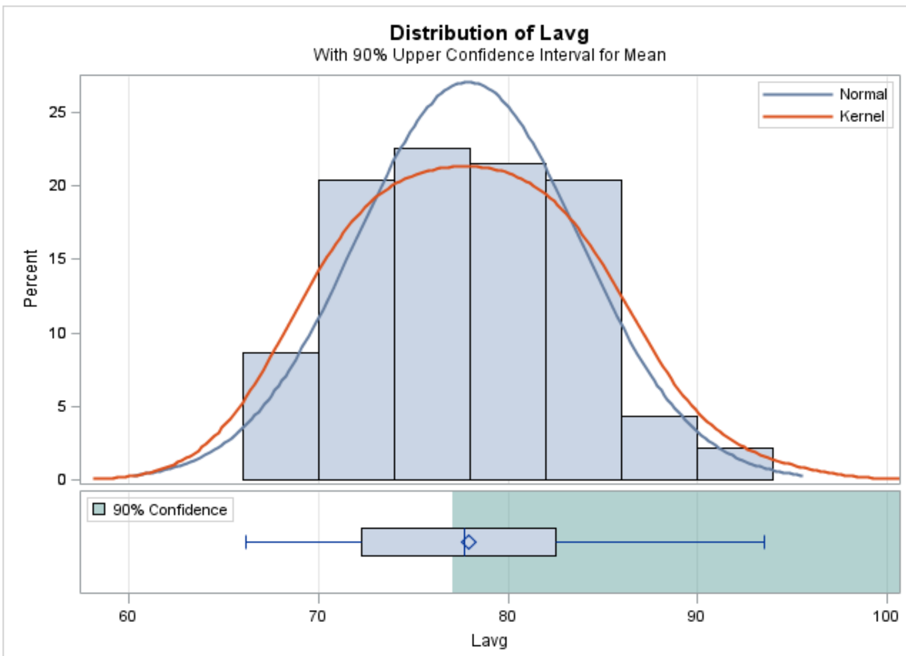

Figure 5.1: Distribution of All L_{avg}

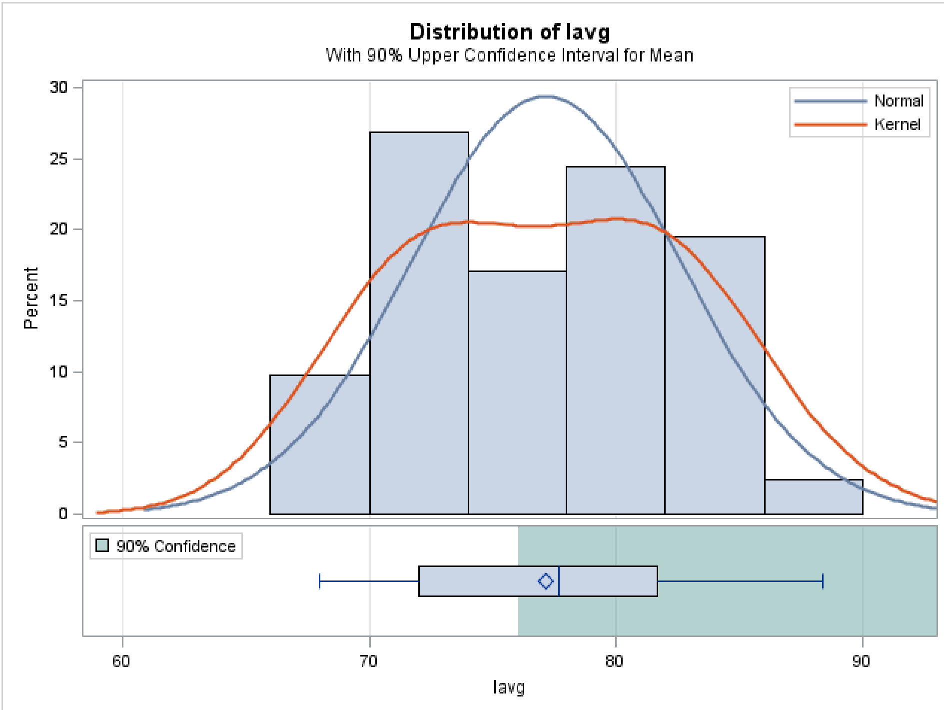

Figure 5.2: Distribution of Interior L_{avg}

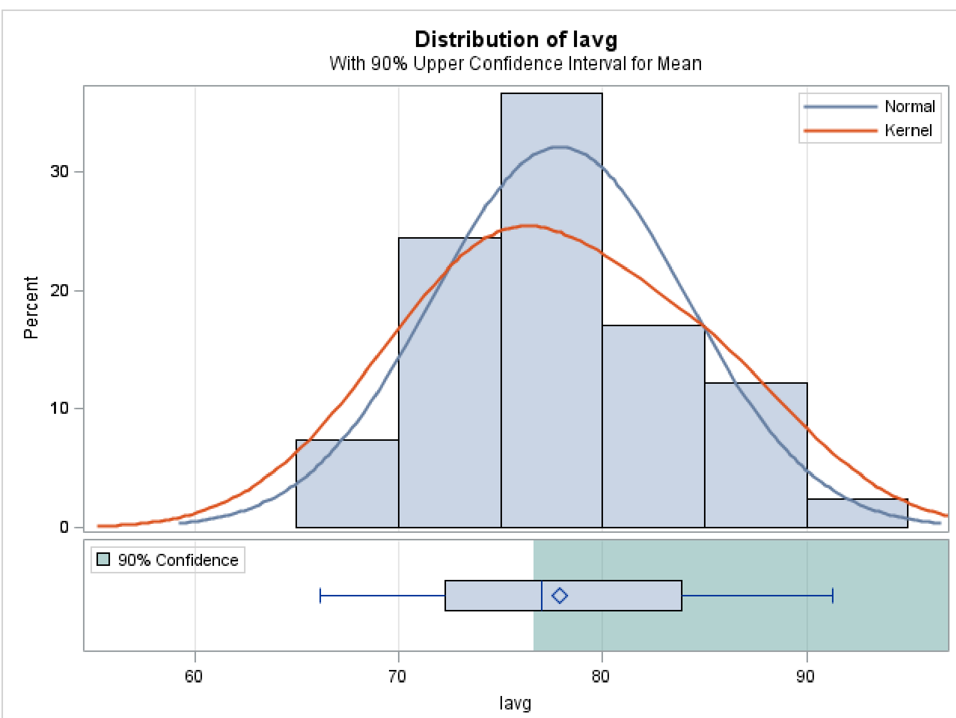

Figure 5.3: Distribution of Exterior L_{avg}

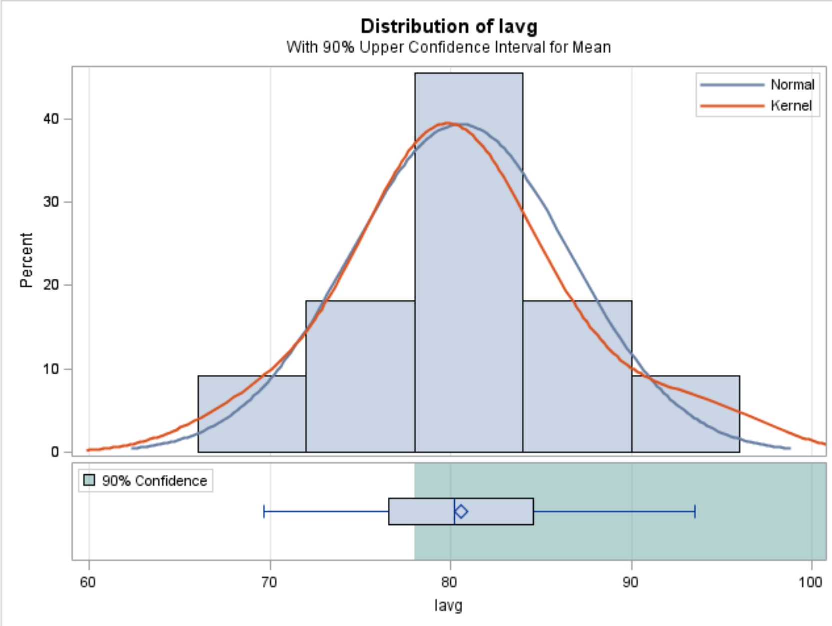

Figure 5.4: Distribution of Engineer L_{avg}

Table 5.2: T-test Values for L_{avg} Comparisons

Category	Degrees of Freedom (DF)	t Value	p-Value
All Data	92	-11.63	1.0000
Interior	40	-9.26	1.0000
Exterior	40	-7.29	1.0000
Engineer	10	-2.42	0.9820

Data from each of the three categories were then analyzed using a generalized linear model or one-way analysis of variance (ANOVA). This test had a power of 0.88. Figure 5.5 shows the distribution of means between each category. Table 5.3 gives the relative p-values between each group. These p-values indicate that there was a statistically significant difference between the mean exposure of the *Engineer* group and the *Interior* group in terms of the L_{avg}.

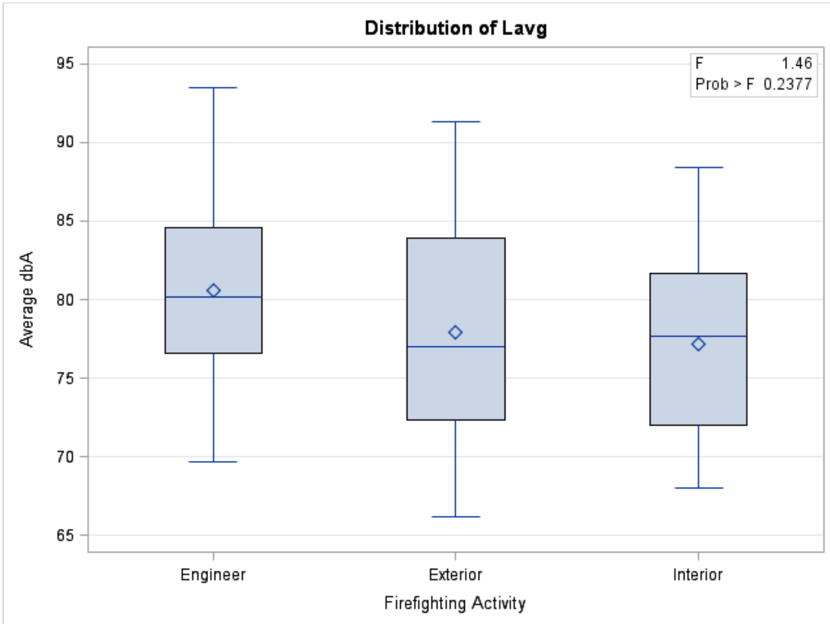

Figure 5.5: Distribution of L_{avg} Group Means

Table 5.3: Relative L_{avg} P-values Between Group

Category	Interior	Exterior	Engineer
Interior		0.1881	0.0910
Exterior	0.1881		0.5585
Engineer	0.0910	0.5585	

<u>Results between Groups</u>

Data collected regarding the dose percent were not normally distributed. Therefore, the data were transformed using the common logarithm. Upon analysis for normality, it was concluded that the dose percent data had a lognormal distribution. Descriptive statistics for dose percent data can be found in Table 5.4.

Table 5.4: Descriptive Statistics for Dose%

Category	N (number of samples)	Mean (%)	Standard Deviation (%)	Extrapolated 8-hour Dose (%)
All Dose % Data	93	2.2	2.7	28.7
Dose % Interior	41	1.4	1.1	21.7
Dose % Exterior	41	1.9	2.3	26.5
Dose % Engineer	11	3.2	4.6	38.0

All data were tested for lognormal distribution (Figures 5.6-5.9). T-test analysis was performed on all the data as well as for each of the groups to test against the OSHA 50% dose in order to validate the conclusions. Table 5.5 provides computed values. Each test had a total power of 1.

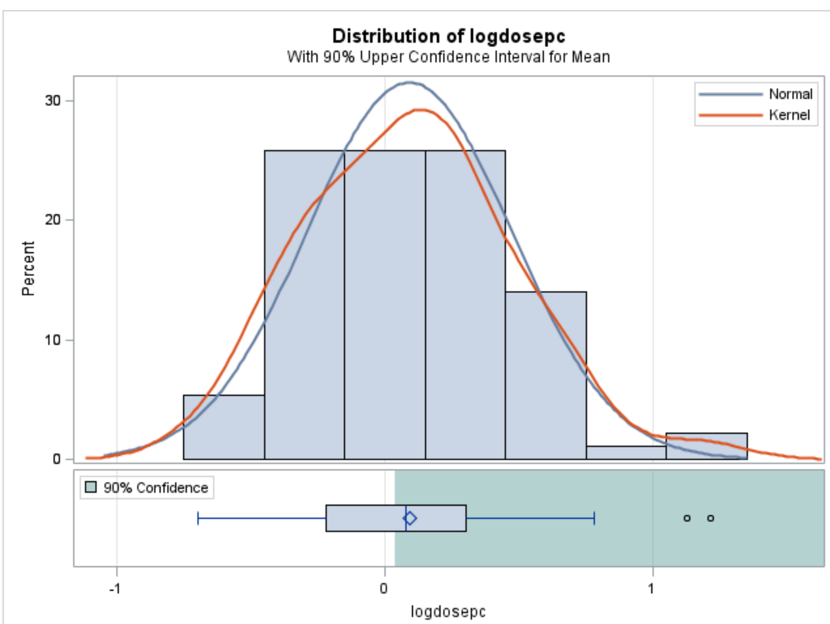

Figure 5.6: Lognormal Distribution for Total Dose%

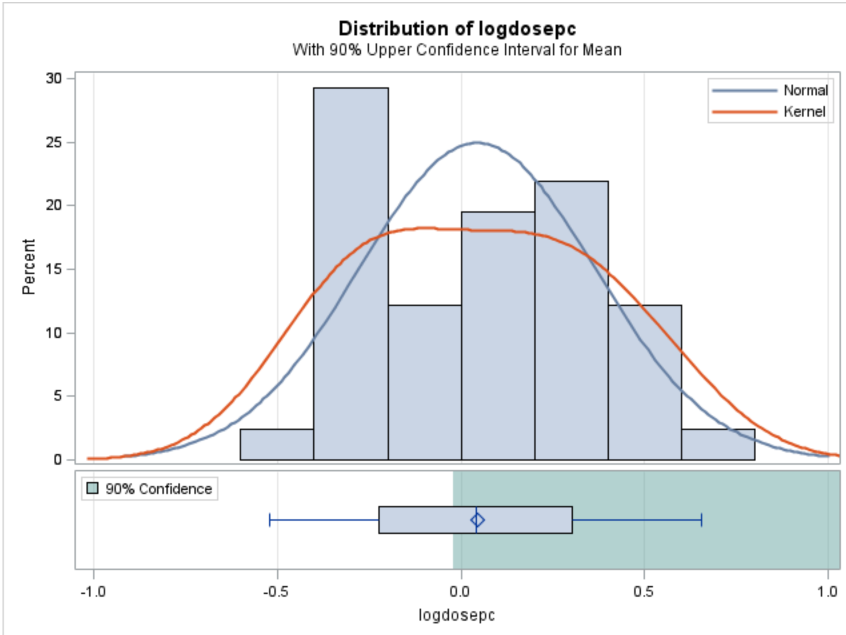

Figure 5.7: Lognormal Distribution for Interior Dose%

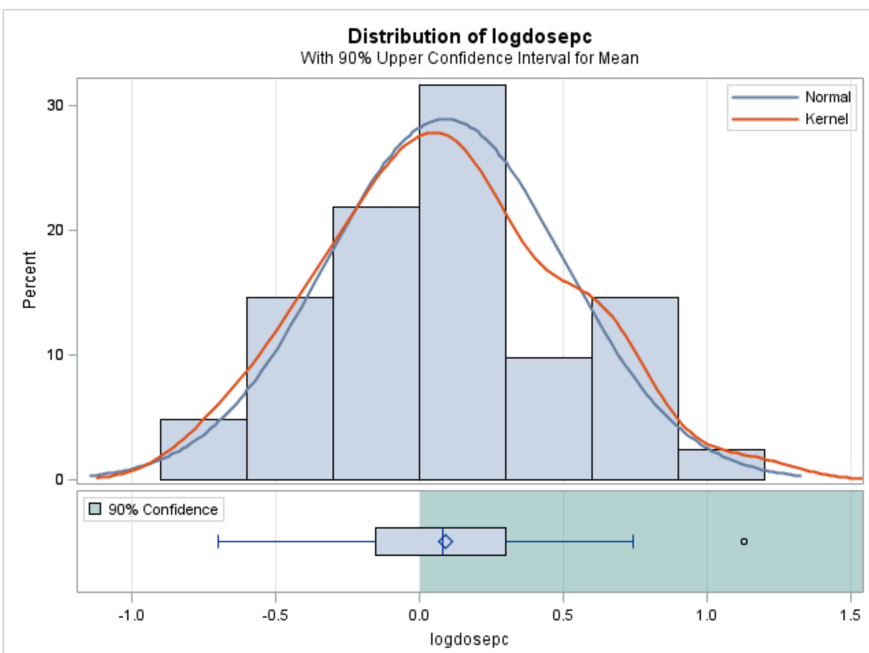

Figure 5.8: Lognormal Distribution for Exterior Dose%

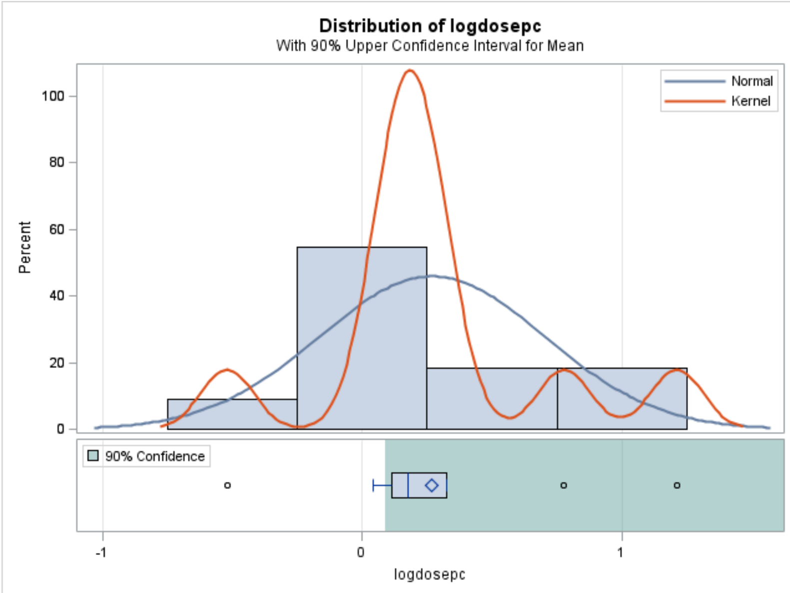

Figure 5.9: Lognormal Distribution for Engineer Dose%

Table 5.5: T-test Values for Log [Dose%]

Category	Degrees of Freedom (DF)	t Value	p-Value
All Data	92	-40.88	1.0000
Interior	40	-33.12	1.0000
Exterior	40	-24.95	1.0000
Engineer	10	-10.92	1.0000

Dose percent data from each category was compared using a one-way ANOVA with a power of 0.65. Distribution of the transformed dose percent data can be seen in Figure 5.10. Relative p-values for comparison between each value can be seen in Table 5.6. P-values indicate that there was a statistically significant difference between the *Engineer* and *Interior* groups.

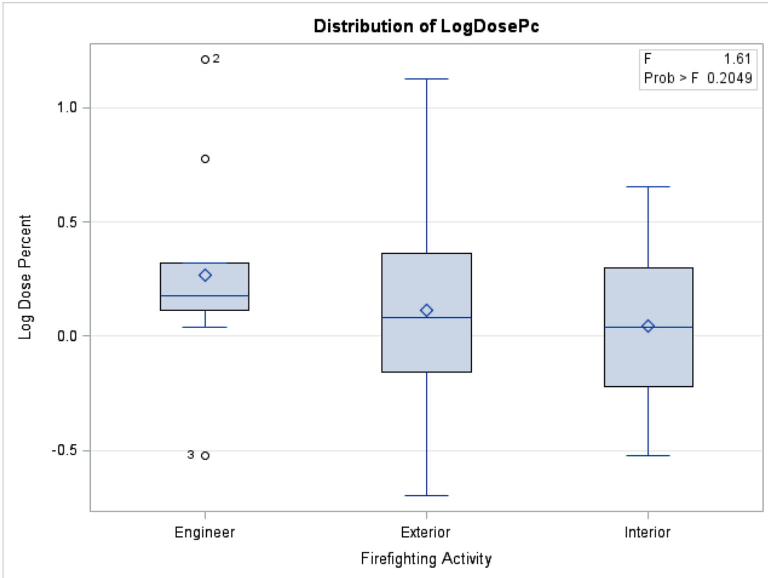

Figure 5.10: Distribution of the Log [Dose%] Between Groups

Table 5.6: Relative P-values for Comparison of Log [Dose%] Between Categories

Category	Interior	Exterior	Engineer
Interior		0.2305	0.0801
Exterior	0.2305		0.3891
Engineer	0.0801	0.3891	

Limitations

There were several limitations in this study that must be acknowledged. The greatest limitation was the short duration of the training exercises. Even though an extrapolation can be made from the 35 minute exercise across an entire 8 hours, this is not realistic. Noise exposure should not remain at a constant level for that entire time. Therefore, in order to account for this limitation it would be necessary to obtain dosimeter data across an entire shift. Furthermore, a firefighter does not work an ordinary 8-hour shift. Normally, a full 24-hour or 48-hour shift is the standard for an average firefighter. Even if dosimeter data became available across 8 hours, additional extrapolation would have to occur in order to estimate noise exposure over the full time period.

Another limitation to the study is that the simulated exercises did not include combustion, sirens, or many of the other noise sources present during an actual emergency response. By not including these extra sources of noise in the dosimeter readings, noise exposure can be expected to decrease. In addition, a typical fire-fighting event may not be represented by the 35 minute average simulated training exercise. From the data, it can be concluded that the groups furthest from the engines received the lowest dose. One might hypothesize that this would be due to the additional barriers between the firefighter and the noise. The majority of noise during the training exercises came from the engines, fans, and chainsaws. The interior crew was within the walls of the house, and therefore may have received additional protection from the engine, fan, and chainsaw noise. The exterior crew was the next highest group being in the middle between the house and the fire engines. The distance from the engine provided some protection from noise in comparison to the engineers. The highest exposure occurred in the engineer group. This was most likely due to the fact that they were closest to the noise being generated by the pumps and generators on the fire engines.

Noise exposure from communication equipment (ear buds) was not measured. Depending on the volume selected by the firefighters, this could have a large impact on the measured noise doses. Excessive volumes would indicate a higher exposure than was actually measured. The implications of radio volume on the impact of NIHL could be significant especially if the radio volume had to be sufficient enough to be heard over the extraneous noise associated with the training activities.

Wind screens were not used on the dosimeter microphones. This creates a limitation in that additional exposure might have been recorded from wind striking the microphones. Without wind screens, data could potentially be higher than the actual noise exposure causing measurements to be elevated in relation to the true exposure.

During the first day of training exercises, the break between activities was included in the overall measurement. This potentially lowered the measurements because of the 10-15 minute period where equipment was not in operation. However, the measurements were not different from the rest of the samples, indicating that the inclusion of the break had little to no effect on the measurement. The noise exposure throughout the training activities was intermittent. The addition of the break in the measurement would not significantly lower the measurement due to averaging of the total measurement over the course of the entire exercise.

Engineers were shown to have the highest exposure over the course of the training activities. However, multiple outliers were seen within this group. This possibly could have occurred due to different designs in the layout of the fire engines and equipment. The positions of stationary equipment (e.g., generators and pumps) could account for this variability in exposure. Given the location of the equipment in relation to the control panel, different levels of noise exposure would be expected according to the differences in distance. This study did not account for those differences.

The measurements obtained in regards to Dose % present another limitation. The data obtained indicate that firefighters were exposed to a relatively small noise dose over the course of the training activities. By these data, approximately 30 training activities would have to be performed in order to reach the 100% dose level. This is due to the short time period of the training activities and the relatively low noise exposure measured. The extrapolated Dose % indicates what the dose would be if exposure were constant over an entire 8-hour period instead of the time of the training activity. However, the likelihood of the exposure from the training activities being constant over 8 hours is questionable.

An error in classification could potentially also violate the results of this study. Firefighting duties are highly variable and given the nature of these duties, it is possible that a firefighter would be required to perform additional duties outside the range of classification. For example, perhaps an individual classified as *Interior* by this study must assist at the truck pumps. Therefore, the classification would in fact be *Engineer*. This represents an issue in determining location when considering overall noise exposure.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

None of the 93 firefighter samples exceeded noise limits during the course of the training activities as compared to the OSHA PEL of 90 dBA 8-hour TWA or a 100% dose. Statistically, a significant difference (alpha = 0.1) in noise exposure between the *Engineer* and the *Interior* was found, however the lower noise exposure to the *Interior* could be attributed to the lack of noise exposures within the structure. It would be expected that there would be additional noise exposure to all groups, especially *Interior* during an actual house fire (e.g., combustion and collapsing structures).

It is difficult to compare the L_{avg} results to the standards. None of the measurements taken showed exposure above the recommended 90 dBA of the NFPA. However, extrapolating the sample measurements to an 8-hour TWA is inaccurate in that the variability of the exposure is too high to assume constant exposure over the course of an entire 8-hour period. Furthermore, firefighter work shifts are not 8 hours but can be either 24 or 48 hours instead. OSHA recommends for an extended work shift of 24 hours a TWA of 83 dBA. Even with that knowledge, extrapolation of the data observed in this study would not give an accurate representation of the exposure in terms of the true exposure over a firefighter's shift but rather a 24 hour period that was all training activities.

When extrapolated across an eight-hour period, nine firefighters were predicted to be exposed to more than 50% of the recommended noise dose. This could be attributed to random variables occurring during the training activities or differences in personal habits while performing duties. However, this illustrates that if noise exposure were to remain constant throughout the entire shift, there is a strong possibility of overexposure.

Recommendations

The PFA should continue a HCP including audiometric testing to monitor possible NIHL. This is especially true for those areas and tasks known to contribute to additional noise exposures (e.g. *Engineer* versus *Interior* tasks). As new technology becomes available, further research and better HPDs should be implemented. Continued research should be conducted to determine noise exposure levels contributed by the many activities performed by firefighters. As more data are collected and analyzed, a better understanding of possible exposures will be obtained and better control strategies will become available.

Specific recommendations were made based on the exposures from this study and also from current literature regarding the subject. Firefighters are normally observed to experience increased hearing loss. The exposure measured from this study is just one piece of an overall shift exposure for firefighters. Caution should be maintained in all facets of firefighting duty until further studies can identify those firefighter duties that pose maximum noise exposure. These recommendations are cautionary in order to protect firefighter hearing health in case of excessive noise exposure in relation to an entire shift and not just training activities.

Further Studies

Further studies should be conducted to evaluate the difference between noise exposures for the different job tasks during actual firefighting responses. The focus should be on obtaining adequate data to statistically compare job tasks to provide a better quantification of the risk associated with each activity. With the accumulation of more data, the correlation between job activity and noise exposure will allow better control methods to be implemented. As new technology becomes available, in terms of more durable (i.e., heat resistant) equipment, studies should be conducted during real-time emergency responses to determine the actual noise dose received by firefighters. Studies should be directed towards obtaining a total-shift noise exposure estimate. Extrapolations can be made from smaller periods of time; however the variability inherent in fire suppression responsibilities and necessary adaptations to the task at hand will continue to prove difficult in assessing a total noise dose.

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