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# Injury Risk and Noise Exposure in Firefighter Training Operations

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## ABSTRACT

**Introduction:** Firefighters have high rate of injuries and illnesses, as well as exposures to high levels of noise. This study explored the relationship between noise exposure and injury among firefighters.
**Methods:** We recruited firefighters undergoing vehicle extrication and structural collapse emergency response training at a highly realistic training facility. Demographics, health status, body mass index (BMI), and history of serious injuries (i.e. injuries requiring first aid treatment, treatment in a medical clinic or office, or treatment at a hospital) were assessed at baseline, and daily activities, injury events, and near misses were assessed daily via surveys. Participants' noise exposures were monitored for one 24-h period using noise dosimeters. We used a mixed-effects logistic regression model to estimate the odds of injury events and near misses associated with noise exposure as an independent variable.
**Results:** Of 56 subjects, 20 (36%) reported that they had ever suffered a serious injury during firefighting activities, and 9 (16%) reported a serious injury within the past year. We estimated rates of 6.6 lifetime serious injuries per 100 FTE 16.1 serious injuries per 100 FTE within the past year. Our models indicated a significant increase in injury events and near misses among those with higher BMI, and as well as a dose–response relationship between near misses/injuries and increasing noise levels. Noise levels >90 dBA in the 30 min prior to time of injury or near miss were associated with substantially increased odds ratios for injury or near miss. Our models further indicated that perceived job demands were significantly associated with increased risk of injury or near miss.
**Conclusion:** Our results suggest that noise exposures may need to be incorporated into injury prevention programs for firefighters to reduce injuries among this high-risk occupational group.

KEYWORDS: firefighting; injury prevention; noise exposure; occupational injury

## INTRODUCTION

Occupational injuries result in a substantial and preventable social and economic burden in the USA. In 2007, the ~5,600 fatal injuries among workers resulted in costs of $6 billion, and the nearly 8.6 million reported nonfatal injuries cost $186 billion (Leigh, 2011). Estimates of nonfatal injuries are undoubtedly low due to underreporting (Spieler and Wagner,

2014) and lack of investigation of minor injury events, despite evidence that prevention of minor injuries and near misses can reduce the likelihood of more serious and expensive injuries (Wright and Van Der Schaaf, 2004; Alamgir *et al.*, 2009).

Firefighting is a high-hazard occupation that involves intense physical activities, dynamic emergency situations, and exposures to heat, air contaminants, and other hazards. As a result, firefighters face an elevated risk of occupational injuries and illnesses (Leigh and Miller, 1997). In 2012, the ~1.1 million firefighters in the USA (NFPA, 2012)—of whom 31% were professional career firefighters—experienced ~69 400 occupational injuries. About 45% of these injuries occurred during fireground operations—which represented only about 5% of all emergency calls (National Fire Prevention Association, 2012)—while 18% occurred at non-fire emergency incidents, 19% occurred during other on-duty activities, and 10% occurred during training (Karter and Molis, 2013). The most common types of injuries experienced during fireground operations were strains, sprains, and muscular pain, followed by lacerations, bruises, thermal stress, and burns, while the most common causes of fireground injuries were overexertion, falls, slips, and jumps (Karter and Molis, 2013).

In addition to acute safety hazards, firefighting involves other health risks. Noise is ubiquitous in occupational settings and is the leading cause of acquired hearing loss among working adults, including firefighters (Kales *et al.*, 2001). A recent review of 10 studies on noise exposure among firefighters (Taxini and Guida, 2014) reported that 50% of the studies confirmed noise-induced hearing loss (NIHL) among firefighters, and 37% considered firefighters to be a population at risk for NIHL. Firefighters with NIHL may no longer be fit for duty in certain hearing-critical activities such as radio communication or listening for victim sounds. Noise exposure is also associated with adverse social, psychological, and health outcomes, including cardiovascular disease (CVD) (Basner *et al.*, 2014). CVD and strokes were responsible for 41 of 83 (49%) occupational fatalities among firefighters in 2012 (USFA, 2013). Noise exposures have not been well-studied among firefighters, but the limited existing data suggest that exposures may be widespread (Tubbs, 1995), specifically during emergency response and training operations (Kales *et al.*, 2001; Neitzel *et al.*, 2013). Neitzel *et al.* (2013) demonstrated potential for exposure >85 dBA, the full-shift time-weighted average limit recommended by the US National Institute for Occupational Safety and Health (NIOSH), and found that the highest levels were associated with saws and pneumatic chisels (Neitzel *et al.*, 2013). For reference, 60 dBA is approximately as loud as normal speech at arm's length, 85 dBA is about as loud as a gasoline-powered lawnmower, and 100 dBA is roughly as loud as a motorcycle.

Several studies have found associations between high noise exposures and injury, and have estimated that 12–63.9% of workplace accidents in the industries studied were attributable to noise exposure or NIHL (Dias and Cordeiro, 2007, 2008; Picard *et al.*, 2008) Researchers have also documented associations between noise exposure and occupational fatalities (Barreto *et al.*, 1997; Melamed and Froom, 2002; Melamed *et al.*, 2004). A potential association between hearing loss and injury has also been identified in workers (Girard *et al.*, 2015; Cantley *et al.*, 2015) including firefighters (Ide, 2007).

The relationship between noise and CVD—the leading cause of death among firefighters (USFA, 2013)—combined with the potential association between noise and injury risk suggests that further study of noise exposures among firefighters is warranted. However, studies of occupational exposures among firefighters are logistically challenging, as conducting research in real emergency situations could create risks for responders, victims, and researchers. To safely and efficiently conduct a study of noise exposures and injury risks, we utilized the Illinois Fire Service Institute (IFSI) training facility in Champaign, Illinois. The IFSI campus is the statutory fire academy for the state of Illinois, but firefighters from Illinois and around the world train at the campus. The facility is comprised of 28 acres of training props and is one of few locations in the USA that uses live-fire structural burns in training. The campus includes real-life training props for hazardous materials, collapsed buildings, high-rise buildings, trenches, and vehicle rescue. The IFSI provides nine training programs to firefighters throughout Illinois and the world. Instructors deliver more than 300 classes and 14,000 class hours to students online, on campus and at regional training centers throughout the state. Our study used a mixed-methods approach to test the hypothesis that higher levels of noise would be associated with a higher risk of injuries and near-miss accidents, even after controlling for known injury risk factors such as body mass index (BMI), age, previous injury experience, and activity performed.

## METHODS

All research procedures were approved by the Institutional Review Boards of the University of Michigan (UM) and the University of Illinois at Urbana Champaign. The research was conducted on the IFSI campus. Research staff identified four 40-h, 5-day firefighter training courses between October 2013 and May 2014 which would involve noise exposure and physically intense training. Two classes focused on vehicle/machinery operations, the third was a vehicle/machinery technician class, and the fourth was a structural collapse class. The vehicle and machinery operation course is a basic training class designed to acquaint students with common techniques used in auto extrication. The vehicle and machinery technician course is an advanced class designed for those who respond to large/heavy vehicle accidents. The structural collapse technician course offers practice in cutting, breaching, lifting, stabilizing, searching, shoring, packaging, and removing victims from a simulated collapse environment. All classes involved extensive application of vehicle and machinery extrication techniques and equipment, and were comprised of individuals with previous firefighting experience and a minimum rating of Firefighter II, indicating that they met basic experience, training, and physical fitness requirements as defined by the National Fire Protection Association. For all of the classes, the first training day (Monday) involved classroom work, though the vehicle and machinery technician and structural classes also involved direct student use of equipment on Monday. Tuesday through Thursday, students performed hands-on training and simulation with equipment, and on Fridays, instructors created a simulated accident situation in which students were tested on their practical skills learned during the course.

Research staff contacted class enrollees by email to provide an overview of the study and invite participation. On the first morning of each class research staff provided an overview of the study, answered questions, and collected informed consent forms from interested volunteers, who were then enrolled in the study.

### Recruitment and baseline survey

UM research staff approached class enrollees by email prior to the training week and also through in-person presentation on the morning of day one to provide an overview of the study and invite participation. Roughly 50% of trainees from the vehicle operation classes and about 30% trainees from structural rescue class agreed to participate in the study. Participants completed research activities during all 5 days of their training class, and received a $100 cash incentive at the end of their participation. Immediately after enrollment, participants completed a baseline survey that contained questions regarding medical history, past-year and lifetime occupational serious injury history (defined as injuries requiring first aid treatment, treatment in a medical clinic or office, or treatment at a hospital), physical activity, current use of tobacco products, health, firefighting experience, and frequency of exposure to high levels of perceived noise. Select baseline questionnaire items are listed in Supplementary Table S1. Participants reported perceived difficulty in hearing, which has been shown to be reasonably well correlated with audiometric threshold levels (Ferrite *et al.*, 2011). Participants also had their height and weight measured, from which BMI was later computed.

### Assessment of injury and near-miss events, activities, and job demands

Participants completed a daily activity diary on each of the 5 days of their class, which provided a complete record of participants' activities over each 24-h period of the study. Select diary elements may be found in Supplementary Table S1. The diary included the timing and duration of their training activities, as well as their other activities (e.g. recreation and exercise) and a sleep diary. All participants also completed an event and near-miss diary at the end of each day which asked about the timing and circumstances of any events that caused an injury, regardless of how minor or the need for first aid or medical treatment, as well as situations in which they were nearly involved in an accident or almost sustained an injury (i.e. near misses), or in which they experienced illness or physical discomfort. Near misses were described to subjects as narrow escapes from injury, as well as incidents in which tools or equipment broke. Injuries, as rare events, are difficult to capture in cross-sectional study design, even in high-hazard occupations like firefighting, hence our inclusion or both injuries and near misses in our analyses. Cases of illness and physical discomfort were not considered in our analyses due to likely differences in the causal mechanism of illnesses/discomfort versus injuries and near misses.

Finally, we assessed daily job demands by including the National Aeronautics and Space Administration (NASA) TLX scale (Hart and Staveland, 1988) with the daily activity diary. The TLX scale assesses overall job demands through six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration. These results will be described in detail elsewhere (manuscript in preparation).

### Assessment of noise exposures

Each participant's noise exposures were measured continuously over a single, randomly-assigned 24-h period during participants' non-classroom days using data-logging noise dosimeters (DoseBadge, Cirrus Research, North Yorkshire, UK) configured according to the NIOSH Recommended Exposure Limit (REL) (NIOSH, 1998). The ~16 daily hours of non-training noise measurement data will be described elsewhere (manuscript in preparation); the analyses presented here address only the roughly 8 h of training time per monitored day. Four to seven participants were monitored per day in each training class due to equipment availability and the varying number of participants by class. Equivalent continuous average ($L_{EQ}$) and peak noise levels were data-logged at 1-min intervals; dosimeter microphones were worn within 6 inches of subjects' ears on the same side as their dominant hand. The 1-min interval noise levels were combined with participants' reported activities from the activity diary to create noise exposure estimates for the monitored day. On each training day, participants reported their perceived noise exposures using a single validated item with a 5-category response scale (Neitzel *et al.*, 2009) and also reported their use of hearing protection devices (HPDs) (Supplementary Table S1).

### Analysis

We conducted descriptive analyses of baseline and training-related noise exposures, reported injuries, events and near misses, as well as demographics and other factors, using SPSS 22.0 (IBM, Armonk, NY, USA). We calculated lifetime and past-year injury risk by dividing the total combined work years over all participants' lifetime and within the past year, respectively, by the number of injuries experienced over each of those time periods.

Attenuation data were not collected on the individual HPD types used by trainees. Instead, attenuation was estimated as 10 dB during HPD use, and 1-min noise levels were reduced by 10 dB during times when subjects reported using HPDs, as we have done previously (Neitzel *et al.*, 2012). HPD-adjusted $L_{EQ}$ noise exposures during training were then logarithmically computed for each subject by day of participation. The association between HPD-adjusted daily $L_{EQ}$ noise exposures during training and perceived daily noise exposures was evaluated using a Spearman correlation coefficient.

We estimated injury/near-miss odds ratios (ORs) using several models. In our basic exploratory model of injury risk during training, we used a mixed-effects logistic regression model (SPSS generalized linear mixed model procedure) with a binary dependent variable (injury yes/no) and measured noise exposure as the independent variable to assess injury risk among the subset of injured subjects who experienced an injury while they were wearing a noise dosimeter. This model was restricted to nonclassroom training time only. We included a random effect for subject to account for repeated injury events within subject. $L_{EQ}$ noise levels associated with injuries, $L_{EQTinj}$, were calculated using equation (1):

$$L_{EQ,T_{inj}} = 10\log_{10}\left[\frac{1}{T_{inj}}\sum t_i \times 10^{L_{EQi}/10}\right] \quad (1)$$

where $L_{EQ,Tinj}$ is the $L_{EQ}$ over time period $T_{inj}$ (in min) prior to injury, computed as the exponential average of the $L_{EQ}$ for each period *I* of duration *t* (exactly 1 min).

To address potential error in reported injury times, in our exploratory model we compared average 1-min noise levels prior to the reported injury time to the average of all other 1-min intervals from the same training day but outside the injury window (i.e. $L_{EQ,Tuninj}$, computed as in equation (1) but restricted to all 1-min intervals outside the injury window $T_{inj}$). This resulted in a dataset wherein each row represented one injury event and had an $L_{EQ,Tinj}$ of duration $T_{inj}$ and a matched $L_{EQ,Tuninj}$, with a duration of $T_{uninj}$, equivalent to (workshift length − $T_{inj}$). We used the time period $T_{inj}$ of 30 min prior to the reported injury as our default assumption, but evaluated iterations of this model using other temporal windows (i.e. 5, 10, 15, 20, and 60 min prior to the reported injury time). We elected to compare the defined period $T_{inj}$ with the remaining workshift length $T_{uninj}$, rather than randomly sampling a period of length equivalent to $T_{inj}$, in order to fully consider all exposure periods in which no injury occurred. In addition to modeling noise as a continuous variable, we also collapsed noise exposure into a binary variable, with cutpoints in 1 dB steps between 85 and 100 dBA, and also as a three-category ordinal variable, with a range of cutpoints between categories. This was done in order to examine potential dose–response relationships between noise and injury/near-miss risk. The time window with the highest ORs for the majority of noise threshold cut-points was selected for further modeling.

The second model of injury risk during training was a mixed effect logistic regression model (SPSS generalized linear model procedure) with a binary dependent variable (injury yes/no) and measured 1-min noise exposure and other covariates as independent variables. We again included a random effect for subject to account for repeated injury events within subject. We created a dummy variable to evaluate whether events and near misses were more likely occur in the first hour of the morning or afternoon training session (e.g. short or long 'time-at-task'). We also created two categorical variables: types of tools used (i.e. unpowered hand tools, power tools, or mixed hand and power tools) and training objects (i.e. automobiles, semi-trucks/school buses, or cement cutting during breaching). Given the distinct nature of classroom activities and the comprehensive practical exercise on the last day of each class, we included these classroom activities and practical exercises as separate categories in the categorical tool use and training object variables. We evaluated the associations between age, BMI, firefighting experience, firefighter type (i.e. career, volunteer, or both), perceived hearing ability, lifetime injuries, smoking status, training class, tools used, training objects, HPDs use, and job demands (from the NASA-TLX scale) and injury/near misses. Inclusion of variables in our final model of measured noise exposure and injuries/near misses was based on statistical significance of parameter estimates, potential confounding, variable collinearity, and model goodness of fit. Variables were retained in the final models where $P < 0.10$.

Our third model of injury risk during training was based on events and near misses from daily reports from all subjects. We used a mixed-effects logistic regression model (SPSS generalized linear model procedure) to estimate ORs for events and near misses associated with perceived noise exposure over the training week. We used a random effect for subject to account for repeated measurements across the five training days and perceived noise exposure from each subject's daily activity diaries as a surrogate for sampled noise, since noise measurements were not collected on all subjects on all days. The perceived noise exposure scale, which originally consisted of five response categories, was collapsed into a binary variable (lowest 3 versus highest 2 response categories). We evaluated the same list of other variables as we did for the first model, and again retained variables where $P < 0.10$. The final model selection was also based on the same criterion as the previous model. We forced age and BMI into both models, as both of these features have been associated with elevated injury risk among firefighters and other workers (Pollack and Cheskin, 2007; Pollack *et al.*, 2007; Kuehl *et al.*, 2012; Lombardi *et al.*, 2012; Jahnke *et al.*, 2013). Note that this model has a substantially more crude measure of noise exposure (self-reported exposure over an entire day) than the previous model, but, importantly, the model allowed us to include all injury and near-miss events, including those that occurred on subjects who were not wearing noise dosimeters at the time of injury, and to evaluate the association between perceived noise exposure and injury risk.

## RESULTS

Fifty-six firefighters participated in the study (Table 1). Most subjects (34 or 60.7%) came from the two vehicle operations classes. Subjects spent an average of 6.8 ± 2.9 h per day training each day.

### Subject characteristics

Participants had a mean age of 31 years, and had an average of nearly 10 years of firefighting service (Table 1). Only four participants (7%) were volunteer

**Table 1. Baseline demographic and health information**

| Variable | Overall | | | Class: Vehicle operations | | | Class: Vehicle technical | | | Class: Structural collapse | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *N* | Mean | SD | *N* | Mean | SD | *N* | Mean | SD | *N* | Mean | SD |
| **Age** | 56 | 31.4 | 7.5 | 34 | 30.8 | 8.5 | 13 | 32.3 | 4.7 | 9 | 32.3 | 6.9 |
| **BMI*** | 56 | 28.2 | 3.6 | 34 | 27.1 | 3.2 | 13 | 30.0 | 3.6 | 9 | 29.6 | 4.2 |
| **Experience (year)** | | | | | | | | | | | | |
| Career | 30 | 10.1 | 8.5 | 16 | 10.1 | 10.5 | 9 | 7.4 | 3.7 | 5 | 14.4 | 6.4 |
| Volunteer | 4 | 1.0 | 0.0 | 3 | 1.0 | 0.0 | 1 | — | — | — | — | — |
| Both | 22 | 10.3 | 3.7 | 15 | 9.6 | 3.8 | 3 | 12.7 | 5.5 | 4 | 11.2 | 0.9 |
| Total | 56 | 9.7 | 7.0 | 34 | 9.0 | 8.0 | 13 | 8.8 | 4.7 | 9 | 13.0 | 4.9 |

| Variable | Overall *N* | Overall % | Vehicle operations *N* | Vehicle operations % | Vehicle technical *N* | Vehicle technical % | Structural collapse *N* | Structural collapse % |
|---|---|---|---|---|---|---|---|---|
| **Perceived health status** | | | | | | | | |
| Health (1–5, ≥3 average or better) | 54 | 96.4 | 33 | 97.1 | 13 | 100.0 | 8 | 88.9 |
| Fitness (1–5, ≥3 average or better) | 53 | 94.6 | 33 | 97.1 | 13 | 100.0 | 7 | 77.8 |
| Nutrition (1–5, ≥3 average or better) | 48 | 85.7 | 29 | 85.3 | 11 | 84.6 | 8 | 88.9 |
| Use stimulants | 46 | 82.1 | 27 | 81.8 | 12 | 100.0 | 7 | 77.8 |
| Use tobacco products | 18 | 32.1 | 11 | 32.4 | 3 | 23.1 | 4 | 44.4 |
| Hearing (1–5, =1 good hearing ) | 38 | 67.9 | 25 | 73.5 | 7 | 53.8 | 6 | 66.7 |
| Difficulty hearing (Y/N) | 7 | 12.5 | 4 | 11.8 | 3 | 23.1 | 0 | — |
| **Diagnosed with hearing loss by a doctor** | 5 | 8.9 | 3 | 8.8 | 1 | 7.7 | 1 | 11.1 |
| **Serious occupational injury over lifetime** | 20 | 35.7 | 13 | 38.2 | 4 | 30.8 | 3 | 33.3 |
| **Serious occupational injury in past year** | 9 | 16.1 | 6 | 17.6 | 2 | 15.4 | 1 | 11.1 |

*ANOVA, $P < 0.05$.

firefighters. Nearly all participants reported better-than-average health, fitness, and nutrition. Only seven participants (12.5%) reported difficulty in hearing; five of these (<10%) reported a diagnosis of hearing loss by a doctor. HPD use was low: only six participants (10.7%) reported that they always wore HPDs while working in noise, and 20 (35.7%) reported that they never wore HPDs (data not shown). The only statistically significant difference among participants in the three types of training classes was related to BMI.

### Injury and near-miss events

Twenty participants (36%) reported a serious injury during firefighting activities some time in their lifetime on their baseline questionnaire, and nine (16%) reported a serious firefighting injury within the past year (Table 1). Among those who had suffered a serious firefighting injury in their lifetime, four (20%) had suffered three serious injuries, eight (40%) had suffered two, and eight (40%) had suffered one (data not shown). Among those who had suffered a serious firefighting injury in the past year, two (22%) had suffered two injuries and the remainder had suffered one injury. Five of past-year injuries resulted in missed workdays, with an average time missed of 13.8 ± 18.8 days. On average, participants had experienced 0.6 ± 1.0 serious injuries in their lifetime, and 0.2 ± 0.5 serious injuries in the past year. Altogether, participants reported 33 lifetime serious injuries, 11 past-year serious injuries, and 12 past-year near misses, and had a combined total of 502.5 lifetime years of firefighting experience and 56.0 years of experience within the past year. We used these values to estimate normalized rates of 6.6 serious injuries per 100 full-time equivalent (FTE) employees over a lifetime and 16.1 serious injuries per 100 FTE within the past year.

Subjects reported 11 injury events and 7 near misses ($N$ = 18 total events) during their 1-week training courses (Table 2). No injuries occurred during classroom activities. The 18 events occurred among 15 subjects, three of whom also reported a previous serious injury at baseline. The 11 reported injury events correspond to a normalized annual injury rate of 19.6 per 100 FTE for the 56 participating firefighters, assuming that training activities are representative of routine firefighting activities and that participants worked 2000 h annually. Injuries and near misses were more common among those with hearing difficulty, those who reported exposure to high noise at least half of the time during their normal work or perceived high noise exposure during the training class, career firefighters, and those with age or BMI greater than the median. Injuries were significantly more common when using power tools or a mix of hand and power tools, and during training on semi-trucks/school buses and during cement breaching operations ($P$ < 0.05, data not shown).

### Noise exposures

Hand tool use during training was associated with the lowest mean $L_{EQ}$ noise level, and power tools the highest (Table 3). Consistent with self-reported use at baseline, HPDs were used infrequently (27% of all monitored min >85 dBA) during training (data not shown). Although 1-min noise levels were reduced by 10 dB during periods when HPDs were reported, average $L_{EQ}$ noise exposures were <3 dB higher when not adjusted for HPD use due to the low usage of HPDs in high noise. Perceived noise levels were highest during mixed tool use and lowest during hand tool use; HPD use followed the same pattern. Average exposures during training activities were 10-17 dB higher than other activities experienced by participants over their 5-day study period (Supplementary Table S2). HPD-adjusted daily $L_{EQ}$ noise exposures during training ($N$ = 56) were found to be significantly correlated with perceived daily noise exposures from the monitored subjects (Spearman correlation coefficient 0.62, $P$ = 0.03).

### Models of injury event risk

Figure 1 displays ORs from the exploratory models of noise levels for a series of binary exposure cutpoints and different windows of time prior to the 15 injuries/near misses reported by the 13 subjects injured while being monitored for noise. ORs generally increased with noise level across time windows; the greatest and most monotonic increase was observed for the window 10 min prior to reported injury/near miss. All ORs were significant in the models with time windows ≥10 min prior to the reported time of an injury event, and the 30-min time window had the highest ORs for all noise cutpoints. With $L_{EQ}$ <90 dBA as the reference group, the unadjusted OR for noise ≥90 and

**Table 2. Number and percentage of near misses/injuries by demographics and other potential predictors**

| Variable | Class type | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Overall | | Vehicle operation | | Vehicle technician | | Structural collapse | |
| | Injury *n* | % | Injury *n* | % | Injury *n* | % | Injury *n* | % |
| **Age** | | | | | | | | |
| <Median (29.0) | 5 | 27.8 | 5 | 71.4 | 0 | 0.0 | 0 | 0.0 |
| ≥Median (29.0) | 13 | 72.2 | 2 | 28.6 | 9 | 100.0 | 2 | 100.0 |
| **BMI** | | | | | | | | |
| Under weight (<18.5) | — | | — | | — | | — | |
| Normal weight (18.5–25.0) | 2 | 11.1 | 2 | 28.6 | 0 | 0.0 | 0 | 0.0 |
| Over weight (≥25.0) | 16 | 88.9 | 5 | 71.4 | 9 | 100.0 | 2 | 100.0 |
| **Use tobacco** | | | | | | | | |
| Never | 13 | 72.2 | 4 | 57.1 | 7 | 77.8 | 2 | 100.0 |
| Ever | 5 | 27.8 | 3 | 42.9 | 2 | 22.2 | 0 | 0.0 |
| **Use stimulants** | | | | | | | | |
| Never | 0 | 0.0Δ | 0 | 0.0 | — | | 0 | 0.0 |
| Ever | 18 | 100.0Δ | 7 | 100.0 | 9 | 100.0 | 2 | 100.0 |
| **Perceived health status** | | | | | | | | |
| Health below average (1–5, <3) | 0 | 0.0 | 0 | 0.0 | — | | 0 | 0.0 |
| Health average or better (1–5, ≥3) | 18 | 100.0 | 7 | 100.0 | 9 | 100.0 | 2 | 100.0 |
| Fitness below average (1–5, <3) | 0 | 0.0 | 0 | 0.0 | — | | 0 | 0.0 |
| Fitness average or better (1–5, ≥3) | 18 | 100.0 | 7 | 100.0 | 9 | 100.0 | 2 | 100.0 |
| Nutrition below average (1–5, <3) | 0 | 0.0 Δ | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Nutrition average or better (1–5, ≥3) | 18 | 100.0 Δ | 7 | 100.0 | 9 | 100.0 | 2 | 100.0 |
| **Firefighter type** | | | | | | | | |
| Career | 13 | 72.2 | 3 | 42.9 | 8 | 88.9 | 2 | 100.0 |
| Volunteer | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | — | |
| Both | 5 | 27.8 | 4 | 57.1 | 1 | 11.1 | 0 | 0.0 |
| **Experience** | | | | | | | | |
| <Median (8.9 years) | 10 | 55.6 | 6 | 85.7 | 4 | 44.4 | 0 | 0.0 |
| ≥Median (8.9 years) | 6 | 33.3 | 1 | 14.3 | 3 | 33.3 | 2 | 100.0 |

**Table 2.** *Continued*

| Variable | Class type | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Overall | | Vehicle operation | | Vehicle technician | | Structural collapse | |
| | Injury *n* | % | Injury *n* | % | Injury *n* | % | Injury *n* | % |
| **Hearing** | | | | | | | | |
| Good hearing | | | | | | | | |
| No | 6 | 33.3 | 1 | 14.3 | 5 | 55.6 | 0 | 0.0 |
| Yes | 12 | 66.7 | 6 | 85.7 | 4 | 44.4 | 2 | 100.0 |
| Difficulty in hearing | | | | | | | | |
| No | 13 | 72.2Δ | 7 | 100.0 | 4 | 44.4* | 2 | 100.0 |
| Yes | 5 | 27.8Δ | 0 | 0.0 | 5 | 55.6* | — | |
| **Perceived noise** | | | | | | | | |
| Low | 9 | 50.0 | 3 | 42.9 | 5 | 55.6 | 1 | 50.0 |
| High | 9 | 50.0 | 4 | 57.1 | 4 | 44.4 | 1 | 50.0 |
| **Baseline noise exposure** | | | | | | | | |
| <½ time | 12 | 66.7 | 6 | 85.7 | 4 | 44.4 | 2 | 100.0 |
| ≥½ time | 6 | 33.3 | 1 | 14.3 | 5 | 55.6 | 0 | 0.0 |
| **Baseline wear hearing protectors** | | | | | | | | |
| <½ time | 9 | 50.0 | 4 | 57.1 | 5 | 55.6 | 0 | 0.0 |
| ≥½ time | 9 | 50.0 | 3 | 42.9 | 4 | 44.4 | 2 | 100.0 |

*Chi-square, $P < 0.05$.
ΔNonsignificant trend, $P < 0.1$.

<95 dBA was 3.93 (95% CI 2.35–6.60), and noise levels ≥95 dBA had an OR of 4.66 (95% CI 3.10–7.10) (data not shown).

Model 1 (Table 4) shows the mixed-effects logistic regression model predicting injury/near miss events using measured noise levels for the 13 participants and 15 events captured during monitoring, with the 30-min injury window coded as injury/near miss and all other 1-min intervals from the same day coded as no injury/near miss. Age was significantly associated with higher injury risk, while greater firefighting experience showed a significant protective effect. BMI, job demands, and perceived hearing difficulty were associated with increased risk of event or near miss, though perceived hearing difficulty did not reach statistical significance. The model indicated a nonsignificant trend of elevated OR for event or near miss with shorter time-at-task (e.g. during the first hour of a training session). The model also showed substantially increased odds of an event or near-miss risk for higher noise levels (90 dBA ≤ $L_{EQ}$ < 95 dBA, and $L_{EQ}$ ≥ 95 dBA). Class type, tool use, and training objects were also tested in the model; none of these variables were significant, and all were highly correlated with job demands, so none of these variables was included in the final model 1. Lifetime injury and smoking status were not significantly associated with injury/near miss, and were also excluded.

Model 2 shows injury/near-miss ORs based on 246 daily reports of perceived noise exposure and

**Table 3. Near misses/injuries, dosimetry and perceived noise levels, and HPD use by type of tools used[a] (*N* = 56 subjects, 246 reporting days that included at least some nonclassroom activities)**

| | Overall (*N* = 246) | | | Tool use: Hand tools (*N* = 34) | | | Power tools (*N* = 72) | | | Mixed tools (*N* = 105) | | | Test (*N* = 35) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | *N* | % | | *N* | % | | *N* | % | | *N* | % | | *N* | % | |
| **Injuries/near misses[a]** | 18 | 100 | | 0 | 0.0 | | 7 | 50.0 | | 7 | 50.0 | | 4 | 50.0 | |
| Near miss | 7 | 38.8 | | 0 | 0.0 | | 4 | 28.5 | | 3 | 21.4 | | 0 | 0.0 | |
| Injury or accident | 11 | 61.1 | | 0 | 0.0 | | 3 | 21.4 | | 4 | 28.5 | | 4 | 50.0 | |
| **Perceived daily noise reports** | 246 | 100 | | | | | | | | | | | | | |
| 1 Normal speaking voice or quieter | 11 | 4.5 | | 0 | 0.0 | | 8 | 11.1 | | 1 | 1.0 | | 2 | 5.7 | |
| 2 As loud as a vacuum | 25 | 10.2 | | 7 | 20.6 | | 10 | 13.9 | | 4 | 3.8 | | 4 | 11.4 | |
| 3 As loud as a motorcycle | 101 | 41.1 | | 17 | 50.0 | | 31 | 43.1 | | 39 | 37.1 | | 14 | 40.0 | |
| 4 As loud as a chainsaw | 83 | 33.7 | | 8 | 23.5 | | 20 | 27.8 | | 45 | 42.9 | | 10 | 28.6 | |
| 5 As loud as a siren or louder | 26 | 10.6 | | 2 | 5.9 | | 3 | 5.2 | | 16 | 15.2 | | 5 | 14.2 | |
| **Daily HPDs use reports(Yes)[b]** | 70 | 28.5 | — | 6 | 17.6 | | 20 | 33.3 | | 36 | 41.4 | | 8 | 22.9 | |
| | *N* | **Mean** | **SD** | *N* | **Mean** | **SD** | *N* | **Mean** | **SD** | *N* | **Mean** | **SD** | *N* | **Mean** | **SD** |
| **$L_{EQ}$ noise level (dBA) during training** | 56 | | | | | | | | | | | | | | |
| HPD-adjusted[c] | 56 | 89.2 | 7.1 | 10 | 86.1 | 4.3 | 13 | 91.8 | 5.9 | 22 | 88.2 | 6.2 | 11 | 88.9 | 8.3 |
| Not HPD-adjusted | 56 | 91.5 | 6.4 | 10 | 88.7 | 4.0 | 13 | 93.3 | 5.4 | 22 | 91.2 | 6.3 | 11 | 90.9 | 7.4 |

[a]Classroom activities excluded; no injuries or near misses were reported in classroom.
[b]Daily HPDs use indicates HPDs worn at some time point of the day regardless of specific times and duration of use.
[c]$L_{EQ}$ noise exposure levels reduced by 10 dB for those reporting HPD use.

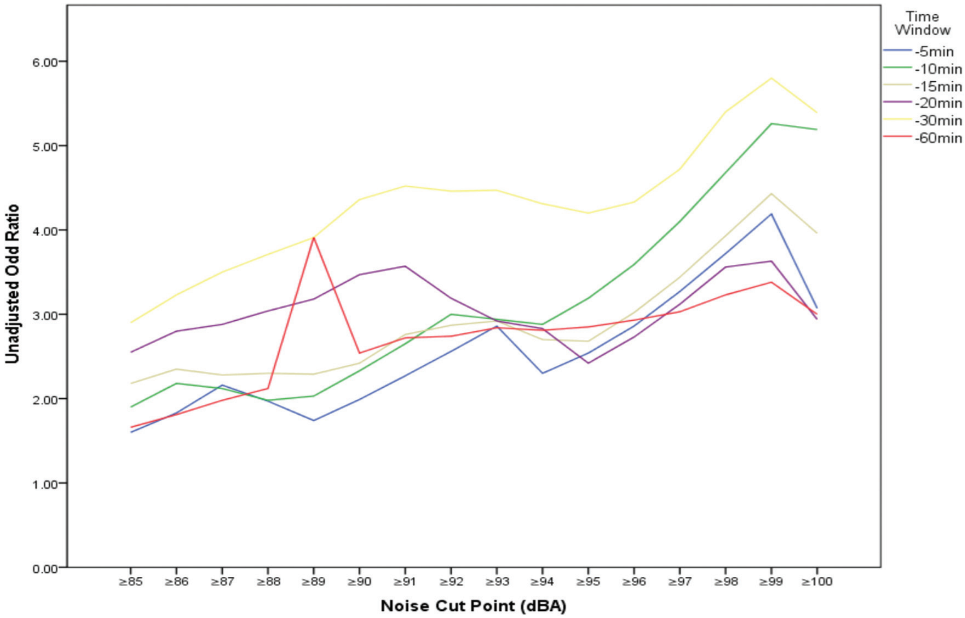


Figure 1 Trends in odds ratios for near misses/injuries by binary noise level across different injury time windows.

other covariates from all training days with at least some non-classroom training time for all 56 all participants (Table 4). The final model included age, BMI, total firefighting experience, perceived hearing difficulty, and job demands. Age and BMI were associated with a small but insignificant risk of event or near miss, while high perceived noise exposure had a small and nonsignificant protective effect on injury risk. Total years of firefighting experience were associated with an insignificant decrease in event or near miss risk. Difficulty in hearing was associated with a substantial but insignificant elevated risk. Increased job demands were associated with a small but significant increase in risk of event or near miss.

## DISCUSSION

We have shown that firefighters are exposed to high noise while participating in realistic training simulations and that injury events and near misses occur even in controlled training environments. The 56 participants reported 33 lifetime serious injuries and 11 injuries within the past year, which yielded rates of 6.6 and 16.1 serious injuries per 100 FTE, respectively. The rate of serious injuries in the past year is far higher than the all-industry average for recordable cases (analogous to 'serious injuries') of 3.7 injuries per 100 FTE in the USA (Bureau of Labor Statistics, 2013). The 11 events that occurred among participants during their 1-week training courses correspond to a normalized annual rate of 19.6 events per 56 firefighters. Though none of the events reported during the study period was serious, this rate is nonetheless high. The pattern we observed in reported injuries and events—with the highest rate determined within the last week, followed by the last year, followed by lifetime—suggests negative bias in reporting of injuries and events that occurred more distantly in time, a well-known phenomenon in injury research (Landen and Hendricks, 1995). The high rate of injuries observed during the training courses assessed suggests that even experienced career or career/volunteer firefighters (which comprised the vast majority of our sample) may be at elevated risk of injury. This risk may be due to uncommon or unfamiliar emergency response scenarios encountered during training or the types and condition of tools encountered during training versus normal operations. While training exercises are very common in firefighting, the training offered at IFSI is much more intense and realistic than typical training. It is also possible that individuals with different roles in the fire service (e.g. command versus line responsibility) have differing injury risks; as we did not assess

**Table 4. Logistic regression model for predicting injury or near-miss situations**

| Variable | Odds ratio | 95% CI |
|---|---|---|
| *Model 1: based on 1-min noise measurements (unadjusted for hearing protection use) for one monitoring day on each subject (N = 13 subjects, 13 monitored days, 15 injury/near-miss events)*[a] | | |
| **Intercept** | 0.000 | $3.81 \times 10^{-9}$ to $4.77 \times 10^{-5}$ |
| **Age (years)** | 1.15 | 1.03–1.29 |
| **BMI** | 1.21 | 1.08–1.36 |
| **Total firefighting experience (years)** | 0.75 | 0.61–0.94 |
| **Difficulty in hearing (yes)** | 1.32 | 0.20-8.55 |
| **Job demands** | 1.04 | 1.01–1.07 |
| **Time <1 hour from training session start**[b] | 1.97 | 0.36–10.8 |
| **Noise** | | |
| <90 dBA | 1 | — |
| ≥90 & < 95 dBA | 4.13 | 1.76–9.65 |
| ≥95 dBA | 4.96 | 1.53–16.1 |
| *Model 2: based on five daily reports from all subjects (N = 56 subjects, 246 monitored days that included at least some non-classroom activities, 18 injury/near-miss events)*[c] | | |
| **Intercept** | 0.00 | $4.95 \times 10^{-6}$ to 0.30 |
| **Age (years)** | 1.09 | 0.97–1.23 |
| **BMI** | 1.09 | 0.98–1.21 |
| **Total firefighting experience (years)** | 0.89 | 0.80–0.99 |
| **Difficulty in hearing** | 2.46 | 0.71–8.55 |
| **Job demands** | 1.05 | 1.02–1.08 |
| **Self-report noise exposure**[b] | | |
| High (Chainsaw, siren, or louder) | 0.96 | 0.37–2.47 |

[a]30-min prior to reported injury time matched to all other uninjured training time of the same day.
[b]Reference categories: vehicle operations class, time ≥1 h from training session start, noise level <90 dBA, low self-reported noise exposure.
[c]Noise measurements were not available from all subjects on all days and could not be modeled.

job title in this study, we can only speculate on this possibility.

Firefighter training noise exposures were comparable to those we have previously documented in firefighting activity (Neitzel *et al.*, 2013). Measurements from these and other studies (Tubbs, 1992; Kirkham *et al.*, 2011) demonstrate the potential for exposure >85 dBA, the NIOSH recommended limit, suggesting increased risk of NIHL. The relationship between noise exposure and injury risk is important given the fact that few firefighters used HPDs here or in other studies (Hong *et al.*, 2013). Hearing protection may actually increase ability to perceive speech and warning signals in noise, so in addition to preventing NIHL, use of HPDs may be an appropriate strategy to decrease injury likelihood though improved communication.

Our results generally support our hypothesis that noise is associated with injury risk. In our first mixed-effects logistic regression event risk model, noise levels ≥90 dBA and <95 dBA were associated with a 413% increase in event risk and noise levels ≥95 dBA were associated with 496% risk. This finding fits within the range of threshold effects for noise and injury that have been reported in other studies of workers with noise-exposed workers. Specifically, workers with full-shift $L_{EQ}$ noise levels ≥90 dBA have been found to have an increased risk of injury (Picard *et al.*, 2008; Girard *et al.*, 2009) as have workers with exposures ≥85 (Melamed *et al.*, 1992), ≥82 (Cantley *et al.*, 2015), and ≥80 dBA (Melamed *et al.*, 2004). It worth noting that the noise thresholds for increased risk reported by Melamed *et al.* and Cantley *et al.* were based on measured or estimated group-average noise exposures, whereas our study used measured individual exposures. Not all authors have reported increased risk of injury during noise exposure, however. Kling *et al.* (2012) found that cumulative noise exposure was associated with a decreased risk of injuries, except for cumulative noise exposure >85 dBA for 90 days to 1 year, which was associated with increased risk of injury. The authors speculated that this decrease in injury over long periods of cumulative noise exposure could be due to increased worker experience—a known protective factor for injuries (Keyserling, 1983).

Our model 2 results did not identify a significantly increased risk of injury/near miss associated with greater levels of perceived noise. This is likely due at least in part to error introduced by our use of perceived noise levels summarizing the entire training day, rather than in a narrow window around the time the injury or near miss occurred. Another potential cause for the lack of convergence between the results of models 1 and 2 could be differences in personal perceptions of noise exposure. While perceived exposure has been shown to be a useful tool for noise exposure assessment among construction workers, it may not work as well among firefighters and other workers with intermittent exposures to noise (Neitzel *et al.*, 2009), although the fact that perceived and measured noise exposures were significantly correlated among the participating firefighters indicates that subjects were on average reasonably accurate in assessing their relative noise exposure levels. The greater accuracy with which noise exposure was evaluated in model 1 means that results from that model should be given priority; additionally, the presence of a greater number of variables with significant ORs in model 1, which was based on a smaller number of injuries and near misses, increases our confidence in the results of that model when compared to model 2. Nevertheless, the discrepancies between the two models indicate that further evaluation of the differences between perceived and measured noise exposure is warranted.

The relationship we have demonstrated between noise and injury risk is important given that most previous studies of noise and injuries have not adequately accounted for the activity being performed, and have relied instead on crude measures of activity such as job title or work department. Activities are a critical determinant of exposure to safety hazards and therefore for injury risk potential; however, accounting for activity in analyses of injury risk is challenging, and only two previous studies appear to have controlled for activity performed in a rigorous fashion (Melamed and Froom, 2002; Melamed *et al.*, 2004). These studies focused on measures of activity complexity (e.g. decision-making latitude, responsibility, independence. activity variety, etc), which may not accurately reflect the degree of hazard inherent to an activity. In restricting our focus to two types of common firefighting situations—i.e. vehicle extrication and structural collapse extrication—we were able to control more closely for activity, and identified an increase in injury risk associated with noise level during these situations. We were also able to evaluate levels of noise associated with different tools and training objects. Additionally, our study used direct noise exposure measurements, rather than relying on crude quantitative or qualitative estimates of exposure, as has been done previously (Dias and Cordeiro, 2008; Amjad-Sardrudi *et al.*, 2012; Girard *et al.*, 2009, 2015).

Our finding that age and BMI were associated with increased injury risk agrees with previous research (Pollack and Cheskin, 2007; Pollack *et al.*, 2007; Kuehl *et al.*, 2012; Lombardi *et al.*, 2012; Jahnke *et al.*, 2013) and confirms that the role of these risk factors warrants further investigation. The significant contribution of age and BMI to injury and near-miss event risk, even when controlling for activity and noise exposure level, suggests that the participating firefighters, who generally had high BMIs due to greater-than-normal muscle mass may have greater exposure to injury risks, perhaps as a function of reduced agility, anthropometry-related issues, or other unrecognized factors. It is worth noting that BMI may not be indicative of overweight for many of our firefighter participants, who generally had athletic builds, since BMI measurements do not distinguish between muscle and fat.

### Limitations

The most significant limitation of our study was the limited range of firefighting activities assessed. Our results should be interpreted with caution, and may not necessarily generalize to other firefighting settings. The study took advantage of highly realistic simulation scenarios to estimate risk in real live events. Despite using a realistic training setting that included an intense training schedule among simulated vehicle accidents and building collapse piles, as well as the acquisition and demonstration of difficult and unfamiliar skills and techniques, the training likely did not induce the same amount of stress in participants as a real-life situation would. Our sample size also constrained our modeling options. Our participation rate among potential subjects was ~40%, and we had no systematic way to assess potential injuries and near misses among nonparticipants. Only one clear injury case was observed on a nonparticipant who sought first aid after being cut on the face during training activities. Interestingly, this individual subsequently enrolled in a second IFSI training course and was willing to participate in our study during the second course. It is possible that recruited firefighters might have either more severe or more frequent injury experience in the past compared to nonparticipants, which could result in an overestimation of injury risk among our participants compared to the broader population of firefighters.

While hearing loss likely plays some role in the causal pathway between noise exposure and injury, we had no direct measurement of hearing acuity in our subjects. We did use self-reported hearing ability as indirect measurement in our injury model. However, because the relationship between self-reported and actual hearing status has not been well characterized, this approach may have attenuated the observed effect of hearing loss on injury risk. Participants reported HPD use by training session rather than minute-by-minute, which yielded a relatively low-resolution measure of HPD use and subsequently reduced the accuracy of our noise exposure estimates. Nevertheless, we used HPD-adjusted noise exposure in our injury models as the best available estimate of noise exposure.

Finally, recall bias likely affected the number of events and near misses reported by subjects at baseline and during the study period. Some subjects may have underestimated or not recognized injuries, events, and near misses, or forgotten injuries or near misses that did occur. Some subjects may also have deliberately underreported injuries and near misses for fear of retribution from the training staff or their fellow workers, though given the confidential nature of our reporting mechanisms, we find this highly unlikely. Reporting of near misses is inherently subjective, and we suspect that there was a downward bias in reporting, which suggests that our results are conservative. Our assessment of near misses is nevertheless a strength of the study, in that we likely captured events that could have resulted in injuries or equipment damage under slightly different circumstances. Participants also may have inaccurately recorded the time at which injuries or near misses occurred. We assumed that any error in reporting of time of injury was random and did not induce bias. We evaluated different intervals of noise measurements around events and near misses, and found the 30 min intervals prior to the reported time of injury and near miss events to be the most appropriate time interval to use. With greater resolution in the reported times of event and near misses, a narrower, more precise time window might be more appropriate; however, the increased risk of injury/near miss across different windows of time (Fig. 1) provides evidence that our analyses had sufficient time resolution. Finally, while we believe the risk and severity of injuries experienced during training at the IFSI training facility likely represent injury risk in real-life emergency response situations, it is possible that injury risk measured among trainees at IFSI differs substantially from that of real-world emergency response situations.

## CONCLUSIONS

We have demonstrated through a training study in a realistic environment that noise greater than 90 dBA may increase injury risk for firefighters. Our results also indicate that injury risk varies with job demands and time-at-task. These findings highlight the inherently hazardous nature of firefighting work, and suggest the potential for noise reduction interventions that may be employed to reduce injury potential among this occupational group. Firefighters appear to have low usage rates of hearing protection, as observed in the training courses studied here and by other authors (Hong *et al.*, 2013). This may result in unnecessary exposure to noise and may increase risk of injury. The results of our study need to be confirmed in subsequent research in real-world emergency response situations in order to evaluate how our injury risk observations from a controlled (though realistic) training setting translate to actual emergencies. If confirmed in these settings, our results may inform occupational health policy among first responders and other personnel working in noisy, high-hazard occupations, guide best practice approaches for training and execution of firefighting activities, and ultimately result in reduced injury rates among firefighters.

## SUPPLEMENTARY DATA

Supplementary data can be found at http://annhyg.oxfordjournals.org/.

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