Introduction
Occupational noise exposure is one of the leading causes of noise-induced hearing loss (NIHL) (Agrawal, Platz, & Niparko, 2008). The regulations protecting the hearing of workers, however, are not always effective. Police officers, firefighters, and construction/trade workers are all occupations for which the Occupational Safety and Health Administration (OSHA) does not have sufficient guidelines for hearing-loss prevention (Martinez, 2012; Occupational Noise Exposure, 2008). Many individuals in these professions have documented NIHL but low 8-hr time-weighted averages (TWAs) (Chung, Chu, & Cullen, 2012; Lesage, Jovenin, Deschamps, & Vincent, 2009; Seixas et al., 2005; Tubbs, 1991). Complexities within these professions limit the usefulness of hearing conservation rules that are delineated in the manufacturing industry. For example, in public safety professions, noise is often unpredictable, transient, and varies acoustically from one instance to the next. Sirens, vehicle noises, radio communications, and equipment noises are all encountered to varying degrees when public safety professionals are on duty.

Public safety professionals function in unpredictable soundscapes and communication is important for safety; thus, it is necessary to address their hearing health needs in order to maintain employability, prevent injuries, and reduce worker compensation claims. As an example, roughly 4% of retirements caused by illness among firefighters in the UK were a result of audiological problems (Ide, 2007). In the U.S., there are more than 1 million firefighters (Evarts & Stein, 2020). Given the published incidence of ill-health retirements, at least 40,000 firefighters in the U.S. retire due to hearing-related injuries. Many of these firefighters experience hearing loss early in their career, leading to hearing health issues over their lifetime (Ide, 2011). In 2010, there were >18,600 reported cases of workplace hearing loss in the U.S. (Martinez, 2012). Reports published by the Wisconsin Department of Workforce Development (2016) show the average claim amount for loss of hearing in Wisconsin was >$14,000.

Hearing loss not only impacts communication and employee job function but also increases an individual’s risk for other health conditions. Data suggest that hearing loss can increase the risk of depression and dementia (Li et al., 2014; Lin et al., 2011). Some data support that hearing loss can lead to hypertension; hypertension is a risk factor for cardiovascular disease (Chang et al., 2011). The health and safety effects of hearing loss are significant. As such, it is important to overcome the unique occupational environment challenges related to noise reduction that firefighters face.

Some of the complications of noise reduction for public safety professionals are equipment limitations and procedure modifications. Firefighters pose one of the

Abstract
Previous research has revealed that firefighters have an increased risk for noise-induced hearing loss; however, firefighters do not reach an 8-hr time-weighted average (TWA) of ≥85 dB. The high variability in occupational tasks and intermittent noise exposure of firefighters offers an explanation for the low 8-hr TWA. Our study evaluated specific occupational tasks, firefighting positions, and fire engine noise during a live fire training exercise. Researchers then identified the tasks and firefighting positions that presented the greatest risk to firefighters’ hearing health. Firefighting positions were statistically significantly different (p = .04) in terms of decibel levels; we determined that the firefighter in the position of water pump operator experienced the greatest decibel level (91 dBA). Noise exposure while traveling in a response vehicle varied by the type of vehicle (p = .009), with the newest vehicle having the smallest noise level (81 dBA). Analysis of the data revealed that the occupational tasks with the highest noise levels were cleanup at the scene and cleanup at the fire station (88 dBA each).
greatest challenges for hearing conservation programs because the high temperatures, moisture, and smoke can affect measurement equipment and hearing protection. In addition, firefighters have limited ability to use hearing protection during live fire activities due to the importance of monitoring environmental sounds and communicating clearly for safety. Adding to these obstacles are the negative beliefs firefighters have toward hearing protection use. Many firefighters have reported understanding the importance of hearing for their occupational success, yet many also admit an aversion to available hearing protection solutions (Hong, Samo, Hulea, & Eakin, 2008).

The first step in addressing these complex work environments and their impact on hearing health is to collect noise exposure measurements while firefighters complete occupational tasks. Researchers have started to categorize the noise levels created by various types of occupational tasks among firefighters (National Institute for Occupational Safety and Health, 2013; Neitzel, Hong, Quinlan, & Hulea, 2013; Root et al., 2013; Tubbs, 1990, 1994). The most prevalent source of noise information collected for professional firefighters is their use of equipment specifically during rescue events, not fire events. This study aims to expand upon the data currently available by further investigating individual variations in noise exposure based on specific occupational tasks, positions or job titles, and use of fire engines during a live fire training.

Methods

Three volunteer firefighters wore a noise dosimeter during a live fire training exercise. The firefighters were paid on-call personnel from a fire department in southern Wisconsin. At the time of the training, 42 firefighters were associated with the fire department, but not all firefighters were present at the training. Three different vehicles were used in the training: one standard engine, one ladder engine, and one water truck with a 3,500-gallon capacity.

The training included a driving portion and a fire portion. The fire portion used a burn building, which is a building specific for fire training that will not catch fire or collapse during an exercise. Instructors bring flammable items into the building to create a fire that can be extinguished and then re-lit multiple times during the training exercise. The training occurred over 2 nights and lasted approximately one hour the first night and four hours the second night. The first night of training only had a driving portion that began at the fire station; the firefighters rode in or drove the engines and support trucks to the facility where the burn building was located and then back to the fire station in order to practice driving the different vehicles. The second night of training also began at the fire station. The firefighters drove the vehicles to the training facility where the burn building was located. The fire training portion then took place at the burn building, after which the firefighters drove the vehicles back to the fire station. During training, the instructors had the firefighters attack the fire three times using multiple approaches and gave them feedback after each attack.

Noise Dosimetry

Researchers conducted personal noise dosimetry monitoring using noise dosimeters (EDGE eg5 and NoisePro DLX). The dosimeters simultaneously measured noise in three virtual dosimeters so that comparisons could be made to three industry standards. The measurement settings for all three virtual dosimeters included A-weighting, slow-response, and a 1-min logging interval. The first and second virtual dosimeters were based on OSHA criteria.

Researchers programmed the first virtual dosimeter (OSHA-HC) to meet OSHA hearing conservation requirements: a noise threshold of 80 dBA, criterion level of 85 dBA, and 5-dB exchange rate. Researchers programmed the second virtual dosimeter (OSHA-PEL) to meet the permissible exposure limit: a noise threshold of 90 dBA, criterion level of 90 dBA, and a 5-dB exchange rate. Researchers programmed the third virtual dosimeter (ACGIH) based on criteria from the American Conference of Governmental Industrial Hygienists (ACGIH): a noise threshold of 80 dBA, criterion level of 85 dBA, and a 3-dB exchange rate (Berger, Royster, Royster, Driscoll, & Layne, 2003).

The EDGE noise dosimeters and the NoisePro DLX microphone were attached to the firefighter’s side to match the dominant ear. All dosimeters were calibrated before and after monitoring using a sound calibrator (QC-10). Once researchers conducted the monitoring, they calibrated the dosimeters again and downloaded the noise exposure data as 1-min noise levels into a spreadsheet that linked the task information to the 1-min noise levels.

To prevent damage to the dosimeters from heat and water, the dosimeters were worn only by individuals who were in positions that did not enter the burn building. Each of the firefighters who wore the noise dosimeters had different overall shift responsibilities or positions during the live fire training. One firefighter (operations) was the scene operation manager and controlled the operations near the active fire scene. A second firefighter (water pump operator) was responsible for operating the water pump and hoses. The third firefighter (command) was responsible for relaying and responding to communication from the other fire squad members on scene.

During both nights, a member of the study team recorded the firefighters’ occupational activities and the times the activities occurred in order to link the task with specific noise levels recorded during the corresponding time on the dosimeter. Tasks logged included travel (to and from the burn building, and by which vehicle), paperwork (firefighters signed releases before they were allowed to use the fire training facilities), setup on scene (removing equipment from trucks and placing it around the burn building), active training scenarios (by position), ambulance response, instructor feedback, cleanup on scene (putting equipment into trucks), and cleanup at fire station (cleaning hoses and filling air tanks). One firefighter being monitored left before training was completed so only two measurements of cleanup at the fire station were analyzed.

Analysis

Using the 1-min noise levels from the dosimeter data and correlating those levels with the logs, the study team determined the noise exposure for all tasks recorded on the firefighters’ log forms and calculated descriptive statistics for all three virtual dosimeters (Berger et al., 2003). The ACGIH virtual dosimeter data determined if all task category noise levels were equivalent in a one-way analysis of variance (ANOVA). Because of post hoc interest in the tasks of travel and
active training scenarios, the study team calculated a one-way ANOVA with a Bonferroni multiple comparison test on each task category. The team calculated one ANOVA with a Bonferroni multiple comparison test to determine if noise exposure while traveling in the different vehicles was equivalent and to identify which vehicles were statistically different. The team calculated another ANOVA with a Bonferroni multiple comparison test to determine if all of the active training scenario positions (operations during fire, water pump operator during fire, command during fire) were equivalent and to identify which positions were statistically different. The confidence level in the statistical significance for all tests was 95%. The analysis was performed using SAS version 9.3.

**Results**

Table 1 shows the descriptive statistic results for each of the three virtual dosimeters. During an actual fire event, each firefighter would be assigned a specific position and thus would not likely complete all the tasks. The tasks with the greatest noise levels were cleanup at the scene and cleanup at the fire station. The times for each task varied and likely are not equal to the time for each task in an actual fire event. The one-way ANOVA of the mean ACGIH levels did not find the noise levels of the eight tasks to be significantly different ($p = .10$).

Table 2 shows the results of noise levels for travel by vehicle. There were significant differences between the noise levels of the three fire engines during the travel to and from the fire station to the live fire training site ($p = .009$). A Bonferroni multiple comparison test found that the ladder engine and the standard engine were significantly different. The noise level for travel in the ladder engine was 81 dBA, while the noise level for travel in the standard engine was significantly greater at 89 dBA.

Table 3 shows the results of noise levels for active training scenarios by position. There were significant differences between the ACGIH noise levels of the positions ($p = .04$). A Bonferroni multiple comparison test found that the positions of command and water pump operator were significantly different. Furthermore, the position of operations had the largest standard deviation (4.5 dBA) of the positions measured.

**Discussion**

Implementing a noise reduction strategy is required if the OSHA-PEL results have an 8-hr TWA >90 dBA. Additionally, a hearing conservation program is required if the OSHA-HC results have an 8-hr time-weighted average above 85 dBA (Occupational Noise Exposure, 2008). Firefighters have a highly variable job in which day-to-day noise exposure depends on the amount and type of calls they receive. Using only legal compliance to address firefighter noise exposure is insufficient. Instead of focusing on the legal requirements of firefighters’ noise exposure, it might be more beneficial to break down the exposure in terms of position, tasks, and equipment operated.

Our study revealed statistically different noise exposure based on firefighter position. For example, the OSHA-HC results for the position of water pump operator were greater than both the OSHA-HC requirement of 85 dBA and the ACGIH recommendation of 85 dBA (Berger et al., 2003). Root and coauthors (2013) reported OSHA-PEL values of 81 dBA for the position of water pump operator and 78 dBA for the position of scene operations. In our study, the position of operations was lower, with a level of 68 dBA. Therefore, one method for preventing NIHL among firefighters could be to rotate their positions or responsibilities for each live fire event. If operating the water pump creates the highest noise levels, then reducing the time of expo-
sure would benefit hearing health. Training multiple firefighters to operate the pump and then rotating the responsibility during each fire call would prevent a single firefighter from routine high noise exposure and reduce the risk of occupation-related hearing loss.

By focusing on frequently occurring tasks in controlled environments, hearing conservation interventions can be effectively applied. Cleanup at the fire station measured one of the longest durations among firefighter tasks and one of the highest mean noise levels. Although the noise exposure while cleaning up at the fire station was one of the greatest exposures to firefighters, there is ample opportunity to reduce the noise level. For instance, while cleaning up at the fire station, firefighters used compressed air located in the middle of the garage area to refill the air tanks. Isolating the compressed air and providing readily accessible hearing protection would reduce the noise exposure of both the compressor operator and the other firefighters conducting additional cleanup tasks in the fire station.

Our study data revealed not only noise level variation based on position and task but also noise variation based on the type of fire engine. Previous research reported a noise level of 75 dBA when a fire engine was in route—when the siren was used, the noise increased by 9 dBA to a noise level 84 dBA. The type of fire engine, however, was not specified (Root et al., 2013).

The three vehicles measured in our study had statistically significantly different mean ACGIH decibel levels, ranging from 81–89 dBA. The vehicle that produced the lowest noise level was the ladder truck, which was also the newest vehicle. Understanding the features of fire engines that contribute to noise output might be helpful when fire departments purchase new fire engines or refurbish old fire engines. Investing in equipment that has been designed to operate with a lower noise output has the potential to preserve hearing health, extend years of active service, and reduce the number of workplace injuries for firefighters.

**Limitations**

There were limitations to this study. Only three volunteer firefighters wore noise dosimeters during the live fire training exercise. This sample size was small because dosimeters were worn only by individuals with positions that did not enter the burn building. This approach was taken to prevent heat and water damage to the dosimeters, as current noise dosimeters are not heat or water resistant.

Another limitation of this study was that it was limited to tasks related to live fire. In addition to these tasks, volunteer firefighters also spend significant amounts of time responding to requests to rescue individuals. Rescue tasks involve the use of additional equipment, such as saws, that might cause significant noise exposures. Additional research is needed to measure noise levels during rescue activities.

**Conclusion**

One focus of environmental health is to prevent human injury and illness by identifying environmental sources that can cause harm (National Environmental Health Association, 2013). There is a focus on preventing injury and illness to professional firefighters because of the occupational risks they face. Many volunteer firefighters, however, face similar risks and it is important for local governmental agencies to be aware of the hazards associated with volunteer firefighters’ service.

Lowering the noise exposure of volunteer firefighters cannot be accomplished by simply providing conventional hearing protection, as has been done in other industries. By focusing on the positions, tasks, and equipment with the highest noise exposures and evaluating the physical limitations of those tasks, large noise exposures can be addressed. The occupational activity that posed the greatest risk to firefighters’ hearing health was the operation of the water pump on the engine. The firefighter who ran the pump on the engine would need to be enrolled in a hearing conservation program if the noise exposure lasted a full 8 hr. Due to the significant differences in noise levels generated by different fire engine vehicles, further investigation into the acoustic properties of the passenger space of fire engines is needed.

**Corresponding Author:** Lynn R. Gilbertson, Department of Communication Sciences and Disorders, University of Wisconsin–Whitewater, 800 West Main Street, 1014 Roseman Hall, Whitewater, WI 53190. E-mail: gilbertl@uww.edu.

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**TABLE 3**

<table>
<thead>
<tr>
<th>Position</th>
<th># of Measurements</th>
<th>Mean OSHA-HC (SD)</th>
<th>Mean OSHA-PEL (SD)</th>
<th>Comparable OSHA-PEL*</th>
<th>Mean ACGIH Criteria (SD)</th>
<th>ACGIH Bonferroni Results**</th>
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</thead>
<tbody>
<tr>
<td>Command</td>
<td>3</td>
<td>77 (1.1)</td>
<td>63 (2.8)</td>
<td>–</td>
<td>81 (0.6)</td>
<td>A</td>
</tr>
<tr>
<td>Operations</td>
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<td>81 (5.3)</td>
<td>68 (13.4)</td>
<td>78</td>
<td>84 (4.5)</td>
<td>AB</td>
</tr>
<tr>
<td>Water pump operator</td>
<td>2</td>
<td>89 (0.8)</td>
<td>84 (2.9)</td>
<td>81</td>
<td>91 (0.7)</td>
<td>B</td>
</tr>
</tbody>
</table>

ACGIH = American Conference of Governmental Industrial Hygienists; HC = hearing conservation; OSHA = Occupational Safety and Health Administration; PEL = permissible exposure limit. Note. Mean OSHA-HC, mean and comparable OSHA-PEL, and mean ACGIH criteria are in dBA.

*Comparable levels are from Root et al. (2013).

**Results with the same letter are not statistically different.
References


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