CDC
Workplace Safety and Health

In-Depth Survey Report

Field-Testing NIOSH HPD Well-Fit:

Off-Shore Oil Rig Inspectors in Texas & Louisiana

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NIOSH

Sites Surveyed: Lake Jackson, TX
Lake Charles, LA
Lafayette, LA
Houma, LA
New Orleans, LA

NAICS Code: 13 (Oil & Gas Extraction)

Survey Dates: February 27-28th, 2012
July 22-25th, 2013

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Abstract

Historically, employers have been reluctant to institute hearing protection device (HPD) fit-testing due to a number of limitations. HPD fit testing is not required by regulations. Previous HPD fit test systems required unique hardware and software. Costs are associated with worker time away from the job. Starting in 2009, the National Institute for Occupational Safety and Health (NIOSH) has developed an HPD fit testing system (HPD Well Fit™) based on a computer with high definition audio, a mouse and noise isolating headphones. The system can determine HPD attenuation quickly for individual workers. During 2012 and 2013, NIOSH conducted field surveys in Louisiana and Texas to test the performance of HPD Well-Fit and provide technical assistance to the U.S. Department of Interior, Bureau of Safety and Environmental Enforcement. Fit tests were performed on over 150 inspectors and engineers working in the off-shore oil industry. Based on the workers' noise exposures, subjects were fit tested with the goal of achieving 25 dBA Personal Attenuation Rating (PAR). Less than half of the workers were achieving sufficient protection from their hearing protectors prior to NIOSH intervention and training; following re-fitting and re-training, over 85% of the workers achieved sufficient protection. Recommendations were made for other hearing protection solutions for workers who could not achieve the target PAR. Average test times were 6 to 12 minutes. HPD Well-Fit demonstrates the need for individual hearing protector fit-testing and addresses many of the barriers, which have prevented its widespread implementation.

Introduction for Physical Hazard Studies

NIOSH Mandate

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational safety and health research. Located in the Centers for Disease Control and Prevention within the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology within NIOSH is responsible for developing methods to prevent adverse health outcomes associated with physical hazards such as noise and reducing harmful exposures through the application of engineering controls.

Occupational Exposure Limits

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH investigators use mandatory and recommended occupational exposure limits (OELs) when evaluating chemical, physical, and biological agents in the workplace. Generally, OELs suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. However, not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit. Combined effects are often not considered in the OEL. Recommendations for exposure limits may change over the years as new information on the toxic effects of an agent become available.

Most OELs are expressed as a time-weighted average (TWA) exposure. A TWA exposure refers to the average level of exposure during a normal 8- to 10-hour workday. Some substances have recommended Short-Term Exposure Limits or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

In the U.S., Federal agencies, professional organizations, state and local governments, and other entities have established OELs. OSHA issues Permissible Exposure Limits, or PELs [CFR, 2003], that are legally enforceable in covered

workplaces under the Occupational Safety and Health Act. NIOSH publishes Recommended Exposure Limits (RELs) based on a critical review of the scientific and technical information available on the prevalence of health effects, the existence of safety and health risks, and the adequacy of methods to identify and control hazards [NIOSH, 1992]. RELs are developed using a weight of evidence approach and formal peer review process. Other OELs published by various professional organizations are also commonly used and cited in the U.S. For example, the American Conference of Governmental Industrial Hygienists (ACGIH®) recommends Threshold Limit Values (TLVs®), which are considered voluntary guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH, 2014] The American Industrial Hygiene Association (AIHA) develops Workplace Environmental Exposure Limits (WEELs) to establish guidelines for some chemicals "when no other legal or authoritative limits exist." [AIHA, 2007].

OSHA requires an employer to furnish workers a place of employment that is free from recognized hazards that are causing, or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 91–596, sec. 5(a)(1)]. To accomplish this, employers are required to comply with OSHA PELs. However, some hazardous agents do not have PELs; for other agents, the PELs do not reflect the most current health-based information. Thus, NIOSH investigators encourage employers to consider the other OELs in making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminating or minimizing identified workplace hazards. This includes, in preferential order, the use of: (1) substitution or elimination of the hazardous agent, (2) engineering controls to reduce the level of exposure to the hazardous agent, (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance) to limit individual worker exposure to the agent, and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection).

Background for this Study

Exposure Limits and Health Effects of Noise

The link between noise exposure and auditory effects such as hearing loss and tinnitus is well established. Furthermore, noise is a non-specific biologic stressor which can lead to a variety of non-auditory effects including hypertension, changes in blood chemistry, and increased accident risk [Themann et al., 2013]. Noise-induced hearing loss (NIHL) is the most common occupational injury in the US and represents a substantial health burden both nationally and globally. Estimates of the number of noise-exposed workers in the US range from 9 to 30 million [Berger, 2000], and as many as 10 million US workers have sustained occupational NIHL [Nelson et al., 2005]. Hearing loss has a substantial impact on the individual worker and on society as a whole in terms of health, economics, and quality of life. While NIHL is permanent and irreversible, it is also completely preventable.

OSHA has issued a standard for occupational noise exposure [29 CFR 1910.95], which set a permissible exposure limit (PEL) of 90 dBA TWA over an 8-hour period with a 5-dB exchange rate. The exchange rate establishes the relationship between exposure time and exposure level. Under a 5-dB exchange rate, the allowable exposure time is halved for each 5 dB increase in exposure level. For example, a worker may be exposed to 90 dBA for 8 hours, 95 dBA for 4 hours, 100 dBA for 2 hours, etc. Exposures in excess of the PEL must be reduced through engineering or administrative controls. If these are insufficient or unfeasible, workers must use hearing protection devices to bring noise levels down to a safe level. In addition, the OSHA standard states that impulse noise exposures should not exceed 140 dB SPL.

The OSHA Hearing Conservation Amendment [OSHA, 1983] established an action level of 85 dBA and requires that employers maintain and administer an effective hearing conservation program for workers exposed at or above this level. The hearing conservation program must include noise measurement and employee notification, noise control, audiometric monitoring, hearing protection, worker training programs, record-keeping, and program evaluation.

The NIOSH REL for noise is 85 dBA (8 hour TWA) with a 3-dB exchange rate. NIOSH recommends that no exposure be allowed above 140 dBA [NIOSH, 1998]. The ACGIH TLV for noise is also 85 dBA with 3-dB exchange rate and 140 dB SPL as a maximum impulse exposure limit [ACGIH, 2014].

Hearing protection devices are required to be labeled with a Noise Reduction Rating [EPA, 1979]. The NRR was designed to predict the amount of noise reduction that would be achieved by 98% of workers; however, research has shown that less than 5% of workers actually achieve the level of protection predicted by the NRR [Berger et al., 1994]. OSHA requires that the NRR be de-rated by 50% in determining whether worker noise exposures have been sufficiently reduced. NIOSH recommends a de-rating scheme that varies from 25% to 70% depending on the type of hearing protector [NIOSH, 1998]. However, hearing protector attenuation varies greatly from worker to worker, and de-rating does not resolve the poor correlation between estimated attenuation and the actual attenuation a given person achieves [Franks et al., 2000]. This problem is significant because failure to properly fit and wear hearing protectors has been cited as the leading cause of occupational hearing loss [Themann et al., 2013].

Hearing Protector Fit-Testing

Because of the large variability across individuals in hearing protector fit and function, the only way to determine if a worker is receiving adequate noise reduction is to test the noise reduction on each worker. This concept of individual fit-testing has been used for other types of personal protective equipment for some time. For example, the OSHA Respiratory Protection standard (1910.134) mandates that employees who wear positive or negative-pressure respirators be individually fit-tested with the exact make. Model, style, and size of the respirator

they will use. However, only recently has fit-testing hearing protectors at the worksite become feasible.

Hearing protector fit-test systems have been in development since the 1970s. Padilla [1976] developed an early fit-testing system, which used pure-tone test signals generated by an audiometer and played through standard audiometric headphones mounted in 19-A David Clark earmuffs. Padilla noted that an earmuff with a larger cuff was ideally required to ensure that the ear was completely free within the test device. Subsequently, NIOSH contracted with the Pennsylvania State University to develop a dedicated hearing protector fit-testing system [Michael et al., 1976]. The system incorporated a modified large volume earmuff with transducers mounted in the ear cups to play the test signals and used a test protocol based on laboratory methods used to evaluate hearing protectors. Subjects' hearing thresholds were obtained across various frequencies with and without hearing protectors in place, and the resulting threshold differences were used to estimate noise reduction. This approach is called Real-Ear Attenuation at Threshold, or REAT. The fit-test system was installed in a mobile van and required a rack of equipment to generate stimuli and record responses. Similar systems were used by Edwards et al. [1978, 1983, 1987] to test the performance of protectors in the workplace. However, these systems were too large and expensive to be routinely implemented in hearing conservation programs.

The advent of the laptop computer enabled the development of fit-testing systems that were more portable. Michael & Associates [1998] re-engineered their original system developed for NIOSH into FitCheck, which runs from a personal computer fitted with digital sound card, external attenuator box, headphones and response switch. Additional hearing protector fit-testing systems have been developed since. Some systems, such as IntegraFit and the NIOSH Multi-Fit use a REAT approach similar to FitCheck. Other systems, including EAR Fit and SafetyMeter, use microphones attached to specially-probed earplugs to objectively measure the noise levels inside and outside the hearing protector. The VeriPRO system uses a loudness balance procedure to estimate the level of protection. (see Murphy, 2013 for a summary of fit-test systems).

Development of HPD Well-Fit

Recently developed hearing protector fit-check systems have made it possible to easily evaluate noise reduction for individual workers. However, most systems still have one or more disadvantages which have hindered widespread implementation of fit-testing at worksites. These issues include:

- The amount of time needed to complete the test
- The inability to use the system to check any hearing protection device
- The need for specialized equipment
- Lack of quantitative results.

NIOSH developed HPD Well-Fit™ to address these issues. HPD Well-Fit uses digital signal generation to replace the external attenuator box and uses the computer mouse as a response device (see Figure 1). Aside from a set of large-volume headphones, HPD Well-Fit requires no specialized equipment beyond a Windows-based computer with a 24-bit audio card and a mouse with a scroll wheel. It uses an REAT approach to determining hearing protector attenuation, but replaces the traditional threshold search procedure with an innovative method of adjustment, which decreases testing times without a significant loss of accuracy. HPD Well-Fit can test any earplug and provides a quantitative measure of sound reduction.

Figure 1. NIOSH HPD Well-Fit™ system: laptop, USB mouse, and noise attenuating headphones. Photo Credit: Mr. Scott Childress USAARL, Fort Rucker.

Test Method

In order to reduce the test time associated with fit testing, NIOSH developed a Method of Adjustment paradigm for determining thresholds in HPD Well-Fit. Subjects listen to pulsed one-third octave band noise signals through the headphones, use the scroll wheel of the computer mouse to adjust the volume of the signal to a level that is just audible, and press the mouse button to record this threshold level. The test signal is then increased by a random amount between 10 and 20 dB and the subject repeats the procedure. Three successive threshold

identifications within a tolerance range of 6 dB are required to establish a final threshold at each test frequency.

HPD Well-Fit also has options for using more traditional methods of threshold determination. These include:

- Bekésy – a procedure based on the method of limits, which provides continuity with the standard laboratory procedures used to determine the Noise Reduction Rating for hearing protectors.

- Modified Hughson-Westlake – a procedure based on the method used in standard clinical audiometric threshold testing which provides a clinical threshold paradigm.

Test Frequencies

The labeled NRR values on hearing protectors are determined through a laboratory-based REAT procedure which measures the noise reduction of the device at nine frequencies: 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz (40 CFR Part 211).   Prior research has shown that dropping the inter-octave frequencies of 3150 and 6300 Hz does not change the calculated NRR by more than a few tenths of a decibel [Berger and Rowland, 1989]. In developing HPD Well-Fit, NIOSH tested whether additional frequencies could be dropped from the protocol without significant loss of accuracy in order to further reduce the time involved in the fit-test procedure. Results indicated that testing at 500, 1000, and 2000 Hz decreased the test time by at least half without sacrificing accuracy [Murphy et al., 2006, 2008; 2011a, 2011b]. The three-frequency fit-test resulted in attenuation estimates within 2 dB of the attenuation estimates based on the seven-frequency fit-test [Murphy, unpublished data]. These three frequencies are therefore the default protocol in HPD Well-Fit; however, the system allows the user to select additional octave test frequencies from 125 to 8000 Hz.

Request from the U.S. Department of the Interior

In 2011, the Bureau of Safety and Environmental Enforcement (BSEE) within the Department of the Interior contacted the NIOSH Hearing Loss Prevention Team (HLPT) about fit-testing for their offshore oil rig inspectors and engineers. These personnel are exposed to very high noise levels from the helicopters used to transport workers between the shoreline and the oil rigs. They are exposed to additional noise sources on the oil rig platforms, including the drilling operation and generator rooms. NIOSH agreed to provide technical assistance in fit-testing these workers and recommending appropriate hearing protection, and the BSEE offered an opportunity to test the implementation of HPD Well-Fit in a field environment.

BSEE had previously conducted a noise survey to document the daily time-weighted average (TWA) exposures and the maximum sound levels that were experienced aboard four helicopters commonly used to make the commute [Radtke, 2007]. Time-weighted-averages were calculated based on a 3-dB exchange rate and comprised the workers' exposures for an entire work shift including both the

commute and the time on the oil rig platform. For trips to the more distant offshore platforms, a helicopter ride could be as long as 2 to 2.5 hours.

As shown in Figure 2, noise levels in the cockpit position were between 87 and 98 dBA. Noise levels in the cabin were higher than those in the cockpit and ranged from 95 to 107 dBA. The motor was directly above the cabin and increased the workers' exposure levels.
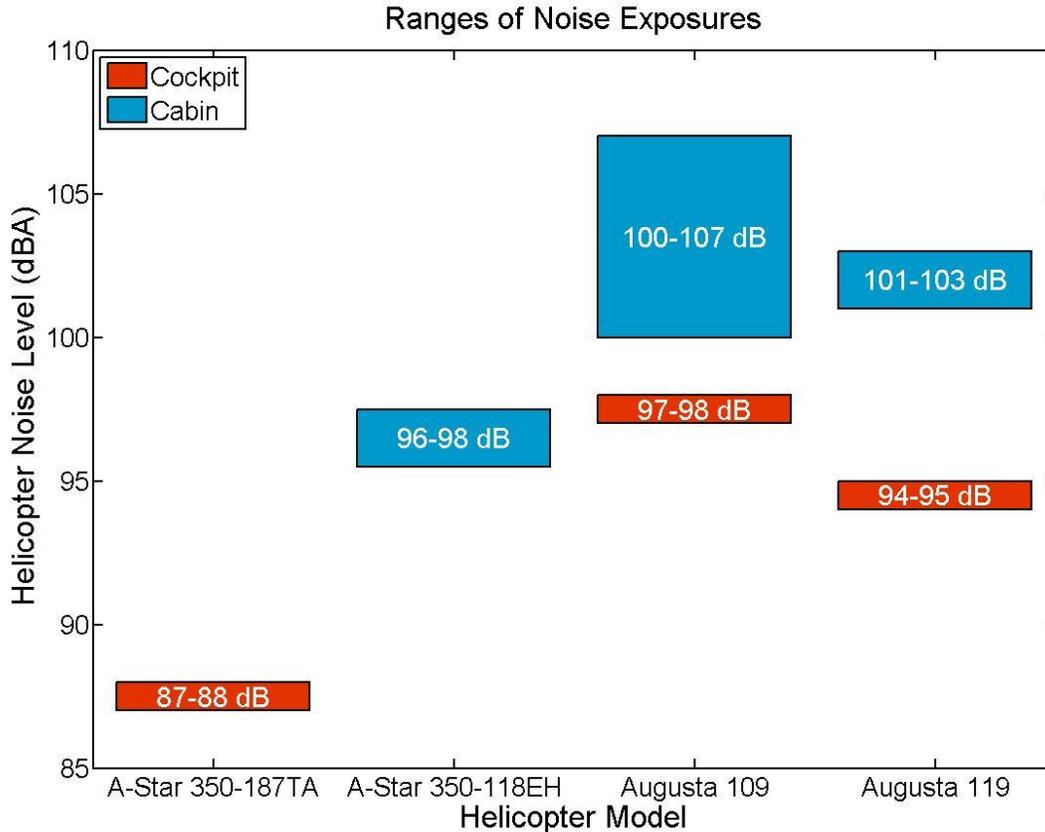

Figure 2. The range of noise exposure levels measured for four helicopters that were used to transport the workers.   The orange bars illustrate levels measured in the cockpits of the helicopters while the blue bars are the levels measured in the cabins of the helicopters. Since the highest level was close to 110 dBA, a PAR value of 25 dB attenuation was chosen to protect the workers to 85 dBA.

Figure 3 provides the octave band noise measures for three of the helicopters (one model measured with and without air conditioning on). Consistent with the noise levels and time-weighted average exposures shown in Figure 2, the Augusta A109 helicopter had the highest noise levels across most frequency bands. Both the Augusta A109 and A119 helicopters exhibited substantially higher levels in the mid- and high frequencies (500 Hz and above) than the A-Star 350 – sometimes more than 20 dB higher. Using the air conditioning reduced the sound levels of the A-

Star 350 helicopter at frequency bands above 63 Hz because the closed windows in this condition blocked some of the rotor and wind noise.
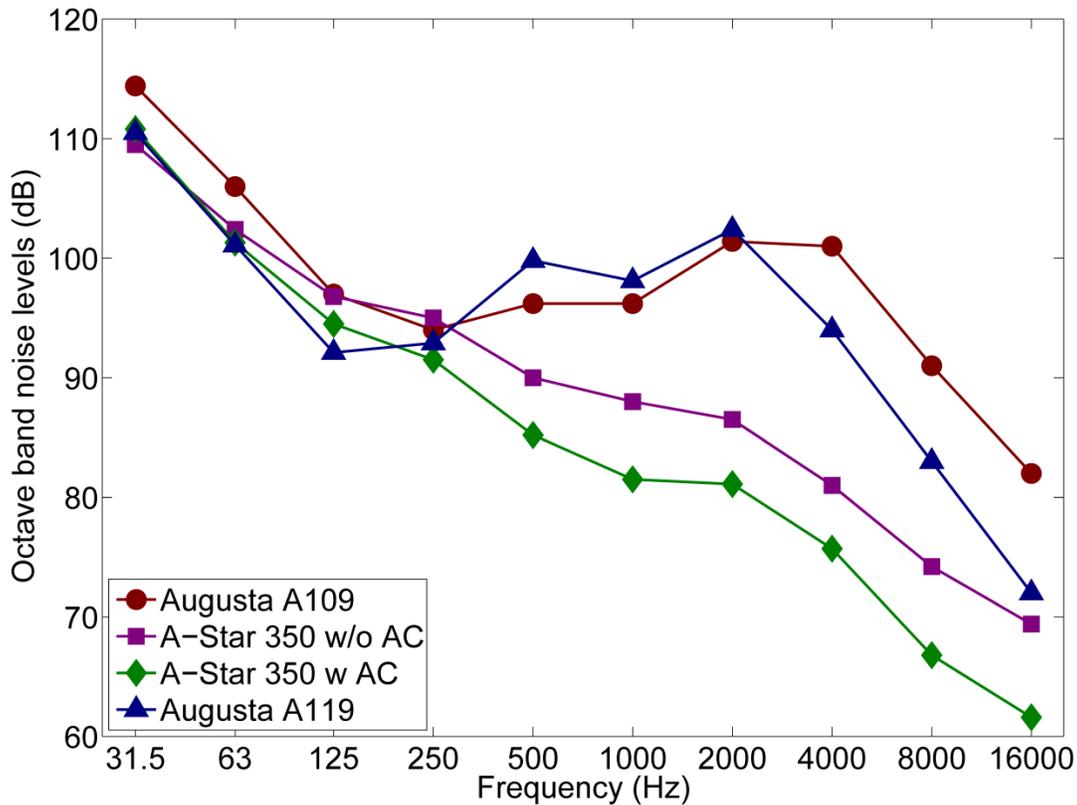

Figure 3. Octave band noise levels in dB SPL for helicopters commonly used to transport BSEE inspectors to off-shore oil rigs.

In order to adequately protect the inspectors' hearing, the noise exposure for all workers was assumed to be a worst-case level of 110 dBA. In order to reduce the exposure level under the hearing protector to less than NIOSH REL of 85 dBA, the target PAR was set at 25 dB or more. Although the A-weighted helicopter noise levels were below 110 dBA (Figure 2), a 25-dB PAR provides an additional safety factor when levels are high.

Methodology

Study Design

Two site visits were made to BSEE locations in Louisiana and Texas. The first was conducted in February 2012 by CAPT William Murphy, Ph.D. (HLPT, NIOSH) and Ms. Roey Holliday (BSEE); sites visited included New Orleans, Lake Charles, Lafayette,

and Houma in Louisiana. The second was conducted in July 2013 by Miss Christi Themann (HLPT, NIOSH) and Ms. Rose Capers-Webb (BSEE); it included the same four sites as 2012 plus a site visit to Lake Jackson, Texas. Table 1 describes the schedule of each visit.

Table 1. Schedule and locations of BSEE field survey visits in 2012 and 2013.

	2012		2013
02/27	New Orleans, LA	07/22	Lake Jackson, TX
	Lake Charles, LA	07/23	Lake Charles, LA
02/28	Lafayette, LA	07/24	Lafayette, LA
	Houma, LA	07/25	Houma, LA
			New Orleans, LA

Workers were tested at the field office site either prior to or following their travel to the off-shore location. As fit-testing looks at threshold differences rather than actual thresholds, potential over-exposure to noise from the helicopter for workers tested at the end of their day should not have significantly impacted their results.

Fit-Testing Protocol

Hardware

In both field surveys, HPD Well-Fit was run on Dell Latitude E6510 laptops with Windows 7. The audio stimuli were generated by a high-definition audio card with 24-bit resolution and 44,100 Hz sampling rate. In 2012, stimuli were delivered through Fit-Check circumaural headphones developed by Michael & Associates (Figure 4 – right headphones). In 2013, signals were delivered through Sennheiser HDA-200 circumaural audiometric headphones modified with extensions to increase the volume of the ear cup (Figure 4 – left headphones). The Sennheiser HDA200 headphones provided at least 15 dB attenuation at 500 to 2000 Hz while the Michael & Associates FitCheck headphones provided at least 25 dB attenuation (see Figure 5 from Schmitt et al., [2015]). The combination of high-definition audio and the sound-isolating headphones yielded a dynamic range of about 85 dB.

Figure 4. The HPD Well-Fit headphones. On the left are the modified Sennheiser HDA-200 headphones with spacers. On the right are the Fit-Check headphones.
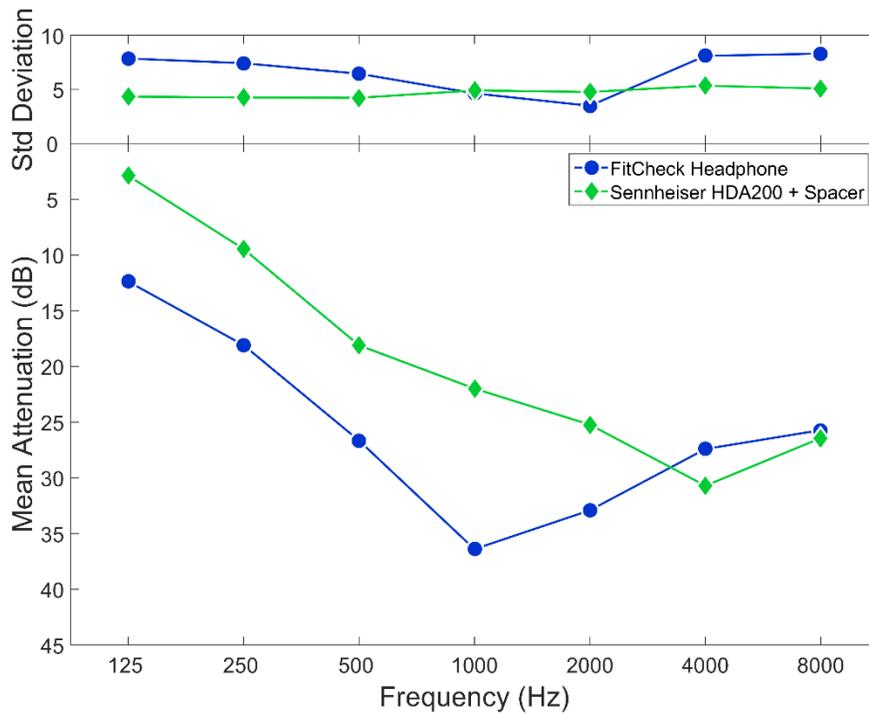

Figure 5. The attenuation as a function of frequency for the two circumaural headphones used with the HPD Well-Fit fit-test system. The attenuations for the Sennheiser HDA200 headphones at 500 to 2000 Hz provide at least 15 dB attenuation and the Michael & Associates FitCheck headphones provide at least 25 dB attenuation.

Personal Attenuation Rating (PAR)

HPD Well-Fit reports the results of a fit-test in terms of a personal attenuation rating, or PAR. The PAR is analogous to an individual NRR, with the following distinctions:

- The NRR is an average value based on results from several test subjects, whereas the PAR is an individual result.

- The NRR reflects the noise reduction of a hearing protector when it is fit by a trained experimenter, whereas the PAR reflects the noise reduction of a protector fit by the user.

- The NRR is determined in controlled laboratory conditions, whereas the PAR is generally determined in less-controlled field environments.

Different fit-testing systems calculate PARs in different ways. HPD Well-Fit calculates the PAR as an A-weighted attenuation, or the difference between an assumed A-weighted noise exposure and the estimated protected A-weighted noise exposure based on the noise reduction (difference between occluded and unoccluded thresholds), which the user received. The formula that HPD Well-Fit uses to calculate the A-weighted attenuation is

$$\text{PAR}_N = 10\log_{10}\sum_{f}^{N} 10^{L_{Af}/10} - 10\log_{10}\sum_{f}^{N} 10^{(L_{Af}-A_f)/10}$$

(1)

where L_{Af} is the assumed A-weighted noise exposure level, A_f is the attenuation measured at a particular frequency on the individual tested, and N is the number of frequencies used in the estimate.

HPD Well-Fit adjusts the A-weighted attenuation estimate to account for uncertainty due to calculating the PAR with a reduced set of frequencies (three versus seven). Based on laboratory attenuation data for a particular earplug, a regression curve and 95th percentile prediction intervals are calculated for the style of earplug being tested (custom, premolded, or formable). The regression curve is used to estimate the correlated attenuation or 7-frequency PAR from the 3-frequency PAR calculated from the NIOSH 100 noises. Finally, the 3-frequency PAR is reduced to the lower bound for the 95th percentile prediction interval of the regression curve. This 95th percentile prediction is then used to calculate the maximum A-weighted noise exposure for a worker based on his or her fit-test results.

Test Paradigm

HPD Well-Fit system was configured to test three frequencies (500, 1000, and 2000 Hz, in that order) using the Method of Adjustment paradigm. Three successive threshold identifications within a 6-dB range were required to advance to the next frequency. Unoccluded testing (without earplugs) was accomplished first, followed by the occluded condition. When formable (e.g., foam) earplugs were tested, a

two-minute waiting period preceded the occluded test in order to make certain the earplugs had fully expanded.

In 2012, workers were instructed as follows:

> "You will hear a series of pulsing sounds through the headphones. They will start at a comfortably loud level. Your task is to adjust the volume of the sounds until you can just barely hear them. Use the scroll wheel of the mouse to make the sounds louder or softer. When you have adjusted the level to the point where you can <u>just barely</u> hear it, click the scroll wheel to move onto the next sound. Do you have any questions?"

In 2013, the instructions were modified as shown below (changes in *italics*):

> "You will hear a series of pulsing sounds through the headphones. They will start at a comfortably loud level. Use the scroll wheel of the mouse to make the sounds louder or softer. *Scroll down until you can no longer hear the sounds, then slowly scroll up until you can just barely hear them.* When you have adjusted the level to the point where you can <u>just barely</u> hear it, click the scroll wheel to move onto the next sound. Do you have any questions?"

If a worker's attenuation was determined to be inadequate after the fit-test, the worker was reinstructed on how to fit the earplugs or provided a different earplugs and re-tested. In order to expedite the testing, the unoccluded condition was not repeated during retesting with a refit or new earplugs.

Test Environment

Fit-testing was conducted in a quiet room in the various field office locations. In most cases, the testing was done in a conference room (see Figure 6); periodically, a small office was used instead. During 2012, background noise levels were continuously monitored in the fit-testing location using a Larson Davis Model 831 Type I sound level meter [ANSI S1.4-1983 (R2007)]. One-third octave band noise levels from 20 Hz to 16,000 Hz levels were averaged over one-second intervals and exported to an Excel data file. Noise monitoring was not conducted during the 2013 field survey.

Figure 6. Fit-testing with HPD Well-Fit in Lake Charles, Louisiana, 2012. CAPT Murphy observed the progress of the workers as they completed the fit-tests. A logging sound level meter monitored noise levels. Workers consented to being photographed; however, their faces have been obscured to maintain their anonymity.

Hearing Protectors Tested

Workers were initially evaluated with the types of protectors they generally wore. Field offices were asked to provide samples of the types of hearing protectors available at the site. The NIOSH and BSEE team also brought a variety of sample earplugs on the survey. If workers did not achieve sufficient attenuation with their usual earplug, other earplugs available at their location were tested. If none of the earplugs used onsite properly protected the worker, earplugs from the NIOSH sample were evaluated. Earplugs evaluated included custom-molded protectors and various pre-molded and formable plugs manufactured by a range of providers. No particular brand was preferred or offered to the workers.

Results

Worker Population

Workers evaluated included BSEE off-shore oil rig inspectors and engineers. These staff members came from a variety of occupational backgrounds including but not limited to engineering, industrial hygiene, oil rig inspectors, production supervisors, and management. Workers were primarily but not exclusively male. Age ranged for the early 20s to the mid-60s. A total of 75 workers were tested during the 2012 field survey and 86 were tested in 2013. Thirty-five (35) workers fit-tested in both years, 2012 and 2013. Worker demographics are summarized in Table 2.

Table 2. Demographics of BSEE workers fit-tested during the 2012 and 2013 field surveys. (In 2012, one worker did not provide an age and in 2013, three workers did not provide their age.)

2012			2013		
Age	*Number*	*Percent*	**Age**	*Number*	*Percent*
20-29	13	17	**20-29**	21	24
30-39	18	24	**30-39**	19	22
40-49	15	20	**40-49**	16	19
50-59	21	28	**50-59**	20	23
60-69	7	9	**60-69**	7	8
Gender			Gender		
male	73	97	male	82	95
female	2	3	female	4	5
Total	75	100	**Total**	86	100

Fit-Test Results

Worker PARs

Figure 7 presents the personal attenuation ratings for each worker fit-tested during the 2012 and 2013 field surveys. In 2012, 127 fit-tests were conducted on the 75 BSEE employees in Louisiana. Thirty workers (39%) did not achieve a 25-dB PAR on their initial fit-test; these workers were retrained or refit with different hearing protectors and then retested, unless time constraints did not permit. Some workers were evaluated multiple times in order to identify a hearing protector that provided sufficient noise reduction. For most workers who were retrained or provided other earplugs, noticeable improvements in the PAR were observed. The blue symbols in Figure 7 represent a worker's initial PAR and the red symbols

indicate the final PAR. If only a blue symbol is shown for a worker, that individual was fit-test only once – either because his initial PAR was adequate or because there was insufficient time to refit and retest.

All but 7 of the 75 workers (89%) eventually achieved the target 25-dB PAR. Three workers with PARs below 25 dB were not retested because they needed to make their departure to the worksite or complete their shift. Four workers could not achieve the target 25-dB PAR in spite of retraining and refitting. Two workers achieved better results on their initial compared to their final fit-tests; these were generally workers who wanted to try another earplug even though their current earplug was providing sufficient noise reduction. In these cases, the workers were advised to continue using their original earplugs.
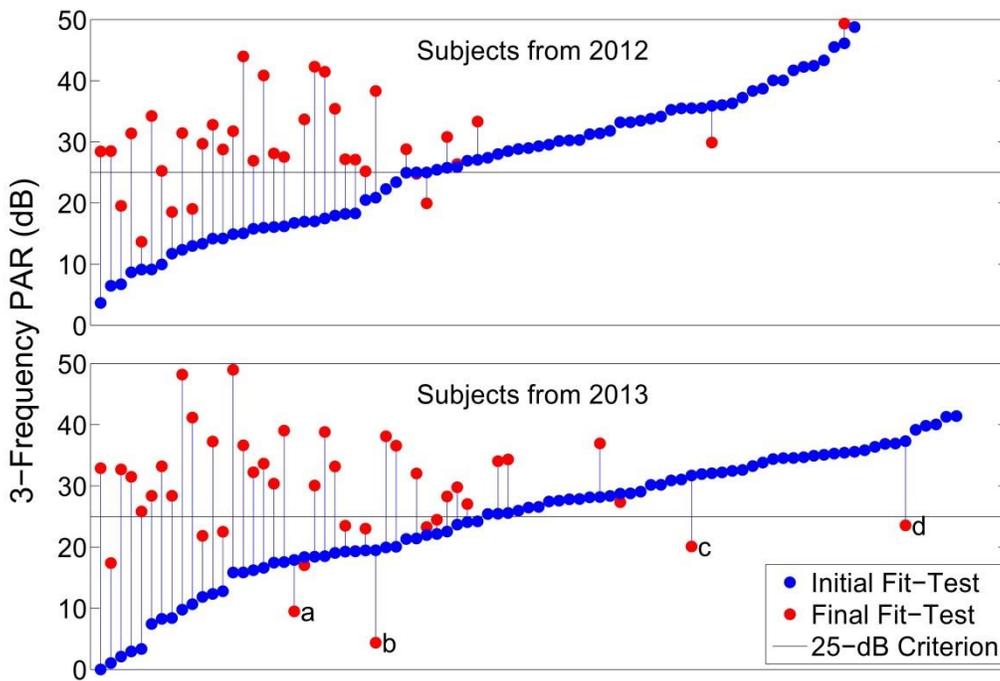

Figure 7. Initial and final personal attenuation ratings for BSEE workers in Louisiana and Texas fit-tested in 2012 (upper graph) and 2013 (lower graph). Results are sorted by ascending initial PARs. If only one result is shown, the worker was not re-tested. A few workers (points a-d) achieved lower PARs on their final fit-test than their initial fit-test; see text for details.

Results were similar in 2013. On this visit, 155 fit-tests were conducted on the 86 workers. Thirty-eight workers (44%) did not initially achieve a 25-dB PAR. Five of these workers could not be retested due to time constraints or did not want to try a different earplug. Twenty-five of the workers with low PARs eventually achieved the target PAR through retraining and/or refitting with different protectors. The remaining eight workers could not achieve the target attenuation even after retraining/refitting.

Ultimately, 73 of the 86 workers (85%) were able to achieve at least a 25-dB PAR. Several workers in 2013 wore custom-molded protectors, which needed to be replaced; these workers did not achieve the target attenuation but wanted to have their custom plugs remade rather than switch to a disposable earplug. These workers were therefore not retested. Several additional workers who could not achieve a 25-dB PAR with their disposable hearing protectors were referred for custom-molded protectors.

The graph shows four workers in 2013 with poorer final than initial PARs. Workers A and B could not achieve 25 dB of noise reduction with any disposable earplug either provided by BSEE or brought by NIOSH; custom plugs were recommended for these two workers. Worker C was initially tested with the foam earplugs he usually wore, but wanted to try flanged earplugs for comfort. He was unable to obtain sufficient attenuation with the flanged plug and was advised to continue using the foam protectors. Worker D was tested twice because he used one type of earplug when riding in the helicopter (displayed as initial PAR) and another type when working on the rig (displayed as final PAR). The 23-dB PAR for the second earplug was just shy of the target PAR for helicopter noise exposure but was sufficient for the noise levels on the oil rig.

Mean frequency-specific attenuations achieved by the oil rig workers in Louisiana and Texas for 2012 and 2013 are presented in Table 3. These statistics include all of the fit-testing data – including multiple tests for some workers and regardless of whether or not the worker achieved the target PAR. Attenuation for the 500 Hz test bands were about 23 and 22 dB for 2012 and 2013, respectively. Attenuation at the 1000 and 2000 Hz test bands were similar between the two years at about 26 and 31 dB respectively.

Table 3. Means and standard deviations for the attenuations measured at 500, 1000, and 2000 Hz.

	Test Frequency (Hz)		
	500	**1000**	**2000**
2012			
Mean Attenuation (dB)	23.4	25.9	31.3
Standard Deviation	12.06	10.6	9.95
2013			
Mean Attenuation (dB)	21.9	25.3	31.6
Standard Deviation	10.8	10.2	10.0

Figure 8 provides median and percentile estimates of the frequency-specific attenuations across all fit-tests in 2012 and 2103. Several of the outlier attenuations indicate that workers achieved attenuation less than about 4 dB. In some cases, the worker did not understand the instructions for finding threshold

and the occluded thresholds were less than the unoccluded thresholds. In other cases, test-retest variability of about 2-4 dB coupled with a poorly fit hearing protectors could be a reason for the negative attenuations. From an interlaboratory study that NIOSH conducted assessing the performance of HPD Well-Fit, a range of ±2 dB can be expected for the repeatability of a threshold assessment [Byrne et al. 2014]. Regardless of the cause, workers with obviously low attenuations were reinstructed, trained and retested.
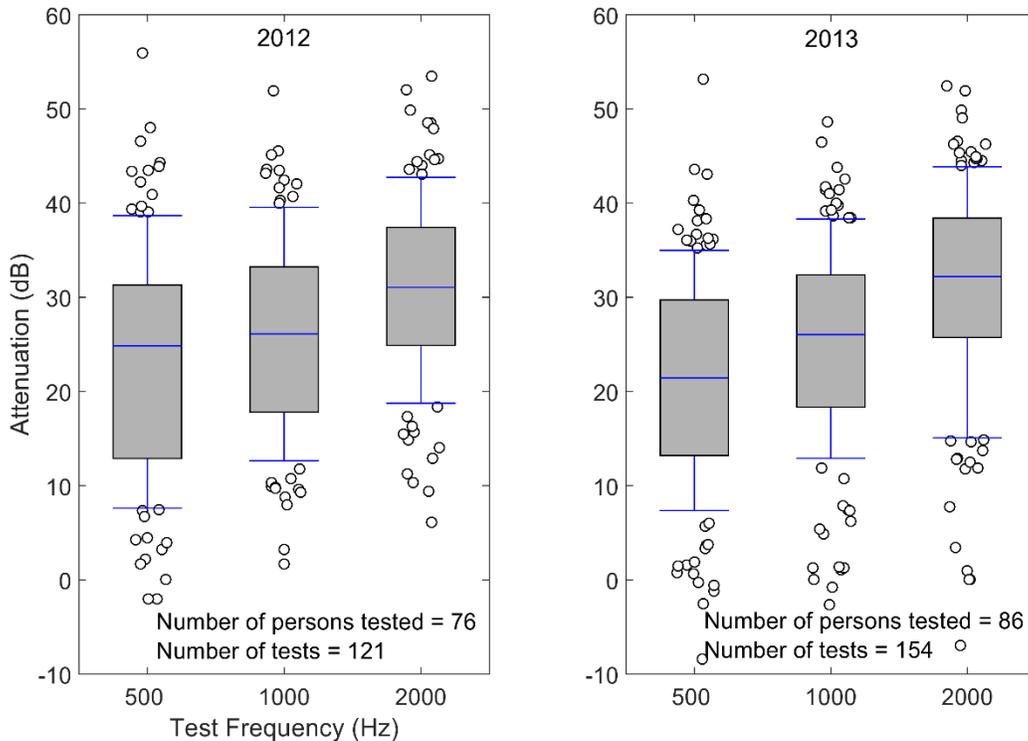

Figure 8. Fit-test results from the two field studies by frequency. The median, 25th and 75th quartiles are depicted with the box. The error bars indicate 5th and 95th percentiles. The data points outside the error bars have been shifted right and left with a random amount of jitter to facilitate visualization. The 2012 Louisiana attenuation data are displayed in the left panel and the 2013 Louisiana and Texas data are displayed in the right panel.

Figure 9 shows the results for 35 workers who were tested during both the 2012 and 2013 visits to the offices in Louisiana. Three data points are provided for each worker – the initial 2012 PAR, the final 2012 PAR, and the initial 2013 PAR. The seventeen workers in the top graph all attained the target PAR of 25 dB on their first 2013 test. The majority of these workers were already fitting their hearing protection correctly when NIOSH first tested them in 2012; however, four workers who had not obtained the target par at their initial 2012 test and had been retrained and achieved the 25-dB PAR are shown to have maintained that target at the initial 2013 test. This illustrates the potential power of individual fit-testing.

However, eighteen workers did not achieve the target PAR at their initial 2013 test. Nearly all of these workers obtained a 25-dB PAR in 2012 (either initially or upon retraining), but were achieving less attenuation the following year. This illustrates the need to conduct periodic fit-testing as a routine aspect of a hearing loss prevention program, as attenuation may change over time either due to a change in how the worker fits the device or deterioration of the device itself.
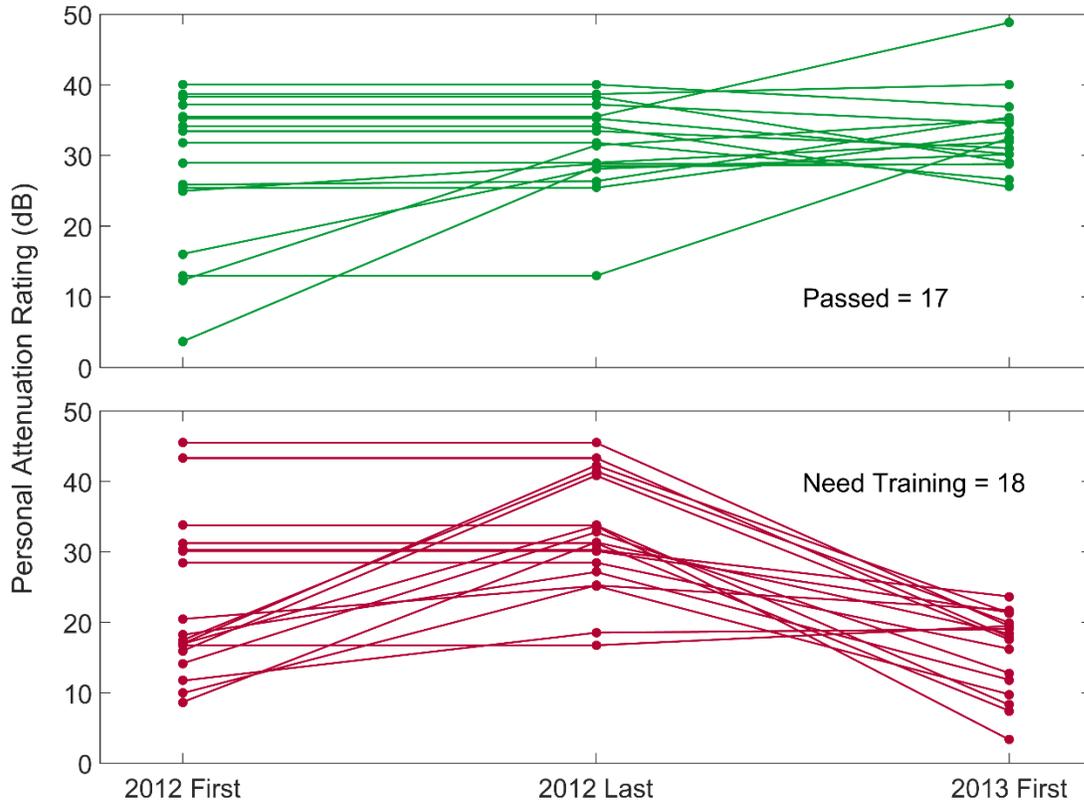

Figure 9. Fit test results over time for workers tested both in 2012 and 2013. Approximately half of the workers maintained the target 25 dB PAR between the final 2012 test and the initial 2013 test. Those who did not were retrained and illustrate the need to conduct fit-testing on a continual basis to ensure workers are properly protected.

Test Times

The time required to conduct fit-testing has been perceived as a barrier to its widespread implementation in workplaces. HPD Well-Fit tracks test times, providing information about the time required to complete the testing procedure that may be helpful in overcoming this obstacle.

Table 4 and Figure 10 summarize the timing data for the 2012 and 2013 field surveys. In general, the time required to complete each portion of the test decreased as the test progressed through successive frequencies and from the

unoccluded to the occluded testing. This is probably due to a learning effect, as the workers became more familiar with the procedure, and is consistent with the well-documented learning effects associated with clinical audiometric threshold testing [Roche et al., 1983; Royster and Royster, 1986]. The Method of Adjustment paradigm was configured to use a 2-dB step size when descending and a 1-dB step when ascending. Consequently, test times in 2013 were somewhat longer than in 2012, most likely as a result of changing the subject instructions from the one-step process of just "scrolling down" until the signal was barely audible to the two-step process of "scrolling down" until the signal disappeared and then "scrolling back up" until the signal was just barely audible.

Table 4. Minimum, median, maximum, and mean (with 95% confidence interval) test times (in minutes) for each segment of the HPD Well-Fit procedure during the 2012 and 2013 field surveys.

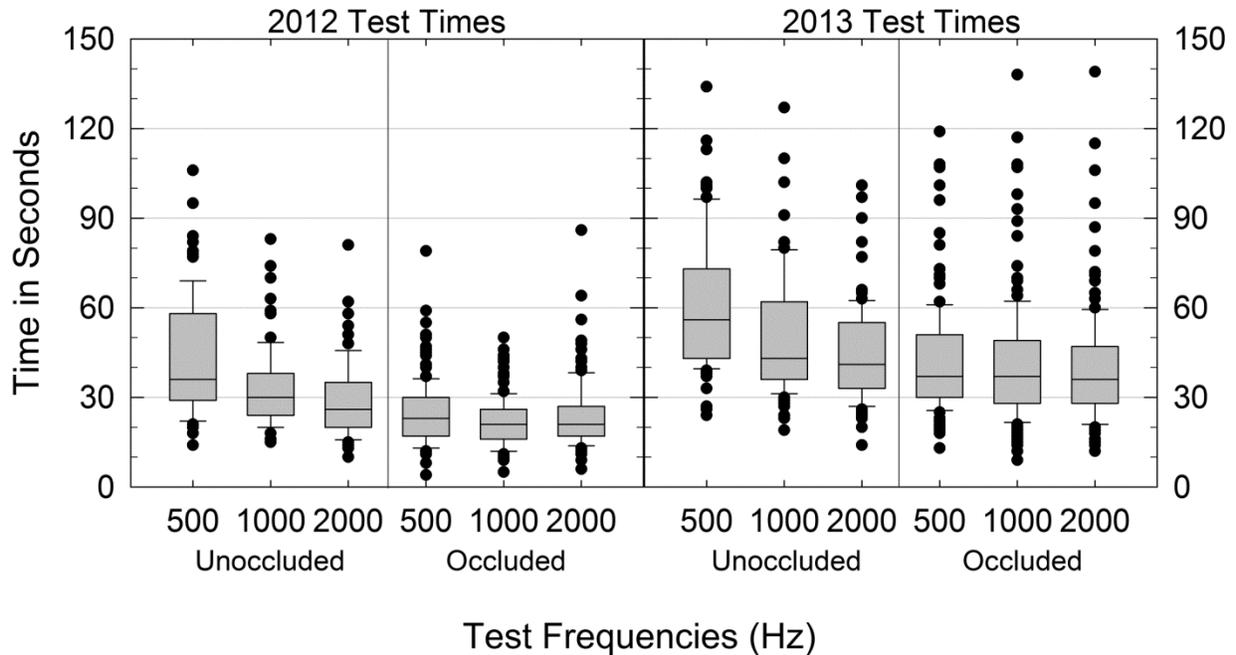|	Frequency (Hz)	Condition	Times (min)			
			Min	Median	Max	Mean [95% CI]
2012 (n = 127)	500	Unoccluded	0.23	0.61	1.77	0.72 [0.66, 0.78]
	1000	Unoccluded	0.25	0.50	1.38	0.55 [0.51, 0.59]
	2000	Unoccluded	0.17	0.43	1.35	0.48 [0.44, 0.51]
	500	Occluded	0.07	0.38	1.32	0.42 [0.38, 0.45]
	1000	Occluded	0.08	0.35	0.83	0.37 [0.34, 0.39]
	2000	Occluded	0.10	0.35	1.43	0.39 [0.36, 0.42]
2013 (n = 155)	500	Unoccluded	0.40	0.93	3.10	1.04 [0.97, 1.11]
	1000	Unoccluded	0.32	0.72	2.12	0.86 [0.79, 0.92]
	2000	Unoccluded	0.23	0.68	1.68	0.75 [0.71, 0.79]
	500	Occluded	0.22	0.63	1.98	0.69 [0.64, 0.74]
	1000	Occluded	0.15	0.62	2.30	0.68 [0.63, 0.73]
	2000	Occluded	0.20	0.60	2.32	0.66 [0.61, 0.71]

Figure 10. Time required to establish threshold using the Method of Adjustment by condition (unoccluded and occluded) and frequency for the 2012 and 2013 field surveys. Boxes indicate the 25th and 75th percentiles with the median noted by the horizontal bar inside the box. Whiskers are the 5th and 95th percentiles. Outliers are displayed as points beyond the box and whisker plots. Tests were conducted in the sequence in which they are shown in the figure.

Table 5 provides information about the amount of training time and the total time involved in each fit-test. The training time was calculated as the interval between the end of the first unoccluded test and the start of the last sequence of occluded tests. Thus, if a worker required more than one earplug fitting, the testing time for those fits are lumped into the estimates of training time. This approach is an accurate reflection of training because it was necessary to instruct, test occluded fit, reinstruct the worker. The average training time in 2012 was about 4.6 minutes with 95% confidence interval (CI) ranging between 3.7 and 5.5 minutes. In 2013, the average training time was 6.1 minutes with a 95% CI between 5.2 and 7.0 minutes. The statistic that is of perhaps greater importance is the total time, which was determined from the start of the first unoccluded test and the end of the last occluded test. This statistic provides the employer with an estimate of how long it will take to conduct the fit testing, but does not include the time spent away from the worker's job. The averaged total time spent on fit-testing in 2012 was 7.6 minutes with a 95% CI between 6.7 and 8.5 minutes. The averaged total time spent fit-testing in 2013 was 10.7 minutes and the 95% CI ranged between 9.8 and 11.6 minutes.

Table 5. HPD Well-Fit Training and Total Times 2012 and 2013. The minimum, median, maximum, average, upper and lower limits of the two-sided 95% confidence intervals (CI) are indicated in minutes.

Year	Condition	N	Time (in minutes)				
			Minimum	Median	Maximum	Mean	95% C.I of Mean
2012	Training	127	0.4	2.8	30.7	4.6	[3.7, 5.5]
2012	Total Time	127	2.0	6.1	33.3	7.6	[6.7, 8.5]
2013	Training	155	0.2	3.1	27.1	6.1	[5.2, 7.0]
2013	Total Time	155	3.5	8.7	32.8	10.7	[9.8, 11.6]

The amount of time ranges from 3 to approximately 7 minutes for the training time and the total time ranged from 6 to almost 12 minutes for the 95% confidence interval. At the outside the longest time was about 33 minutes that included 4 tries to fit a protector. Both the training and total testing times increased between 2012 and 2013. This difference has been attributed to the instructions that were being provided by the personnel conducting the testing.

Background Noise Levels

Background noise levels were monitored at each of the four study sites during the 2012 field survey. Testing was conducted in conference rooms or office areas. The two primary noise sources were the ventilation systems and conversations between other oil rig personnel waiting to be fit-tested.

ANSI S3.1-1999 (R-2013) "American National Standard Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms" specifies background noise levels for audiometric testing. The levels in this standard are designed to allow accurate measurement of hearing thresholds down to audiometric zero (0 dB HL per ANSI S3.6-2010 "Specification for Audiometers") without masking interference from room noise. Levels are specified based on the range of audiometric frequencies being tested, as signals are not readily masked by sounds higher in frequency than themselves. The ambient noise environment at the fit-testing locations was judged against the ANSI S3.1 specifications for testing 500-8000 Hz, adjusted upward for the additional attenuation provided by the fit-test headphones relative to the attenuation provided by the supra-aural headphones on which the standard is based. Results above 2000 Hz are not provided as these frequencies were not tested.
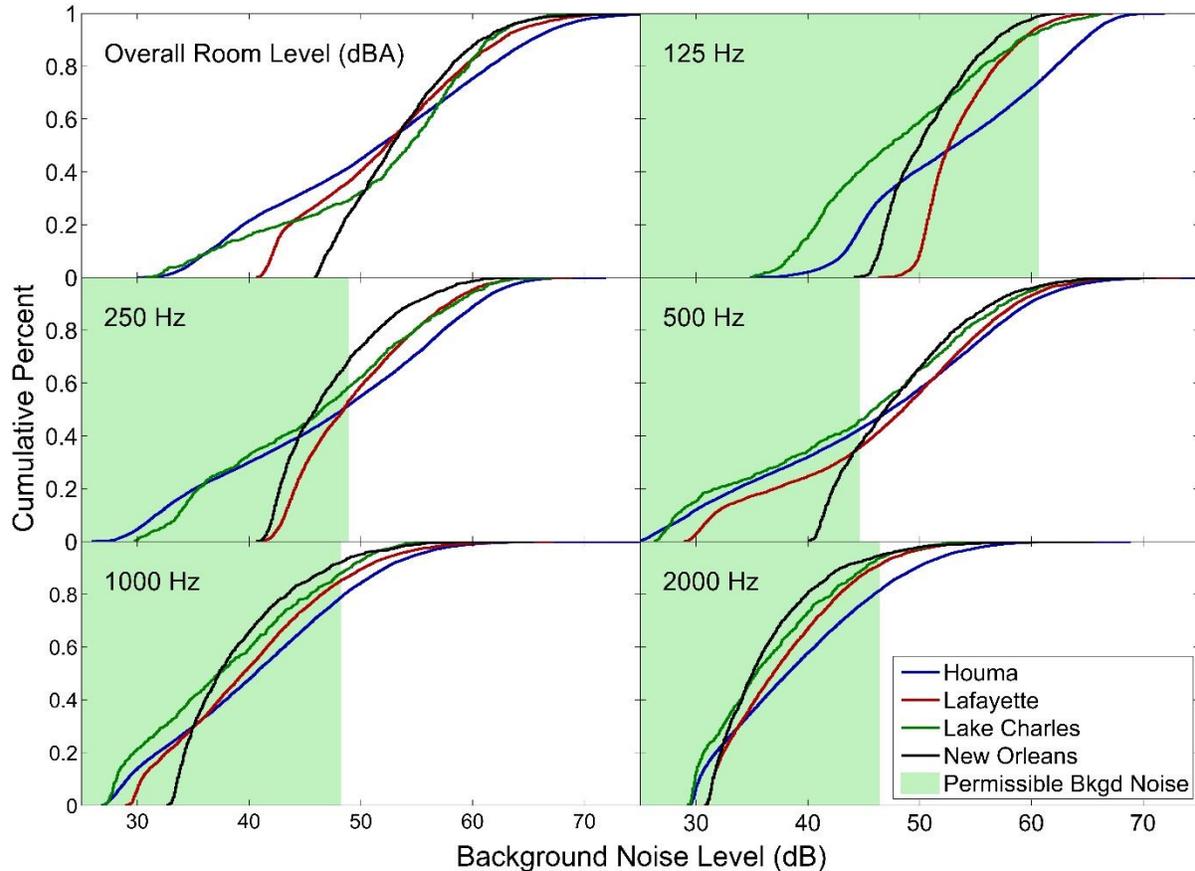
Figure 11. Cumulative distributions of overall and third-octave band ambient noise levels at each 2012 field survey site. The shaded area indicates the maximum level at which thresholds can be measured to audiometric zero, assuming a test range of 500 to 8000 Hz and taking into account the additional attenuation provided by the HPD Well-Fit headphones.

Figure 11 summarizes the results of the background noise level monitoring. In general, the environment met the ambient noise specifications the majority of the time at the 125, 1000, and 2000 Hz third-octave bands, but less than half the time at the 250 and 500 Hz third-octave bands. Ventilation system noise is generally centered around 250-500 Hz, explaining the greater difficulty meeting the background noise level requirements at these two frequencies. In the lower frequency bands, cumulative distributions for Houma and Lake Charles are distinctly different than the distributions for Lafayette and New Orleans. In the latter two locations, workers waited in the same room as the fit testing, creating additional background noise from conversation; in Houma and Lake Charles, however, workers waited outside the test area so the main source of background noise was the ventilation. In addition to background noise, the tester's verbal instructions and training are included in the cumulative distributions, which increase the incidence of higher levels. More detailed information about the ambient noise levels is provided in the Appendix.

Although in many cases the background noise in the test environment was too high to allow threshold testing to 0-dB HL, HPD Well-Fit determines PAR based on threshold differences, not absolute thresholds. Therefore, the ability to test to 0-dB HL is not strictly necessary. The important issue is to have sufficient dynamic range to accurately assess the difference in thresholds with and without earplugs. A large dynamic range is necessary for persons who may have a hearing loss, which prevents the headphone from generating an audible stimulus when the subject's ears are occluded. The fit-testing headphones were calibrated at each frequency prior to commencing the testing in 2012 and 2013. At the frequencies used in the fit-testing – 500, 1000 and 2000 Hz – both headphones were able to produce tones ranging from 5 to 85 dB SPL output when measured on a flat plate IEC 318 coupler. Less than five workers had unoccluded thresholds at 5 dB according to the presentation levels recorded in the database, and only a couple of workers had occluded thresholds at the highest presentation level of 85 dB. This indicates that the majority of the workers were able to be tested with the either the FitCheck or the modified Sennheiser HDA-200 headphones.

In the event that a threshold cannot be achieved, the missing frequency can be omitted from the calculation. In this data set, all of the subjects had data at the three test frequencies. If a subject were affected by a high background noise level, the unoccluded threshold would be elevated and would reduce the PAR for that person's measurement. Thus the PARs that are reported represent a lower limit with respect the higher background noise levels observed in New Orleans and Lafayette.

The Method of Adjustment approach to fit-testing also minimizes problems with periodic background noise issues. In the Hughson-Westlake audiometric test paradigm, the test signal is presented in a specific time window and the subject must respond in the same window. Sporadic background noise can mask the signal, resulting in a false negative. With the HPD Well-Fit Method of Adjustment, subjects have complete control over the stimulus. The pulsing stimulus remains at the same level while the subject determines whether the sound is audible. Consequently, if momentary masking noises such as conversation or other noises occur, the subject can wait until the noise subsides before proceeding with the test.

Conclusions and Recommendations

BSEE oil rig inspectors are exposed to very high noise levels (up to 110 dBA) on the job, particularly during helicopter transport to and from the offshore rigs. Effective hearing protection is essential to preserving auditory function in these workers. The labeled Noise Reduction Rating on hearing protection devices has been repeatedly shown to have little predictive value in determining the level of noise reduction a particular worker receives from that protector. Individual fit-testing is the only way to definitely know whether a worker is adequately protected from noise, and it is especially critical when a substantial level of noise reduction is required.

NIOSH conducted hearing protector fit-tests of 76 workers in 2012 and 86 workers in 2013.   Forty percent or more of the workers were not getting sufficient attenuation from their hearing protectors. Through training and re-fitting, NIOSH was able to help 85% or more of the workers receive the appropriate amount of noise reduction; recommendations for other hearing protection options were made for those workers who could not be properly fit with available protection during the site visit. Without fit-testing, nearly half of the oil rig inspectors would have been at risk for developing noise-induced hearing loss from their job exposures. Training in proper wearing and fitting techniques was not persistent. Only about half of the workers tested in 2012 and 2013 maintained the target attenuation level of 25 dB. Other workers who had been trained and achieved the target PAR in 2012 exhibited a low attenuation on the first test in 2013.

The field surveys also provided valuable information on implementing hearing protector fit-testing in the workplace and feedback on the utility of the HPD Well-Fit system specifically. Timing data indicated that between 7 and 12 minutes per person was required to fit-test the majority of the workers. Testing times improved as workers gained more experience with the procedure, so the time investment involved in fit-testing can be expected to lessen over time as workplaces begin to include fit-testing in their hearing conservation programs. The efficient performance of the NIOSH HPD Well-Fit™ system allowed workers to be fit-tested within a 10-minute time-frame. This allows personnel to maintain productivity while being cognizant about hazardous levels of noise that necessitates hearing protection.

Test instructions make a difference in test time. Average training and total test time differed between 2012 and 2013 due to changes in how the tester/instructor handled the protocol for oil rig personnel to be fit-tested. The total time for fit testing was between about 7 and 12 minutes and the time devoted to training ranged from approximately 4 to 7 minutes. At the outside, the longest fit-test time was about 30 minutes which included four attempts to fit a protector. Small differences in attenuation at 500 Hz were noted between the two test years, although it is unclear if this was related to instructions or simply normal variability.

Background noise issues did not present a significant problem. Although noise levels exceeded the ANSI standard for testing to audiometric zero, the fit-testing procedure is based on threshold differences rather than actual thresholds. The dynamic range of the HPD Well-Fit system made it possible to test in standard office or conference room space. Rooms were quieter when employees waiting to be tested remained outside. Conversations among waiting employees can also sometimes present a distraction. On the flip side, however, workers together in the same room provided a level of camaraderie and sharing of experiences, which can be very valuable in maintaining a successful hearing loss prevention program.

Recommendations for BSEE oil rig inspectors

Because workers experience high noise levels during transit to and from the off-shore platforms, we recommend that the hearing protector fit-testing program be maintained. Workers should be able to demonstrate a 25-dB PAR and need to be educated regarding the hazard of excessive exposure to noise levels above the 85 dBA recommended exposure limit. Helmets worn during the helicopter rides do provide a limited amount of attenuation, but without attenuation data for the actual workers, earplugs are recommended.

For persons who must maintain communication with the pilot(s), a communication system that is integral to the helmet is recommended. Several companies – for example, Aegisound, CavCom Inc., Sound Innovations, Westone Laboratories, and Communications & Ear Protection Inc. – have developed helmet systems that are approved for flight operation with the US Department of Defense and Coast Guard. The advantage of the communication system is a reduced burden to transmit an intelligible signal in the presence of high levels of noise. Some of the more advanced systems can pick up speech in the ear canal or through a bone conduction or throat microphone, further improving the signal to noise ratio.

Recommendations for future fit-test field studies

Using HPD Well-Fit in a field environment highlighted several issues would be useful in future fit-testing applications:

1. Identify the best set of instructions for minimizing test time while maximizing precision and repeatability.
2. Allow ears to be tested individually. Frequently, a worker would achieve a very good fit in one ear but not the other. Sometimes the tester can identify this visually, but sometimes visual inspection cannot identify the root of the problem. PARs for individual ears would reduce frustration for some workers by showing them that they are achieving a good fit in one ear and helping them try to match that fit in the other ear.
3. Bring an otoscope to help determine ear canal direction in difficult-to-fit ears.
4. Bring a mirror or digital camera as a way of showing workers the difference between good and poor fits in their own ears.
5. Provide a wide selection of HPDs for workers to try; in some cases, none of the employer-provided plugs were able to provide sufficient attenuation.

Reasons to fit-test

This field study highlighted the most important reasons for incorporating fit-testing into hearing loss prevention programs. The primary role of the hearing conservationist is to prevent noise-induced hearing loss. This can only be accomplished by knowing worker exposures and ensuring that the noise levels are reduced to a safe level. When relying on hearing protection devices to reduce exposure, individual fit-testing is the only way to confirm that workers are

sufficiently protected. This is especially true for very high exposures such as those experienced by the BSEE oil rig inspectors. The OSHA Hearing Conservation Amendment mandates educating noise-exposed workers about the hazards of noise induced hearing loss [OSHA, 1983].

The interaction between the tester and the worker during fit-testing is a natural opportunity to provide education on selecting, wearing and correctly fitting hearing protection. In fact, the OSHA-NHCA-NIOSH Alliance Best Practice Bulletin identified individual fit testing as an emerging trend and best practice [OSHA, 2008]. Selection of suitable protection requires knowledge of the worker's noise exposure. Not all employers will provide an extensive selection of earplugs or earmuffs. In these cases, fit testing identifies whether the worker can correctly wear the protection that is available. If the available protectors do not provide adequate attenuation, fit testing can document this result and provide justification for investigating other protection solutions. Finally, fit testing can be used to document worker training and to demonstrate a worker's proficiency in fitting his or her protection.

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Appendix: Background Noise Levels in 2012

This appendix reports the one-third octave band measurements of the ambient noise levels at the test locations in Louisiana in 2012 as histograms. Histograms of the noise levels at frequencies for which headphone attenuation are known are reported in the graphs in this appendix. In the main text of the report, a series of cumulative distributions for four test locations from 2012 are reported.

Each histogram represents the number of times (counts) the background noise (in dB SPL) was at a given level where the fit-testing took. Background noise was measured at 125, 250, 500, 1000, and 2000 Hz. Within the figures, the shaded area represents the highest background noise level which a zero dB HL threshold can be measured. The highest level was calculated by summing from the maximum permissible background noise for testing at 500 Hz and above [ANSI S3.1-1999] and the attenuation provided by the FitCheck headphones measured according to ANSI S3.19-1974 (Revised 1979).

Figures 12 and 13 show the results of ambient noise monitoring in Houma and Lake Charles, Louisiana, respectively. The distribution of noise levels in the 125, 1000, and 2000 Hz frequency bands are mildly right-skewed; most noise measurements were low enough to permit threshold testing to 0 dB HL.   However, the distributions at the 250 and 500 Hz frequency bands are much different; at least half of the time, the noise in these bands exceeded the maximum permissible level for testing to 0 dB HL. As indicated in the text, though, this does not mean the fit-testing results were inaccurate, as fit-testing relies on relative rather than absolute threshold measures.
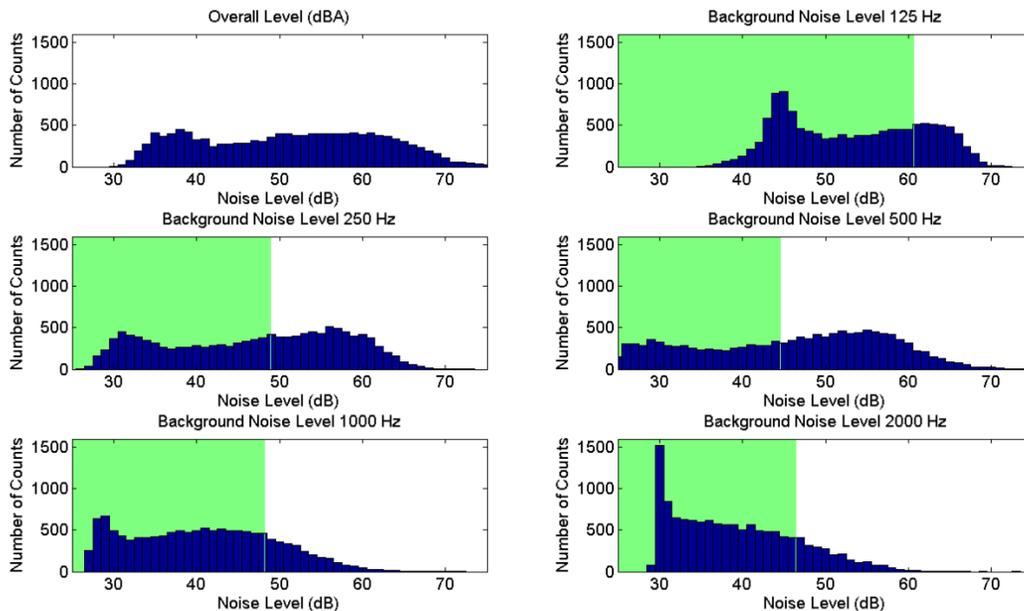

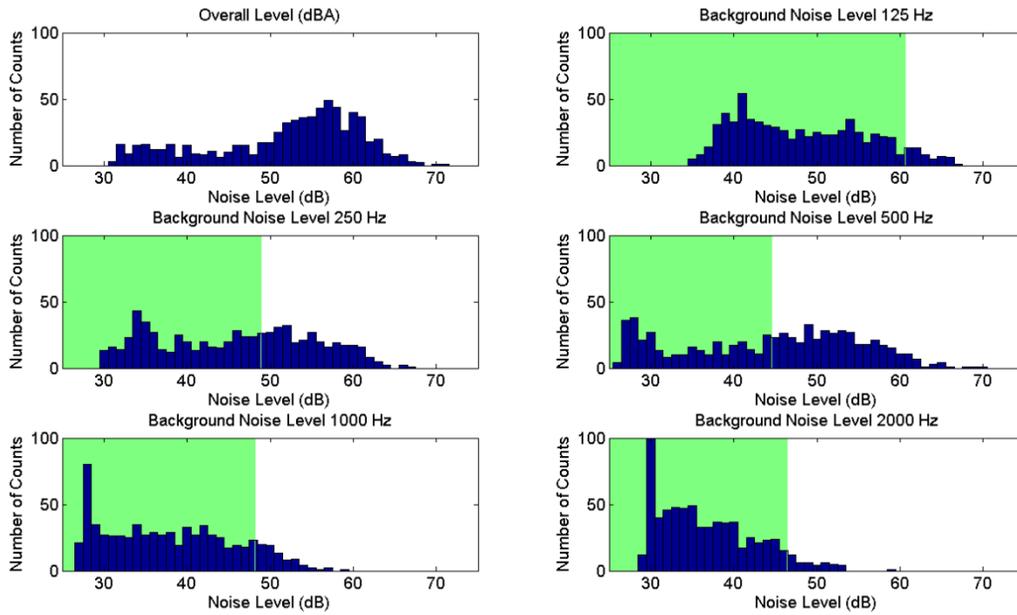**Figure 12**. Histogram of Background Noise Level for Houma, LA (2012)

Figure 13. Histogram of Background Noise Level for Lake Charles, LA (2012)

Figures 14 and 15 describe the background noise levels for Lafayette and New Orleans, Louisiana, respectively. Again, at the 125, 1000, and 2000 Hz frequency bands, most background noise levels were under the highest background level in which a 0 dB HL threshold can be measured. However, the distributions at all the frequency bands are all more strongly right skewed, reflecting the additional background noise from quiet talking among workers waiting to be tested.
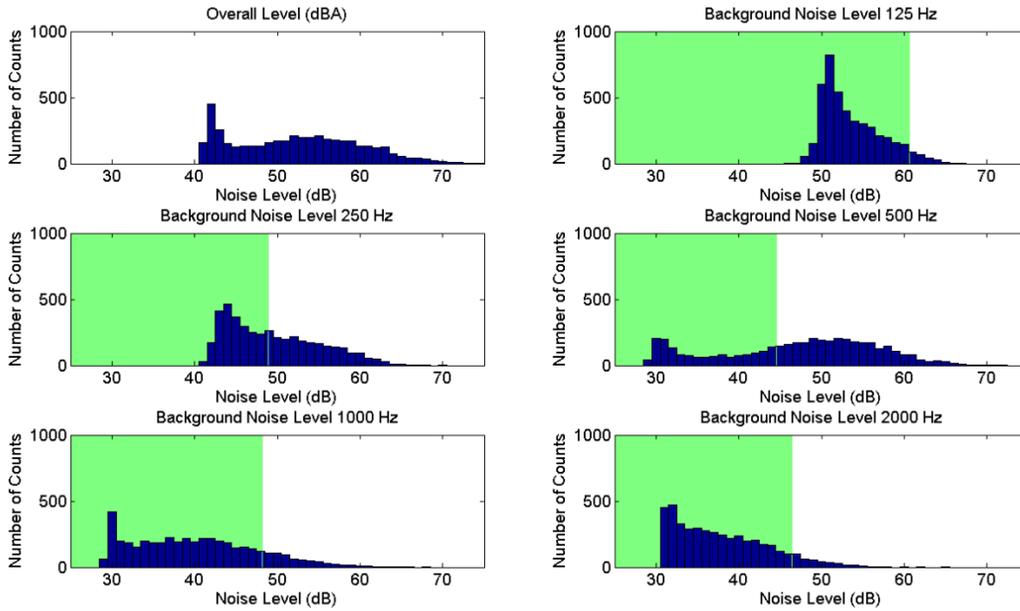
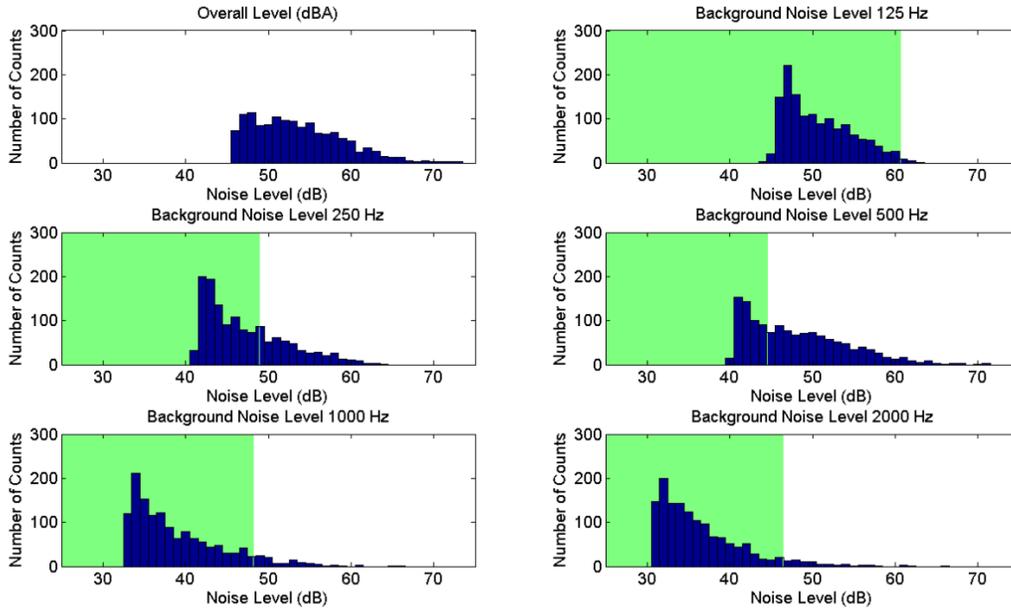**Figure 14**. Histogram of Background Noise Level for Lafayette, LA (2012)

Figure 15. Histogram of Background Noise Level for New Orleans, LA (2012)

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