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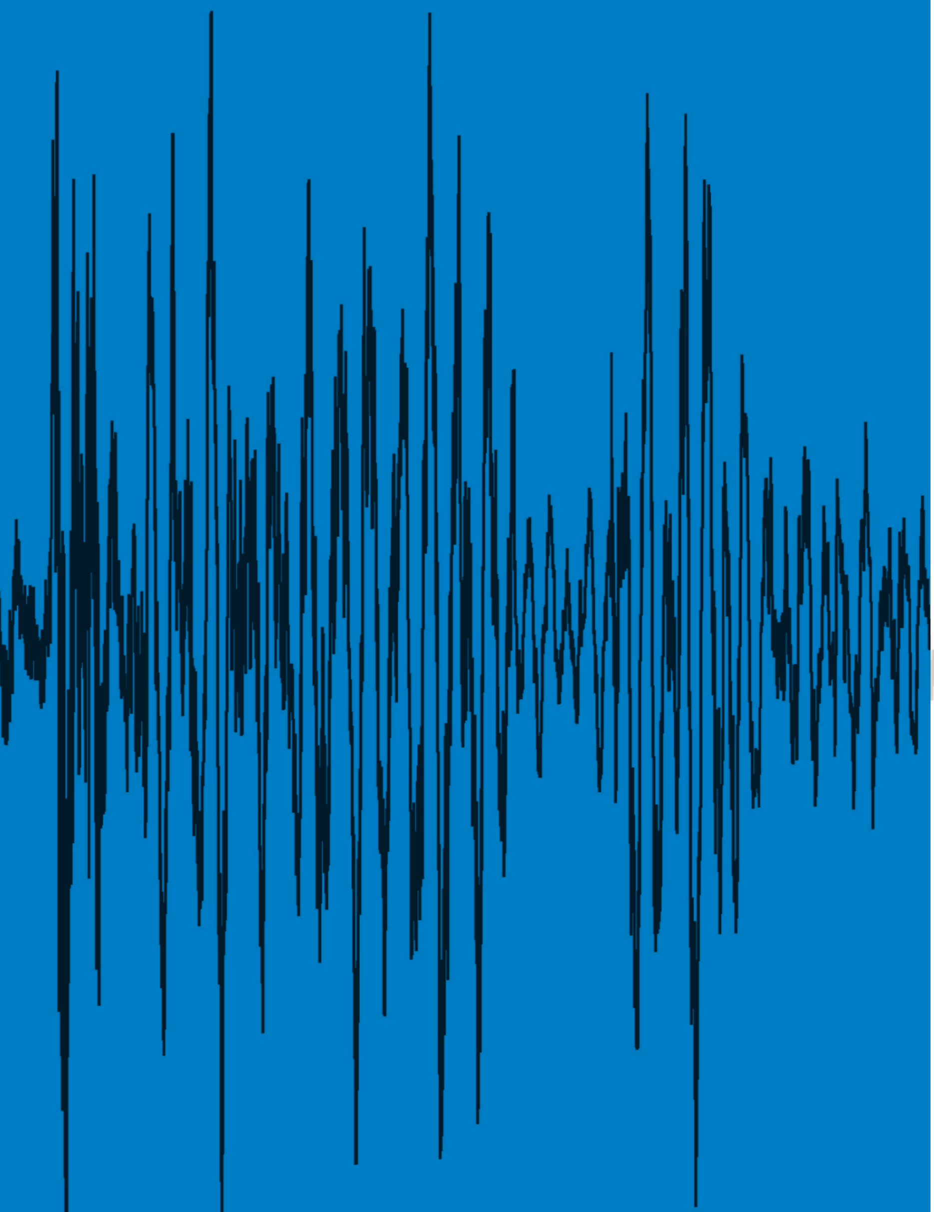

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Effects of training on hearing protector attenuation

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Abstract

The effect of training instruction, whether presented as the manufacturer's printed instructions, a short video training session specific to the product, or as a one-on-one training session was evaluated using four hearing protection devices with eight groups of subjects. Naïve subjects were recruited and tested using three different forms of training: written, video, and individual training. The group averages for A-weighted attenuation were not statistically significant when compared between the video or the written instruction conditions, regardless of presentation order. The experimenter-trained A-weighted attenuations were significantly greater than the written and video instruction for most of the protectors and groups. For each earplug, the noise reduction statistic for A-weighting (NRS_A) and the associated confidence intervals were calculated for the 80^{th} and 20^{th} percentiles of protection. Across subject groups for each protector, the differences between NRS_A ratings were found to be not statistically significant. Several comparisons evaluating the order of testing, the type of testing, and statistical tests of the performance across the groups are presented.

Keywords: Hearing protection device, noise reduction rating statistic for A-weighting (NRS_A), repeatability and reproducibility, training effects

Introduction

Occupational hearing loss is a serious problem among American workers. Although precise numbers are difficult to come by, between 5 and 30 million American workers are thought to be occupationally exposed to hazardous noise.[1,2] The U.S. National Institute for Occupational Safety and Health (NIOSH) recently estimated that 22 million workers are exposed to hazardous levels of noise in the workplace. With such large numbers of noise-exposed workers, it comes as no surprise that a correspondingly large number of workers suffer from occupational hearing loss. Since 2004, the U.S. Bureau of Labor Statistics (BLS) has reported prevalence data on hearing loss obtained from the U.S. Occupational Safety and Health Administration (OSHA Form 300). These reports have shown that hearing loss is the second-most common recordable, occupational illness. Using control technologies to eliminate the hazard is, of course, the preferred method for dealing with hazardous noise. However, when engineering or administrative controls cannot eliminate the hearing hazard, or are not feasible, the use of hearing protectors remains the only means of reducing noise exposures.

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Although hearing protection devices (HPDs) provide an effective means of reducing a worker's noise exposure, it is equally true that for many users the effectiveness of HPDs is compromised by the inability to correctly fit the protector on the head or in the ear canal. For this reason, education and training in hearing protector use is a required element of hearing conservation programs.[3-5] While HPD education and training may be required, current hearing conservation regulations provide few details on how this can best be accomplished. NIOSH is currently researching the best practices for fitting hearing protectors and is developing better training methods for fitting earplugs. As a part of this effort, the effect of training modality on subsequent hearing protector attenuation is being investigated. This paper describes the effect of video-based training as compared with training based on written materials and training based on fitting demonstrations provided by an instructor on a one-to-one basis.

Several purposes were served by conducting this study. The foremost was to confirm the results that were presented by Joseph *et al.,* where the effects of group and individual training were demonstrated with inexperienced subjects. The second purpose was to investigate the merits of using video-based training for fitting instructions relative to providing only the manufacturer's printed instructions as compared with individual instruction given by an experienced tester. The third purpose was to evaluate whether tests of different groups of subjects evaluated in the same facility with the comparable levels of instruction would demonstrate agreement using the ANSI/ASA S12.6-2008 real-ear attenuation at threshold (REAT) standard. The final purpose was to evaluate whether the methods defined in the ANSI/ASA S12.68-2007 hearing protector rating standard were valid when used to compare the various products and testing groups.

Background

According to Frost and Sullivan,[6] the U.S. industrial hearing protector market of $297.9 million in annual sales is divided between 62% of sales for earplugs and 35% for earmuffs. With respect to the units sold, the number of earmuffs is approximately 3.8 million units, while the number of earplugs is approximately 1,014.6 million units. The number of units sold for earplugs exceeds one billion units, exceeding earmuff sales by almost three orders of magnitude. Comparatively, earplugs typically have higher laboratory-tested noise reduction ratings (NRRs) than earmuffs due to their ability to create an effective seal at the ear canal and the lack of interference with hair, head gear, and head shape.[7] However, a review of studies investigating hearing protector performance found that under "real world" conditions and fit, earplugs were more likely to perform poorer, relative to their NRR, than were ear muffs.[8]

Several studies have investigated methods to assess the performance of earplugs in the work place. In the 1970s, Michael *et al*. developed a method to assess the real ear attenuation of insert earplugs.[9] A set of earmuffs was modified to hold transducers (loudspeakers), which were connected to a signal generation and attenuator system. This equipment was used to obtain REAT measurements that were previously only possible in a sound-field laboratory setting. The new system was fit into a mobile vehicle with an integral sound booth and used to assess earplug attenuation performance in occupational environments. Michael *et al*. demonstrated a strong correlation between the field and the laboratory methods of measuring attenuation. Nevertheless, generally speaking, performance in the workplace was degraded significantly from the attenuations published for specific products. Edwards *et al*.[10,11] conducted more than 1,400 attenuation tests in 10 factories and found that average protection ranged between 9 dB at 125 Hz and 29 dB at 3150 Hz. Large discrepancies were observed between laboratory and field measurements. Berger *et al*.[8] reviewed 22 studies of real world attenuation and determined that average attenuations for earplugs fitted by users in the workplace were typically 20 dB less than the manufacturer's values. Furthermore, Berger *et al.*[12] compared the results of an interlaboratory study conducted with inexperienced subjects who fitted the protectors using just the manufacturer's written instructions. The inexperienced subject-fit protocol attenuations were representative of the upper quartile of the real world attenuations. As a result, the National Hearing Conservation Association Task Force on Hearing Protector Attenuation Testing proposed that the subject-fit protocol ANSI S12.6-1997 Method B should be used by the U.S. Environmental Protection Agency (EPA) to rate the performance of the HPDs.[13]

Training in the use of hearing protection is crucial to attaining a performance level that approximates what the manufacturer publishes. In two interlaboratory studies using inexperienced subjects,[14,15] a 10–20 dB improvement was observed when the experimenter provided fitting instructions. Joseph *et al*.[16] demonstrated for naïve subjects an improvement in the NRR (subject fit) of 15 dB following individual training and 11 dB following training in small groups.[17] Joseph's study was conducted with the FitCheck system (Michael & Associates Inc., State College, PA http:www.michaelassociates.com), which is a commercially available field measurement system developed from the 1976 Michael *et al*. prototype. A modest amount of training (15–20 min) resulted in a statistically significant improvement in attenuation.[16] Interestingly, however, while the data were trending in favor of individual training over small-group training, there was no statistical difference. If the number of subjects, 25 persons per group, were doubled, then the difference may have been shown to be statistically significant.

In 2009, the US EPA proposed a revision to the federal regulation for product noise labeling for HPDs.[18] The EPA has proposed that REAT testing should be conducted with experimenter-trained subjects in accordance with ANSI/ASA S12.6-2008 Method A. The ANSI/ASA S12.68-2007 standard has been proposed as the basis of the revised hearing protector device rating.[19,20] Although inexperienced subject-fit protocols will yield attenuation that is more representative of real-world performance, the EPA's mandate is to provide an accurate assessment of the acoustic performance of only the product.[21] The EPA has proposed using a 3-dB difference limit for the trigger to require relabeling of a product during recurrent testing. While the ANSI/ASA S12.68 standard provides methods to determine the 95% confidence intervals for a given REAT test, the concept of estimating the confidence interval is new and has not been evaluated for products tested according to ANSI/ASA S12.6-2008 Method A. Furthermore, recurrent testing (and compliance audit testing) would typically be conducted in the laboratory where the product was originally tested. The study described herein provided a means of evaluating these questions prior to the promulgation of a final rule.

For this study, the effect of the training instructions – whether given as the manufacturer's printed instructions, a short video training specific to the various products, or as an individual one-on-one training session with the experimenter – were evaluated for four products with two groups of subjects per product. Naïve subjects were recruited and tested three times using different forms of training: written, video and experimenter training. The results of using video or written training first followed by written or video training second and finally experimenter training third are reported. The subjects and test facilities in this investigation met the requirements of ANSI/ASA S12.6-2008. This study measured the attenuations for two foam insert earplugs and two pre-molded earplugs (per ANSI/ASA S12.6-2008 Methods B and A), and estimated the Noise Reduction Statistic for A-weighting (NRS_A per ANSI/ASA S12.68-2007). Several comparisons evaluating the order of testing, the type of testing, and statistical tests of the performance across the groups are presented in this paper.

Methods

NIOSH conducted this study through a competitively awarded contract with Sperian Hearing Protection LLC during 2008 and 2009. Partial funding for the data collection was provided by an interagency agreement with the U.S. EPA (DW75921973-01-0). The general design was to recruit eight panels of 20 naïve subjects to test four earplugs where the training order (video-written-experimenter and written-video-experimenter) was counterbalanced between groups and products.

Subject recruitment and testing

Subjects were recruited from the San Diego area through newspaper advertisements and were paid a nominal fee for participation in the study. The NIOSH Human Subjects Review Board (HSRB) approved the procedures used in this study under protocol HSRB 07-DART-08. Sperian was approved under the NIOSH HSRB certificate as a contractor.

Each subject required about 1 h of audiometric testing to screen his or her hearing according to ANSI/ASA S12.6-2008 (≤25 dB HL at all test frequencies bilaterally) and to train and qualify in diffuse sound-field threshold testing using an automated threshold tracking paradigm. Subjects were tested with the NIOSH HPDLab software version 1.2 and were required to achieve three consecutive open-ear threshold tests in the diffuse sound field with a range of thresholds ≤6 dB. The sound-field threshold was determined using a modified Bekesy procedure, where the rate of change was 5 dB/s and the third octave band noise stimulus was presented for 0.25 s with a 0.25 s interstimulus interval. The Bekesy procedure allowed the subjects to control the presentation level by pressing and releasing a response switch. The first two reversals (range finding) were rejected and the threshold was determined from the next six reversals as long as the range was <20 dB and consecutive reversals were more than 3 dB. The mean of the midpoints for each excursion was determined to estimate the threshold and the variance of the individual thresholds.

Product selection

Four earplugs were selected for this study: Moldex Pura-Fit® (Moldex, Culver City, CA) E-A-R Classic® (3M, Minneapolis, MN) foam earplugs, Howard Leight Fusion®, and AirSoft® (Sperian Protection, Smithfield, RI) pre-molded earplugs. The primary reason for selecting these products was to be able to relate the laboratory results to previous studies for which field data were collected; however, comparisons to those data are outside the scope of this paper.[15,22,23]

Subject instruction

Stephenson and Stephenson[24] initially developed the video fitting instructions for use with construction workers. The NIOSH laboratory used a modification of the video during the experimenter-trained portion in its interlaboratory study.[15] Following the interlaboratory study, a training video specific to each earplug was developed that incorporated the necessary elements to properly select and fit a formable or pre-molded earplug and that described a method to perform a self-check of the fit using one's own voice. The script for the fitting of formable plugs is given in Appendix A. The pre-molded script is not included because it is closely related to the formable earplug script.

The written instructions provided by each manufacturer on the respective packaging were provided to each subject. Subjects were allowed 5 min to read the instructions and practice inserting the protector. For those subjects who were tested according to the video method first, they were not given access to the written instructions. Similarly, those subjects tested with the written instructions did not view the video training until the second test.

One of the authors (J.D.) trained the subjects for the experimenter-trained portion of the study. He has conducted experimenter-fit and informed-user tests for the Howard Leight Acoustical Test Laboratory for over 10 years, including those published in Murphy *et al*.[15] Each subject was given individualized instruction for 5–10 min until the subject demonstrated that he or she was capable of achieving an acceptable visual fit. After the training was completed, the subject was ushered into the testing room and testing commenced without further instruction from the investigator. The fit of the protectors in each subject's ears were photographed for later analysis.

Attenuation calculations

The performance rating was determined using the ANSI/ASA S12.68-2007 method to estimate the effective level at the ear when hearing protectors are worn. The overall dual-number rating estimates the 20th and 80th percentiles of performance for the NRS_A. The NRS_A metric incorporates the variability of both the fit that the subjects achieved and the variability of the noise spectra in which the protectors might be worn. In Annex D of the standard, the method to estimate the 95% confidence intervals of the NRS_A rating is described. Essentially, the subject population is considered to be statistically representative of the larger potential pool of subjects. The subject population is randomly sampled to create groups of 20, where an individual's results may occur more than once or not at all. For each group, the NRS_A rating is calculated and stored to create a statistical sampling of possible ratings. The process is referred to as a bootstrap procedure first developed by Efron and Tibshirani.[25]

Statistical differences

A three-factor experimental design with repeated measures was used to test for the effects of product (AirSoft, Classic, Fusion, Pura-Fit), instruction protocol (video, written, experimenter-trained), order of testing (video-written or written-video, followed by experimenter-trained), and their interactions. Product and order of testing were between-subjects factors. Instruction protocol was a within-subjects (repeated measures) factor. The SAS® procedure MIXED was used to analyze the data.[26] The model was fit using restricted maximum likelihood and had an unstructured covariance matrix.

Results

Audiometry

Pure tone audiometric thresholds were obtained for all subjects using a calibrated Grason Stadler GSI 1761 audiometer. First thresholds were bracketed to a 5 dB range and then a 1 dB step-size was used to determine the subject's threshold. Subjects were required to have hearing thresholds at all test frequencies (125–8000 Hz) that were better than or equal to 25 dB HL. As can be seen from Table 1, the 1-dB hearing thresholds of the different groups exhibited no significant statistical differences. The subject groups are separated based on the earplug they were testing and the order of training they received. VWE indicates Video 1st, Written 2nd and Experimenter-Trained, whereas WVE indicates Written 1st, Video 2nd and then Experimenter-Trained. Subjects were recruited according to the criteria specified in ANSI/ASA S12.6-2008 Method B, which means that the subjects were to have no prior individual, video, or group-based training in the fitting and use of HPDs and a limited use of HPDs during the previous year.

Average hearing protection attenuations

Tables 2–5 contain the average attenuations at each of the test frequencies for the four earplugs and experimental groups. Generally, the improvement from the second and third trial across protectors and groups was statistically significant.

Attenuations for the first experimental condition (video instructions 1st or written instructions 1st) exhibited the lowest attenuation at all frequencies for the Moldex Pura-Fit [Table 2]. For the lower frequencies, the improvement from the first video or written trial trended lower on average, but the differences were not found to be statistically significant. Between the second trial (video 2nd or written 2nd instruction conditions) and the third experimenter-trained trial, the improvement was found to be statistically significant.

Table 3 reveals similar trends for the E•A•R Classic, except that the Video 1st and Written 2nd group showed a slight decrease in attenuation from the first to the second series of tests. The Written 1st and Video 2nd group exhibited a slight increase between the first and second set of tests. However, the increased attenuation between the first and second tests relative to the third tests was about 8–10 dB at the lower frequencies and 2–8 dB at the higher frequencies. These improvements were found to be statistically significant.

Similar to what was observed for the E•A•R Classic, the

Table 1: Mean pure-tone hearing thresholds and standard deviations in dB HL measured under headphone to a 1-dB step size

Group	Ear	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
Classic VWE	Right	5.5 ± 6.4	6.8 ± 6.6	3.9 ± 6.3	2.8 ± 4.6	1.7 ± 5.7	0.1 ± 3.1	2.2 ± 6.6	4.2 ± 5.9	1.6 ± 5.5
Classic VWE	Left	5.7 ± 7.2	4.7 ± 7.4	2.4 ± 5.8	1.7 ± 5.0	1.7 ± 5.4	0.1 ± 5.4	0.8 ± 7.0	5.6 ± 6.8	4.1 ± 6.2
Classic WVE	Right	7.5 ± 5.5	6.9 ± 3.6	3.6 ± 4.4	4.6 ± 4.4	3.4 ± 6.5	4.6 ± 6.1	8.6 ± 9.0	8.8 ± 8.4	7.6 ± 6.8
Classic WVE	Left	4.9 ± 3.7	6.4 ± 5.3	2.9 ± 4.9	2.3 ± 5.7	2.2 ± 7.9	3.8 ± 7.5	4.0 ± 5.8	10.9 ± 8.3	10.2 ± 5.3
Airsoft VWE	Right	4.3 ± 4.7	6.1 ± 5.7	3.1 ± 5.0	3.9 ± 4.3	2.0 ± 4.6	2.8 ± 5.5	3.9 ± 7.9	6.0 ± 6.4	6.0 ± 7.7
Airsoft VWE	Left	4.9 ± 6.1	4.7 ± 5.7	3.4 ± 5.5	2.4 ± 2.9	-0.3 ± 5.3	2.0 ± 5.5	1.0 ± 4.1	9.4 ± 8.4	6.0 ± 6.6
Airsoft WVE	Right	5.1 ± 5.4	6.5 ± 5.9	1.6 ± 4.3	2.2 ± 4.7	1.3 ± 4.8	2.9 ± 4.9	2.2 ± 4.5	9.5 ± 6.6	5.6 ± 6.1
Airsoft WVE	Left	3.2 ± 6.2	3.2 ± 6.1	1.6 ± 5.6	0.9 ± 3.5	0.1 ± 3.4	3.1 ± 6.0	1.2 ± 5.3	7.4 ± 6.9	6.9 ± 7.3
Pura-Fit VWE	Right	6.0 ± 5.9	6.4 ± 5.5	3.8 ± 4.9	3.6 ± 2.6	3.6 ± 5.0	5.7 ± 7.1	6.0 ± 4.9	9.4 ± 7.7	10.3 ± 6.9
Pura-Fit VWE	Left	5.7 ± 5.3	6.2 ± 5.6	4.0 ± 4.1	3.1 ± 4.1	1.9 ± 4.0	2.9 ± 5.3	4.4 ± 6.5	9.3 ± 6.2	11.1 ± 6.3
Pura-Fit WVE	Right	6.6 ± 5.3	7.6 ± 6.3	3.7 ± 4.3	5.0 ± 5.1	3.8 ± 5.2	5.2 ± 6.1	5.7 ± 8.1	9.4 ± 5.3	7.3 ± 5.2
Pura-Fit WVE	Left	6.9 ± 5.2	6.9 ± 5.4	3.0 ± 3.3	4.9 ± 4.8	3.0 ± 3.2	2.1 ± 4.0	4.5 ± 4.8	11.0 ± 6.4	9.2 ± 6.7
Fusion VWE	Right	4.8 ± 5.0	4.4 ± 4.8	1.9 ± 3.8	1.7 ± 3.2	1.6 ± 3.7	1.4 ± 4.9	2.8 ± 4.6	7.6 ± 6.1	5.5 ± 5.9
Fusion VWE	Left	3.6 ± 4.1	2.9 ± 3.2	1.0 ± 2.9	0.5 ± 2.8	2.0 ± 4.4	1.1 ± 3.2	2.8 ± 4.3	6.7 ± 6.2	6.4 ± 7.2
Fusion WVE	Right	3.7 ± 4.2	4.0 ± 4.7	3.4 ± 5.2	3.6 ± 4.7	2.1 ± 4.2	5.1 ± 5.7	6.8 ± 8.0	8.8 ± 6.3	5.2 ± 6.1
Fusion WVE	Left	3.6 ± 5.6	3.5 ± 5.0	1.2 ± 2.3	2.5 ± 4.0	1.2 ± 3.1	4.4 ± 6.2	3.3 ± 6.4	9.2 ± 8.1	6.1 ± 6.4

Table 2: Mean attenuations and standard deviations in dB for the Moldex Metric Pura-Fit foam earplug

Instruction	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Video 1st	25.5 ± 10.2	27.9 ± 12.2	28.9 ± 13.3	28.7 ± 8.7	31.5 ± 6.4	40.6 ± 6.4	40.5 ± 5.9
Written 2nd	25.5 ± 8.5	29.0 ± 9.3	29.6 ± 9.4	28.8 ± 8.6	32.2 ± 6.6	42.1 ± 5.0	41.2 ± 4.8
Exp-trained	35.0 ± 6.4	37.9 ± 7.7	41.1 ± 7.0	38.3 ± 5.8	35.5 ± 3.2	44.0 ± 3.8	44.4 ± 3.9
Written 1st	21.8 ± 8.6	24.3 ± 8.3	24.5 ± 8.1	27.0 ± 8.3	32.5 ± 5.4	40.8 ± 5.4	41.8 ± 8.2
Video 2nd	25.5 ± 9.0	30.0 ± 9.6	31.8 ± 10.9	32.1 ± 10.1	34.5 ± 6.6	41.2 ± 6.3	42.2 ± 6.9
Exp-trained	33.8 ± 6.7	39.1 ± 7.2	41.9 ± 6.6	40.3 ± 5.9	37.0 ± 5.6	45.6 ± 5.5	45.3 ± 5.2

Table 3: Mean attenuations and standard deviations in dB for the Aearo/E•A•R Classic foam earplug

Instruction	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Video 1st	24.5 ± 7.2	26.0 ± 6.2	27.9 ± 7.4	29.8 ± 7.3	32.6 ± 4.5	42.8 ± 5.5	41.9 ± 8.5
Written 2nd	21.7 ± 4.5	23.7 ± 4.4	25.6 ± 6.0	27.4 ± 5.2	33.2 ± 4.5	41.4 ± 7.1	38.8 ± 8.8
Exp-trained	32.6 ± 6.2	35.7 ± 4.6	36.6 ± 6.6	38.7 ± 5.2	37.2 ± 6.2	45.0 ± 5.7	46.6 ± 6.0
Written 1st	22.7 ± 5.5	23.1 ± 6.5	25.7 ± 5.9	27.2 ± 5.9	32.0 ± 3.4	41.3 ± 5.6	41.5 ± 5.9
Video 2nd	25.6 ± 6.2	26.9 ± 6.1	29.2 ± 6.5	29.4 ± 6.8	32.8 ± 3.9	43.2 ± 3.9	42.6 ± 6.8
Exp-trained	33.6 ± 6.6	36.5 ± 7.0	38.1 ± 7.3	36.5 ± 7.5	34.1 ± 3.2	44.8 ± 4.3	45.5 ± 5.0

Table 4: Mean attenuations and standard deviations in dB for the Howard Leight AirSoft pre-molded earplug

Instruction	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Video 1st	20.2 ± 8.2	21.2 ± 7.7	22.8 ± 9.1	23.1 ± 7.1	30.1 ± 8.0	31.8 ± 9.5	34.8 ± 11.7
Written 2nd	19.5 ± 7.0	20.6 ± 6.8	21.8 ± 8.3	22.2 ± 5.9	29.1 ± 6.7	31.5 ± 8.7	33.3 ± 10.8
Exp-trained	27.0 ± 5.7	27.6 ± 5.4	31.2 ± 6.5	29.5 ± 6.9	34.0 ± 4.5	36.7 ± 6.8	42.2 ± 7.8
Written 1st	18.4 ± 11.3	18.1 ± 9.1	19.9 ± 9.2	23.6 ± 8.2	26.5 ± 8.7	29.1 ± 10.0	32.2 ± 12.3
Video 2nd	17.7 ± 9.9	17.8 ± 9.9	20.1 ± 9.4	23.7 ± 7.1	28.3 ± 7.0	31.3 ± 8.8	32.9 ± 12.8
Exp-trained	26.1 ± 4.5	26.4 ± 4.8	29.0 ± 4.8	29.2 ± 5.5	32.0 ± 4.0	36.6 ± 5.5	43.5 ± 5.9

Table 5: Mean attenuations and standard deviations in dB for the Howard Leight Fusion pre-molded earplug

Instruction	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Video 1st	24.1 ± 7.4	25.3 ± 7.8	26.8 ± 6.7	29.2 ± 6.8	27.8 ± 5.5	37.9 ± 10.2	41.3 ± 8.9
Written 2nd	21.0 ± 9.0	22.1 ± 8.5	25.5 ± 7.9	26.8 ± 8.3	26.5 ± 6.9	31.0 ± 10.7	36.9 ± 11.1
Exp. trained	28.8 ± 5.8	29.0 ± 6.4	29.3 ± 6.3	32.7 ± 6.4	31.7 ± 5.9	42.7 ± 6.8	47.1 ± 5.5
Written 1st	26.1 ± 10.4	26.8 ± 10.2	27.7 ± 10.2	29.9 ± 10.6	31.2 ± 11.0	33.0 ± 12.4	39.3 ± 12.6
Video 2nd	25.5 ± 8.8	25.4 ± 9.6	26.8 ± 9.5	28.2 ± 10.7	29.3 ± 10.3	32.4 ± 12.7	37.6 ± 14.5
Exp. trained	29.5 ± 3.3	29.0 ± 3.9	31.5 ± 3.6	34.9 ± 4.9	34.5 ± 3.9	42.0 ± 6.3	44.3 ± 5.2

attenuations for the Howard Leight AirSoft earplug Video 1st condition were slightly greater than the second trial, where the subjects were given the written fitting instructions [Table 4]. However, the differences were not statistically significant between the first and the second trials. Statistically significant improvements in attenuation were found between the second set of attenuation tests and the experimenter-trained condition.

Table 5 contains the attenuations for the Howard Leight Fusion earplug. Once again, the attenuations tended to be greater for the first trial compared with the second trial; however, the differences were not significant. Differences between the second and third trials (experimenter-trained) were found to be statistically significant.

Comparisons between the various protectors on a frequency-by-frequency basis are of less interest than the composite estimate of the A-weighted attenuations for the different conditions. Individual comparisons tend to a more ambiguous result, and the overall attenuation is more pertinent when estimating effective exposure. A-weighted attenuation is determined as follows:

$$\text{Awt Atten} = 10\log_{10}\left(\sum_{f=125}^{8000} 10^{(100+\text{Awt}(f))/10}\right) - 10\log_{10}\left(\sum_{f=125}^{8000} 10^{(100-\text{Atten}(f)+\text{Awt}(f))/10}\right), \quad \text{....(1)}$$

Where, 100 is the one-third octave band sound pressure level (in dB) of a pink-noise spectrum (where there is equal energy in each band), Awt(*f*) represents the A-weighting correction factors (-16.1, -8.6, -3.2, 0.0 1.2, 1.0, -1.1) for each band (125, 250, 500, 1000, 2000, 4000 and 8000 Hz), and values for Atten(*f*) are the average attenuations across the two trials in a given instruction condition. A-weighted attenuations were determined for each subject in each condition. The average A-weighted attenuations and standard deviations are reported in Table 6 for each protector and test condition. The general trend observed is that the first measurement was within 1 or 2 dB of the second set of measurements. However, in the third trial, where the subjects received one-on-one experimenter training, the A-weighted attenuations improved by 4–7 dB.

The next analysis was performed to assess whether the effect of training on attenuation was significant. The use of a statistic such as the NRS_A provides only an estimate of the group performance that is discounted by a multiple of the standard deviation (±0.8416 for the 80th and 20th percentiles). In Murphy *et al*.,[15] comparisons between the conditions and the groups were performed by first estimating the average A-weighted attenuation for each subject across a given condition (e.g., Video first), and then determining the difference with the other conditions for that particular subject. Once the individual differences were determined, the groups were evaluated to identify whether the 95% confidence intervals for the differences included zero. If 0 dB fell within the confidence interval, then the null hypothesis could not be rejected and the two groups were not significantly different.

In Table 7, the paired comparisons for the attenuation differences are reported. For every product, the Experimenter-trained condition exhibited significant improvement relative to the Video and the Written instruction sets. For the E•A•R Classic and the Howard Leight Fusion earplug, the Video 1st – Written 2nd comparison were also significantly different. However, a learning effect might be indicated because the confidence interval was close to including 0 dB. For the Written 1st – Video 2nd comparison, the Moldex Pura-Fit was significantly different, with a lower 95% confidence interval limit of 1.5 dB. The E•A•R Classic was also significantly different, with a lower limit of 0.2 dB. Again, perhaps a minor learning effect was evident for the E•A•R Classic and the Pura-Fit. In this case, the use of the video training may have provided more information for the test subjects with their second trial than would have been provided by written instruction alone. Also shown in Table 7 are the comparisons between the groups for the first, second, and third trials. For each product and test condition, no significant differences were observed, which indicates that all groups exhibited the same performance across product tests.

Lastly, the attenuations of the groups were evaluated using the NRS_A. The NRS_A statistic is a new method for estimating the attenuation of HPDs and assigns two numbers that reflect the upper and lower expected limits of attenuation provided by a given product tested by the REAT method. As specified in ANSI/ASA S12.68-2007, the 80th and 20th percentiles of protection were determined and are presented in Table 8. Following the methods outlined in ANSI/ASA S12.68-2007 Annex D, the 95% confidence intervals of the NRS_A statistic were determined. The trends observed in the A-weighted attenuation are confirmed in the NRS_{A80} data. For the individual groups, the first two trials are not significantly different. However, for the third trial, the experimenter-trained results do not fall within the confidence interval of the first or second trials. With the exception of the Fusion earplug, the upper confidence intervals of the second trial do not overlap the lower confidence interval of the 3rd trial.

For the NRS_{A20} data, the results are more complex and require careful consideration. For all of the earplugs, the improvement

Table 6: Average A-weighted attenuations and standard deviation in dB for each product and instruction mode

Instruction	Pura-Fit	Classic	AirSoft	Fusion
Video 1st	30.3 ± 8.3	28.9 ± 5.6	24.0 ± 6.8	26.0 ± 7.8
Written 2nd	29.9 ± 8.5	30.8 ± 6.3	25.4 ± 7.7	28.4 ± 5.6
Exp. trained	37.3 ± 3.1	36.7 ± 4.9	31.6 ± 5.3	32.3 ± 5.2
Written 1st	28.3 ± 7.9	29.0 ± 5.0	22.9 ± 8.9	29.3 ± 10.3
Video 2nd	32.5 ± 8.0	31.2 ± 5.2	23.6 ± 8.4	28.3 ± 10.3
Exp. trained	38.7 ± 4.5	36.2 ± 4.3	30.7 ± 4.0	34.5 ± 3.5

Table 7: Comparison of the A-weighted attenuations across the different test conditions. The 95% confidence intervals of the average differences in A-weighted attenuation for each protector and condition are presented

Instruction	Pura-Fit	Classic	AirSoft	Fusion
Video 1st – Written 2nd	(-3.5, 2.2)	(0.2, 3.4)	(-2.1, 4.4)	(0.1, 4.8)
Video 1st – Exp. trained	(4.0, 9.3)	(5.8, 10.2)	(3.5, 11.2)	(2.7, 9.8)
Written 2nd – Exp. trained	(3.5, 11.2)	(3.6, 8.6)	(1.9, 10.4)	(1.4, 6.2)
Written 1st – Video 2nd	(1.5, 6.4)	(0.2, 4.2)	(-1.4, 2.9)	(-3.7, 1.7)
Written 1st – Exp. trained	(3.1, 9.0)	(2.4, 7.5)	(2.9, 11.1)	(1.7, 10.6)
Video 2nd – Exp. trained	(7.4, 12.7)	(4.8, 9.5)	(3.5, 11.9)	(0.8, 9.6)
Video 1st – Written 1st	(-2.9, 6.9)	(-1.0, 5.5)	(-5.6, 4.6)	(-3.2, 7.8)
Written 2nd – Video 2nd	(-6.3, 3.7)	(-5.6, 1.9)	(-6.8, 2.0)	(-4.3, 6.0)
Exp trained – Exp. trained	(-1.2, 4.0)	(-3.3, 1.7)	(-4.1, 2.4)	(-0.2, 4.6)

Table 8: Noise reduction statistic for A-weighting 20th and 80th percentiles and 95% bootstrapped confidence intervals (in parentheses) for all protectors

NRSA 80	Video 1st	Written 2nd	Exp-trained	Written 1st	Video 2nd	Exp-trained
Pura-Fit	23.8 (19.9, 27.1)	22.3 (15.4, 27.1)	34.3 (32.1, 36.1)	21.7 (18.0, 25.1)	25.2 (20.9, 29.2)	34.7 (31.4, 36.6)
Classic	24.0 (21.5, 26.0)	25.0 (21.4, 28.0)	34.0 (32.1, 35.2)	23.7 (21.4, 25.9)	26.1 (23.2, 27.9)	31.9 (28.9, 33.8)
AirSoft	18.1 (13.5, 21.1)	18.2 (12.9, 22.7)	26.3 (24.1, 28.4)	15.1 (9.4, 19.2)	16.3 (11.6, 20.9)	26.4 (24.2, 28.0)
Fusion	19.2 (15.9, 22.0)	23.3 (21.5, 25.6)	27.2 (24.4, 29.8)	20.5 (11.0, 27.4)	19.4 (11.0, 25.0)	30.9 (29.0, 32.3)
NRSA 20	**Video 1st**	**Written 2nd**	**Exp-trained**	**Written 1st**	**Video 2nd**	**Exp-trained**
Pura-Fit	36.3 (33.4, 39.6)	36.7 (34.4, 39.4)	40.3 (39.0, 41.5)	34.4 (31.5, 37.3)	39.2 (36.2, 43.5)	42.6 (40.6, 44.4)
Classic	32.9 (30.8, 36.3)	35.6 (33.6, 38.0)	39.7 (38.3, 41.8)	32.9 (30.8, 35.5)	35.1 (32.8, 38.0)	40.0 (38.0, 42.9)
AirSoft	29.3 (26.8, 31.9)	31.3 (28.8, 33.6)	35.6 (33.2, 39.6)	30.1 (26.7, 33.7)	30.3 (27.1, 32.6)	33.8 (31.9, 35.8)
Fusion	32.3 (28.3, 36.9)	32.9 (30.2, 36.1)	36.5 (34.3, 38.4)	37.7 (35.3, 40.8)	36.7 (33.7, 39.4)	37.1 (35.8, 38.5)

from the first trial to the second was not significant as the confidence intervals overlap. For the E•A•R Classic Video 1st to Written 2nd group, the NRS_{A20} result did not fall within the confidence interval of the second trial, but the confidence intervals overlap. Similarly, for the Pura-Fit, the same trend is observed in the Written 1st to Video 2nd group. For all other protectors and testing orders, the result obtained in the first trial fell within the 95% confidence interval of the second trial. For the comparisons between the 2nd and 3rd trials, only for the Fusion earplug was the 2nd trial within the confidence interval of the 3rd trial (for the Written 1st – Video 2nd group). The results in Table 8 are plotted in Figures 1–4.

Discussion

The inexperienced subjects did not exhibit any substantive improvement in attenuation between testing using the manufacturer's written instructions as compared with the video-based instructions. While the video-based instructions were expected to yield better overall attenuation relative to the written instructions, video-based instructions exhibited no performance decrement relative to the written instructions. The expectation was based on the use of similar video-based instructions in Joseph *et al.*'s study and in the NIOSH/EPA interlaboratory study.[15,16] In both those studies, the experimenter asked the subject to demonstrate the techniques shown in the video and provided an opportunity to correct poor fitting technique. The results from the written and video instruction modalities were not significantly different. In the results reported by Joseph *et al.*,[16] the individual instruction demonstrated a 15-dB increase in the average attenuation and the small-group training exhibited an 11-dB increase. Joseph's subject population primarily comprised of young adults on a college campus, whereas the subjects in this study were recruited from the general population. One might argue that education level of the study population in Joseph *et al.* contributed to the greater level of improvement. However, the present study did not control the level of education and, therefore, the associated effect cannot be tested. That said, the average improvements between written/video instruction and the experimenter-trained conditions were statistically significant and were between 5 and 8 dB. This result agrees with Joseph's 8-dB effect size.

Other factors that could be considered would include the interpersonal interaction between the subject and the experimenter. In this study, the video was presented without explanation by the experimenter prior to the attenuation assessment. If the video-based instructions had yielded better attenuations, then the demonstration of proper insertion technique would have been identified as a critical skill that earplug users could learn just by watching the video. If the second test demonstrated significant increases in attenuation, then perhaps a learning effect would be an important element for consideration. The data, however, did not exhibit these effects. In deliberations of the ANSI S12 working group 11 responsible for developing S12.6-2008, the possibility of a learning effect has been discussed at length (Authors Murphy and Witt have been members of the ANSI S12 working group 11 since about 2004.) Formal studies have not been conducted, but the ANSI/ASA S12.6-2008 limits the number of times subjects may be tested with earplugs and earmuffs. Determination of the role that interpersonal interactions between the subject and the experimenter, or the worker and the hearing conservationist, should be a part of the development of better hearing loss prevention programs.

The average A-weighted attenuations demonstrated no significant differences between the first trials for the different protectors, no differences between the second trials, and no differences between the third trials. A comparison of the averages considers the central tendencies of the data. Examination of the NRS_{A80}/NRS_{A20} values demonstrates the same trends as the averages: the respective trials are not significantly different. The differences in the average attenuations and ratings of the subject groups for a given protector were not statistically significant. Subsequent analyses could combine the two groups for a protector to investigate the sample size effects.

Methods for developing the video-based training were derived from work that Stephenson *et al.*[24] conducted with the United Brotherhood of Carpenters. The intent was to demonstrate the proper techniques to fit the protector, provide information about how to size the protector, and give some means of

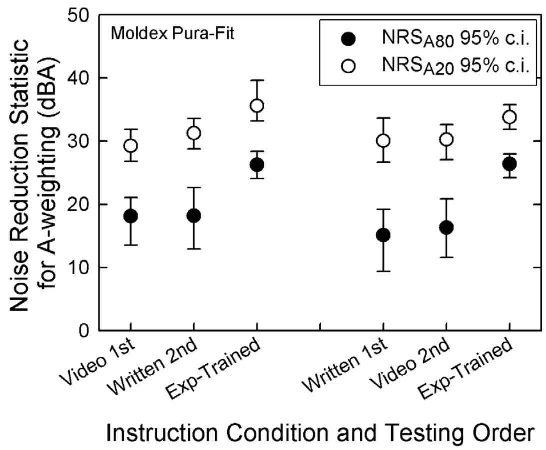

Figure 1: Noise reduction statistic for A-weighting (NRSA) computed for each instruction modality for the two groups of subjects tested with the Moldex Pura-Fit formable earplug. The NRS_{A80} are the filled symbols and the NRS_{A20} are the open symbols. The error bars represent the 95% confidence interval

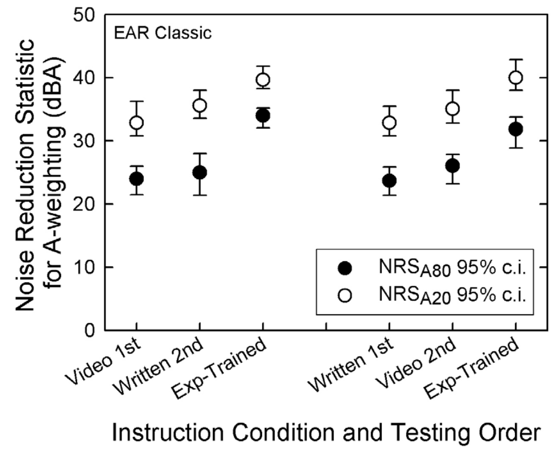

Figure 2: Noise reduction statistic for A-weighting (NRSA) computed for each instruction modality for the two groups of subjects tested with the EAR Classic formable earplug. The NRS_{A80} are the filled symbols and the NRS_{A20} are the open symbols. The error bars represent the 95% confidence interval

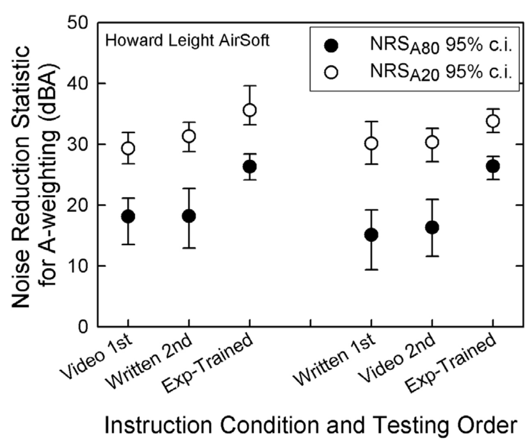

Figure 3: Noise reduction statistic for A-weighting (NRSA) computed for each instruction modality for the two groups of subjects tested with the Howard Leight AirSoft pre-molded earplug. The NRS_{A80} are the filled symbols and the NRS_{A20} are the open symbols. The error bars represent the 95% confidence interval

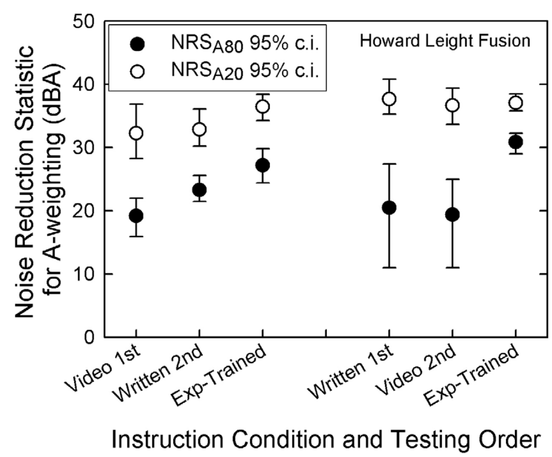

Figure 4: Noise reduction statistic for A-weighting (NRSA) computed for each instruction modality for the two groups of subjects tested with the Howard Leight Fusion pre-molded earplug. The NRS_{A80} are the filled symbols and the NRS_{A20} are the open symbols. The error bars represent the 95% confidence interval

verifying whether the fit was good or bad. Discussions with other hearing protector researchers spawned the idea of the NIOSH Voice-Check method (described in Appendix A), that use of the occlusion effect does not appear to be a practical self-test method. From our personal experience, identification of a good fit requires an ability to know when the sound bypassing the protector is excessive. Because this skill typically improves with experience, simple and efficient quantitative fit-testing methods should be developed to train workers to fit hearing protectors and to assess the adequacy of attenuation. Once a worker is able to establish a good fit, then minor adjustments could be made to increase or decrease attenuation without a fit-testing system.

These data are quite useful for demonstrating that the methods proposed by the U.S. EPA have merit. The EPA has proposed a 3-dB threshold for recurrent or compliance audit testing. On retesting, if a product exhibits a rating that is more than 3 dB less than the manufacturer's published NRR, then the product should be relabeled to reflect the new rating. Across protectors, the Experimenter-trained NRS_{A80} values exhibited very similar results for both orders of instruction. If we assume that the group with the higher rating was the original rating for the product, then only the Fusion earplug would have required relabeling; the NRS_{A80} would be changed from 31 dB to 27 dB. The maximum difference for the Pura-Fit, Classic, and AirSoft products was 2.1 dB for the NRS_{A80}. For the NRS_{A20} values, none of the ratings would have required a relabeling. However, if the EPA had proposed ANSI S12.6-2008 Method B, the confidence intervals for NRS_{A80} for the naïve subjects tested with the manufacturer's written instructions first tended to be larger than the 3-dB threshold.

Recurrent testing for the purpose of relabeling has largely been ignored prior to the EPA's proposed rule and the development of the ANSI/ASA S12.68-2007 standard. Annex D in ANSI/ASA S12.68 describes the computation of the 95% confidence intervals for the NRS_{A80}/NRS_{A20} ratings. If the first rating is contained within the confidence interval of the second rating, then the two ratings can be assumed to not be significantly different. However, if the rating falls outside the confidence interval, then other tests of statistical significance need to be applied. What makes the NRS_A or any of the hearing protector ratings unique is that the comparisons are being made between points on the tail of the distributions and not between the descriptors of central tendency such as the mean or median. Manufacturers now have the ability to estimate the confidence intervals for the rating. The EPA has proposed that products will be relabeled if the rating computed from recurrent or audit test is more than 3 dB below the published NRR NRS_{A80}. In the Experimenter-trained data for the Pura-Fit, Classic, and AirSoft products, the 95% confidence intervals were <3 dB, suggesting a 5% probability of failing the recurrent test. The two groups for each of those products were not significantly different and passed the 3-dB criterion. However, for the Fusion earplug Experimenter-trained data, the confidence intervals were larger than 3 dB, suggesting that the probability of relabeling is greater than 5%. Depending on which group might have been tested first, the lower test would have required the product to be relabeled. To reduce the risk of failing recurrent testing, testing more subjects can narrow the confidence intervals. Because the 95% confidence interval is a multiple of the standard error of the NRS_A rating, the power is expected to be inversely proportional to the square root of the number of subjects tested, $\sqrt{N}$. Thus, the required number of subjects may be estimated as follows: $N = 20\left(\frac{CI}{3}\right)^2$, where 20 is the number of subjects tested, CI is the confidence interval, and 3 is the EPA 3-dB criterion. A more detailed analysis of the power calculation is outside the scope of this paper.

Conclusions

This investigation yielded a wealth of findings. The video-based training produced the same performance as the manufacturer's printed instructions. The experimenter-trained subjects demonstrated significant improvement in every case relative to the inexperienced subjects. Attenuation performance of four products tested in the same laboratory was confirmed as largely not significantly different. The EPA's proposed 3-dB criterion for relabeling appears to be reasonable for earplugs.

These findings corroborate Joseph *et al.*'s[16] results and support the trend in the hearing protector industry to promote individualized or small-group training for all hearing protector users. The data demonstrated that, after receiving individual instruction, poorly performing subjects were able to properly insert the earplugs and achieve sufficient attenuation. Proven training methods must be developed and incorporated into hearing conservation programs. For now, the most effective method appears to be individual one-on-one training. Perhaps more important is a commitment from supervisors and management that hearing protection is not an option for noise-exposed workers. It is absolutely necessary whenever high levels of noise are present. However, merely providing hearing protectors is not enough to prevent noise-induced hearing loss. Personal training in the proper fitting of the protector can make the difference between adequate or marginal protection.

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Appendix A

This Appendix contains the script, with suggested video shots given in brackets and italics. For this study, four different videos were created, which were customized for each hearing protector. The additional narrative for fitting formable foam earplugs is provided rather than the shorter script for the pre-molded earplugs. These videos required approximately 4 h of time to shoot the footage with a high-definition consumer-grade video camera. Approximately 16 h were required to edit the videos using iMovie 6 on an Apple Macintosh computer.

Formable Fitting Script

Formable plugs come in a variety of shapes, sizes, and colors. [*Show a shot of several plugs*]

For this test, you will be fitting the E•A•R Classic/Moldex Pura-Fit earplugs. [*Show the particular earplug*]

To fit formable plugs, they have to be rolled and compressed small enough to fit at least half of the plug inside your ear canal. [*Show rolling of earplug*] One critical thing to remember is that you need to roll the plug into a small crease-free cylinder or into the shape of a golf tee. [*Show rolled earplug*] There are a number of ways to do this; some people roll between the thumb and the forefinger. You can also roll using the palm of your hand, or you can use both hands. [*Show both methods*] No matter what method you choose, be careful to avoid creases that can act as a tunnel to let in dangerous noises. [*Show an earplug with a crease and X out graphic*]

Once you have rolled the earplug down, use your other hand to reach over your head. Pull the ear up and out or up and back to straighten your ear canal and make it easier to insert the plug. [*Show actor inserting the earplug from a chest up then zoom to ear close-up shot*] When you insert the plug, hold it in place for a few seconds to give it time to expand.

Remember that there are some things to avoid when fitting formable plugs. These creases will allow noise to leak right in. [*Show creased plug with X out graphic*] This plug is too small or it is not inserted deeply enough. Notice the large gaps. [*Show earplug in small canal poorly inserted*] This plug is too large or has not been rolled down small enough, giving this person virtually no protection. Simply pushing on the plug will not work. [*Show poorly inserted earplug being pushed without compression*] Some people with irregular or very small ear canals may find it difficult to properly use formable plugs.

Voice check

Now that you know how to fit your earplugs, you need to know how to tell if you have a good fit. One way is with a Voice Check.

Before you insert your earplugs, press the palms of your hands against your ears. Start counting out loud. [*Voiceover of subject counting while holding hands tightly over ears*] While you are counting, repeatedly uncover and cover your ears.

Notice the change in the sound of your voice. Your voice should sound louder and deeper when your ears are covered. Next, insert your earplugs as instructed. [*Show earplugs being inserted*]

Repeat the voice check while wearing your earplugs. [*Show actor performing Voice Check*]

If your earplugs are properly fit, there will be very little change in the sound of your voice when you cover and uncover your ears.

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