Hearing Protection Fit-Testing

Daniel Mitchem

Problem Report submitted to the
Benjamin M. Statler College of Engineering and Mineral Resources
At West Virginia University
In a partial fulfillment of the requirements
For the degree of

Master of Science
In
Industrial Hygiene

Steven Guffey, Ph. D., CIH, Chair
Michael Klishis, Ph. D
Mark Druga

Department of Industrial and Management Systems Engineering

Morgantown, West Virginia
2012

Keywords: Hearing Protection, Fit Testing,

Abstract

Hearing Protection Fit Testing

Daniel L. Mitchem

Fit testing of hearing protection devices (HPDs) may be useful in determining if a hearing protector's attenuation on a worker is sufficient for the area he or she is working. This study fit tested each of the 44 volunteer at a coal-fired power station in the mid-West United States. The fit testing device was a Veri-PRO®, which uses "loudness balancing". Participating employees were fit-tested with their preferred ear plug and with up to 3 other plugs used by employees at the worksite.

The results show that all four makes of earplugs provided similar attenuation levels. Observed attenuation values, represented as personal attenuation rating (PAR), were adequate for their respective work environments but were 10-18 dBA lower than the respective NRR ratings. ANOVA found that Subject was the single largest factor affecting the attenuation results. No other test variables achieved statistical significance ($p < 5\%$), including pre-insertion training, ear plug type, and ease of insertion.

Subjectivity and variability were the biggest concerns for the efficacy of the loudness balancing method. This could be partially addressed by adjusting the software.

Table of Contents

Introduction

Noise-induced hearing loss is a significant problem for workers in industry. OSHA regulations designed to ensure worker protection from high noise exposures have been in effect since the inception of OSHA in 1970. Nevertheless, NIOSH estimated that over 30 million workers were still exposed to hazardous noise levels in 1999 (Lusk, 1999), despite OSHA's enforcement of the 1970 noise standards and the subsequent hearing conservation amendments in 1981 and 1983. Although one would reasonably expect to see a decrease in occupational hearing loss over the years since OSHA began, there is evidence that no such improvement has occurred (Daniell, et al., 2002).

The lack of improvement is striking given that OSHA mandates that economically and technically feasible engineering controls must be employed to control work site noise and that hearing protection devices (HPDs) are to be used until those controls are effective. It is likely that it is very common that effective controls are still not in place because the nature of the equipment, process and other factors make engineering controls infeasible. Consequently, it is very likely that workers must continue to rely on hearing protection devices (HPD) to prevent hearing loss over many years of exposure.

Hence, it is crucial that HPD are effective in dramatically reducing the noise levels that would otherwise reach the eardrums of workers. For that reason, under the terms of the Noise Control Act (EPA, 1972), manufacturers of HPDs are required to determine the Noise Reduction Rating (NRR) for each make of HPD that they sell and label packaging with that value.

Berger *et al.* (1996) reviewed the evidence supporting the notion that "real world" performance of hearing protection is much less than the NRR rating. This is particularly troubling since protectors are often selected using this number. For example, when asked which was his preferred HPD one subject in a study was quoted as saying "Well this one (indicating E-A-R Max protector); it has the highest number on it". The lack of confidence in the applicability of NRR values is indicated by the fact that OSHA recommends dividing the published NRR by 2 to simulate real world protection levels (OSHA, 1987). If the laboratory-based NRR values are distrusted, perhaps workers themselves can select the most protective HPD to wear if given enough choices. However, it is not known if worker preference is a reliable selection method for effectiveness. It is likely that worker preferences are based mostly on comfort, and it has not been demonstrated whether comfort is positively related to effectiveness.

Perhaps the most prudent selection method is to test each employee individually to determine the effectiveness of his or her chosen HPD. If it proves adequate, then have them continue to use it. If not, try another. Individual testing is important because, as Berger stated, "Fit-testing is a potentially valuable tool since earplugs may not be effective for all employees" (Berger, 2005). Ideally, such individual fit-testing would be a fast and unobtrusive way of ensuring optimal protection for each employee from noise exposures. Fit-testing plausibly could determine the adequacy of any HPD.

This study investigates fit testing results for workers at a coal-fired power station owned by a large utility company in the U.S.A. At this power station company policy requires use of HPDs in all areas where noise levels may exceed 85 dBA. The company provides four different types of ear plugs to its employees for use in those high noise areas. The Company generally has little issue with enforcing this requirement, but they expressed concern about whether employees were being adequately protected by their HPD. For that reason they agreed to this investigation.

The aims of this study were to determine the protection offered by each of the four HPDs provided by the company, then use that information to: (i) compare the efficacy of the employee's "preferred" HPD compared to "non-preferred" HPDs, (ii) determine the effect pre-insertion training has on insertion loss with the employee's selected HPD, and (iii) compare the measured efficacy of the HPDs to the NRR provided by the HPD manufacturers.

Background

The Personal Attenuation Rating, (PAR) is an A-weighted value produced by various fit testing devices that is supposed to be equivalent to NRR. As of this writing the formula to calculate PAR has not been standardized. As such, each manufacturer uses their own proprietary formula.

For this study the VeriPro (Howard Leight, San Diego) was used to estimate the effectiveness of each HPD on each employee. The Veripro uses the "loudness balancing" (PAR) method rather than the traditional insertion loss or noise reduction methods. This PAR method exposes one ear to a reference noise level and the noise level in the other controlled by the tested subject's responses. The subject is instructed to indicate when the noise level in both ears seem to be the same.

In an unpublished study Larson (Larson, 2008) at Sperian describes the calculations used for the PAR method.

Attenuation for the two ears is calculated from three loudness balance results: LD_1, LD_2, and LD_3. First, LD_1 is calculated from the imbalance between the two unoccluded ears.

$$LD_1 = L_{Right\ Ear} - L_{Left\ Ear} \qquad (1)$$

Where: L = measured noise level

LD_2 is calculated with the right ear occluded by the ear plug underneath the circumaural earmuff. LD2 is again the imbalance between the two ears.

$$LD_2 = L_{Right\ Ear\ Occluded} - L_{Left\ Ear} \qquad (2)$$

The attenuation for the right ear (PAR_{Right}) is calculated using the values of LD2 and LD1.

$$PAR_{Right} = LD_2 - LD_1 \qquad (3)$$

LD_3 is calculated with both ears occluded by the ear plug underneath the circumaural earmuff. LD3 is calculated from the difference in attenuations of the right and left ear plug (ATD).

$$ATD=LD_3-LD_1 \qquad (4)$$

Where: ATD = attenuation difference between the right and left ear plug.

$$LD_3=ATD+LD_1 \qquad (5)$$

The attenuation for the left ear (PAR_{Left}) can be calculated using ATD and PAR_{Right}.

$$PAR_{Left}=PAR_{Right} - ATD \qquad (6)$$

Insertion loss (IL) is a more traditional evaluation parameter defined as the difference in noise levels at the eardrum with and without the use of the hearing protection device (HPD):

$$IL = SPL_{Without\ HPD} - SPL_{With\ HPD} \qquad (7)$$

Where SPL is the observed sound level with and without HPD as determined by audiometric testing

Noise reduction (NR) is another traditional method, defined as the difference in sound level between the ear and the ambient sound level:

$$NR = SPL_{ambient} - SPL_{ear} \text{ db} \qquad (8)$$

Where: $SPL_{ambient}$ = measured noise level

Literature Review

A study by Lusk *et al* (1999) notes that NIOSH estimates that more than 30 million workers in the US were exposed to hazardous levels of noise in 1999, despite OSHA's enforcement of noise standards.

Studies have indicated that 30-60% of workers, depending on the industry, are exposed to hazardous noise levels on a daily basis (Melamed, et al., 1996). Published research on the use of hearing protection devices (HPDs) strongly support that use of HPD protection in areas of harmful noise is far lower than ideal (Melamed, et al., 1996). Depending on their study, only 20-50% of workers exposed to hazardous noise wore their HPDs.

Arezes *et al* (2005) found that workers who are exposed to high noise often appear to ignore the potential consequences of their exposure. They discussed the limited research on an individual's perception of noise and how those perceptions might affect worker compliance in wearing HPDs. The authors also discuss the assumption that HPDs should be considered a temporary solution, arguing that economic and technical difficulties in reducing noise levels often lead HPD to becoming the permanent solution. For the effectiveness of HPDs, they noted that simply providing the HPD to the worker does not guarantee improved worker protection. Improved worker protection is only highly likely when the HPDs are well-fitted and used at all times when needed.

Arezes *et al* (2002) also discussed HPDs and how they should be chosen. They state that when choosing the HPD, both the user and the work environment should be taken into consideration. When making this decision they stated that is imperative that the attenuation performance of the HPD not be the only quality that is considered. The HPD also should be both comfortable and acceptable to the users. Furthermore the authors state that workers' compliance in wearing their HPD is imperative. For that reason, workers must understand that the HPD must be worn continuously in hazardous noise areas to ensure the effectiveness of the HPD.

Arezes *et al* (2002) also found a positive correlation between the "Comfort Index", a quantification of the subjective feeling of comfort based a comfort questionnaire used in the study, and duration of use. The authors found that Comfort Index values differed significantly when comparing ear plugs and ear muffs but not when comparing different types of earplugs or ear muffs to each other.

Berger *et al* (2003) noted that sound is transmitted through the bony structures in the head even when the air conduction pathway to the ear drum is blocked. Noise conducted by bone is not protected by HPD that circumscribe the ear such as the ones typically worn in workplaces (Berger, et al., 2003).

Berger (2005) discussed subjective and objective methods of measuring hearing protector attenuation. He emphasized the importance of the "gold standard", which in his opinion is a subjective method for measuring attenuation called "Real –Ear Attenuation at Threshold" (REAT). The concept of REAT is straight forward; it simulates the performance experience of the user, and is the method with the least number of measurement errors. REAT measures the difference in thresholds between occluded and unoccluded conditions for a subject; that difference is the "insertion loss" (See Equation 7).

Berger also stated that the subject's training, coaching, and fitting with the HPDs were the dominant factors influencing results. Finally, Berger pointed out that REAT accounts for all relevant pathways of sound to the ear, including bone conduction.

Daniell *et al.* (2002) discussed hearing conservation practices in industries that have experienced high numbers of workman's compensation claims for hearing loss. The authors made several key points. First, the causative relationship between noise exposure and hearing loss is well documented and that there is a consensus about safe levels of exposure for nearly all individuals. Second, despite the knowledge and regulations in place, occupational hearing loss is not diminishing. For instance, in Washington State workman's compensation hearing loss claims rose from 500 in the 1980s to more than 5000 in 1998. Finally, the authors also stated that with annual audiometric testing it is possible to detect minute changes in hearing before clinically significant hearing loss sets in.

Melamed *et al* (1994) also discussed noise exposure, annoyance, and the use of HPDs among blue collar workers. Their study found that the use of HPDs is unpopular for a variety of reasons, including: (1) incompatibility with other required head gear, (2) irritation of the ear canal, (3) general feelings of discomfort, (4) interference with job performance, (5) interference with communication, and (6) the belief that continual wearing of the HPD reduces a worker's prestige among peers. The authors also noted that noise is a general stressor that produces a variety of psychological and physiological responses. From their study one can reasonably conclude that workers are much more likely to use their HPDs when the noise is annoying to them. Sixty percent of the workers in their study stated that they wore the HPDs during high noise because they were highly annoyed by the noise.

Noise control, and specifically Noise Reduction (NR) and the associated Noise Reduction Rating are important to understand when discussing attenuation. The definition of NR is the difference of noise levels measured between two locations (see Equation 8). In the case of the HPD, the two locations are inside the HPD and outside the HPD (Ostergaard, 2003). NRR is an estimate of protection offered by the HPD. Standardized in 1979 in the US; it is provided by the manufacturer and can be found on HPD packaging. The NRR calculation method is assumed to be accurate to within 0.5 dB of NIOSH Method #2, from which it was based (Berger, 2003).

Other studies were prompted by the concern that laboratory attenuation determinations significantly overestimate the real world attenuation of HPDs. Berger (2003) states that over-estimation may be due to the "optimum attenuation" conditions of laboratory settings and by the fact that HPDs generally are fitted by trained personnel, as is required for NRR determinations (Hudak, 2005).

In a 2011 review of fit testing procedures, Schulz (2011) discussed the findings of Vermiglio (2005) which showed that the loudness balancing method of fit testing agrees very well with REAT estimates. She also considered how the VeriPRO® method calculates its "personal attenuation rating" (PAR). She described the VeriPRO® loudness balancing method as being very similar to REAT, with the difference that the VeriPRO® uses an "above threshold" measure rather than at threshold. In an unpublished experimental study at the House Ear Institute (Vermiglio, 2005), the loudness balancing method of fit testing was found to agree with REAT estimates of attenuation. According to Schulz the inter-subject variability for the VeriPRO® was found to be significantly less than the corresponding values observed in REAT measures. An independent test of the VeriPRO® performed by Ewa Kotarbinska of the Warsaw University of Technology (Kotarbinska, 2009) using 16 trained subjects found that the VeriPRO® PAR values close to the manufacturer-supplied NRR.

Materials and Methods

This study was performed on 44 volunteer subjects who worked at a coal-fired power station in the mid-West of the US. Fit testing was performed using the Veri-Pro® Fit Testing Device manufactured by Howard Leight (San Diego, California). Version 2.0 of the Veri-Pro® software was used for testing.

Veri-Pro® System and Software

The Veri-Pro® device helps determine the insertion loss in both the right and left ear when the user is wearing ear plugs. As a constant noise level at a given frequency is played at a constant level in one ear the sound level in adjusted in the other ear until the tested subject indicates that the noise levels are the same in both of his or her ears. This is repeated each ear at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. From that data the software computes a “PAR” value (see Background Equations 1-6) for each ear. The PAR is intended to compare to the manufacturer-supplied NRR.

During initial user setup for fit testing, just before a given employee was tested, his or her name, date, department, location, exposure level from prior company noise surveys, and type of ear plug were recorded. After this data was entered either a "quick" test or "complete" test was performed for that subject. The quick test tests insertion loss at 500 Hz only, while the complete test tests all 5 frequencies.

To perform the test a reference tone is played under an earmuff outside the right ear. The tone in the left ear is to be adjusted up or down until the subject indicates that the loudness of the left ear matches that of the right ear. The level at which a match is found is then logged. This matching is repeated three times. The first test is done with no ear plugs in the ears to provide a baseline. For the second test, the matching procedure is repeated with the ear plug fitted into the right ear. Finally the test is repeated with both ear plugs in.

Subject Selection

All power station employees except for clerical workers were encouraged by their safety and health manager to participate in the hearing protection fit testing. Participation was completely voluntary with neither rewards nor punishments for participating or not participating. Roughly 80 employees had the option of participating in this study. Of the roughly 80 potential participants 44 were tested. Many of the subjects that agreed to test were interested in their performance of their preferred ear plug, expressing the desire to know if it wasn’t working. Some of those subjects believed the study may provide valuable information and thus decided to support it. The primary reason subjects declined participation were fears that the company would use the information against the employee during any union disputes.

Half of the volunteers were randomly selected to receive training on properly inserting their ear plugs prior to participating in the test. The other group had neither insertion training nor any instruction by the tester. Pre-insertion instruction was provided using the instructional videos that were part of the Veri Pro® software version 2.0. In the case where the exact model number of the ear plug was not available in the video library, the video for the most similar model was used for the instruction.

Employees who consented to be fit-tested were fit tested on their preferred HPD and at their discretion, on up to 3 of the other plugs provided by the company. Thirteen had PARs of less than 10 dB with their preferred plugs. Each was immediately informed of the fact and was offered the choice of being tested with the other 3 plugs. 10 of the 13 chose the additional testing and 3 declined.

Prior to fit testing the subjects were asked to fill out the questionnaire and consent form in the Appendix 1. Following the completion of the consent form, the investigator answered consent related questions, including the purpose of the study and how they would be tested. The verbatim explanation was:

> "I am testing these hearing protectors as a service to the company and to gather data for my thesis research. This data will be able to help determine the best hearing protector for you to use. Any data used for my thesis research will remain anonymous."

Following the completion of the consent form and the verbal explanation for the study; fit testing began.

Test Room

Testing was performed in three separate areas. Every area tested had a recorded ambient sound level that was less than 55 dBA. In the testing area there was a laptop computer, the Veri-Pro® fit testing device, and an abundance of the four ear plugs that the company supplies to its employees. No pictures of the testing locations or setup were permitted by the company.

Testing Procedures

The following is a step by step procedure for testing:

1. Test subject dons Veri-Pro® ear muffs sans any HPD.
2. Test subject then indicates in what direction the volume (up or down) of the tone in the left earmuff should be adjusted to match the volume of the reference tone in the right ear. This step is repeated across all tested frequencies.
3. Test subject then inserts HPD into right ear and the procedure in step two is repeated across all frequencies.
4. Test subject then inserts HPD into both ears and the procedure in step 2 is repeated across all frequencies.
5. Following the completion of steps 1-4, the software will calculate a PAR, or "personal attenuation rating (see PAR Calculation in Background).
6. The subject was then tested with any additional HPD's they agreed to have tested.

Primarily test subjects were tested using the "Complete" test found in the Veri-Pro® software. However, there were six tests where the "Quick" test was performed in an effort to save time for the test subject.

There were 3 times when the VeriPRO® software indicated that the reliability of the test was questionable. This occurred when the volume slider was shifted too high or low and when the software indicated that the HPD wasn't providing enough attenuation. When this happened the subject was allowed to reseat the HPD before proceeding again with the test. However, the warnings were repeated all 3 times. The tests proceeded despite this. It was suspected that on occasions when reseating the HPD did not fix the problem it was probably due to the subjects inability to hear the very high or very low frequencies. However, confirming this would require audiogram results, which were not part of the human subjects testing protocol in this study.

Data was collected and stored in a Microsoft Excel®"book". Initial results were available to the employee subjects participating in the study at the time of their testing. Final results will be given to the safety and health manager of the power station, who in turn may make the results available to the corporate Certified Industrial Hygienist and the tested employees per the company's corporate practices.

Hypotheses

The first null hypothesis was that the mean insertion loss for the preferred ("pref") ear plug was equal to the mean insertion loss for the non-preferred plug ("not pref").

H_0: $PAR_{pref} = PAR_{not\ pref}$

H_A: $PAR_{pref} > PAR_{not\ pref}$

The alternate hypothesis was the mean insertion loss was greater for cases where the subjects were tested with their preferred ear plug than for cases when their non-preferred ear plug was tested, regardless of the identity of the preferred plug.

The second null hypothesis was that the mean PAR value for those with pre-insertion training (train) was equal to the mean PAR for those without pre-insertion training (no train).

H_0: $PAR_{train} = PAR_{no\ train}$

H_A: $PAR_{train} > PAR_{no\ train}$

The alternate hypothesis is the mean insertion loss is greater with pre-insertion training than it is without pre-insertion training.

The third null hypothesis was that the tested PAR was equal to or greater than the NRR for each particular plug.

H_0:$PAR_{plug} \geq NRR_{plug}$

H_A:$PAR_{plug} < NRR_{plug}$

Where "plug" is the identity of each specific plug brand.

The alternate hypothesis was that the tested noise reduction was less than the NRR.

ANOVA and other statistical tests were performed using DataDesk 6.3.1 (Data Desk, Ithica, NY).

Results

As shown in Table 1, the ear plugs had PAR values that were roughly one-half of their corresponding NRR values, with average PAR values from 12.6 to 16.9 dB. However, analysis of variance (ANOVA) determined that the choice of HPD did not have a significant effect (p<5%) on PAR values (see Table 2 and 3).

Table 1: Descriptive statistics of each ear plug's NRR and observed PAR values, all listed in dB.

Moldex Purafit 6800	**Frequency (Hz)**	**Overall**	**250**	**500**	**1000**	**2000**	**4000**
	NRR (dB)	33	43.5	45.9	39.8	36.8	46.6
	NRR Standard Deviation (dB)	N/A	4.2	4.9	3.4	2	2.9
	PAR (Overall in dBA)	17.5	21.8	24.5	22.1	25.2	28.4
	PAR Standard Deviation(dB)	N/A	13.7	10.6	12.1	11.3	17.5
Howard Leight Max	**Frequency (Hz)**	**Overall**	**250**	**500**	**1000**	**2000**	**4000**
	NRR (dB)	33	36.3	36.8	38.4	38.7	45.9
	NRR Standard Deviation (dB)	N/A	1.8	2.1	1.7	2.1	2.2
	PAR (Overall in dBA)	17.9	20.3	24.1	22.7	28.2	29.2
	PAR Standard Deviation(dB)	N/A	12.8	11.7	12.1	12.1	15.2
E-A-R Express Pod	**Frequency (Hz)**	**Overall**	**250**	**500**	**1000**	**2000**	**4000**
	NRR (dB)	25	32.1	32.2	36.9	35.7	35.7
	NRR Standard Deviation (dB)	N/A	4.6	4.8	4	3.3	4.2
	PAR (Overall in dBA)	15.4	13.4	21.0	18.3	20.6	20.7
	PAR Standard Deviation(dB)	N/A	9.7	10.9	11.1	11.7	12.2
E-A-R Classic	**Frequency (Hz)**	**Overall**	**250**	**500**	**1000**	**2000**	**4000**
	NRR (dB)	29	40.9	44.8	43.8	36.3	42.6
	NRR Standard Deviation (dB)	N/A	5	3.3	3.6	4.9	3.1
	PAR (Overall in dBA)	12.8	12.5	16.8	16.2	16.0	21.1
	PAR Standard Deviation(dB)	N/A	10.8	11.8	12.1	11.0	18.0

Table 2: ANOVA Left PAR analyzing significance of the type of Ear Plug and the test subject

Source	df	Sums of Squares	Mean Square	F-ratio	Prob ⍰
Const	1	20003	20003	344.89	0.0001
Ear Plug Name	3	113.85	37.95	0.65434	0.5888
User ID	40	3528.74	88.22	1.521	0.1478
Error	22	1275.98	57.99		
Total	65	4857.95			
	R^2 =	**0.7373**			

Table 3: ANOVA Right PAR analyzing significance of the type of Ear Plug and the test subject

Source	df	Sums of Squares	Mean Square	F-ratio	Prob ⍰
Const	1	25057.5	25057.5	311.15	0.0001
Ear Plug Name	3	23.29	7.76	0.096391	0.9612
User ID	40	2899.88	72.50	0.90022	0.6238
Error	22	1771.71	80.53		
Total	65	4702.48			
	R^2=	**0.6232**			

As shown in Tables 2 and 3, ANOVA showed that the differences in PAR values for different HPD were not significant ($p > 5\%$).

As shown in Table 4, analysis of variance determined that average PAR values were not significantly (p>5%) affected by pre-insertion training. Likewise, the subjects' evaluations of ease of use and protectiveness was not predictive of average PAR values.

Table 4: ANOVA analyzing the significance of , effectiveness of pre-insertion training, ease of insertion, and perceived protection

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	10568.3	10568.3	137.61	0.0001
Pre Insertion Training (Y/N)	1	192.19	192.19	2.5025	0.1245
Ease of Insertion (1-5)	3	177.75	59.25	0.77148	0.5194
Protection (1-5)	2	149.06	74.53	0.97047	0.3909
Error	29	2227.16	76.8		
Total	38	2807.69			
	R^2 =	**0.2068**			

Table 5: Comparison of observed Right PAR and manufacturer alleged NRR. E A R Pushins and Max Lite were too few to test.

Group	Count	Mean	StdDev	Ho:	H_A:	T	p-value	Concl
E A R Classic	6	17.3	8.85	μ=29	μ<29	-4.76	0.25%	reject Ho
E A R Pushins	1	12.0	Insufficient	μ=28	μ<28			
Express	15	19.8	6.66	μ=25	μ<25	-1.342	10%	cannot reject
Max Lite	1	17.0	Insufficient	μ=30	μ<30			
Max	36	19.7	9.52	μ=33	μ<33	-2.22	2%	reject Ho
Pura-Fit 6800	9	19.6	7.81	μ=33	μ<33	-4.48	0.10%	reject Ho

Table 6: Comparison of observed Left PAR and manufacturer alleged NRR. E A R Pushins and Max Lite were too few to test.

Group	Count	Mean	StdDev	Ho:	H_A:	T	p-value	Concl
E A R Classic	6	14.833	7.68	μ=29	μ<29	5.7835	0%	reject Ho
E A R Pushins	1	7	Insufficient	μ=28	μ<28			
Express	15	17	7.37	μ=25	μ<25	-2.07	3%	reject Ho
Max Lite	1	23	Insufficient	μ=30	μ<30			
Max	36	17.833	9.24	μ=33	μ<33	-2.53	1%	reject Ho
Pura-Fit 6800	9	18.111	9.78	μ=33	μ<33	-5.00	0%	reject Ho

As shown in Table 5, t-test comparisons showed that only for the right ear, when using the E-A-R Express ear plug was the test result not significantly different from the manufacturers NRR rating.

As shown in Figure 1 and Tables 7-9, there were substantial differences between PAR left and PAR right values for subjects. The correspondence was only moderately linear (adjusted R^2=48.8%) even when 3 outliers were removed (adjusted R^2=59.6%). With the outliers removed the regression coefficient was 0.682 for Left PAR ($p < 0.001$) and the constant was 6.88. Ideally, the regression coefficient would be unity and the constant would be zero. On average, the Right PAR values were significantly ($p<5\%$) higher than the Left PAR values.

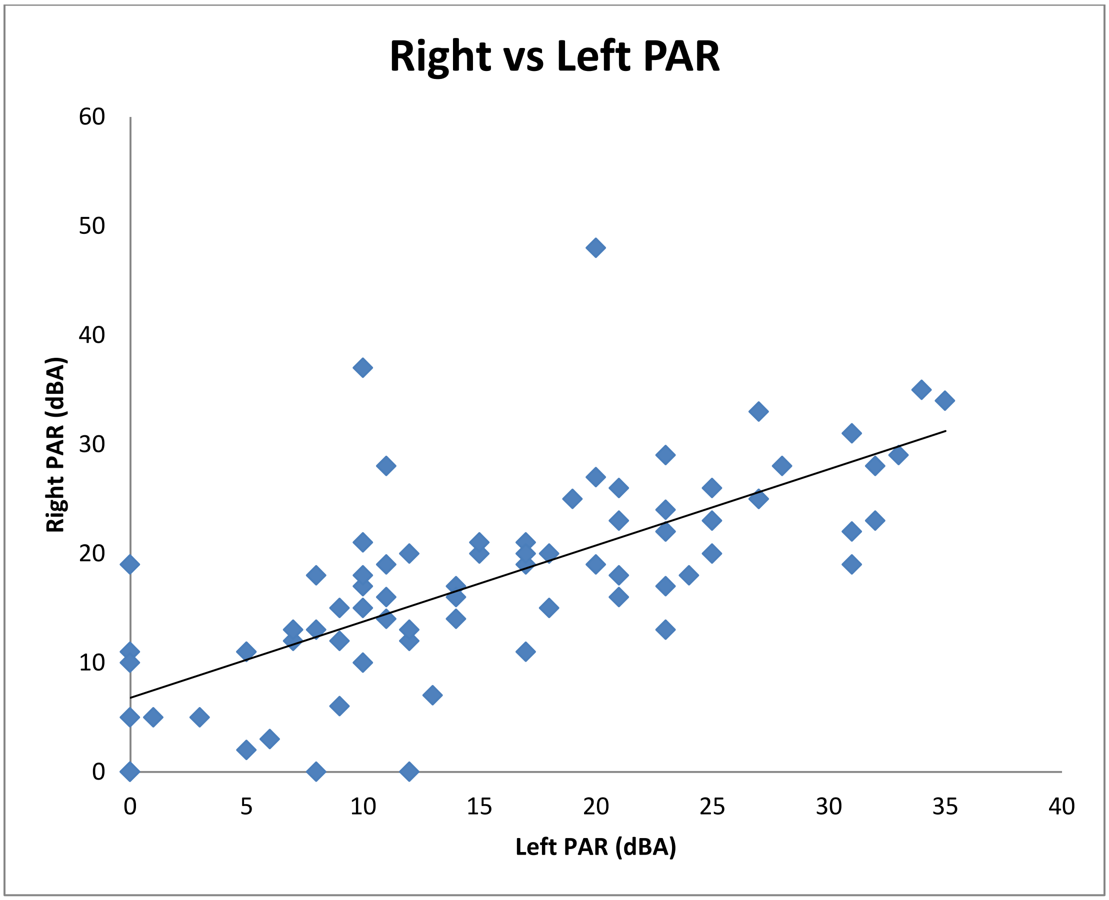

Figure 1: Comparison of Left and Right PAR values

Table 7: PAR Correspondence Regression (Outliers Included)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Regression	1	1840.45	1840.45	58.3	0.0001
Residual	59	1862.99	31.58		
	R^2 =	**0.488**			

Table 8: PAR Correspondence Regression (Outliers Removed)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Regression	1	2027.12	2027.12	88.1	0.0001
Residual	58	1334.82	23.01		
	R^2 =	**0.596**			

Table 9: Right and Left PAR Average Value and Standard Deviation

PAR	Count	Mean	Standard Deviation
Right	61	18.67	7.86
Left	61	16.72	8.57

As shown in Table 10 in the Appendix, the average of all PAR values averaged over each subject showed that in 71 of 77 fit tests performed, subjects had PAR values that were lower than the corresponding NRR values. The average of all subjects HPD PAR values was 16.6 dBA, while the average NRR was 30.5 dB. The average difference between PAR and corresponding NRR values was 14.28 dB.

Discussion

One of the aims of this study was to determine the protection offered by each of the four HPDs provided by the company and to compare the efficacy of the employee's "preferred" HPD compared to "non-preferred" HPDs. Tables 2 and 3 in the results show that there was no significant (p>5%) difference in protection between any of the four ear plugs. The subject was the only statistically significant factor in effectiveness of the HPD.

Another goal was to determine the effect pre-insertion training has on insertion loss. This was tested only with the employee's preferred HPD. Table 4 shows that pre-insertion training had no significant effect (p >5%) on the attenuation provided by the HPD. Table 4 also shows the ease of insertion and perceived protection did not significantly (p>5%) affect attenuation.

This study's last goal was to compare the PAR values for the HPDs to the NRR provided by the HPD manufacturers. Tables 5 and 6 compare the right and left PAR values to the NRR values for each ear plug. All of the PAR values for the four main ear plugs tested (EAR Classic, EAR Express Pod, Moldex Purafit 6800, and Howard Leight Max) were significantly lower (p<5%) than the NRR values, with the exception of the right PAR value for the EAR Express Pod. These findings agree with the findings by Berger *et al* (1996). Employers and employees should be skeptical when choosing an HPD based on the NRR.

There were two other interesting observations. Results show that the right PAR values were 13% higher than the left PAR values (see Figures 1, Tables 7-9), a statistically significant result (p< 5%). It may seem plausible to attribute the difference to the dominance of right-handed in the population (70-95%) (Holder, 1997). One might suppose that those individuals that were right handed were more adept at getting a better "fit" with the HPD in their right ear as opposed to their left ear. However, an exhaustive review of literature found nothing to support this explanation.

A comparison of manufacturer NRR claims and the observed PAR values across the test frequencies of 250, 500, 1000, 2000, and 4000 Hz showed (see Table 1) that the NRR values were much higher than the observed PAR values. The standard deviation values also were much lower for the NRR values than for the observed PAR values. The findings of this study support the review conducted by Berger *et al* (1996) that NRR ratings over-estimate protection.

It is likely that observing the manufacturer intended insertion techniques should lead to higher protection values. Many of the subjects were aware of the "correct" method of HPD insertion yet still chose not to follow that protocol. If those subjects were to use the correct method it is possible that they would experience higher attenuation values.

The difficult question to answer however is, "How do you convince employees to take the time to follow proper insertion techniques?"

It isn't a question of the employee not knowing. It's a matter of the employee not believing that correct technique matters. One example of this happening in the study occurred while the site safety specialist was being fit-tested; despite knowing the correct technique to insert the ear plug and the fact he was being fit tested, he inserted the ear plugs using a method different than that of the manufacturer.

This study seems to have raised more questions than it has answered. There are several different avenues of research that one could pursue now, most interestingly being the question of why the right PAR was significantly higher than the left PAR. Other questions to pursue would be whether results would be comparable in a non-union environment? Do new employees differ from veteran employees in their willingness to use “proper methods” of inserting the HPDs? Of the employees that watched the pre-insertion training video, how many of them actually inserted the HPD the correct way?

Conclusions and Limitations

The HPDs worn by the workers provided no less than 10 dBA noise reduction for all but five workers tested. One subject in particular tested three different ear plugs and received a 0 value for PAR for each plug. For all but the above mentioned five subjects, this is sufficient protection for all but the loudest of impact noises at this work place. The five subjects that had inadequate protection levels should have additional measurements taken to find an adequate HPD. Even though the observed attenuations ratings were largely satisfactory for these workers' exposures, the PAR values were low enough that the same scores would not be sufficiently protective to workers with substantially greater exposures.

Interestingly, the right PAR was almost always higher than the left PAR, an unexpected finding. Otherwise, the most important factor affecting the attenuation provided by the HPD was the subjects themselves. The differences between subjects were highly statistically significant ($p < 5\%$). No other test variable was statistical significant. Pre-insertion training made no difference in the observed attenuation values ($p > 5\%$). Choice of HPD was not significant ($p > 5\%$) and neither were evaluations of ease of use and protectiveness ($p > 5\%$). Neither survey item was predictive or related to actual effectiveness of the HPD.

In agreement with Berger (1996), the NRR values did not correspond to the observed PAR values. Despite the wide range of NRR ratings of the four tested HPDs (25-33 dB), for the workers tested here the earplugs all offer similar levels of protection with average PAR values ranging from 12.8 to 17.9 dB. The PAR values were roughly 53% of their corresponding NRR values, supporting OSHA's policy of dividing the NRR by one-half.

This study had several limitations. First, and most important, was the subjectivity of the testing procedure . The Veri-Pro® system relies on the test subject's ability to match the volumes of the tones accurately. This can be especially difficult for some people, especially those who have experienced hearing loss in one or both ears. Secondly, replication would have provided more power to discern the effects of independent variables. However, this was not possible for this study. Thirdly, was the lack of willingness on the part of most subjects to test more than their "preferred ear plug." It would have been advantageous to have larger number of people who agreed to be fit tested on all 4 provided ear plugs. Finally, having access to the employee's audiogram results prior to testing could have proven valuable when evaluating the results. While not a limitation per say, it may also be prudent to consider that the data gathered from volunteers may not be representative of non-volunteers in future studies.

References

Arezes P.M. and Miguel A.S. Hearing Protectors Acceptability in Noisy Environment [Journal] // Ann. Occupation Hygiene. - 2002. - 6 : Vol. 46. - pp. 531-536.

Arezes Pedro and Miguel Sergio Hearing protection use in industry: The role of risk perception [Journal] // Safety Science. - 2005. - 43. - pp. 253-267.

Berger E. H. Hearing Protection Devices [Book Section] // The Noise Manual. - [s.l.] : American Industrial Hygiene Association, 2003.

Berger E.H. Hearing Protection Devices [Book Section] // The Noise Manual / ed. Berger E.H. [et al.]. - Falls Church : AIHA Press, 2003. - Revised Fifth Edition.

Berger EH, Franks JR and F Lindgren International review of field studies of hearing protector attenuation [Book Section] // Scientific Basis of Noise-Induced Hearing Loss / book auth. Axelson A [et al.]. - New York : Thieme, 1996.

Berger Elliot H. and Kieper Ronald W. Hearing protection: Surpassing the Limits to attenuation imposed by the bone-conduction pathways [Journal] // Acoustical Society of America. - October 2003. - pp. 1955-1967.

Berger Elliot H. Preferred Methods for Measuring Hearing Protector Attenuation [Conference] // The 2005 Congress and Exposition on Noise Control Engineering. - Rio de Janeiro : E-A-R / Aearo Company, 2005.

Daniell William E. [et al.] Noise Exposure and Hearing Conservation Practices in an Industry With High Incidence of Workers' Compensation Claims for Hearing Loss [Journal] // American Journal of Industrial Medicine. - 2002. - 42. - pp. 309-317.

EPA EPA- Laws and Regulations [Online] // epa.gov. - 1972. - August 7, 2012. - http://www.gsa.gov/graphics/pbs/Noise_Control_Act_of_1972.pdf.

Holder M. K. Why are more people right-handed? [Online] // Sciam.com. - Scientific American Inc., August 18, 1997. - 2 26, 2012. - http://www.scientificamerican.com/article.cfm?id=why-are-more-people-right.

Hudak Roberta Hearing Protection Devices [Online] // www.CDC.gov. - June 21, 2005. - August 8, 2012. - http://www.cdc.gov/niosh/mining/workshops/hearingloss/hlprevworkshop/05-HudakHearingProtectors.pdf.

Kotarbinska E [Interview]. - 7 6, 2009.

Larson V VeriPRO and ANSI S12.6 REAT Results in the Laboratory [Report]. - San Diego, California : Howard Leight, 2008.

Lusk Effectiveness of an Intervention to Increase Construction Worker's Use of Hearing Protection [Journal] // Human Factors. - September 1999. - 3 : Vol. 41. - pp. 487-494.

Melamed Samuel [et al.] Usefulness of the Protection Motivation Theory in Explaining Hearing Protection Device Use Among Male Industrial Workers [Journal] // Health Psychology. - 1996. - Vol. 15. - pp. 209-215. - 3.

Melamed Samuel, Rabinowitz Stanley and Green Manfred S. Noise exposure, noise annoyance, use of hearing protection devices and distress among blue-collar workers [Journal] // Scandinavian Journal of Work, Environment, & Health. - 1994. - 20. - pp. 294-300.

OSHA OSHA Instruction CPL 2-2.20A, Change 2, March 1 [Book Section] // Industrial Hygiene Technical Manual. - Washington, DC : US Government Printing Office, 1987. - Vol. VI.

Ostergaard Paul B. Physics of Sound and Vibration [Book Section] // The Noise Manual / book auth. Berger E.H.. - [s.l.] : American Industrial Hygiene Association, 2003.

Schulz Theresa Y Individual fit-testing of earplugs: A review of uses [Journal]. - San Diego, CA : Noise Health, 2011. - 13. - pp. 152-162.

Vermiglio A HLI Study Review v. 3 Unpublished Laboratory Report [Report]. - Los Angeles : House Ear Institute, 2005.

Appendix

Consent Form

Name: ____________________________________

Employee Number: _________________________

Job Class: __________________________________

Age: _______

Sex: _______

1. How long have you been working at this power station?
2. Where is your primary work area?
3. How long have you been wearing your current ear plugs?
4. Have you ever received training on the proper insertion of your current ear plugs?
5. Is there any reason you should not be fit tested today? (ears hurt, ear infection, etc)

Your Preferred Hearing Protection Device (Circle One)

E-A-R Classic E-A-R Express MOLDEX PURA-FIT 6800 Howard Leight MAX

1. Is this protector comfortable?
2. Is it the most comfortable of those protectors tested on you?
3. Of those ear plugs tested on you today which is the most comfortable?
4. On a scale of 1-5 (5 is most protective), how would you rate how well it seems to reduce noise getting to your ear?
5. On a scale of 1-5, (with 5 being the worst), how difficult is it to put the protector on so that it is as effective as you can get it?
6. Which protector do you wear most often during loud work?
7. How many years have you worn these ear plugs?

Do you consent to fit-testing on all three Hearing Protection Devices? (Yes/No)

Acceptable Attenuation (Yes/No or N/A)

E-A-R Classic:

E-A-R Express:

MOLDEX PURA-FIT 6800:

Howard Leight MAX

By signing below you agree that the data determined from your fit-testing may be published along with other fit –testing data without revealing your identity.

Subject Signature:_____________________________ Date:______________

Researcher Signature: _________________________ Date:______________

Table 10: Test Subject Average PAR Values

User Id	Test Type	Earplug Name	Left PAR	Right PAR	AVG PAR	Published Attenuation
1002196	Complete Check	Express	5	11	8	25
1002196	Complete Check	MAX	17	19	18	33
1002196	Complete Check	E A R Classic	10	17	13.5	29
1002196	Complete Check	Pura-Fit 6800	18	20	19	33
10120178	Complete Check	MAX	32	23	27.5	33
10120178	Complete Check	Pura-Fit 6800	5	11	8	33
10120178	Complete Check	Express	10	15	12.5	25
10072833	Complete Check	E A R Pushins	7	12	9.5	28
2840	Complete Check	MAX	11	16	13.5	33
27912	Complete Check	MAX	31	19	25	33
46235	Complete Check	MAX	6	3	4.5	33
46235	Complete Check	Pura-Fit 6800	3	5	4	33
80484	Complete Check	MAX	8	18	13	33
40618	Complete Check	MAX	0	11	5.5	33
4499	Complete Check	MAX	13	7	10	33
6304	Complete Check	Express	0	5	2.5	25
6304	Complete Check	Pura-Fit 6800	23	22	22.5	33
6304	Complete Check	MAX	10	37	23.5	33
6304	Complete Check	E A R Classic	10	18	14	29
44941	Complete Check	Express	0	0	0	25
44941	Complete Check	MAX	0	0	0	33

44941	Complete Check	E A R Classic	0	0	0	29
13632	Complete Check	MAX	10	10	10	33
13632	Complete Check	Express	8	0	4	25
10007898	Complete Check	MAX	1	5	3	33
10007898	Quick Check	MAX	20	48	34	33
2832	Complete Check	MAX	21	18	19.5	33
10018663	Complete Check	Express	21	23	22	25
10018663	Quick Check	Express	27	25	26	25
10018663	Quick Check	Express	32	28	30	25
10018663	Complete Check	MAX	31	31	31	33
2683	Complete Check	MAX	15	20	17.5	33
2329	Complete Check	MAX	25	23	24	33
21605	Complete Check	Pura-Fit 6800	19	25	22	33
10725	Complete Check	MAX	11	19	15	33
56762	Complete Check	E A R Classic	18	15	16.5	29
2576	Complete Check	MAX	9	15	12	33
2576	Complete Check	MAX	8	13	10.5	33
6460	Complete Check	MAX	9	12	10.5	33
10121855	Complete Check	MAX	23	29	26	33
10121855	Complete Check	Express	0	19	9.5	25
14928	Complete Check	MAX	23	13	18	33
4341	Complete Check	MAX	9	6	7.5	33
4341	Quick Check	Pura-Fit 6800	0	10	5	33
4341	Quick Check	E A R Classic	25	26	25.5	29
77438	Complete Check	MAX	34	35	34.5	33

83501	Complete Check	Express	10	21	15.5	25
6478	Complete Check	MAX	27	25	26	33
6478	Complete Check	Pura-Fit 6800	33	29	31	33
1446	Complete Check	E A R Classic	5	2	3.5	29
54148	Complete Check	MAX	7	13	10	33
2055	Complete Check	Express	14	14	14	25
2055	Complete Check	E A R Classic	12	0	6	29
10121545	Complete Check	MAX	23	22	22.5	33
10121545	Complete Check	Express	12	12	12	25
10036079	Complete Check	MAX	21	16	18.5	33
10036079	Complete Check	Express	27	33	30	25
10036079	Complete Check	Pura-Fit 6800	14	17	15.5	33
10036079	Complete Check	E A R Classic	21	26	23.5	29
10120906	Complete Check	Max Lite	23	17	20	30
10120906	Complete Check	MAX	31	22	26.5	33
10120906	Complete Check	Express	20	27	23.5	25
1297	Complete Check	MAX	11	28	19.5	33
10723	Complete Check	MAX	35	34	34.5	33
16089	Quick Check	MAX	25	20	22.5	33
4697	Complete Check	MAX	15	21	18	33
4697	Complete Check	Pura-Fit 6800	28	28	28	33
2923	Complete Check	Express	17	21	19	25
2923	Complete Check	MAX	23	24	23.5	33
2923	Complete	Pura-Fit 6800	20	19	19.5	33

	Check					
1610	Complete Check	Express	14	16	15	25
5983	Complete Check	MAX	11	14	12.5	33
2188	Complete Check	MAX	24	18	21	33
2188	Complete Check	Express	17	20	18.5	25
73320	Complete Check	Express	17	11	14	25
73320	Complete Check	MAX	12	13	12.5	33
79263	Complete Check	Express	12	20	16	25