Evaluation *of* Muff Type Hearing Protectors
As Used In The Mining Industry

by

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ABSTRACT

Studies were conducted for the evaluation of muff type hearing protector devices (HPDs) as worn by miners working in a mining environment. Noise reduction measurements were made using a physical method composed of an instrumentation system with miniature microphones inside and outside the HPD cup. Prior to performing field evaluations, laboratory tests were conducted which showed that the results of the physical method instrumentation system were similar to the results of the American National Standards Institute (ANSI) Real-Ear-Attenuation at-Threshold (REAT) method. A total of 23 different models of HPDs and 545 different machines (20 different machine types) were evaluated in the field phase of the study. This resulted in 1265 separate HPD evaluations. The effectiveness of each model of HPD, in terms of the dBA noise reduction, is presented as a function of the metric (C-A), which characterizes the spectrum of the machine noise. The dBA reductions for various combinations of HPD models and machine types are also presented. The results show that the field performance of muff type HPDs is significantly less than that predicted by the Environmental Protection Agency Noise Reduction Rating (EPA NRR), especially for low frequency noise sources such as equipment powered by internal combustion engines. Fully 32% of the operators of internal combustion engine powered machines had noise reductions of 10 dBA or less. Across all machine types 20% of the workers had a noise reduction of 10 dBA or less. From the results it is concluded that the EPA NRR grossly overestimates HPD performance. In addition the EPA NRR is not a good indicator for comparing one model of HPD to another since--in many instances HPDs with lower NRR outperformed those with higher NRR values.

INTRODUCTION

The Environmental Protection Agency Noise Reduction Rating (EPA NRR) method for the evaluation of hearing protection devices

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(HPDs) has been in use for a number of years. The NRR rating is based on Real-Ear-Attenuation at-Threshold (REAT) using an American National Standards Institute (ANSI)[2,3], laboratory, psychophysical method. It was originally conceived as a standard rating method for comparing the optimum effectiveness of different models of HPDs given a standardized noise spectrum. As such, the variability of parameters involved in the ANSI testing method and subsequent NRR calculation are tightly controlled. These include, trained subjects, professional fitting, minimum subject movement, and a pristine laboratory setting. The REAT results are then used in conjunction with a standardized spectrum (pink noise) for the NRR calculation. Because of these unrealistic test conditions the NRR value ascribed to a particular HPD is not necessarily achievable in a real-world work environment.

HPDs have become an integral part of most hearing conservation plans[4]. They are assumed to provide a convenient and economical way to reduce worker noise exposure. Several agencies, recognizing that the NRR is an inaccurate predictor of HPD effectiveness, provide a method for adjusting the NRR. Some derate the NRR by subtracting a constant such as 7 or 10, while others derate it by 50% or assign a constant value of 15 as the noise reduction value for every model of HPD[5]. It will be shown. that even with these NRR adjustment methods, the protection afforded the worker is often grossly overestimated, especially for low frequency noise. This can result in worker overexposure to noise and subsequent hearing loss.

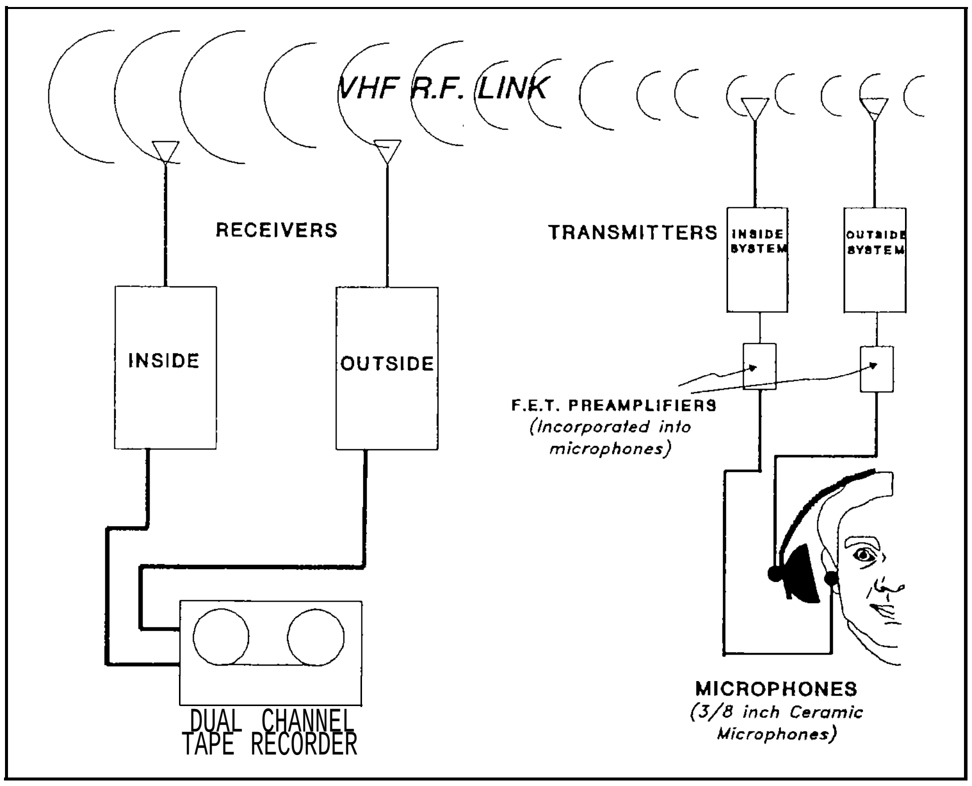
Recently an extensive study was undertaken by two separate Divisions within the Mine Safety and Health Administration (MSHA) to measure the on-the-job effectiveness of muff type HPDs as used in mining industry. This report describes both methods used in performing the tests, the data analysis, and the results of the investigation. Because many of the machine types used in the study are common to other industries and since the analysis is made with respect to spectrum as well as machine type, the results should be applicable to other industries.

INSTRUMENTATION

A physical, non subjective method was used to evaluate the HPDs in this study. It was based on a method developed by Stewart and Burgi[6]. Basically, it is a physical-noise reduction measurement. Psychophysical or physical-insertion loss measurements are too cumbersome in the field. Psychophysical tests require the subject to evaluate the perceived noise in third octave noise bands. Physical-insertion loss measurements would require the machine to operate at the same noise level and mode of operation for both the occluded ear as well as the unoccluded ear for the data to be meaningful. Because of these constraints, the physical-noise reduction measurement method was chosen. There are conversion factors that can be applied to the physical- noise reduction data for conversion to physical-insertion loss data. Because the third octave band data for the western team tests are no longer available these conversion factors were not used in this report.

The instrumentation system selected for the physical-noise reduction method permitted the simultaneous measurement of the noise level inside and outside the muff cup. Figure 1 is a block diagram of the system used by the Eastern MSHA Team.

figure 1. Block Diagram of Instrumentation System Used for Hearing Protector Evaluation

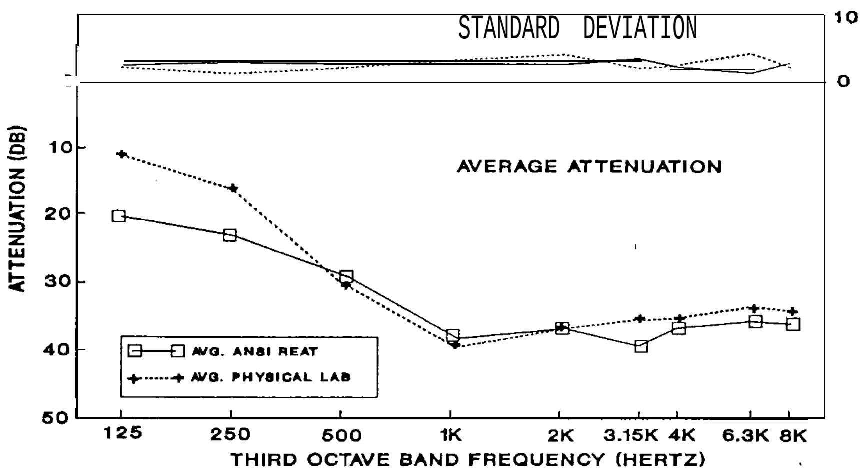


Both the inside and outside measuring systems consisted of a miniature 3/8" ceramic microphone and signal conditioning pre-amplifier. Care was taken to match the response of the two measuring systems. For the inside system the microphone and cabling were small enough so that placement under the earmuff cup, next to the ear canal, did not significantly alter the fit of the HPD. For the outside system the microphone was taped to the earmuff cup being tested.

To allow the worker to perform his normal duties unencumbered by the testing apparatus, a dual channel VHF frequency modulated (FM) telemetric link with an effective range of 500 feet was used to record inside and outside sound pressure levels (dB linear) on a dual channel magnetic tape recorder. Analysis was performed on a dual channel real time spectrum analyzer in 27 third octave bands in the frequency range of 25 to 10,000 Hertz (Hz).

Prior to performing any field testing of HPDs a series of noise reduction measurements were conducted in the laboratory for the purpose of comparing the physical field measuring system to the ANSI REAT method for HPD evaluation. Seven subjects and 11 earmuff type HPDs were tested in a reverberant chamber. Different combinations of subjects and HPDs, with three repetitions each, produced 21 tests for each HPD. A good example of a response for a broadband noise stimulus is shown in Figure 2.

figure 2. Comparison of ANSI REAT and Physical Laboratorv Test Results for the EAR-3000 Hearing Protector



Except for the 125 and 250 Hz bands, the physical and ANSI REAT methods produced similar results, differing by about + 2.5 dB in most bands. The standard deviations associated with each method tracked fairly well with frequency. The difference in attention at low frequency has also been observed by other researchers [8, 9], and is thought ,to be due to physiological noise interfering with the subjects response to the ANSI REAT method.

METHODOLOGY

When the teams arrived at a mine site, a quick walk-around was performed to determine those machines that were fully engaged in normal mining activities. From this pool, machine operators were selected as participants in the study. Once selected the worker was instructed to wear the HPD in the usual manner. No special instructions were given and no special care was taken to fit the HPD. The HPDs used were either newly purchased units brought by the team to the site or the worker's personal HPD. If the worker's HPD was to be used it was first inspected for wear. If the unit was not in good condition, it was rejected for the test and a replacement was provided. Rejection was based on several factors. These were weakened headbands, cracked earcups, torn or missing earcup pads, as well as deteriorated earcup foam material. After the instrumentation package was installed and calibrated the worker was told to operate the machine in the usual manner.

During the course of the test the inside and outside noise spectrums were recorded on a dual channel tape recorder in the dB linear mode using the VHF RF-telemetric link. Each of the tests was approximately 40 minutes in duration. At the laboratory the tapes were analyzed through a dual channel real time analyzer using 27, l/3 octave bands in the frequency range of 25 to 10000 Hz. From the two noise spectra the overall A-weighted outside noise level, L,(out) and inside noise level, L,(in) were obtained. The A-weighted noise reduction, NR,, for the HPD was calculated as:

$$NR_A = L,(out) - L,(in) \quad (1)$$

The NR_A for a particular HPD-machine test, was evaluated only for those modes of operation when the machine was under load, those portions of the spectrum corresponding to down time or idle time were not included in the evaluation. From the outside spectrum the value of L,(out) - L,(out) was obtained. This metric is used as an indicator of spectral content for the calculated NR_A and is referred to as the C-A value, denoted (C-A).

To facilitate the collection of field data, a second MSHA team evaluated HPDs, at geographically different mine sites concurrently with the first team. This team used similar instrumentation and analysis techniques except that the data acquiring system was hard-wired instead of telemetered. The inside noise level L,(in) and outside noise level L,(out) and L,(out) were recorded. The laboratory analysis was performed in 25, l/3 octave bands within the frequent range of 31.5 to 8000 Hz. Subsequent analysis of the reports[10], [11] written by both teams showed the results to be similar.

A total of 23 different models of HPDs and 545 different machines (20 different machine types) were evaluated in the study. This resulted in 1265 separate HPD evaluations. The matrix given in Table 1 shows the distribution of the tests conducted as a function of HPD model and machine type.

Table 1 - Distribution of HPD Evaluations per Machine Type and HPD Model

	MACHINE TYPE																				
HPD MODEL	Dozer	FEL Loader	Hyd Drill	Prep Plant	Pneu Drill	Crusher	Truck	Mucker	Face Drill	Rotary Drill	Dragline Oi	Dragline Op	Drill Helper	Shovel	Fan	Grader	Scraper	LHD	Scaler	Dredge	Total HPDs
MSA Mark IV	44	31	27	8	25	18	7	6	0	1	0	0	0	0	3	8	1	0	2	2	184
Bilsom Vik	26	15	12	28	21	4	18	0	0	0	4	0	0	4	10	0	1	5	3	1	152
David Clark 310	25	23	28	8	0	8	0	0	0	0	4	0	0	0	0	8	0	0	0	0	104
David Clark 805V	30	22	23	7	0	8	0	0	0	0	0	0	8	0	0	0	0	0	0	0	98
Ear 3000	10	0	15	14	11	5	10	3	0	4	4	8	0	4	0	0	2	7	0	0	97
Wilson 365	0	31	8	28	0	3	0	0	0	0	0	0	9	0	0	0	0	9	0	0	88
Ear 1000	0	22	16	14	0	0	0	0	17	0	0	0	7	0	0	0	0	0	0	0	76
Bilsom UF2	0	20	8	0	0	3	0	0	14	0	9	8	0	0	0	0	0	0	0	0	62
MSA 500	6	15	22	8	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	59
Wilson 381	0	9	7	28	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47
Am. Optical 1720	11	2	0	0	10	4	6	3	0	2	0	0	0	2	3	0	2	0	2	1	45
Allsafe 1820	11	0	1	0	5	2	4	3	0	4	0	0	0	3	0	0	1	0	0	0	34
Norton 4530	8	0	1	0	5	2	5	7	0	0	0	0	0	1	0	0	2	0	0	0	31
Wilson 365A	8	0	7	0	0	3	0	0	0	0	0	8	0	0	0	0	0	0	0	0	26
Tasco	5	0	4	0	11	1	0	2	0	0	0	0	0	2	0	0	1	0	0	0	26
Flents 085	10	2	3	0	0	0	4	0	0	4	0	0	0	0	0	0	1	0	0	0	24
Safe ear	9	0	1	0	0	0	4	0	0	4	0	0	0	2	0	0	2	0	0	0	22
Glendale Optical	4	2	0	0	3	2	3	0	0	5	0	0	0	0	0	0	1	0	0	0	20
Flents SE	3	0	1	0	0	0	3	7	0	4	0	0	0	0	0	0	1	0	0	0	19
Glendale 900	0	0	0	0	0	0	0	0	12	0	4	0	0	0	0	0	0	0	0	0	16
Am. Optical 1275	0	0	0	0	9	0	0	0	0	0	0	0	0	0	3	0	0	0	4	0	16
Allsafe 2023	4	0	0	0	2	2	5	0	0	0	0	0	0	0	0	0	1	0	0	0	14
Wilson 155	0	0	0	0	2	0	1	7	0	0	0	0	0	0	0	0	0	0	0	0	10
Total Machines	**214**	**194**	**184**	**143**	**104**	**76**	**70**	**38**	**43**	**28**	**25**	**24**	**24**	**18**	**16**	**16**	**16**	**21**	**11**	**4**	**1265**

The majority of HPDs evaluated were the personal models of the workers that were being worn at the work site. This resulted in an uneven distribution in the number of tests among models of HPDs. The distribution may not reflect the population of muff type HPDs used in mining.

The large number of tests conducted on surface diesel powered equipment operators was intentional since the Agency is particularly interested in the effectiveness of HPDs for this category of machine operator.

RESULTS/DISCUSSION

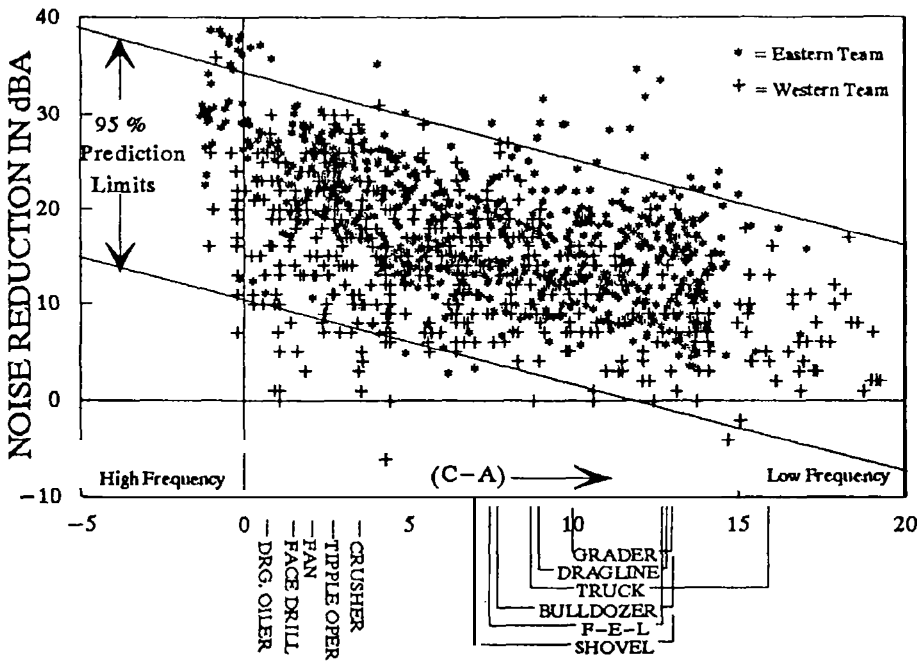
All of the field data collected is shown graphically in Figure 3. Here the ordinate is given as noise reduction in dBA while the abscissa is given in terms of (C-A). The metric (C-A), which is the difference between the C-weighted outside noise level and the A-weighted outside noise level, is a convenient parameter for characterizing the machine noise.

Where:

$$(C\text{-}A) = L_{,}(out) - L_{,}(out) = \frac{1}{PREDOMINATE\ \ FREQUENCIES} \qquad (2)$$

So that when (C-A) is large, the radiated noise is predominately low frequency and when (C-A) is small, the major components of the noise are predominately high frequency. The abscissa is also labelled with some of the machine types studied showing the range of (C-A) values expected for these machines.

figure 3. Scattergraph Results of All Hearing Protector Field Evaluations



There are 1265 data points in this graph with different symbols used for the data from the two teams. With the exception of some outliers the two data bases are similar to each other.

The best fit average line for the data was calculated using a linear regression technique as:

$$NR_A = -.86(C\text{-}A) + 22.42 \qquad (3)$$

The square of the correlation coefficient for the regression is

R^2 = 32%. This indicates that 68% of the variation in the data is not explained by Equation (3). The introduction of a second variable, NRR, and the utilization of a multiple regression technique did not appreciably increased the explained variation. For this regression:

$$NR_A = -.88(C\text{-}A) + .50NRR + 10.86 \qquad (4)$$

the square of the correlation coefficient is, R^2 =36%. This indicates that, marginally, the field measured noise reduction does not correlate well with the NRR values ascribed to different models of HPDs.

A similar regression analysis, based on equation 3, was done on the data for each HPD model evaluated in the study. Graphs for two typical examples, the MSA Mark IV and the Bilsom UF2, are shown in Figures 4 and 5.

Figure 4. Regression Results on MSA Mark IV Field Evaluation Data

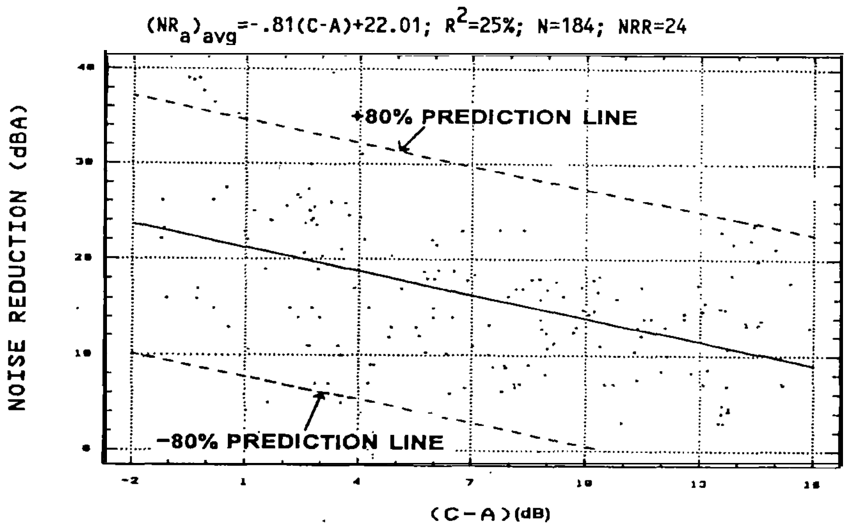
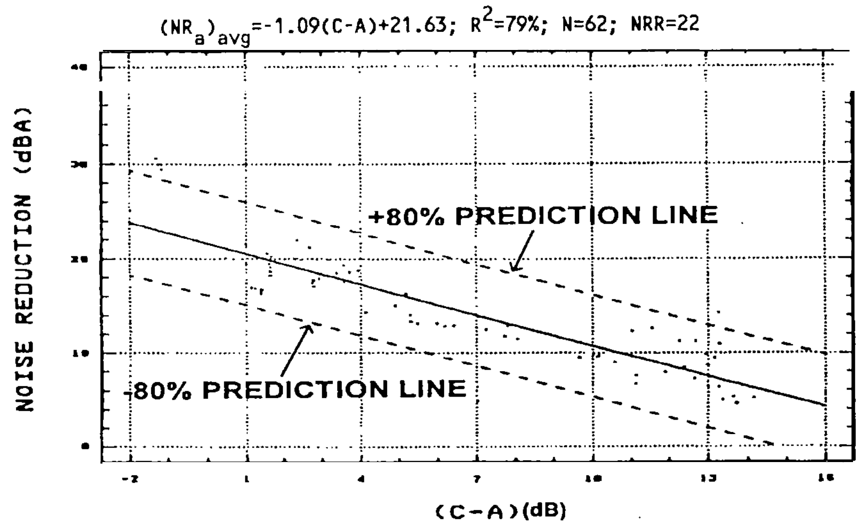


Figure 5. Regression Results on Bilsom UF2 Field Evaluation Data



In Figures 4 and 5 the noise reduction is plotted as a function of (C-A). Shown are all the data points along with the average regression line and the upper and lower 80% prediction limit lines. 80% was chosen as an arbitrary value. It is apparent from the negative slopes that the effectiveness of the HPDs decreases with increasing values of (C-A) approaching minimal effectiveness for large values of (C-A), low frequency noise, such as that encountered in equipment powered with internal combustion engines.

As can be seen from both graphs, uncertainty in the regression estimate is quite large. For example consider a noise source having a spectral content such that (C-A)=10. For the MSA Mark IV (R=25%) the 80% limits define a predicted noise reduction of between 3 to 25 dBA. For the Bilsom UF2 (R^2=79%), the same limits predict a noise reduction between 6.5 to 16 dBA. This large variation in noise reduction is due to parameters which were not measured in the evaluation. Physical characteristics such as head size, head shape and amount of hair can affect HPD performance from individual to individual. The physical activity of the worker can induce a relative motion between the cup seal and the side of the head which degrades the integrity of the seal and reduces HPD performance. This effect is further enhanced due to perspiration and/or use of safety glasses. All of these parameters which degrade HPD performance are in most part uncontrollable during the normal work day. They are the realistic conditions encountered in a real life working environment as contrasted to the controlled ANSI test conditions.

The regression results for all of the models of HPDs evaluated are shown in Table 2.

Table 2. Summary of Regression Analysis on the HPD Data

HPD Mode 1	EPA WRR	Regression Equation for Average $NR_A = m(C-A)+b$	Fit R^2	Numberof Evaluations
MSA Hark IV	24	-.81(C-A)+22.01	25%	184
Bilsom Viking	28	-.81(C-A)+25.30	33%	152
David Clark 310	20	-1.70(C-A)+31.28	75%	104
David Clark 805V	23	-.80(C-A)+26.57	33%	98
EAR 3000	27	-.86(C-A)+22.60	30%	97
Uilson 365	23	-.70(C-A)+20.28	42%	88
EAR 1000	21	-.98(C-A)+21.79	39%	76
Bilsan UF2	22	-l.O9(C-A)+21.63	79%	62
MSA 500	18	-1.33(C-A)+25.90	59%	59
Wilson 381	19	-l.Ol(C-A)+25.11	48%	47
Am. Optical 1720	18	-.82(C-A)+20.05	35%	45
Allsafe 1820	20	-.70(C-A)+17.57	41%	34
Norton 4530	23	-.53(C-A)+13.32	36%	31
Wilson 365A	2 6	-l.O7(C-A)+27.78	64%	26
Tesco	23	-.55(C-A)+20.64	17%	26
Flents 085	16	-.61(C-A)+14.83	42%	24
Safe Ear	15	-.59(C-A)+14.20	41%	22
Glendale Optical	24	-.94(C-A)+19.51	56%	20
Flents SE	24	-.63(C-A)+17.72	51%	19
Glendale 900	23	-.79(C-A)+24.88	10%	16
Am. Optical 1275	18	-.62(C-A)+16.06	5%	16
Allsafe 2023	20	-.92(C-A)+19.96	62%	14
Wilson 155	20	-.42(C-A)+ 9.92	47%	10

In Table 2 the intercept b, of the regression equation, describes the limiting high frequency performance of the HPD when (C-A)=O. For some of the HPDs the value of the intercept exceeds the NRR. This indicates that on average, the high frequency performance of the HPD is better than that predicted by the NRR. The David Clark model 310, for example, has an average measured noise reduction at high frequency of 31 dBA. This by far exceeds the NRR of the unit given as 20 dB.

For all of the HPD models the estimated coefficients of (C-A), m, is negative, ranging in value from -1.7 to -.42 dBA per unit (C- . The HPD models with larger negative m values have a larger rate of performance degradation with increasing values of (C-A). The ability of a unit to reproduce performance characteristics from worker to worker is expressed in the R^2 value of the regression. For example, the Bilsom UF2 (R^2 =79%) performed more consistently across workers than did the MSA Mark IV (R^2 = 25%). This disparity is evident throughout the list of R^2 values in Table 2. It is not known if this is due to an experimental artifact or the test subjects work movements and/or HPD design and fit.

The evaluation results for all HPD models with more than 30 evaluations is presented in Table 3. Table 3 is divided into 3 main sections. The first gives the HPD specifications. The second shows the average noise reduction predicted for 5 different values of (C-A). Fifty percent of workers are predicted by the model to experience noise reductions equal to or less than the values shown in this section. The third section shows the noise reductions at the lower 80% prediction limit for 5 different values of (C-A). At the lower 80% prediction limit, at most 10% of the workers tested are predicted by the model to experience noise reductions equal to or less than the values shown.

Table 3. Performance of Selected HPDs as a Function of (C-A)

HPD Specifications		Predicted Average Noise Reduction (dbA)					Lower 80% Prediction Limit Noise Reduction (dbA)				
		(C-A) Values					(C-A) Values				
HPD Model	EPA NRR	-2	5	10	15	18	-2	5	10	15	18
HSA Mark IV	24	23.6	17.9	13.9	9.8	7.4	14.7	8.0	6.0	2.0	0.0
Bilsom Viking	28	26.9	21.2	17.2	13.1	10.7	20.5	15.0	11.0	6.9	4.5
David Clark 310	20	34.6	22.8	14.3	5.8	0.7	28.4	16.2	8.0	0.0	0.0
David Clark 805V	23	28.2	22.6	18.5	14.5	12.1	21.0	16.0	12.0	8.0	5.0
EAR 3000	27	24.3	18.3	14.0	9.7	7.2	16.0	10.0	5.8	1.0	0.0
Wilson 365	23	21.7	16.8	13.2	9.7	7.6	17.0	12.0	8.5	5.0	2.7
EAR 1000	21	23.7	16.9	12.0	7.1	4.1	18.2	11.8	7.0	2.0	0.0
Bilsom UF2	22	23.8	16.2	10.8	5.3	2.1	20.0	12.8	7.2	1.5	0.0
MSA 500	18	28.6	19.2	12.6	5.9	1.9	22.2	13.0	6.5	0.0	0.0
Wilson 381	19	27.1	20.1	15.0	10.0	7.0	21.5	14.7	9.5	4.7	1.8
Am. Optical 1720	18	21.7	15.9	11.8	7.7	5.2	14.0	8.5	4.0	0.0	0.0
Allsafe 1820	20	19.0	14.1	10.6	7.1	5.0	12.0	7.5	4.0	0.5	0.0
Norton 4530	23	14.4	10.7	8.0	5.3	3.7	8.0	4.5	1.5	0.0	0.0

To more easily compare the performance of different models of HPDs the data of Table 3 are graphically presented in Figures 6 and 7. Figure 6 shows the average noise reduction predicted by the regression model while Figure 7 shows noise reduction at the lower 80% prediction limit (projected to be unmet by at most 10% of the workers).

Figure 6. Hearing Protector Predicted Average Noise Reduction for Selected Values of (C-A) in dB.

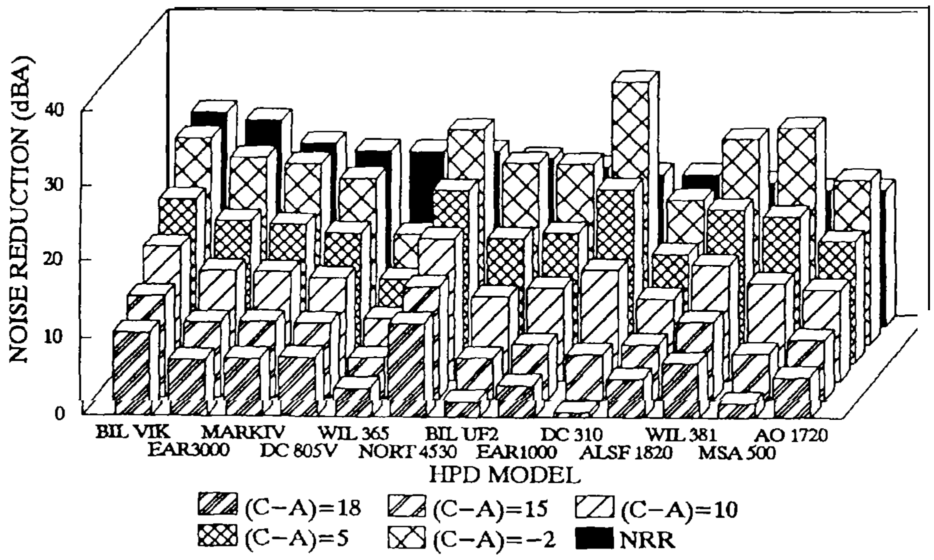
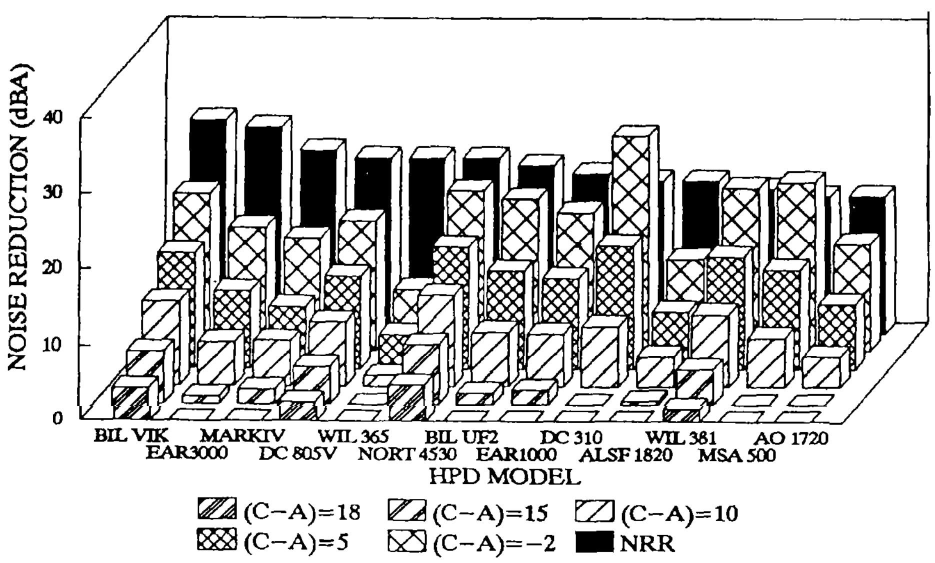


Figure 7. Lower 80% Prediction Limit for Hearing Protector noise Reduction for Selected Values of (C-A) in dB.



As expected, Table 3 and Figures 6 and 7 show that the noise reduction decreases, in every case, with increasing values of (C-A). In addition they show that the NRR is not a good predictor of relative HPD performance. Many HPDs with lower NFW values out performed those with higher NRR values. Except for extremely small values of (C-A), the noise reduction received is substantially less than that predicted from the NRR. For example, with a (C-A) value of 15, 50% of the workers are predicted in the regression model to receive a noise reduction within a range of 5-15 dBA (bars 2nd from the front, Figure 6), while for 10% of the workers, there is no assurance that noise reduction will exceed 8 dBA (bars 2nd from the front, Figure 7).

The performance of the HPDs for the operators of various machine types is illustrated in Figures 8 through 19. These graphs are derived from the data tables in Appendix A which present the results of the field HPD evaluations for 20 categories of machine operators. For the graphs, however, only those HPD model-machine type combinations with the largest number of tests are shown. In each graph the ordinate is in terms of noise reduction (dBA) while the abscissa lists the various models of HPDs tested. Presented in each graph is the NRR of the HPD, the average noise reduction measured, the average noise reduction minus 1.28 times the standard deviation (SD), and the average noise reduction minus 1.65 times the SD. The legend at the bottom of each graph explains the assignment of the bars to each of these parameters. It should be noted that the Average minus 1.28 SD, (Avg-1.28 SD) bars can be interpreted as meaning that 10% of the operators received a noise reduction less than or equal to the values shown. The Avg-1.65 SD bars can be interpreted as meaning that 5 % of the operators received a noise reduction less than or equal to the values shown.

Figure 8. Hearing Protector Results for Bulldozer Operators

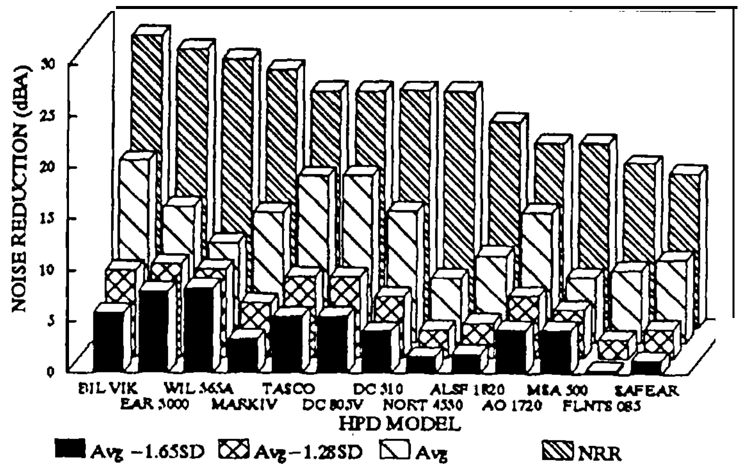


Figure 9. Hearing Protector Results for Crusher Operators

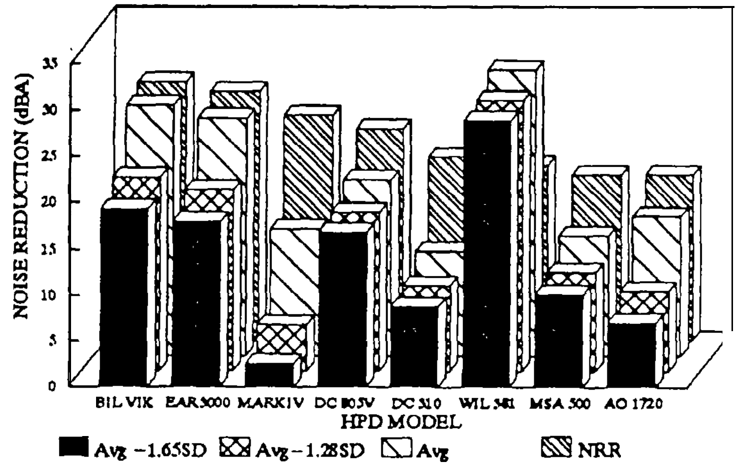


Figure 10. Hearing Protector Results for Hydraulic Drill Operators

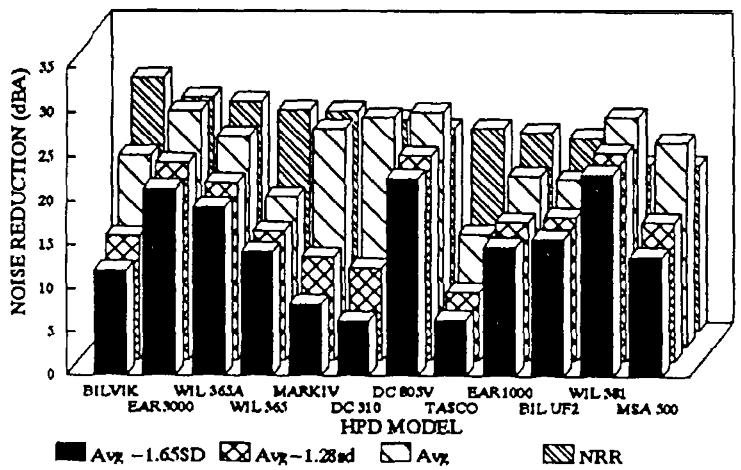


Figure 11. Hearing Protector Results for Front End Loader Operators

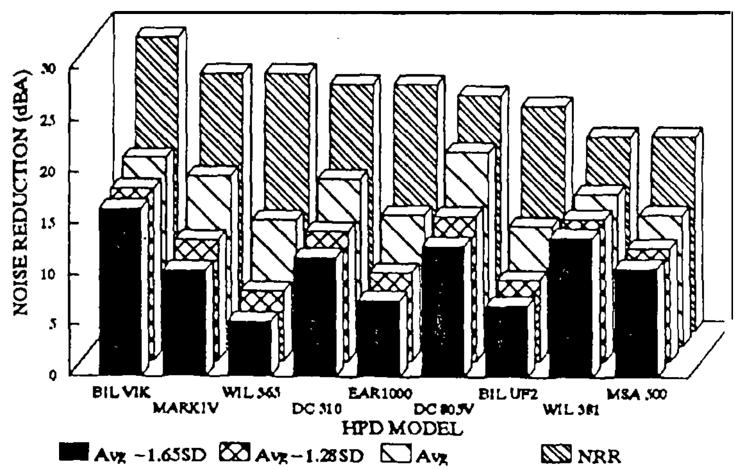


Figure 12. Hearing Protectot Results for Truck Operators

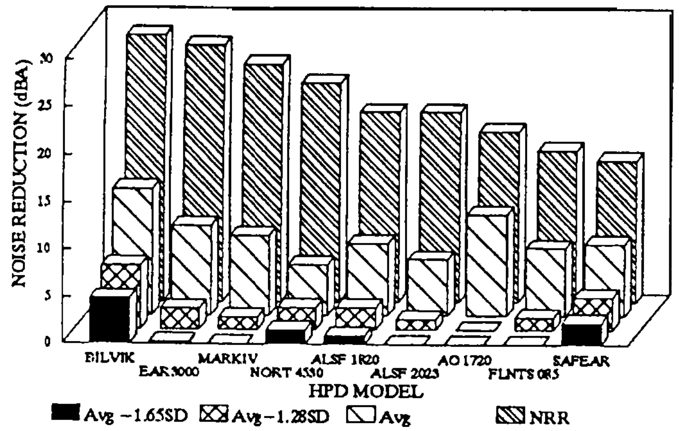


Figure 13. Hearing Protector Results for Pneumatic Drill Operators

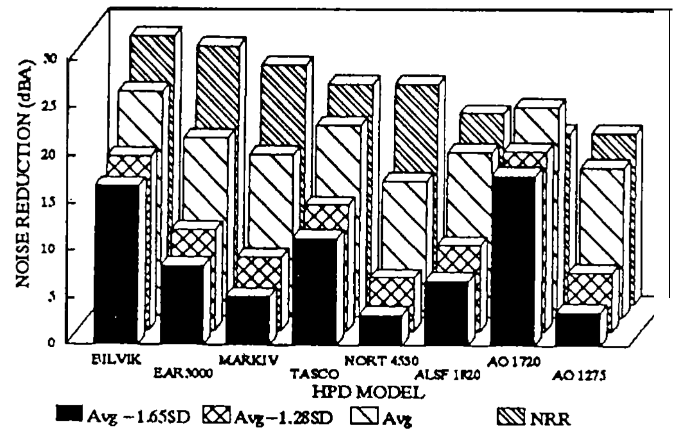


Figure 14. Hearing Protector Results for Panel/Tipple Operators

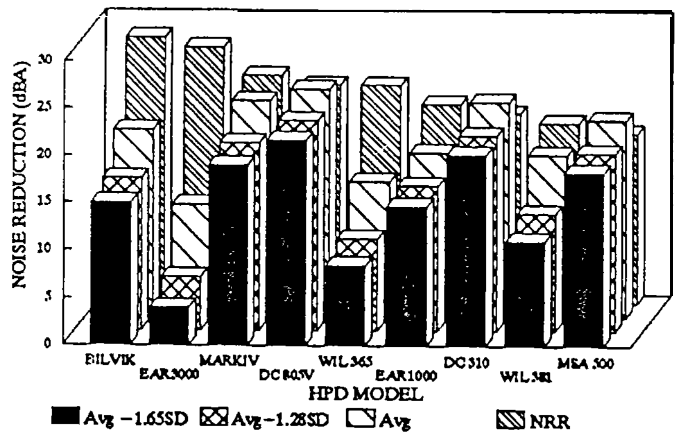


Figure 15. Hearing Protector Results for Mucker Operators

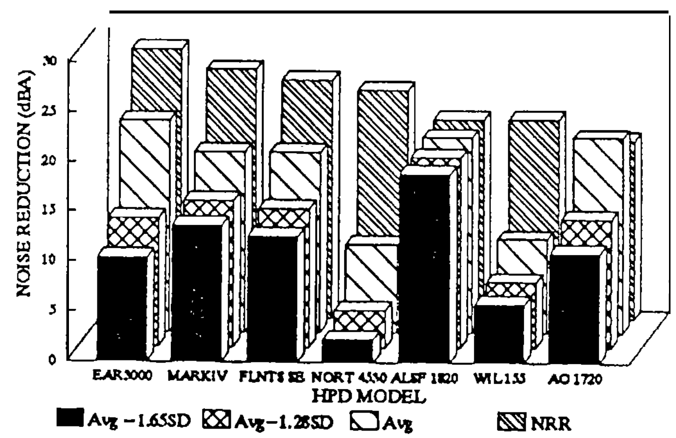


Figure 16. Hearing Protector Results for Rotary Drill Operators

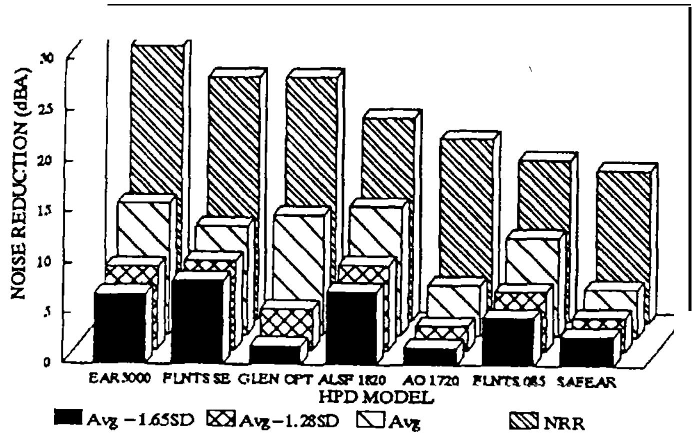


Figure 17. Hearing Protector Results for Power Shovel Operators

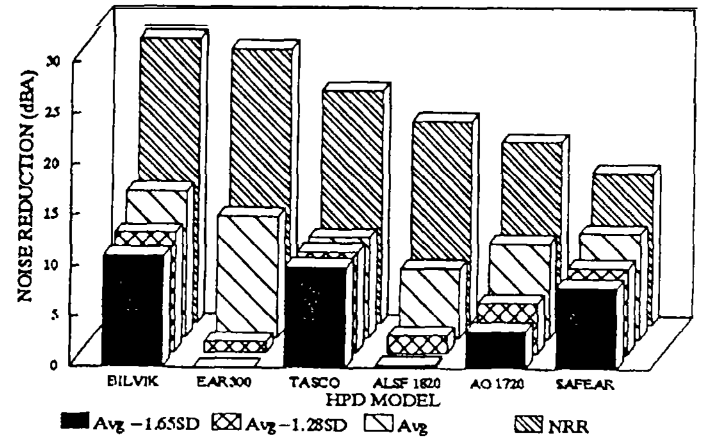


Figure 18 Hearing Protector Results for Dragline Oilers

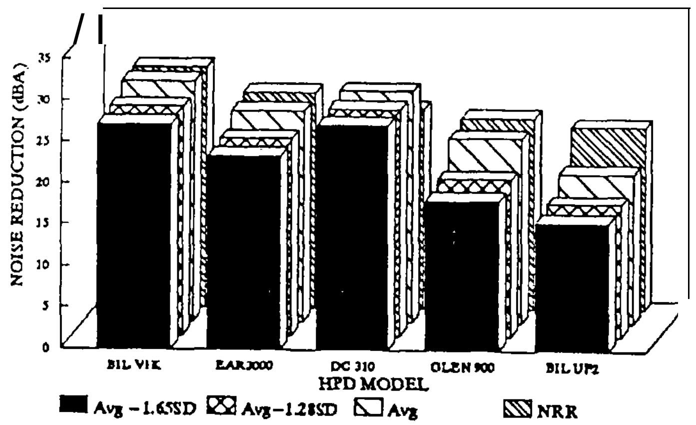
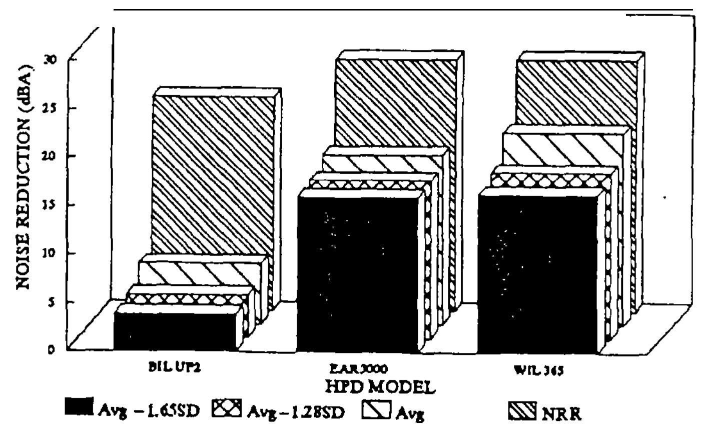


Figure 19. Hearing Protector Results for Dragline Operators



From the graphs and the data in Appendix A the following observations can be made concerning the performance of HPDs in the field tests conducted:

1. For most machine types and HPD models the average measured noise reduction is less than the NRR value assigned to the HPD.
2. For operators of machines powered by internal combustion engines such as bulldozers, front end loaders, trucks, power shovels and dragline (operators), the average measured noise reduction is substantially less than for other categories of machines. This undoubtedly is due to the predominately low frequency noise emitted by these machine types (large (C-A) values) and the ineffectiveness of HPDs for these lower frequencies. This effect is also apparent for rotary drills which are driven by diesel powered air compressors.
3. Fully 32% of the operators of internal combustion engine powered machines were measured as having noise reductions of 10 dBA or less while 8% were found to have a noise reduction of 5 dBA or less.
4. For bulldozers, trucks, power shovels and rotary drills less than 5 dBA noise reduction was measured for 14% of the operators.
5. From a study of the percentiles across all machine types and all HPD models, it can be concluded that 50% of the workers had a noise reduction of 16 dBA or less while about 20% of the workers had a noise reduction of 10 dBA or less and 5% of the workers had a noise reduction of 5 dBA or less.

CONCLUSIONS

This study has shown that the performance of muff type HPDs as used in a work environment is significantly less then that predicted by the EPA NRR. For low frequency noise sources, such as equipment powered by internal combustion engines, the resulting noise reduction is minimal. It was also shown that the EPA NRR is not a good indicator for comparing one model of HPD to another since in many instances those HPDs with lower values of NRR out-performed those with a higher value of NRR.

The on-the-job performance of earplugs or insert type devices has been studied by others with findings that are similar to ours [12] [13,14,15]. Their results also show that the performance of these devices, in a working environment, is substantially less than that predicted by the EPA NPR.

In light of these results i.e., the effect of (C-A), the current practice of adjusting the NRR by subtracting 7 or 10 or by assigning a constant value of 15 for all HPD models may not be a realistic derating for the NRR value. Continuation of this current practice can result in a gross overestimation of the protection afforded the worker and thus increase the risk of occupational hearing loss.

APPENDIX

Table 1. Hearing Protector Results for Bulldozer Operators (N=214)

HPD MODEL	NRR	NRA * SD	(C-A) ± SD	# TESTS
ALLSAFE 1820	20	a.5 ± 4.0	8.7 ± 2.9	11
ALLSAFE 2023	20	7.8 ± 5.9	8.3 ± 2.7	4
AM. OPTICAL 1720	la	12.6 ± 5.1	a.9 ± 3.3	II
BILSOH VIKING	28	17.7 ± 7.1	10.3 ± 2.2	26
DAVID CLARK 310	23	12.8 ± 5.2	12.2 ± 1.7	25
DAVID CLARK aO5V	23	16.2 ± 6.5	12.4 ± 1.4	30
EAR-3000	27	13.2 ± 3.1	8.3 ± 2.7	10
FLENTS 085	16	7.2 ± 4.2	10.1 ± 2.6	IO
FLENTS-SE	24	12.3 ± 1.2	a.1 ± 1.3	3
GLENDALE OPTICAL	24	9.8 ± 3.6	8.6 ± 1.3	4
HSA-500	18	6.4±1.3	12.9 ± 1.1	6
HSA-MARKIV	25	12.6 ± 5.6	10.8 ± 3.0	44
NORTON 4530	23	6.4 ± 2.8	10.5 ± 2.9	8
SAFE EAR	15	8.2 ± 4.2	9.5 ± 2.8	9
TASCO	23	16.2 ± 6.4	9.4 ± 2.2	5
WILSON 365A	26	9.7 ± 0.8	12.0 ± 0.8	8

Table 2. Hearing Protector Results for Crusher Operators (N=75)

HPD MODEL	NRR	NR$_A$ ± SD	(C-A) ± SD	# TESTS
ALLSAFE 1820	20	20.5 ± 2.5	3.6 ± 0.1	2
ALLSAFE 2023	20	19.5 ± 3.5	4.8 ± 1.0	2
AM. OPTICAL 1720	la	15.3 ± 5.0	3.4 ± 0.5	4
BILSW UF-2	21	30.0 ± 0.5	-1.2 ± 0.1	3
BILSCM VIKING	28	27.2 ± 4.7	0.3 ± 2.8	4
DAVID CLARK 310	20	11.4 ± 1.5	9.1 ± 1.2	a
DAVID CLARK aO5V	23	19.2 ± 1.4	6.6 ± 1.0	a
EAR-3000	27	25.8 ± 4.8	0.9 ± 2.5	5
GLENDALE OPTICAL	24	17.0 ± 3.0	2.8 ± 0.1	2
HSA-500	18	13.2 ± 1.8	6.6 ± 0.8	a
WA-HARKIV	24	13.8 ± 6.8	5.2 ± 4.0	18
NORTON 4530	23	20.0 ± 2.0	3.9 ± 0.1	2
WILSON 365	23	28.9 ± 0.1	-1.1 ± 0.0	3
WILSON 365A	26	29.4 ± 0.1	-1.2 ± 0.1	3
WILSON 381	19	31.0 ± 1.2	-1.0 ± 0.1	3

Table 3. Hearing Protector Results for Hydraulic Drill Operators (N=180)

HPD MODEL	NRR	NR$_A$ ± SD	(C-A) ± SD	TESTS
BILSOM UF-2	22	19.1 ± 1.9	3.8 ± 1.1	8
BILSOM VIKING	29	21.7 ± 5.8	5.1 ± 2.7	12
DAVID CLARK 310	24	26.0 ± 11.8	3.2 ± 4.0	28
DAVID CLARK 805V	23	26.6 ± 2.4	4.3 ± 3.6	23
EAR-1000	23	19.5 ± 2.7	3.3 ± 0.9	16
EAR-3000	26	26.8 ± 3.2	2.7 ± 2.1	15
FLENTS 085	16	11.7 ± 3.7	3.0 ± 1.6	3
WA-500	19	23.3 ± 5.7	4.2 ± 3.8	22
HSA-HARKIV	25	24.7 ± 9.9	3.8 ± 3.7	27
TASCO	23	12.8 ± 3.7	5.5 ± 2.8	4
WILSON 365	25	17.1 ± 1.7	3.3 ± 0.9	8
WILSON 365~	26	23.9 ± 2.7	3.5 ± 1.6	7
WILSON 381	19	26.2 ± 1.8	3.1 ± 1.2	7

Table 4. Hearing Protector Results for Front End Loader Operators (N=194)

HPD MODEL	NRR	NR$_A$ ± SD	(C-A) ± SD	# TESTS
AM. oPTICAL 1720	la	13.0 ± 5.0	4.4 ± 2.1	2
BILSOM UF-2	22	11.8 ± 2.8	9.6 ± 3.4	20
BILSDM VIKING	29	la.5 ± 1.1	10.1 ± 2.2	15
DAVID CLARK 310	24	16.4 ± 2.8	9.5 ± 2.7	23
DAVID CLARK 805V	23	19.0 ± 3.7	11.0 ± 3.2	22
EAR-1000	24	12.9 ± 3.2	7.9 ± 2.7	22
FLENTS 085	16	10.0 ± 4.0	8.2 ± 0.7	2
GLENDALE OPTICAL	24	6.5 ± 1.5	9.8 ± 4.2	2
HSA-500	19	12.9 ± 1.3	9.1 ± 2.0	15
USA-MARKIV	25	16.7 ± 3.7	10.6 ± 3.3	31
UILSON 365	25	12.4 ± 4.2	12.9 ± 1.5	31
WILSON 381	19	14.9 ± 0.7	12.4 ± 0.7	9

Table 5. Hearing Protector Results for Truck Operators (N=69)

HPD MODEL	NRR	NR$_A$ ± SD	(C-A) * SD	# TESTS
ALLSAFE 1820	20	7.8 ± 4.1	15.9 ± 2.0	4
ALLSAFE 2023	20	6.0 ± 3.7	17.2 ± 1.4	5
AM. OPTICAL 1720	18	10.8 ± 8.5	10.4 ± 7.6	6
BILSOM VIKING	28	13.4 ± 5.1	9.3 ± 3.2	18
EAR-3000	27	9.6 ± 5.7	12.7 ± 4.1	IO
FLENTS 085	16	7.3 ± 4.6	14.6 ± 4.4	4
FLENTS-SE	24	8.0 ± 2.9	15.9 ± 0.8	3
GLENDALE OPTICAL	24	16.3 ± 7.0	6.5 ± 5.0	3
MSA-HARKIV	25	8.6 ± 5.6	6.4 ± 2.9	7
NORTON 4530	23	5.4 ± 2.3	15.5 ± 3.6	5
SAFE EAR	15	7.8 ± 3.3	15.3 ± 2.7	4

Table 6. Hearing Protector Results for Pneumatic Drill Operators (N=104)

HPD MODEL	NRR	NR$_A$ ± SD	(C-A) ± SD	# TESTS
ALLSAFE la20	20	17.4 ± 6.3	4.8 ± 7.7	5
ALLSAFE 2023	20	19.0 ± 4.0	2.5.± 2.2	2
AM. OPTICAL 1275	18	15.9 ± 7.4	3.4 ± 2.0	9
AM. OPTICAL 1720	18	22.2 ± 2.5	3.1 ± 1.9	IO
BILSOM VIKING	28	23.7 ± 4.1	3.8 ± 2.3	21
EAR-3000	27	18.9 ± 6.3	4.2 ± 2.0	11
GLENDALE OPTICAL	24	18.7 ± 0.9	2.0 ± 1.1	3
MSA-MARKIV	25	17.1 ± 7.2	3.2 ± 2.0	25
NORTON 4530	23	14.4 ± 6.7	6.3 ± 9.0	5
TASCO	23	20.3 ± 5.3	5.0 ± 2.7	11
UILSON 155	20	7.0 ± 3.0	2.2 ± 1.3	2

Table 7. Hearing Protector Results for Dredge Operators (N=Z)

HPD MODEL	NRR	NR$_A$ ± SD	(C-A) ± SD	# TESTS
MSA-MARKIV	25	17.0 ± 1.0	9.8 ± 1.0	2

Table 8. Hearing Protector Results for Grader Operators (N=16)

HPD MODEL	NRR	NR$_A$ ± SD	(C-A) ± SD	# TESTS
DAVID CLARK 310	24	6.6 ± 1.1	13.2 ± 1.1	8
MSA-MARKIV	25	9.1 ± 1.7	12.4 ± 1.0	8

APPENDIX A

Table 9. Hearing Protector Results for Panel/Tipple Operators (N=143)

HPD MODEL	NRR	NR_A ± SD	(C-A) ± SD	# TESTS
BILSOM VIKING	28	19.7 ± 2.9	6.4 ± 2.1	28
DAVID CLARK 310	20	22.7 ± 1.6	2.9 ± 0.1	8
DAVID CLARK 805V	23	24.0 ± 1.4	3.0 ± 0.5	7
EAR-1000	21	17.4 ± 1.6	8.6 ± 1.2	14
EAR-3000	27	11.7 ± 4.7	4.0 ± 2.3	14
MSA-500	18	20.9 ± 1.6	3.2 ± 0.7	8
MSA-HARKIV	24	22.8 ± 2.3	2.9 ± 0.4	8
UILSON 365	23	14.2 ± 3.5	7.2 ± 2.4	28
WILSON 381	19	17.1 ± 3.6	5.6 ± 1.7	28

Table 10. Hearing Protector Results for Mucker Operators (N=38)

HPD MODEL	NRR	NR_A ± SD	(C-A) ± SD	# TESTS
ALLSAFE 1820	20	19.7 ± 0.5	1.1 ± 1.1	3
AM. OPTICAL 1720	18	19.7 ± 5.3	1.1 ± 1.1	3
EAR-3000	27	21.3 ± 6.6	1.1 ± 1.1	3
FLENTS-SE	24	18.1 ± 3.4	2.1 ± 1.2	7
MSA-MARKIV	25	18.2 ± 2.7	0.6 ± 1.4	6
NORTON 4530	23	8.9 ± 4.0	0.9 ± 0.8	7
TASCO	23	16.5 ± 3.5	0.4 ± 0.6	2
UILSON 155	20	9.4 ± 2.2	2.4 ± 1.5	7

Table 11. Hearing Protector Results for Rotary Drill Operators (N=27)

HPD MODEL	NRR	NR_A ± SD	(C-A) ± SD	# TESTS
ALLSAFE 1820	20	12.8 ± 3.3	11.3 ± 3.5	4
AM. OPTICAL 1720	la	5.0 ± 2.0	a.9 ± 7.9	2
EAR-3000	27	13.0 ± 3.7	10.7 ± 4.5	4
FLENTS 085	16	9.8 ± 3.0	11.4 ± 5.3	4
FLENTS-SE	24	10.8 ± 1.5	10.8 ± 4.5	4
GLENDALE OPTICAL	24	11.8 ± 6.0	9.4 ± 5.4	5
SAFE EAR	15	4.8 ± 1.1	11.3 ± 3.4	4

Table 12. Hearing Protector Results for Power Shovel Operators (N=17)

HPD MODEL	NRR	NR_A ± SD	(C-A) ± SD	# TESTS
ALLSAFE 1820	20	7.0 ± 4.1	11.1 ± 4.1	3
AM. OPTICAL 1720	18	9.5 ± 3.5	4.3 ± 2.7	2
BILSOM VIKING	28	14.5 ± 2.1	11.7 ± 5.1	4
EAR-3000	27	12.0 ± 8.5	6.5 ± 2.7	4
SAFE EAR	15	10.5 ± 1.5	5.5 ± 0.7	2
TASCO	23	10.0 ± 0.0	16.6 ± 1.3	2

Table 13. Hearing Protector Results for Dragline Oilers (N=25)

HPD MODEL	NRR	NR_A ± SD	(C-A) ± SD	# TESTS
BILSOM UF-2	22	17.9 ± 1.5	1.4 ± 0.2	9
BILSON VIKING	29	29.1 ± 1.1	1.5 ± 0.0	4
DAVID CLARK 310	24	27.9 ± 0.4	1.9 ± 0.2	4
EAR-3000	26	25.4 ± 1.2	0.9 ± 0.2	4
GLENDALE 900	23	22.2 ± 2.5	1.4 ± 0.3	4

Table 14. Hearing Protector Results for Scaler Operators (N=11)

HPD MODEL	NRR	NR_A ± SD	(C-A) ± SD	# TESTS
AM. OPTICAL 1275	18	10.8 ± 7.0	1.4 ± 0.3	4
AM. OPTICAL 1720	18	22.0 ± 1.0	0.6 ± 0.4	2
BILSOM VIKING	28	19.0 ± 6.4	0.9 ± 0.4	3
MSA-MARKIV	25	8.0 ± 3.0	2.5 ± 0.9	2

Table 15. Hearing Protector Results for Scraper Operators (N=8)

HPD MODEL	NRR	NR_A ± SD	(C-A) ± SD	# TESTS
AM. OPTICAL 1720	18	11.5 ± 0.5	5.7 ± 1.4	2
EAR-3000	27	19.5 ± 2.5	5.6 ± 1.4	2
NORTON 4530	23	11.5 ± 2.5	5.5 ± 1.2	2
SAFE EAR	15	13.0 ± 1.0	5.7 ± 1.4	2

Table 16. Hearing Protector Results for Face Drill Operators (N=14)

HPD MODEL	NRR	NR_A ± SD	(C-A) ± SD	# TESTS
BILSOM UF-2	22	15.9 ± 2.9	4.2 ± 2.0	14
EAR-1000	24	21.0 ± 1.7	2.1 ± 1.1	17
GLENDALE 900	23	23.8 ± 2.3	2.1 ± 1.1	12

Table 17. Hearing Protector Results for Drasline Operators (N=24)

HPD MODEL	NRR	NR_A ± SD	(C-A) ± SD	# TESTS
BILSOM UF-2	22	6.2 ± 1.4	13.1 ± 0.7	8
EAR-3000	26	17.4 ± 0.9	12.6 ± 0.9	8
WILSON 365A	26	19.8 ± 2.2	12.3 ± 1.5	8

Table 18. Hearing Protector Results for Drill Helpers (N=14)

HPD MODEL	NRR	NR_A ± SD	(C-A) ± SD	# TESTS
DAVID CLARK 805V	23	12.7 ± 2.2	5.4 ± 1.5	8
EAR-1000	21	7.3 ± 2.0	4.9 ± 1.2	7
WILSON 365	23	16.4 ± 2.1	4.0 ± 1.3	9

Table 19. Hearing Protector Results for Load Haul Dump Operators (N=21)

HPD MODEL	NPR	NR_A ± SD	(C-A) ± SD	# TESTS
BILSOM VIKING	29	19.9 ± 0.9	12.0 ± 1.4	5
EAR-3000	26	11.8 ± 0.8	11.4 ± 0.6	7
WILSON 365	25	10.8 ± 0.7	11.0 ± 0.6	9

Table 20. Hearing Protector Results for Exhaust Fan Exposure (N=16)

HPD MODEL	NRR	NR_A ± SD	(C-A) ± SD	# TESTS
AM. OPTICAL 1275	18	15.0 ± 0.8	5.4 ± 3.0	3
BILSOM VIKING	28	23.3 ± 1.8	1.4 ± 0.6	10
MSA-MARKIV	25	16.3 ± 6.2	4.6 ± 2.5	3

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