Four Earplugs in Search of a Rating System

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Objective: **The performance of four insert earplugs was evaluated by determining the Noise Reduction Rating (NRR) and the Subject-Fit Noise Reduction Rating [NRR(SF)]. The NRR and NRR(SF) were calculated from real-ear attenuation at threshold (REAT) data collected using the experimenter-fit protocol described in the now-rescinded ANSI S3.19-1974 (American National Standards Institute, 1974) and the subject-fit protocol of the recently revised ANSI S12.6-1997 (American National Standards Institute, 1997) standards for REAT measurement.**

Design: **A comparison of the experimenter-fit and subject-fit REAT performance was conducted using four pools of subjects, one pool per protector. Each device was tested with at least 20 subjects, the minimum size necessary to estimate the NRR(SF) for an earplug. The REAT was measured with third-octave narrowband noise stimuli for center frequencies at 0.125, 0.25, 0.5, 1, 2, 3.15, 4, 6.3, and 8 kHz. The REAT means and standard deviations were compared with the manufacturer data.**

Results: **This study showed that the NRR(SF) is typically lower than the NRR and that the NRR(SF) is not well-predicted by the NRR derating schemes recommended by the National Institute for Occupational Safety and Health and required by the Occupational Safety and Health Administration.**

Conclusion: **The difference between the present NRR on hearing protector labels and the NRR(SF) is sufficiently large and unpredictable enough to render the application of derating schemes meaningless even though these schemes attempt to account for the difference between the laboratory and real-world outcomes. The only way to provide a protector noise rating that is predictive of a real-world outcome is to retest the protector according to the subject-fit method of ANSI S12.6-1997 (American National Standards Institute, 1997).**

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The Noise Reduction Rating (NRR) is required for on the label of every hearing protector sold in the United States (U.S. Environmental Protection Agency, 40 CFR Part 211[b]). The NRR is used to estimate the protected noise exposure level for workers wearing a hearing protection device (HPD) according to the manufacturer's instructions. The NRR is calculated from the real-ear attenuation at threshold (REAT) mean minus two standard deviations at each frequency across subjects tested measured with the experimenter-fit (EF) protocol described in the now-rescinded standard ANSI S3.19-1974* (American National Standards Institute, 1974). The testing procedure requires a laboratory with a reverberant sound field meeting a ANSI S3.19 set of specifications. Work-site studies find workers using HPDs achieve between 5 and 95% of the manufacturer's NRR depending on the protector (Berger, Franks, & Lindgren, 1996). To bridge this gap, the Occupational Safety and Health Administration (OSHA) inspectors are instructed to derate the NRR by 50% (Occupational Safety and Health Administration, 1999) when evaluating use of HPDs in lieu of noise control. The National Institute for Occupational Safety and Health (NIOSH) recommends the NRR be derated by 25% for earmuffs, 50% for slow-recovery foam earplugs, and 70% for all other earplugs and semi-insert devices (National Institute for Occupational Safety and Health , 1998). Although OSHA inspectors typically use the OSHA derating, may they also use the Subject-Fit Noise Reduction Rating [NRR(SF)] if the hearing protector manufacturer has published the subject-fit (SF) data.

After two rounds of inter-laboratory testing over a 10-yr period, the American National Standards Institute working group S12/WG11 developed a standard method for measuring the REAT for a protector that utilizes an SF protocol. This method appears to better predict the real-world outcomes (Berger et al.,

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*The U.S. Environmental Protection Agency's hearing protector labeling rule requires use of the ANSI S3.19-1974 (American National Standards Institute, 1974) experimenter-fit method even though the standard has been rescinded by The American National Standards Institute. The rule cannot accommodate changes in American National Standards Institute standards unless the entire rule-making process is reopened. Thus, manufacturers must test products according to the older standard and label products accordingly or face citations from the Environmental Protection Agency for failure comply with the labeling requirements. However, manufacturers are not restricted from providing secondary labels that reflect newer methods for specifying hearing protection performance.

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1998). The current ANSI S12.6–1997 (American National Standards Institute, 1997) standard defines two protocols, an experimenter-supervised fit and an SF protocol, Methods A and B, respectively. The protocols have been tested against one another in an inter-laboratory study (Royster et al., 1996). Method A yielded greater attenuation but more variability between laboratories. Method B yielded better inter-laboratory agreement, but lower attenuations and greater inter-subject variability.

In 1994, the National Hearing Conservation Association (NHCA) formed the Hearing Protector Task Force, which was charged with developing a revision of the NRR calculation that could be applied to SF data. In 1996, the task force presented its recommendation for an NRR(SF). The NRR(SF) differs slightly from the NRR in that it uses the mean attenuation minus one standard deviation for the assumed protection value. The NRR(SF) is also meant to be directly applied to A-weighted sound pressure levels whereas the NRR must be adjusted for the C-A weighted difference (Royster, 1995).

The current study was undertaken to compare EF and SF REATs within subjects. Four protectors were tested, each with EF and SF methodologies, on a pool of at least 20 subjects. The magnitude and variance of the REAT averages by frequency, protocol and protector were examined to understand the effect on the NRR and NRR(SF) ratings. Lastly, because the details of the NRR(SF) method are not widely available, a detailed description and example are included as an Appendix to this paper.

METHODS

Description of HPDs

Four devices were tested because of their widespread use in the military and civilian sectors. The E·A·R® Classic Foam Earplug (Classic) is a disposable yellow, cylinder-shaped, slow-recovery vinyl foam, one-size earplug with an NRR of 29 dB (Fig. 1a). The Bilsom Quietzone Earplug (Quietzone) is a premolded, reusable, soft polymer, single-flange earplug that comes in five sizes with an NRR of 24 dB (Fig. 1b). The Quietzone earplugs were fit without a seating device that the military provides to soldiers. The Howard Leight MAX-1™ (Max) is a single-size, disposable, orange preshaped urethane foam earplug featuring a smooth outer skin with an NRR of 33 dB (Fig. 1c). The E·A·R® Express™ Pod Plug™ (Express) is a single-size, disposable, yellow hemispherical shell of vinyl foam attached to a flexible plastic stem with an NRR of 25 dB (Fig. 1d).

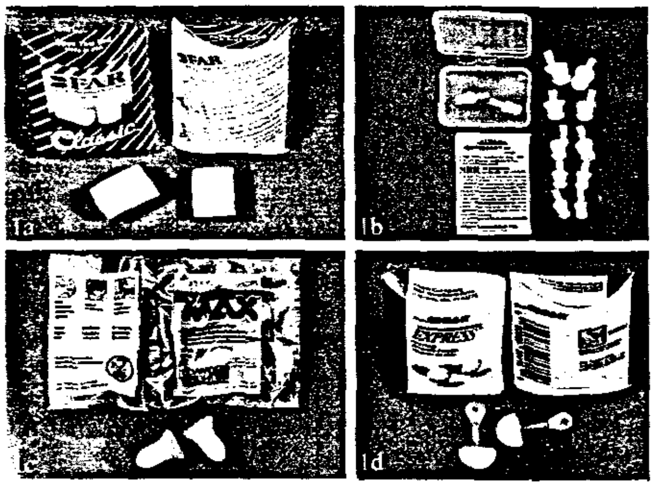

Figure 1. The hearing protectors tested by subject- and experimenter-fit methods. a) The E·A·R® Classic Foam Earplug (Classic); b) The Bilsom Quietzone Earplug; c) The Howard Leight MAX-1™ (Max); and d) The E·A·R® Express™ Pod Plug™ (Express).

Subject Recruiting and Audiometric Qualification

Subjects were recruited from local universities, temporary employment agencies, and newspaper advertisements and were interviewed to assess their naive status as HPD users, a qualification for SF testing. Subjects were disqualified if:

1. They had received personal instruction in the use of HPDs.
2. They had worn HPDs to reduce noise exposure in a job setting.
3. They had worn earplugs more than two times in the past month or more than five times in the past year (including use for sleeping or swimming).
4. They were aware of an existing hearing loss.

At the time of the first laboratory visit, subjects had to demonstrate the ability to read and understand the manufacturer's fitting instructions. Subjects were required to have hearing sensitivity of ≤25 dB HTL re ANSI S3.6–1996 (American National Standards Institute, 1996) for the octave test frequencies from 125 to 8000 Hz, including 3000 and 6000 Hz. They had to have normal tympanograms (MEP −100 to +50 daPa, compliance 0.3 to 1.3 ml). Lastly, subjects had to perform three to five unoccluded training sound field audiograms and achieve a 6-dB range of thresholds for each test frequency for three consecutive audiograms.

Room Description and Electronics

All testing was conducted at the NIOSH Hearing Protector Laboratory inside a Tracoustics RE-245 double-wall, double-floor test booth with interior panel surfaces of 16-gauge steel to provide reflectivity instead of the fiberglass backed perforated steel typically found in audiometric rooms. Three loudspeaker panels were orthogonally positioned in the chamber to produce a diffuse sound field environment re ANSI S12.6–1997 (American National Standards Institute, 1997). The critical volume in the center of the room had a radius of 300 mm wherein sound levels varied less than 1 dB across the frequency range 100 to 10000 Hz. The critical volume was large enough to maintain a subject's head within the volume without reliance on head rests, bite bars, or plumb-bobs that could disrupt the diffusivity of the sound field.

The test signal was a train of three 200 msec third-octave noise bursts with 50% duty cycle. Across listening trials, unoccluded and occluded hearing thresholds were measured to the nearest 1 dB with a modified Hughson-Westlake method (Carhart and Jerger, 1959) for nine center frequencies: 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz. Test equipment was controlled by the Automated Sound Field Threshold Testing system (Franks, Engel, & Themann, 1992).

Subject-Fit (Method B)

According to ANSI S12.6–1997 Method B (American National Standards Institute, 1997), no assistance, intervention, critique, or comment by the experimenter was permitted when subjects fit their HPDs. Subjects were provided with the manufacturers' instructions for fitting the devices and informed that the experimenter was not allowed to assist them. Subjects selected a new pair of earplugs for each earplug fitting when testing the Express, the Classic, and the Max. When testing the Quietzone, they were allowed to reselect the size of earplug for each ear before each test. ANSI S12.6–1997 (American National Standards Institute, 1997) requires that 20 subjects be tested twice at the octave frequencies from 125 to 8000 Hz to yield two estimates of the REAT.

Experimenter-Fit

In ANSI S3.19–1974 (American National Standards Institute, 1974), the experimenter fits the HPD for each occluded test; the subject does not adjust the protector. EF earplugs are typically more deeply inserted than SF earplugs. For this study, experimenters inserted the earplugs to achieve maximum attenuation while avoiding undue discomfort for the subjects. ANSI S3.19–1974 (American National Standards Institute, 1974) requires 10 subjects be tested three times at octave band frequencies to yield three estimates of the REAT.

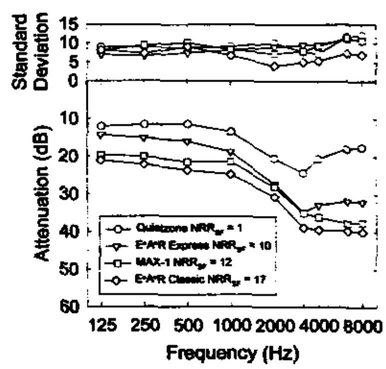

Figure 2. Means, standard deviations, and Subject-Fit Noise Reduction Ratings [NRR(SF)s]: subject-fit real-ear attenuations at threshold for the Classic, Quietzone, Max, and Express earplugs.

RESULTS

The data were collected from three studies conducted at NIOSH during the period 1994 to 1998. The first study was conducted in parallel at NIOSH and at the Auditory Systems Laboratory at Virginia Tech University to assess inter-laboratory variability. The Classic and Quietzone were tested with the EF and SF protocols. The second and third studies were conducted at NIOSH for the Max and Express devices. Only data collected at NIOSH are reported here.

Data Used

Twenty-five subjects were tested for the Classic, Quietzone, and Max earplugs. Twenty subjects were tested for the Express device. To make the sample sizes the same, the first 10 men and 10 women were used for determining the SF and EF REAT means and standard deviations. Using the EF data, an exhaustive computerized search of all possible permutations of 10 subjects' data was performed to determine the highest possible NRR rating for the NIOSH subject pool for a given HPD. Because the NRR increases with higher mean REATs and smaller standard deviations, the highest experimenter fit (HEF) subset should be representative of a highly screened and well-matched population.

Comparison of SF REAT and NRR(SF) for Four Insert-Type Protectors

Figure 2 displays the average SF REATs, standard deviations of the REATs and NRR(SF)s for the Classic, Quietzone, Max, and Express earplugs at each frequency (see Table 1 as well). The Classic has the highest NRR(SF) of 17 dB, followed by the Max (12 dB), the Express (10 dB), and the Quietzone (1 dB). The rank order of the NRR(SF) rating is the

TABLE 1. Mean real-ear attenuations at threshold in dB and standard deviations for the data sets, along with the Noise Reduction Rating (NRR) calculated according to the test method.

Protector	Fit	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	3150 Hz	4000 Hz	6300 Hz	8000 Hz	NRR(SF)	NRR
Classic	SF	22.0 ± 8.4	23.2 ± 7.4	24.4 ± 9.5	25.0 ± 6.7	31.6 ± 4.4	39.7 ± 3.9	40.1 ± 5.2	40.2 ± 6.6	39.7 ± 6.9	17	
	EF	33.6 ± 6.6	37.4 ± 6.9	39.5 ± 6.0	37.6 ± 5.6	35.3 ± 3.4	42.8 ± 3.2	43.6 ± 3.0	44.1 ± 4.0	46.0 ± 5.0		27
	HEF	36.4 ± 6.3	40.9 ± 4.3	43.7 ± 3.4	41.2 ± 3.3	37.7 ± 2.8	43.5 ± 2.8	43.4 ± 3.4	44.7 ± 3.5	46.8 ± 4.7		32
	MD	37.4 ± 5.7	40.9 ± 5.0	44.8 ± 3.3	43.8 ± 3.6	36.3 ± 4.9	41.9 ± 3.0	42.6 ± 3.1	46.1 ± 3.5	47.3 ± 2.7		29
Quietzone	SF	12.0 ± 9.9	10.7 ± 9.2	9.6 ± 9.0	12.2 ± 9.8	19.6 ± 10.9	23.0 ± 8.2	19.3 ± 8.4	16.5 ± 11.5	16.7 ± 12.5	1	
	EF	17.8 ± 10.2	18.3 ± 9.8	18.1 ± 10.1	20.9 ± 9.1	27.5 ± 7.2	29.1 ± 6.5	26.7 ± 7.1	26.9 ± 10.5	27.2 ± 13.3		2
	HEF	24.8 ± 4.3	25.7 ± 2.9	25.0 ± 4.5	27.6 ± 3.0	31.8 ± 4.6	33.5 ± 3.4	31.5 ± 5.2	33.4 ± 7.6	36.5 ± 5.7		19
	MD	20.4 ± 2.2	23.2 ± 2.2	25.4 ± 2.3	29.0 ± 1.8	34.9 ± 2.0	37.6 ± 2.5	38.6 ± 3.3	38.2 ± 3.3	38.7 ± 2.8		24
Max	SF	19.7 ± 8.7	19.7 ± 9.7	20.7 ± 9.4	21.2 ± 8.4	28.3 ± 7.4	34.7 ± 7.3	36.6 ± 9.1	37.5 ± 11.0	37.8 ± 10.4	12	
	EF	29.0 ± 9.0	30.2 ± 9.77	33.2 ± 9.2	30.8 ± 8.5	31.6 ± 6.0	40.2 ± 6.2	42.5 ± 6.8	42.7 ± 8.1	43.0 ± 8.6		16
	HEF	36.9 ± 4.9	38.6 ± 5.2	43.0 ± 4.6	38.6 ± 5.3	36.6 ± 3.7	43.2 ± 4.8	45.9 ± 4.0	47.2 ± 3.9	47.0 ± 3.9		29
	MD	33.1 ± 2.7	36.3 ± 1.8	36.8 ± 2.1	38.4 ± 1.7	38.7 ± 2.1	44.1 ± 2.3	45.9 ± 2.2	45.4 ± 2.2	46.0 ± 2.4		33
Express	SF	14.3 ± 6.9	15.2 ± 6.7	16.0 ± 7.4	18.8 ± 8.2	27.3 ± 9.1	34.8 ± 9.5	33.0 ± 9.6	31.8 ± 11.2	32.1 ± 10.7	10	
	EF	16.5 ± 5.1	19.0 ± 3.7	20.0 ± 4.8	23.1 ± 3.9	30.6 ± 3.7	36.2 ± 3.9	35.2 ± 3.7	37.4 ± 3.9	37.1 ± 3.4		15
	HEF	17.1 ± 3.1	19.9 ± 2.3	21.3 ± 2.8	24.6 ± 2.9	30.0 ± 3.4	35.9 ± 3.9	35.0 ± 4.0	38.0 ± 3.9	38.6 ± 2.4		19
	MD	31.6 ± 4.3	32.1 ± 4.6	32.2 ± 4.8	36.9 ± 4.0	35.7 ± 3.3	37.0 ± 3.3	35.7 ± 4.2	38.7 ± 5.1	40.5 ± 3.4		25

The different fits were subject-fit (SF), experimenter-fit (EF), highest experimenter fit (HEF), and manufacturer's published data (MD). The HEF data represent a group of 10 subjects whose standard deviations and attenuations yielded the maximum NRR for a given protector.
NRR(SF) = Subject-Fit Noise Reduction Rating.

same as the rank order of the average SF REAT at all frequencies except at 3150 Hz where the attenuation of the MAX was 34.7 and the Express was 34.8 dB. Because the standard deviations were similar across frequencies and devices, the rank order of the average attenuations determined the final order of the NRR(SF) ratings.

Comparison of EF REATs and NRRs for Four Insert-Type Protectors

Figure 3 displays the EF, HEF, and published manufacturers' data for the four insert earplugs examined in this paper. The E·A·R Classic REATs, standard deviations, and resulting NRRs were consistent across the EF, HEF, and manufacturer groups. The labeled NRR of 29 dB was a good descriptor of the product when tested according to EF procedures (EF = 27 dB). The differences between the HEF and manufacturer groups were negligible. However, the NRR for the HEF group is 32 dB compared with the manufacturer's rating of 29 dB.

The Quietzone REATs and standard deviations were not consistent across the EF, HEF, and manufacturer's data. The EF group had the lowest REATs and largest standard deviations, which yielded an NRR of 2 dB. The HEF group had smaller REATs and larger standard deviations than the manufacturer's data. Consequently, the HEF group yielded an NRR of 19 dB, less than the manufacturer's labeled value of 24 dB.

Like the Quietzone, the Max's data were inconsistent across groups. The EF group had the smallest REATs and largest standard deviations, which yielded an NRR of 16 dB. Although the REATs for

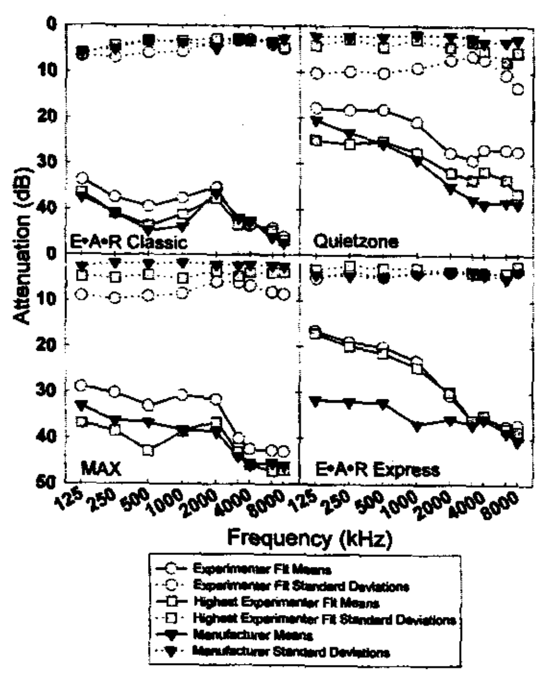

Figure 3. Means, standard deviations, and Noise Reduction Ratings for experimenter-fit, highest experimenter fit, and manufacturer groups. The white circles, gray squares, and black triangles represent the EF, HEF, and manufacturer groups, respectively. The mean attenuations are shown with solid lines, and the standard deviations are indicated with dotted lines.

TABLE 2. Estimates of the effective A-weighted noise levels (ENLs) for a worker exposed to 97 dBA while wearing different earplugs using the Noise Reduction Rating (NRR) and Subject-Fit Noise Reduction Rating [NRR(SF)].

HPD Method	NRR or NRR(SF)	Derating Factor	Derated NRR	ENL dBA
Classic				
OSHA	29	1–0.5	11	86
NIOSH	29	1–0.5	8	89
NHCA	17 NRR(SF)	NA	NA	80
MAX				
OSHA	33	1–0.5	13	84
NIOSH	33	1–0.7	3	94
NHCA	12 NRR(SF)	NA	NA	85
Quietzone				
OSHA	24	1–0.5	9	88
NIOSH	24	1–0.7	0	97
NHCA	1 NRR(SF)	NA	NA	96
Pod				
OSHA	25	1–0.5	9	88
NIOSH	25	1–0.5	6	91
NHCA	10 NRR(SF)	NA	NA	87

HPD = hearing protection device; OSHA = Occupational Safety and Health Administration; NIOSH = National Institute for Occupational Safety and Health; NHCA = National Hearing Conservation Association.

the HEF group were similar to or greater than the labeled data, the small standard deviations of the manufacturer's data resulted in a labeled NRR of 33 dB versus the HEF NRR of 29 dB.

The Express data exhibited a pattern that was substantially different from the other three devices. The EF and HEF data had nearly identical REATs, but the manufacturer REATs were considerably larger at the low frequencies. The standard deviations across the different groups were comparable. The EF NRR was 15 dB, the HEF NRR was 19 dB, and the manufacturer's NRR was 25 dB.

Comparison of Labeled NRR with NRR(SF)

Table 2 shows a comparison of HPD performance under EF and SF conditions. Means and standard deviations of the REATs are given for each subject panel along with the manufacturer's data for each protector. Without exception, the labeled NRRs are greater than the NRR(SF)s. The differences between the manufacturer's label and the NRR(SF) are 12, 23, 21, and 15 dB for the Classic, Quietzone, Max, and Express, respectively.

Discussion

This study compared the attenuations achieved by EF and SF protocols. The data demonstrated that the manufacturers' REATs were typically greater than the 20-subject EF groups. When the EF groups were culled to find the HEF NRR, the mean attenuations approximated but remained less than the manufacturers' data except for the Express earplug. The standard deviations for the manufacturers' data for the MAX and the Quietzone were considerably smaller than the NIOSH data and contributed to the disparity between EF, HEF, and manufacturer NRR ratings.

The attenuations measured with an SF protocol exhibited lower mean attenuations and larger standard deviation than the EF protocol. SF data for the Quietzone and the Classic earplugs were comparable with the larger attenuations from real-world studies examined by Berger et al. 1998. In the absence of real-world studies for the Express and Max earplugs, no comparison can be made to the SF data for those devices. However, given the experience with the other devices with real-world data, the SF data for the Pod and Max earplugs should be predictive of future real-world studies that find larger attenuations.

Relating real-world performance to the NRR label is probably the most critical issue for hearing protector evaluation. One aspect of the problem is knowing what error can be assigned to the NRR rating. The Environmental Protection Agency's regulation for determining the NRR utilizes the mean minus two standard deviations to estimate an assumed protection value for each octave band. The log sum that is performed across bands does not define an error term for the NRR. The regulation stipulates that manufacturers will test 10 subjects according to the ANSI S3.19–1974 (American National Standards Institute, 1974) standard for REAT measurement. However, no provision is made for subject selection to ensure that it is representative of normal, untrained listeners and, in fact, testing laboratories rely on experienced panels of listeners when testing HPDs for rating purposes. Consequently, a high NRR reflects subject panels selected to maximize the mean attenuations and minimize the standard deviations.

EF NRRs versus Labeled NRRs

The NRRs for the Classic earplug were comparable across all of the test groups. The attenuations for the EF were slightly less than the other two groups and had slightly larger standard deviations at 250, 500, and 1000 Hz. The differences between the manufacturer's data and the HEF group were evident at only a few frequencies. However, the NRR for the HEF was 3 dB more than the manufacturer rating of 29 dB owing to smaller standard deviations of the REATs for the HEF group.

The data for the Quietzone exhibited considerable variation across groups. The EF group had the largest standard deviations and the smallest attenuations. In spite of the earplugs being fit by competent experimenters, the means minus two standard deviations were negative for the EF group at 125, 250, and 500 Hz. Although the HEF group achieved attenuations comparable with the manufacturer's data, the standard deviations were larger than the manufacturer's values. The small standard deviations achieved by the manufacturer and the higher mean attenuations above 2000 Hz contributed to the high NRR of 24 dB for the Quietzone.

The data for the Max earplug exhibited trends similar to the Quietzone earplug. The EF attenuations were all less than the other two groups, whereas the standard deviations were larger. Similar to the Quietzone, the HEF mean attenuations were greater than the manufacturer's data for frequencies below 1000 Hz, but the larger standard deviations still resulted in a lower NRR. The manufacturer's standard deviations were the smallest at all frequencies. The 16 dB NRR for the EF group was 17 dB less than the published value of 33 dB.

The data for the Express were interesting in that there was very little difference between the EF and HEF groups. The HEF standard deviations were less than the EF, which resulted in a slightly greater NRR for the HEF group. The manufacturer's low-frequency mean attenuations were considerably larger than either the EF or HEF groups. The E·A·R/Aearo experimenters inserted the protector about 2 mm deeper than NIOSH investigators (Reference Note 1).

Estimation of Exposure level with NRR and NRR(SF)

The NRR and NRR(SF) were designed to be subtracted from the noise exposure level to estimate the protected exposure level. Owing to the discrepancy of the laboratory NRR with the real-world data, both OSHA and NIOSH have recommended derating strategies. The OSHA Technical Manual (OTM) (Occupational Safety and Health Administration, 1999) applies a derating factor of 0.5 to the NRR for all HPDs when HPDs are being considered in lieu of noise control. NIOSH recommends derating factors of 0.25 for earmuffs, 0.50 for slow-recovery foam earplugs and 0.75 for all other earplugs. If the noise exposure level is measured in dBC, the effective A-weighted noise level (ENL) is

$$\text{ENL} = \text{dBC} - ((1 - \text{derating}) \times \text{NRR}).$$

If the noise exposure level is measured in dBA, the OSHA method is

$$\text{ENL} = \text{dBA} - [(1 - \text{derating}) \times (\text{NRR} - 7)],$$

and the NIOSH method is

$$\text{ENL} = \text{dBA} - [((1 - \text{derating}) \times (\text{NRR})) - 7].$$

The 7-dB adjustment for A-weighted noises represents the C-A weighted difference reported by Johnson and Nixon (1978). The OSHA method incorrectly derates the 7 dB by 50%, whereas the NIOSH method retains the full correction and derates only the NRR.

The Hearing Protector Task Force of the NHCA recommends using the NRR(SF) to determine the ENL (Royster, 1995) as follows,

$$\text{ENL} = \text{dBA} - \text{NRR(SF)}$$

for A-weighted exposure levels and

$$\text{ENL} = \text{dBC} - \text{NRR(SF)} + 5$$

for C-weighted exposure levels.

Consider the case of a worker with an 8-hr time-weighted average noise exposure of 97 dBA. Table 1 reports the effective A-weighted exposure levels for each of the HPDs presented in this paper using the OSHA, NIOSH, and NHCA methods with the manufacturer's NRR and the NRR(SF). The NIOSH and OSHA derating methods differ by as least 9 dB for the MAX and Quietzone earplugs. According to the NRR(SF), both the Max and Classic would provide sufficient protection against the 97 dBA noise, and the Pod would be adequate for a lower noise exposure. Berger et al. (1998) demonstrated that the SF REAT data were more representative of real-world data, which suggests the NRR(SF) may give a better estimate of the ENL.

The inability of this study to replicate the manufacturers' NRRs for three of the four products tested suggests NRRs themselves may be dishonest. The present system encourages manufactures to obtain data for experienced listener panels who are known to obtain high attenuations and to be very consistent from fitting to fitting. Thus, it is not surprising that these same NRRs when derated by either an OSHA or NIOSH scheme can not be made predictive of real-world outcomes.

CONCLUSIONS

This study that tested HPDs by both the EF and SF methods using the same subject panels for a given protector and found no consistent ordering of the NRRs and NRR(SF)s. This finding is consistent with Berger et al. (1996) who found no consistent rank order correlation between the real-world NRRs and labeled NRRs for earmuff and earplugs. Similarly, Berger et al. (1998) found no consistent ordering for the EF and SF results for three different earplugs when the devices were tested with separate subject panels. Thus, applying an across-the-board derating value as the OSHA OTM requires or a derating value based on protector type as NIOSH recommends will not effectively resolve the differences between the current NRR labeled protection and the protection that workers are likely to receive. One consequence of this inability to successfully apply a derating scheme for the labeled NRRs is the inability to predict the NRR(SF) of hearing protector based on the labeled NRR.

With the NRR(SF), the procedure to predict protected noise exposure level is very simple: subtract the NRR(SF) from the noise exposure level in dBA to calculate the protected noise exposure level in dBA. For this simple procedure to be used, it will be necessary for every HPD sold in the United States to be tested by the SF method of ANSI S12.6–1997 (American National Standards Institute, 1997). The NHCA document on the NRR(SF) provides recommendations for a secondary label to accompany the Environmental Protection Agency's label. So waiting for the Environmental Protection Agency to modify the HPD labeling rule may be unnecessary—the NRR(SF) is ready for use. As well, both NIOSH and OSHA recognize the NRR(SF) as the preferred method for evaluating the effectiveness of HPDs.

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ersonal communication with Mr. Elliott Berger at EAR/ earo revealed the differences between the insertion depth :iterion between the NIOSH Hearing Protector Laboratory nd EARCal. Mr. Berger indicated that the protector should e positioned so that the trailing edge of the foam portion of ıe protector is 2 mm beyond the floor of the concha. NIOSH ıvestigators positioned the protector so that it was flush ith the floor of the concha. For a subsequent EF panel ested to replicate the insertion depth that Mr. Berger escribed, the NRR of 19 dB matched the earlier NIOSH anel.

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›pendix A

ılculation of the NRR(SF) • The NRR(SF) is a ıgle-number rating method that describes REAT easurements for the ANSI S12.6–1997 Method B merican National Standards Institute, 1997). The RR(SF) was developed by the National Hearing nservation Association's Task Force on Hearing otector Effectiveness to address labeling related ues (Royster, 1995). The NRR(SF) calculation ethod is derived from the Single Number Rating NR) method for a protection performance of 84% ıternational Organization for Standardization, 92). In principle, the rating methods examine the ıount of noise reduction achieved by a hearing otector, but minor differences separate the meths. Like the NRR, the NRR(SF) uses a pink noise at level of 100 dB SPL in the octave bands. Like the IR, the NRR(SF) includes the octave band freıencies between 63 and 8000 Hz in its calculation ıereas the NRR includes only frequencies between 5 and 8000 Hz and includes the half-octave freıencies 3150 and 6300 Hz.

The NRR(SF) is calculated with the following equation:

$$NRR_{SF} = 10\mathrm{Log}_{10} \sum_{f=63}^{8000} 10^{0.1 L_{Cf}} - 10\mathrm{Log}_{10} \sum_{f=63}^{8000} 10^{0.1(L_{Af}-APV_{f84})} - 5\mathrm{dB}, \quad \text{(A1)}$$

$$= 108.5 - 10\mathrm{Log}_{10} \sum_{f=63}^{8000} 10^{0.1(L_{Af}-APV_{f84})} - 5\mathrm{dB},$$

where L_{Cf} are the C-weighted noise levels, L_{Af} are the A-weighted unprotected noise levels, and APV_{f84} are the assumed protection values for 84% performance.

The C-weighted noise levels are determined by subtracting the C-weighted corrections from 100 dB for each of the octave band frequencies (see Berger, 1986 for a table of the C and A weighting corrections). The sum of the C-weighted noise levels is 108.5 dBC. Similarly, the L_{Af} are determined by correcting the 100 dB octave band noise levels with the A-weighted corrections at each frequency. The APV_{f84} are determined by subtracting one standard deviation from the mean REAT attenuation measured for the noise band centered at frequency, *f*. The half octave data at 3150 and 6300 Hz are not used in the calculation of the NRR(SF). The 5 dB that is subtracted at the end of the calculation is representative of the approximate difference between C-weighted and A-weighted industrial noise (Miller, Reference Note 2). By compensating for the difference in the calculation, the NRR(SF) may be subtracted directly from A-weighted noise to estimate the noise level under the protector. When data for 63 Hz are lacking, one should use the 125 Hz data in its place and apply the appropriate corrections for that frequency. A pedagogical example for the NRR(SF) is shown in Table A1. These data, measured for the MAX ear plug, represent the SF subject group (first 10 men and first 10 women).

TABLE A1. The Subject-Fit Noise Reduction Rating [NRR(SF)] calculation for the subject-fit group of the MAX.

	Frequency (Hz)								Lc Su
	63	125	250	500	1000	2000	4000	8000	
1. Assumed pink noise (dB)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
2. C-weighted correction (dB)	−0.8	−0.2	0.0	0.0	0.0	−0.2	−0.8	−3.0	
3. Unprotected ear C-weighted level (dB) (Line 1 − Line 2)	99.2	99.8	100.0	100.0	100.0	99.8	99.2	97.0	10(
4. A-weighted correction (dB)	−26.2	−16.1	−8.6	−3.2	0	1.2	1.0	−1.1	
5. Unprotected ear A-weighted level (dB) (Line 1 − Line 4)	73.8	83.9	91.4	96.8	100.0	101.2	101.0	98.9	
6. Average REAT attenuation at each frequency (dB)	19.7	19.7	19.7	20.7	21.2	28.3	36.6	37.8	
7. REAT standard deviation at each frequency (dB)	8.7	8.7	9.7	9.4	8.4	7.4	9.1	10.4	
8. Assumed protection value for 84% performance (dB) (Line 6 − Line 7)	11.0	11.0	10.0	11.3	12.8	20.9	27.5	27.4	
9. Protected ear A-weighted level (dB) (Line 5 − Line 8)	62.8	72.9	81.4	85.5	87.2	80.3	73.5	71.5	9(
10. Log sum of line 3 (dB)	108.5								
11. Log sum of line 9 (dB)	90.7								
12. NRR(SF) (dB) (Line 10 − Line 11 − 5 dB)	12.8								