50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO.
2.
3. PB92-124015

4. Title and Subtitle: Analyses on the E-A-R Foam Earplug for the Dynamic Work Activity Experiment

5. Report Date: 1990/01/01

6.

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8. Performing Organization Rept. No.

9. Performing Organization Name and Address: Department of Industrial Engineering and Operations Research, Virginia Polytechnic Institute and State University, Blacksburg, Virginia

10. Project/Task/Work Unit No.

11. Contract (C) or Grant(G) No.
(C)
(G) R01-OH-02540

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words) A controlled laboratory experiment was conducted to investigate the effects of different levels of subject fit, wearing time, and subject movement activity, on the frequency specific attenuation achieved with particular slow recovery foam earplugs. A psychophysical real ear attenuation at threshold testing procedure was used to collect attenuation data from ten subjects at nine test frequencies. While prior research suggested that attenuation may decrease over time with aural inserts, these compliant inserts were stable in the face of vigorous temporomandibular and highly kinetic bodily activity, thus exhibiting negligible degradation in attenuation over time. Improvements in attenuation provided by trained subject fit versus naive subject fit of the earplugs were large at 1000 hertz (Hz) and below, ranging from gains of 12 to 14 decibels (dB). The gains were smaller, but still statistically at 2000 to 8000Hz, ranging from 3 to 5dB.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms NIOSH-Publication, NIOSH-Grant, Grant-Number-R01-OH-02540, End-Date-08-15-1990, Noise-induced-hearing-loss, Ear-protectors, Personal-protective-equipment, Hearing-impairment, Hearing-protection

c. COSATI Field/Group

18. Availability Statement

19. Security Class (This Report)

20. Security Class (This Page)

21. No. of Pages: 34

22. Price

PB92-124015

Analyses on the E-A-R Foam Earplug for the Dynamic Work Activity Experiment

Audio Lab 10/01/89/9-HP
IEOR Technical Report Number 8905

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Final Version

January 1, 1990

ABSTRACT

Overestimation of hearing protector noise attenuation--as based on laboratory-obtained, manufacturer-supplied data- combined with several in-field factors which often degrade protector performance, poses the threat of underprotection for industrial workers. A controlled laboratory experiment was conducted to investigate the effects of different levels of subject fit, wearing time, and subject movement activity, on the frequency-specific attenuation achieved with particular slow-recovery foam earplugs. Using a psychophysical real-ear-attenuation-at-threshold testing procedure, attenuation data were collected from 10 subjects at nine test frequencies. Statistical analyses of the spectral attenuation data supported several important results. Although prior research suggested that attenuation may decrease over time with aural inserts, these compliant inserts were found to be stable in the face of vigorous temporomandibular and highly kinetic bodily activity, thus exhibiting negligible degradation in attenuation over time. However, improvements in attenuation provided by trained-subject fit vs. naive-subject fit of the earplugs were large at 1000 Hz and below, ranging from gains of 12 to 14 dB, and were smaller, but still statistically significant, at 2000 to 8000 Hz, ranging from gains of 3 to 5 dB.

INTRODUCTION

The Need of Personal Hearing Protection

Occupational noise exposure is a major threat to industrial workers' hearing. Repeated exposure to loud noise usually results in the tragic consequence of permanent hearing loss or noise-induced hearing loss (NIHL). Estimates indicate that more workers experience occupational hearing loss than all other occupation-related disabilities combined (Miller, 1978), and over 9.2 million American workers are threatened by the exposure to daily noise levels of above 85 dBA (EPA, 1981). In addition, pervasive, insidious, and cumulative characteristics of NIHL have often aroused concern among management, safety personnel, and industrial hygienists. Furthermore, worker compensation for occupational NIHL is gradually becoming a major expense in industry, and this trend may continue unless efficient counteractions are taken.

Currently in actual U.S. industrial practice, hearing protection devices (HPDs) are the most popular countermeasure of choice against occupational NIHL, although HPDs are generally considered as a third line of attack for noise abatement (OSHA, 1988). This is because other abatement strategies such as engineering control measures (e.g., enclosures and absorption) and administrative controls (e.g., rotation of the work force among noisy and quiet jobs) are often ineffective, infeasible, or too expensive.

Overestimation of Hearing Protector Performance

There exists much diversity among HPD designs and their protective effectiveness. For a given noise exposure problem, an HPD which adequately and reliably attenuates the noise spectrum to safe levels must be selected and worn properly. To aid in this selection process, manufacturers must provide an EPA-required (EPA, 1984) Noise Reduction Rating (NRR) for each HPD sold in the U.S., which is intended to be subtracted as an attenuation value from the actual C-weighted workplace noise level to estimate the wearer's A-weighted protection under the HPD. Alternatively, if a measured C-weighted level is not available, the NRR, after being reduced by a safety factor of 7 dB, may be subtracted from the A-weighted noise level to yield the protection level. This attenuation rating is the primary basis by which industrial safety personnel can decide which HPDs will provide adequate protection from, and OSHA compliance in, specific noise exposure situations. The NRR is established on the basis of psychophysical laboratory tests in a specific sound field presentation, as per ANSI S12.6-1984 (ANSI, 1984), usually incorporating well-fitted HPDs, trained and motivated subjects, and near-optimal test conditions. In other words, the conditions under which HPDs are attenuation-tested and subsequently protection-rated are quite different from those in the industrial environment where HPDs are typically used. Thus, laboratory-obtained NRR values tend to overestimate the average protection afforded in-field, and the attenuation variance in-lab is considerably less than that found in-field. Based on a comprehensive review of 10 studies which compared laboratory and in-field HPD performance results, Berger (1983) concluded that, on average across all HPDs tested, the NRR overestimated real-world protection by 13 dB or even more, depending on the standard deviation adjustment used. This is a significant reduction considering that the range of NRRs for most standard (i.e., non-amplitude sensitive) HPDs is 10-35 dB. Clearly, workplace influences such as poor device fit, extended wearing periods, physical work activity, and ambient temperature are not accounted for in laboratory NRR tests. Several prior studies have attempted to isolate the magnitude of effect of specific in-field factors on the attenuation of certain HPDs.

Prior Investigation of In-Field Effects on HPD Attenuation

In two laboratory studies addressing the user fitting instruction effect on achieved HPD attenuation, Casali and Epps (1986) and Casali and Lam (1986) measured attenuation for a variety of earplug, earmuff, and canal cap HPDs which were fit by subjects according to one of five different instruction sets. In general, the attenuation provided by the sample of earplugs (slow recovery foam, double-flange premolded, ear down, waxed cotton, cone-shaped premolded) was more affected by differences in user fitting instruction than was that of the earmuff/canal cap sample. That is, for some earplugs, attenuation afforded by very brief instructions or none at all was tripled when more comprehensive instructions, such as experimenter-modeled fitting procedures, were given to subjects. Also, the modeled instructions yielded significantly better attenuation than either auditory feedback or manufacturer's on-package instructions. For the earmuffs and canal caps tested, there was little difference in attenuation achieved under different user instruction conditions. However, the no instruction condition consistently provided poorer attenuation than any of the other four instruction sets. The collective results of these two studies suggest that proper fitting instruction is critical to obtaining good protection performance in-field with most HPDs. Unfortunately, in some industrial plants, HPDs are often fitted by workers with little or no supervision, using at best only the manufacturer-provided instructions which may be overly brief and hard to read, especially if printed on small earplug packages.

In addition to the aforementioned experiments concerning instruction effects, five other studies (Abel and Rokas, 1986; Berger, 1981; Cluff, 1989; Kasden and D'Aniello, 1976; Krutt and Mazor, 1980) have investigated the in-field influence of wearing time on the attenuation afforded by several types of HPDs, and detailed review may be found elsewhere (Park, 1989). Collectively, the five studies concerning wearing time effects indicate that the attenuation of certain premolded rubber or vinyl plugs and that of mineral down plugs may decrease over wearing periods on the order of one hour or longer. However, the type of physical activity performed by the wearer would be expected to influence, but this activity was not typically controlled, except in the Cluff study (1989). For expandable, slow-recovery foam earplugs (i.e., E-A-R or Deci-Damp plugs) the data are not as clear-cut. For example, discrepancies between the results of the Abel and Rokas study (1986), in which slight *reductions* in foam plug attenuation occurred over time, and those of the Krutt and Mazor study (1980), in which consistent *improvements* in foam plug attenuation occurred, give rise to several important questions. First, since foam plugs have a slow recovery expansion time, it could be possible that expansion time prior to initial (pre-wearing period) testing in the Krutt and Mazor study (1980) was insufficient for the plugs to fully expand inside the ear canal. If this did in fact occur, the plugs would continue to recover and the resultant improvement in seal would be evidenced as increased attenuation over the wearing period. Such plugs are known to reach near-complete expansion in 2-3 minutes, but given that the pre-test expansion time in both studies (Abel and Rokas, 1986; Krutt and Mazor, 1980) was not specified, the potential influence of this variable on the obtained results is unknown. Another important difference in the protocol between these two studies was that the wearing period (1-1.5 hours) of the Abel and Rokas (1986) study included lunch in which head/jaw movement was induced by eating, while Krutt and Mazor (1980) did not allow eating during their wearing period of 2 hours. It was concluded that the jaw movement, often considered a severe test for earplugs' stability of fit, might have induced slippage which accounted for the reduced attenuation in the Abel and Rokas (1986) study, but this was not borne out in the Cluff (1989) results. Of course, eating snacks, chewing gum or tobacco, and talking are all typical behaviors of the employee who may be wearing hearing protection.

A major premise providing impetus for these efforts is that the standardized laboratory tests (e.g., ANSI S12.6-1984) for attenuation rating of an HPD yield data which are representative of the device's performance only at a single point in time during the test, which is conducted soon after initial fit is established. These procedures in no way predict the actual protection provided later by the HPD during a typical wearing period.

Research Objective

The experiment described herein was aimed at empirically determining slow-recovery foam earplug attenuation performance under two different dynamic conditions, including temporomandibular joint movement (induced by chewing) and vigorous whole-body physical activity. Partly because these earplugs require more manipulation by the wearer during fitting than do most premolded plugs (i.e., they must be rolled and compressed prior to insertion), once they are donned it is often the case that they are left in continuously for several hours during work. Furthermore, because the plug is highly compliant, users may find it comfortable enough to be worn for extended periods without removal. As such, it is important to ascertain if attenuation degrades over time as a function of wearer activity for a single fitting of the plug. If so, there is a need to periodically remove and reinsert the plugs to maintain a consistent level of protection.

Another objective of the study was to determine the magnitude of frequency-specific attenuation differences between the levels of foam earplug fit attained by trained versus naive subjects. If user training produces significant attenuation improvement, there is evidence that package fitting instructions need to be augmented with other training materials. Training supplements may be necessary for all types of earplugs, but seem particularly important for plugs which require user forming and manipulation (Casali and Epps, 1986).

To establish the necessary control of experimental conditions, the variables of interest were implemented in a laboratory environment. This allowed the magnitude of effect of wearing time, type of dynamic activity, and quality of fit to be experimentally determined without contamination from in-workplace factors. It is stressed that there was no intent to provide results which could be transferred directly to the field environment, where a multitude of factors, in addition to those investigated herein, typically combine to reduce protection levels from those established under laboratory conditions.

EXPERIMENTAL METHOD

Subjects

The paid volunteer participants (five males and five females) had mean age of 21.5 years, inexperience with protector use (less than one use every 6 months), no evidence of otopathic problems or head lesions, and normal hearing as defined below. Headgear, ear jewelry, and eyeglasses were removed prior to participation. Ten subjects were used, in adherence with ANSI S12.6-1984 and because this sample size has been demonstrated to yield ample statistical power in prior studies with similar variables (Casali and Epps, 1986; Casali and Lam, 1986).

Experimental Design

All independent variables were manipulated in within-subjects format, with equal subjects from each gender assigned to each cell. Each subject attended one audiometric screening session and then four separate data collection sessions, in which the following independent variables were applied.

Fitting procedure variable. Because subjects were non-users of the E-A-R foam plug, they were naive with respect to its relatively special fitting procedure of 1) rolling the plug between the finger and thumb into a tight cylinder, 2) pulling the pinna upward and outward to straighten the ear canal, 3) quickly inserting the compressed plug well into the canal, and 4) allowing the plug to fully expand inside the canal. Subjects accomplished earplug fitting under two conditions. In the ***subject-fit*** condition, subjects were given the standard industrial (i.e., "pillow") pack containing an E-A-R earplug pair and told to insert the plugs according to the manufacturer's on-package instructions. In the subject-fit condition, which mimicked many typical industrial fitting practices, no experimenter guidance or assistance was given. Fitting was done without the presence of a fitting noise (ANSI, 1984) for feedback. The alternate condition was ***trained-fit*** in which the experimenter provided verbal clarification (but not additional information) of the manufacturer's on-package instructions, answered questions, and provided feedback (but did not physically touch the plugs) while the subject donned the plugs outside the test chamber. After learning the proper fitting techniques, the subject removed the plugs, entered the test chamber, and re-fitted the plugs on his/her own. A 70 dBA pink noise was then presented to give the subject an acoustic basis for checking the earplug seal. If the subject detected a poor fit, he/she completely removed and re-inserted the plugs and the pink noise was again presented for feedback. One of the two fitting procedures was used during each of the four data collection sessions. To preclude training transfer effects, the subject-fit procedure was always used in the first two sessions and the trained-fit procedure in the final two sessions for each subject.

Movement activity and wearing time variables. During each experimental session, subjects underwent two separate 30-minute periods of one activity task while wearing the earplugs. In the ***jaw movement*** task, subjects were seated while alternating 5-minute periods of reading aloud with 5-minute periods of chewing gum or eating a snack for the full 30-minute period. To elicit forced vocal effort during reading, subjects were asked to glance at an analog sound level meter display and attempt to maintain their uttered words at about 70 dBA. This speaking/chewing task required almost continuous temporomandibular movement, but no other physical activity, during the wearing period. For the ***work activity*** task, subjects performed a set of six simulated industrial jobs using a Baltimore Therapeutic Equipment Work Task Simulator during each 30-minute session. This upper torso and limb movement task, paced with a metronome to achieve near-equal work per subject, was reported by most participants to be physically taxing and caused some perspiration in the 28° C ambient temperature. Job activities, which included ladder climbing, valve turning, crowbar pulling, load pushing, lever pulling, and bar (shoulder) rotation, were each performed for 3 minutes continuously, separated by 2-minute rest breaks, for the 30-minute period. While performing these activities from a fixed standing position, the subject was required to turn the head and neck approximately 110° every 5 seconds to monitor a video display. This induced rapid head acceleration which could contribute to HPD slippage. The order of presentation of the jaw movement and work activity conditions was counter-balanced between subjects.

Experimental Apparatus and Protocol

Screening session. Pure-tone audiograms were obtained in an IAC booth using a Beltone Model 114 manual audiometer and a modified Hughson-Westlake method of limits procedure (Morrill, 1986). Subjects qualified if their hearing threshold levels were within -10 to 20 dB at pure-tone frequencies of 125-8000 Hz in octave steps, as per ANSI S12.6-1984.

Experimental sessions. Earplug attenuation data in each session were collected according to a REAT (real-ear attenuation at threshold) procedure in which the dB difference between occluded (plug in ear) and unoccluded (open ear) hearing thresholds for each test frequency was taken as the attenuation for a given frequency band (ANSI, 1984). Békésy tracking procedures were used to determine threshold for each of nine one-third octave bands, presented in order (of center frequencies) of 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz, with a return to 125 for a reliability check. Threshold was computed as the midpoint of the subject's tracings at each frequency.

To perform these psychophysical attenuation tests, the Virginia Polytechnic Institute Hearing Protector Research Facility incorporates an IBM PC/AT-controlled Norwegian Electronics Model 828 test signal generation, filter, and attenuator system, which presents calibrated one-third octave band signals through four frequency response-matched loudspeakers (TEP S-2) arranged at corners of an imaginary tetrahedron. A diffuse sound field around the subject's head is achieved in an Eckel chamber having reverberation time for all test frequencies of less than 0.20 sec and octave-band ambient noise levels in dB linear (center frequencies in Hz) of: 23.3 (125), 5.5 (250), 5.7 (500), 7.5 (1000), 5.6 (2000), 7.3 (4000), and 9.3 (8000). All electro-acoustic requirements of ANSI S12.6-1984 are met by this facility, and other specification details appear elsewhere (Casali, 1988). For the present experiment, calibration was verified daily using a Larson-Davis 800-B analyzer with integral one-third octave filter set and an ACO 7013 microphone.

For each of the four experimental sessions, with a break of 24 hours between sessions, the subject underwent the following scenario. First, practice in the Békésy threshold tracking procedure was given, and the subject was then checked for temporary threshold shift from the original audiogram. Given no shift, the first (pre-task) unoccluded thresholds were obtained at each test band. Then, the plugs were inserted according to the appropriate fitting condition, and five minutes were allowed for the plugs to fully expand. *Once fit was established, the subject was not allowed to touch or readjust the earplugs for the ensuing two-hour wearing period.* Pre-task occluded threshold data were next obtained, the subject exited the test chamber and provided a comfort rating, and then the first 30-minute jaw movement or work task period commenced. Then after a 5-minute break, the first post-task occluded thresholds were obtained in the chamber. After again exiting the chamber, the subject underwent the second 30-minute task period, took another 5-minute break, and then re-entered the chamber for the second post-task occluded threshold determination. At this point, the earplugs had been continuously worn, without adjustment, for two hours, and attenuation data had been collected three times: after initial fit and plug expansion, again after one hour, and then again after two hours. Next, the subject exited the chamber, provided another comfort rating, doffed the earplugs, and took a 5-minute break. Finally, a post-task unoccluded threshold was obtained and the subject was dismissed.

RESULTS

By differencing the raw occluded and unoccluded threshold data for the earplug, a dependent measure of attenuation, or noise reduction, in dB was achieved. For each subject in each experimental session, three attenuation data points were computed at each test frequency. Initial fit or pre-task attenuation (AT1 - attenuation at time 1) was computed as the difference between the pre-task occluded and unoccluded thresholds.

For attenuation after one hour of wearing time including the assigned activity task (AT2), the first post-task occluded thresholds were paired with the mean of the pre-task and final post-task unoccluded thresholds. Finally, the second post-task occluded thresholds and corresponding unoccluded thresholds were paired to obtain attenuation after the two-hour wearing period (AT3). For each combination of subject- vs. trained-fit condition and jaw movement vs. work activity condition, the mean (and standard deviation) attenuation values for the group of 10 subjects at each time juncture (AT1, AT2, AT3) are presented in Table 1.

Statistical analysis of the fit, subject activity, and wearing time effects on frequency-specific attenuation was performed by means of a three-way, repeated-measures analysis of variance (ANOVA) at each test frequency. (In these ANOVAs, all two- and three-way interactions of the three independent variables were included, and the error term used for the *F*-test on each source of variance was the interaction of each source with subjects, considering subjects as a random-effects and factors as fixed-effects variables.) All nine frequency ANOVA tables, which are identical in terms of the sources of variance and *F*-tests applied, are presented in Appendices 1 through 9.

Perusal of the attenuation means in Table 1 for each measurement period reveals that there was little, if any, change in protection over the course of the wearing period, irregardless of the type of subject activity during the period. There was no ANOVA main effect of subject activity, or interaction thereof, on the foam plug's attenuation at any test frequency. The wearing time main effect was significant only at the high

Table 1. Attenuation means (standard deviations) in dB for each experimental condition at each measurement period. (Each cell represents mean (standard deviation) of 10 subjects, one attenuation measurement for each subject.)

Fit	Wearing Period Activity	Attenuation Measurement	1/3 - Octave Test Band Center Frequency (Hz)								
			125	250	500	1000	2000	3150	4000	6300	8000
Subject-Fit	Jaw Movement	AT1	20.7 (4.3)	22.5 (3.6)	23.5 (3.4)	25.4 (2.9)	32.4 (4.0)	39.7 (4.1)	38.8 (4.0)	44.4 (5.3)	40.1 (5.4)
		AT2	20.4 (4.4)	21.5 (2.5)	22.9 (4.7)	24.5 (3.7)	32.8 (4.1)	39.1 (3.7)	38.4 (4.3)	43.5 (4.7)	39.4 (6.7)
		AT3	20.4 (3.6)	20.8 (2.4)	22.7 (3.5)	24.7 (3.7)	31.7 (4.1)	38.7 (3.5)	38.3 (5.4)	42.9 (5.5)	38.8 (7.7)
	Physical Work	AT1	19.5 (4.8)	21.9 (3.7)	23.7 (5.3)	25.5 (4.3)	32.5 (2.6)	37.5 (3.3)	39.7 (4.3)	43.2 (4.0)	40.2 (7.2)
		AT2	19.5 (4.7)	21.6 (4.0)	23.9 (4.7)	25.9 (4.8)	32.6 (2.7)	37.5 (3.3)	39.6 (3.3)	43.2 (3.9)	39.9 (6.4)
		AT3	20.0 (5.4)	21.4 (3.7)	23.3 (5.1)	25.7 (3.7)	32.8 (2.6)	36.8 (3.8)	39.5 (3.3)	42.3 (4.3)	39.0 (6.6)
Trained-Fit	Jaw Movement	AT1	32.2 (6.2)	35.3 (5.7)	37.3 (5.7)	39.7 (5.3)	35.0 (4.0)	41.9 (2.6)	43.2 (2.7)	45.7 (3.3)	44.4 (3.0)
		AT2	32.1 (7.1)	35.6 (5.7)	37.2 (6.0)	39.7 (5.0)	35.0 (3.7)	41.0 (1.5)	42.0 (2.2)	45.5 (3.2)	44.4 (2.1)
		AT3	31.9 (7.6)	34.4 (5.4)	37.1 (6.1)	39.2 (4.9)	35.9 (4.1)	41.6 (2.2)	42.5 (3.8)	45.4 (3.7)	43.8 (3.0)
	Physical Work	AT1	32.7 (7.8)	33.6 (6.6)	37.2 (5.5)	39.3 (5.1)	35.7 (4.1)	43.2 (3.0)	43.0 (3.8)	47.5 (4.4)	45.5 (3.9)
		AT2	32.0 (7.2)	33.1 (6.6)	36.3 (4.6)	39.2 (4.9)	36.1 (3.9)	41.9 (2.9)	42.8 (3.5)	46.4 (4.2)	45.0 (2.8)
		AT3	31.3 (7.3)	33.1 (6.0)	36.3 (3.8)	39.2 (4.7)	36.2 (5.1)	41.6 (2.4)	42.1 (1.9)	45.5 (4.2)	43.8 (2.7)

frequencies, 6300 Hz - $F(2,18) = 6.92$, $p < 0.01$; 8000 Hz - $F(2,18) = 4.33$, $p < 0.05$, but the degradation in attenuation over time was practically negligible between AT1 and AT3, at 1.2 dB for 6300 Hz and 1.1 dB for 8000 Hz. There were also no statistically-significant interactions involving the wearing time variable. Furthermore, whether the subject was highly trained to fit the plug or not did not discernibly influence the time course of attenuation achieved. However, there was a strong *main* effect of level of fit on attenuation when this variable was considered by itself. The ANOVA statistical results pointed to a significant fit effect for all test frequencies except 6000 Hz: 125 Hz - $F(1,9) = 32.91$, $p < 0.01$; 250 Hz - $F(1,9) = 53.06$, $p < 0.01$; 500 Hz - $F(1,9) = 71.18$, $p < 0.01$; 1000 Hz - $F(1,9) = 108.48$, $p < 0.01$; 2000 Hz - $F(1,9) = 46.37$, $p < 0.01$; 3150 Hz - $F(1,9) = 24.89$, $p < 0.01$; 4000 Hz - $F(1,9) = 12.95$, $p < 0.01$; 8000 Hz - $F(1,9) = 8.45$; $p < 0.05$. After collapsing across the work activities and three measurement periods, the mean attenuation values for the subject-fit and trained-fit condition yield the spectral attenuation functions shown in Figure 1, labeled "VPI" (Virginia Polytechnic Institute) data. As depicted, the improvement in protection afforded by training subjects to achieve proper fit was dramatic and especially evident at 1000 Hz and below, where increases in attenuation ranged from 12 to 14 dB over the subject-fit condition. Significant, though smaller, improvements of 3 to 5 dB occurred at 2000 to 8000 Hz. The VPI subject-fit results are in general agreement with those obtained on the same earplug under a similar protocol reported by another laboratory (EARCAL laboratory, Figure 1 in Berger, 1988a). The VPI trained-fit results coincide closely with those obtained under "experimenter-supervised" conditions and designated as "typical

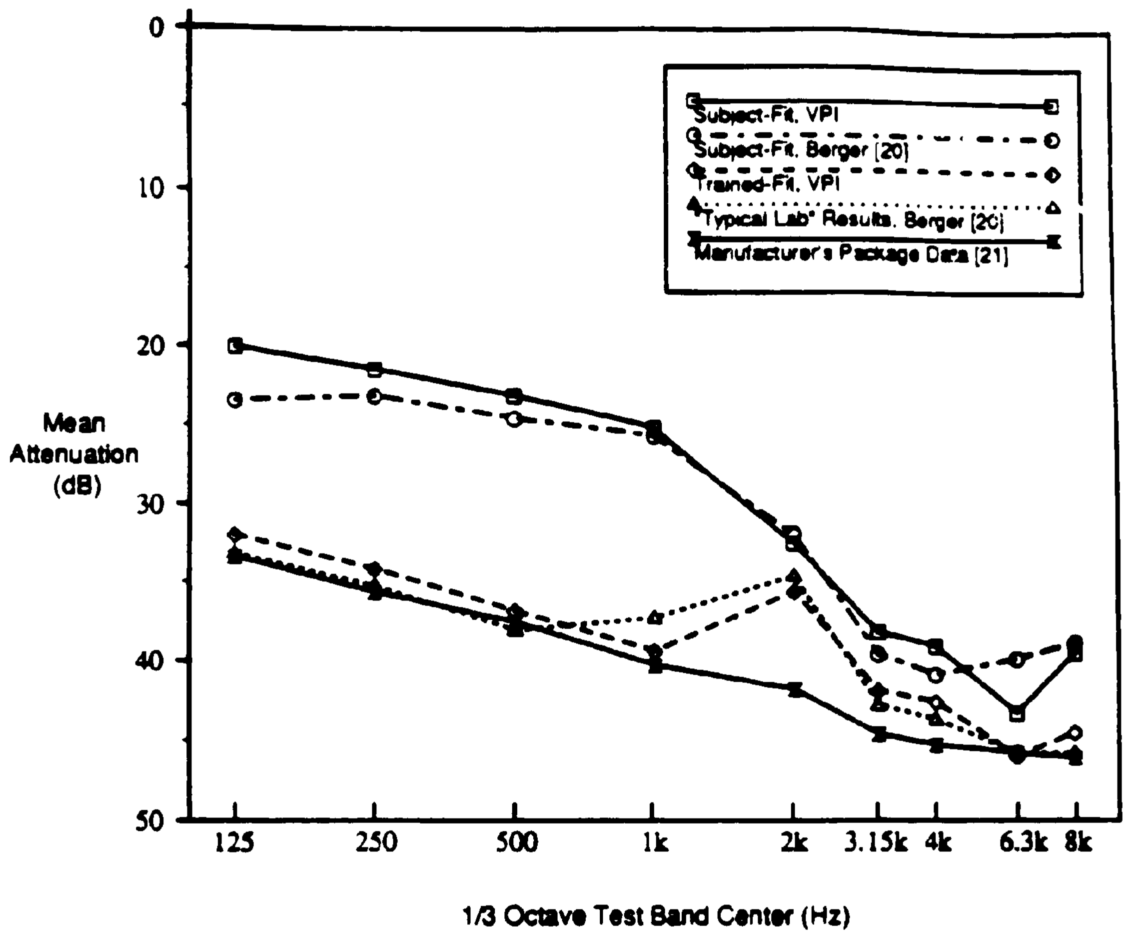

Figure 1. Foam earplug attenuation at each test frequency as fit by subjects using package instructions only (Subject-Fit, VPI) and by subjects receiving training from experimenter (Trained-Fit, VPI). Data collapsed across activity and measurement period. Berger (1988a) data and manufacturer's package data E-A-R (1989) shown for comparison.

laboratory" results for 100 subjects on the foam earplug (Berger, 1988a). These results are presented in Figure 1 for comparison. The subject-fit condition also yielded considerably lower attenuation than that supplied by the manufacturer on packaging (EAR, 1989), and the trained-fit condition attenuation was slightly lower than the manufacturer's at nearly all test frequencies, as shown in Figure 1.

DISCUSSION AND CONCLUSIONS

It is clear from these data that with only brief (i.e., 5 minutes) instruction on slow-recovery foam earplug fitting from a qualified individual, subjects greatly improve their protection levels as compared to those achieved with use of only earplug package instructions. Though the subjects were required to don the earplugs without any physical assistance from the experimenter in both fitting conditions, the verbal interaction inherent in the trained-fit condition yielded much better attenuation results. When left to rely solely on the manufacturer's on-package instructions, subjects generally did fit the foam plug longitudinally in the ear canal but often obtained too shallow an insertion and/or a crease in the plug. This is not to fault on-package instructions; they are often the only information the end-user ever sees. But especially for protectors such as the slow-recovery foam plugs that require several critical steps to don properly, the individual package instructions (in contrast to more comprehensive supplementary materials) may be somewhat lacking if for no other reason due to the small printing space available. In any case, comprehensive instruction on proper protector fit and use goes hand-in-hand with enhanced noise protection. As such, training programs and videotapes are available from some hearing protection manufacturers to augment their package instructions. Unfortunately, in many industrial plants such instructional programs are not employed. It is important to note that specific fitting instructions are needed for each hearing protector model selected for the workforce, as demonstrated by Casali and Epps (1986). However, a useful set of *generic* tips on improving earplug and earmuff fit appears in Berger (1988b).

One of the most important outcomes of this study was that slow-recovery foam earplug protection levels did not significantly degrade over the course of a two-hour wearing period, but that attenuation was maintained at levels nearly equal to those measured just after initial fit. In contrast to the results of Krutt and Mazor (1980), a slight *improvement* in attenuation over time was not revealed either, perhaps because in this experiment the plugs were allowed to stabilize in the ear canal for five minutes prior to testing. The need for sufficient time after insertion for the foam plug to expand and seat itself in the ear canal is evident. Observation of the foam plug's recovery time following compression to a thin cylindrical shape indicates that five minutes is more than enough for sufficient in-canal expansion to occur. In fact, two to three minutes is probably sufficient.

As indicated by the results of Abel and Rokas (1986) and as suggested by other authors, physical activity and/or jaw movement may loosen certain earplugs and reduce protection afforded. However, the present study suggests that the slow-recovery foam earplug is resilient to such effects. The lack of a temporomandibular effect corroborated that of Cluff (1989), and the results are in general agreement with the findings of Berger (1981), who did not allow subjects to chew gum or consume a full meal and whose subjects did not undergo highly vigorous activity. When inserted and allowed to expand, the foam plug generates small radial forces on, and develops friction with, the ear canal walls. Furthermore, because the plug is highly compliant, it will conform to dynamic distortions of the ear canal and then return to its previous shape when the distortion subsides. These inherent properties probably aid in preventing loosening of the plug in the face of jaw movement and head accelerations. This behavior was clearly evidenced by the consistency in attenuation achieved before and after the protracted temporomandibular joint movement in the chewing/speaking task. Likewise, the vigorous physical activity task, designed to elicit bodily movements representative of those in much industrial manual work, did not degrade the foam plug's performance at any test frequency. It is often thought that head and jaw movements are a severe test for earplugs and thus may compromise protection afforded. However, this was not supported by the data for the foam plugs in this experiment. Further parallel studies are currently underway on other earplug styles to ascertain if insert protectors should be selected with the nature of the work activity as a criterion. For dynamic situations, such as high-G in-vehicle environments, or where operators must repeatedly speak aloud, selection of an insert-type hearing protector may be particularly critical.

REFERENCES

Abel, S. M. and Rokas, D. (1986). The effect of wearing time on hearing protector attenuation. Journal of Otolaryngology, 15(5), 293-297.

ANSI S12.6-1984. (1984). Method for the measurement of real-ear attenuation of hearing protectors. New York: American National Standards Institute, Inc.

Berger, E. H. (1981). Details of real-world hearing protector performance as measured in the laboratory. In Proceedings of Noise-Con 81 (pp. 147-152). New York, NY: Noise Control Foundation.

Berger, E. H. (1983). Using the NRR to estimate the real world performance of hearing protector. Sound and Vibration, 17(1), 12-18.

Berger, E. H. (1988a). Can real-world hearing protector attenuation be estimated using laboratory data? Sound and Vibration, 22(12), 26-31.

Berger, E. H. (1988b). EARlog #19 - Tips for fitting hearing protectors. Indianapolis, IN: Cabot Corporation.

Casali, J. G. (1988). A facility for hearing protection research and testing incorporating the Norwegian Electronics 828 system: Verification re ANSI S12.6-1984. IEOR Technical Report No. 8801. Virginia Polytechnic Institute and State University, Blacksburg, VA.

Casali, J. G. and Epps, B. W. (1986). Effects of user insertion/donning instructions on noise attenuation of aural insert hearing protectors. Human Factors, 28(2), 195-210.

Casali, J. G. and Lam, S. T. (1986). Effects of user instructions on earmuff/earcap sound attenuation. Sound and Vibration, 20(5), 22-28.

Cluff, G. L. (1989). Insert-type hearing protector stability as a function of controlled jaw movement. American Industrial Hygiene Association Journal, 50(3), 147-151.

E-A-R Division, Cabot Corporation. (1989). Real-ear attenuation data appearing on E-A-R Plug 200 pair box packing.

Environmental Protection Agency (EPA). (1981). Noise in America: the extent of the noise problem. EPA Report 550/9-81-101. Washington, D.C.: U.S. Government Printing Office.

Environmental Protection Agency (EPA). (1984). Product noise labeling. Code of Federal Regulations, 40 Part 211, 120-137. Washington, D.C.: U.S. Government Printing Office.

Kasden, S. D. and D'Aniello, A. (1976). Changes in attenuation of hearing protectors during use. In Proceedings of the Technical Program: NOISEXPO 1976 (pp. 28-29). New York, NY: National Noise and Vibration Control Conference.

Krutt, J. and Mazor, M. (1980). Attenuation changes during the use of mineral down and polymer foam insert-type hearing protectors. Audiology and Hearing Education, Winter, 13-14.

Miller, R. (1978). Hearing Protection: the state of the art. National Safety News, 117(3), 91-92.

Morrill, J. C. (1986). Hearing measurement. In E. H. Berger, J. C.Morrill, L. H. Royster, and W. D. Ward (Eds.), Noise and hearing conservation manual (pp. 233-292). Akron, OH: American Industrial Hygiene Association.

OSHA (1988). Occupational noise exposure. 29 Code of Federal Regulations, 1910.95, pp. 176-191. Occupational Safety and Health Administration. Washington, D.C.: U.S. Government Print Office.

Park, M.-Y. (1989). Laboratory investigation of in-field influences on spectral noise attenuation and comfort of insert and circumaural hearing protectors. Unpublished M.S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

APPENDICES

ANOVA Summary Tables for Attenuation Results

Appendix 1. Analysis of variance summary table for attenuation results at 125 Hz.

Source	df	SS	F	p
Between-Subjects				
Subject(S)	9	1683.83		
Within-Subjects				
Activity Movement (M)	1	5.90	0.10	0.7641
M x S	9	554.67		
Fitting Procedure (F)	1	4288.86	32.91	0.0003*
F x S	9	1172.90		
Wearing Time (T)	2	2.70	0.36	0.7000
T x S	18	66.81		
M x F	1	4.37	0.13	0.7315
M x F x S	9	313.85		
M x T	2	0.18	0.07	0.9351
M x T x S	18	23.67		
F x T	2	4.17	0.62	0.5500
F x T x S	18	60.67		
M x F x T	2	4.87	0.61	0.5529
M x F x T x S	18	71.59		
Total	119	8259.04		

*Statistically significant.

Appendix 2. Analysis of variance summary table for attenuation results at 250 Hz.

Source	*df*	*SS*	*F*	*p*
Between-Subjects				
Subject(S)	9	1032.65		
Within-Subjects				
Activity Movement (M)	1	24.12	0.59	0.4618
M x S	9	367.48		
Fitting Procedure (F)	1	4760.28	53.06	0.0001*
F x S	9	807.43		
Wearing Time (T)	2	16.16	2.49	0.1109
T x S	18	58.38		
M x F	1	25.85	1.14	0.3143
M x F x S	9	204.88		
M x T	2	4.57	1.78	0.1976
M x T x S	18	23.13		
F x T	2	1.59	0.29	0.7541
F x T x S	18	49.95		
M x F x T	2	2.89	0.69	0.5151
M x F x T x S	18	37.81		
Total	119	7417.17		

*Statistically significant.

Appendix 3. Analysis of variance summary table for attenuation results at 500 Hz.

Source	*df*	*SS*	*F*	*p*
Between-Subjects				
Subject(S)	9	805.28		
Within-Subjects				
Activity Movement (M)	1	0.74	0.01	0.9327
M x S	9	667.77		
Fitting Procedure (F)	1	5524.35	71.18	0.0001*
F x S	9	698.47		
Wearing Time (T)	2	6.84	0.81	0.4620
T x S	18	76.32		
M x F	1	10.38	0.37	0.5556
M x F x S	9	249.47		
M x T	2	0.27	0.05	0.9478
M x T x S	18	45.75		
F x T	2	0.84	0.14	0.8694
F x T x S	18	53.52		
M x F x T	2	4.09	1.13	0.3451
M x F x T x S	18	32.58		
Total	119	8176.67		

*Statistically significant.

Appendix 4. Analysis of variance summary table for attenuation results at 1000 Hz.

Source	*df*	*SS*	*F*	*p*
Between-Subjects				
Subject(S)	9	914.72		
Within-Subjects				
Activity Movement (M)	1	1.90	0.05	0.8347
M x S	9	370.47		
Fitting Procedure (F)	1	5957.25	108.48	0.0001*
F x S	9	494.25		
Wearing Time (T)	2	1.57	0.18	0.8405
T x S	18	80.73		
M x F	1	9.69	0.52	0.4911
M x F x S	9	169.31		
M x T	2	2.36	0.45	0.6431
M x T x S	18	47.04		
F x T	2	0.35	0.06	0.9401
F x T x S	18	50.60		
M x F x T	2	2.99	1.34	0.2863
M x F x T x S	18	20.07		
Total	119	8123.30		

*Statistically significant.

Appendix 5. Analysis of variance summary table for attenuation results at 2000 Hz.

Source	*df*	*SS*	*F*	*p*
Between-Subjects				
Subject(S)	9	1232.32		
Within-Subjects				
Activity Movement (M)	1	8.35	0.73	0.4159
M x S	9	103.30		
Fitting Procedure (F)	1	301.94	46.37	0.0001*
F x S	9	58.60		
Wearing Time (T)	2	1.70	0.68	0.5203
T x S	18	22.55		
M x F	1	1.00	0.12	0.7418
M x F x S	9	77.90		
M x T	2	0.59	0.20	0.8219
M x T x S	18	26.66		
F x T	2	5.48	2.13	0.1483
F x T x S	18	23.18		
M x F x T	2	6.38	2.56	0.1050
M x F x T x S	18	22.41		
Total	119	1892.36		

*Statistically significant.

Appendix 6. Analysis of variance summary table for attenuation results at 3150 Hz.

Source	*df*	*SS*	*F*	*p*
Between-Subjects				
Subject(S)	9	462.50		
Within-Subjects				
Activity Movement (M)	1	10.33	0.80	0.3930
M x S	9	115.47		
Fitting Procedure (F)	1	402.97	24.89	0.0008*
F x S	9	145.73		
Wearing Time (T)	2	18.22	3.29	0.0604
T x S	18	49.80		
M x F	1	52.01	2.88	0.1239
M x F x S	9	162.52		
M x T	2	1.78	0.39	0.6803
M x T x S	18	40.78		
F x T	2	4.01	0.88	0.4310
F x T x S	18	40.94		
M x F x T	2	3.38	0.91	0.4192
M x F x T x S	18	33.35		
Total	119	1543.79		

*Statistically significant.

Appendix 7. Analysis of variance summary table for attenuation results at 4000 Hz.

Source	*df*	*SS*	*F*	*p*
Between-Subjects				
Subject(S)	9	500.11		
Within-Subjects				
Activity Movement (M)	1	9.80	0.35	0.5676
M x S	9	250.71		
Fitting Procedure (F)	1	377.37	12.95	0.0058*
F x S	9	262.22		
Wearing Time (T)	2	7.76	2.10	0.1518
T x S	18	33.29		
M x F	1	7.91	0.35	0.5667
M x F x S	9	201.14		
M x T	2	2.46	0.37	0.6964
M x T x S	18	59.92		
F x T	2	1.13	0.21	0.8150
F x T x S	18	49.11		
M x F x T	2	1.28	0.14	0.8663
M x F x T x S	18	79.77		
Total	119	1843.98		

*Statistically significant.

Appendix 8. Analysis of variance summary table for attenuation results at 6300 Hz.

Source	*df*	*SS*	*F*	*p*
Between-Subjects				
Subject(S)	9	636.29		
Within-Subjects				
Activity Movement (M)	1	0.75	0.02	0.8800
M x S	9	280.74		
Fitting Procedure (F)	1	228.80	4.04	0.0754
F x S	9	509.89		
Wearing Time (T)	2	28.32	6.92	0.0059*
T x S	18	36.84		
M x F	1	19.20	0.44	0.5215
M x F x S	9	388.46		
M x T	2	1.77	0.31	0.7369
M x T x S	18	51.30		
F x T	2	0.40	0.10	0.9077
F x T x S	18	36.52		
M x F x T	2	6.68	1.39	0.2736
M x F x T x S	18	43.10		
Total	119	2269.07		

*Statistically significant.

Appendix 9. Analysis of variance summary table for attenuation results at 8000 Hz.

Source	*df*	*SS*	*F*	*p*
Between-Subjects				
Subject(S)	9	1433.49		
Within-Subjects				
Activity Movement (M)	1	4.49	0.16	0.7002
M x S	9	255.35		
Fitting Procedure (F)	1	740.03	8.45	0.0174*
F x S	9	787.93		
Wearing Time (T)	2	28.41	4.33	0.0291*
T x S	18	58.99		
M x F	1	1.28	0.05	0.8313
M x F x S	9	239.74		
M x T	2	1.38	0.34	0.7132
M x T x S	18	36.07		
F x T	2	0.29	0.04	0.9573
F x T x S	18	60.35		
M x F x T	2	2.49	0.59	0.5654
M x F x T x S	18	38.07		
Total	119	3688.36		

*Statistically significant.