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The effectiveness of hearing protectors in practice

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Abstract. A series of workmen being evaluated for pensions for occupational hearing loss were asked to bring their own hearing protectors from work, to fit them themselves, following which attenuation studies were made. The muffs and most earplugs produced similar attenuation levels at high frequencies, although the muffs produced less attenuation at low frequencies. In all cases the mean attenuation was significantly lower than optimum figures suggested in the literature, and the standard deviation was relatively high. Personally molded earplugs were significantly less effective than the other plugs used. Reasons are discussed for the relatively poor performance of these devices and the concept of assumed protection, *i.e.* mean minus one standard deviation, is discussed. There is need for better instruction on how to use hearing protectors if they are to be effective.

Considerable emphasis is placed upon the use of personal hearing protective devices in current hearing conservation programs^{1,2}. Although good hearing protectors have been available since the 1940's in the form of both plugs and muffs, they have only come into widespread use in the last decade. Hearing protectors are usually accompanied by a label indicating the attenuation, which they are claimed to provide at various 1/3 octave bands.

Various standardized techniques³⁻⁶ have been developed to measure the attenuation

of hearing protectors and lists have been published of the attainable protection for many types⁷⁻¹⁰; classifications have been produced dividing protectors into classes A, B, and C⁶, according to amount of attenuation found; regulations have been written identifying the need to wear certain classes of protector in certain noise levels. The U.S. Environmental Protection Agency has produced a draft document¹¹ for the labelling of hearing protectors, and indeed states that they have chosen hearing protector devices as the first product for which labelling will be required under Section 8 of the U.S. Noise Control Act in the belief that this can be readily done. All of this presupposes that the protective devices provide the same attenuation when worn by the workman as they apparently do under rigorous laboratory conditions.

Many industrial noise-exposed workmen are seen in our department for the Workmen's

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Compensation Board of Ontario (WCBO). So many adverse comments were heard about personal hearing protectors from workmen that we questioned whether the figures obtained for attenuation under ideal laboratory conditions using ideally fitted and new protectors on trained subjects was a valid basis for making generalizations about the practical, day to day effectiveness of personal hearing protective devices. We therefore decided to evaluate the attenuation of protectors as actually worn by the workforce. The WCBO kindly cooperated by requesting that the workmen bring their own hearing protectors with them from their place of work so that they could be tested with their own devices during the routine pension assessment. This study is a report of the preliminary findings based on an evaluation of those data.

METHOD

The subjects were 88 workmen referred for assessment of noise-induced hearing loss by the WCBO. Their age range was 35-65 years, with a mean of 53 years. The type, location, and duration of noise exposure varied widely amongst individuals in the group, although all had been exposed to noise levels considered by the WCBO to be potentially hazardous for periods of time of more than five and usually closer to 20 years. The majority were miners and steelmakers. Each subject brought his own ear defenders from his place of work and fitted the device himself as he would wear it at work. There were four types: three commonly used earplugs — the EAR (N = 22), Willson Sound Silencer (N = 21), and custom molded (N = 28), and a group of assorted muffs, some on a headband and some attached to hard hats (N=17). A log was kept of comments about the protectors made by the workmen and observations of method of wearing them, and the condition of the protectors.

For the test each workman was seated in a RINK double walled, soundproof booth.

Two six-inch diameter round speakers (Madsen Electronics (Canada) Limited) were used for presentation of the test sounds. These were mounted on the side walls of the booth about 38 inches on either side of the subject's chair, the position of which was carefully marked so that it could be replicated from test to test. Ambient noise levels within the booth were within the permissible level of ANSI S3.1-1977. The test sounds were narrow band noises centered at the following frequencies: 125, 250, 500, 1,000, 2,000, 3,000, 4,000, and 6,000 Hz. They were generated by a Madsen OB 70 audiometer. The audiometer and the booth were calibrated prior to and during the experimental period.

Free field hearing thresholds were determined by the method of limits for each of the eight test sounds with the open ear. The subject then fitted his own protective device and the threshold was again measured. The difference between the two measures at each frequency gave the attenuation score.

RESULTS

The mean open ear free-field hearing thresholds for the four protector groups are shown in Figure 1. The change in threshold with frequency is typical of a noise-induced high frequency hearing loss. It should be noted the figure is calibrated in SPL rather than the more commonly used HL. At 125 Hz the thresholds are about 30 dB SPL and at 6 kHz they are about 55 dB SPL. The groups are not significantly different at most of the frequencies tested: of the 42 possible pairwise comparisons of the four groups at eight frequencies only six showed statistically significant differences ($p < .05$) of the order of 10 dB.

The mean attenuation scores for the four types of protector are shown in Table 1 and Figure 2.

The attenuation increases with the frequency from 125 Hz to 3 kHz for each type, although above 3 kHz there is some dropoff.

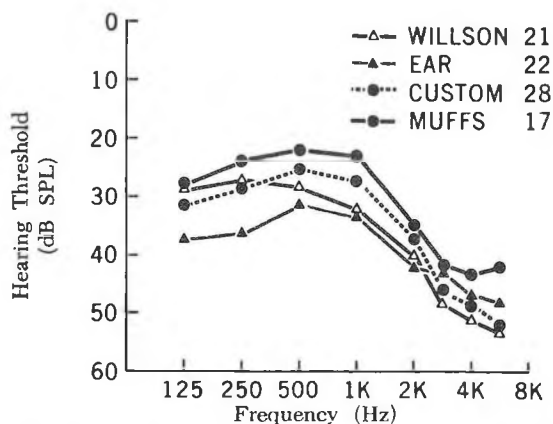


Fig. 1. Free field hearing thresholds for four groups of subjects.

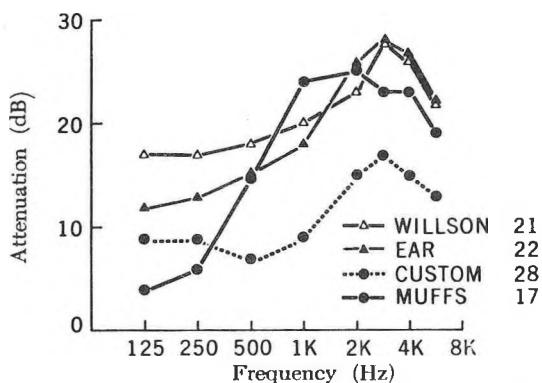


Fig. 2. Average attenuation for four types of protector.

At the lowest frequencies, 125 and 250 Hz, the Willson and EAR plugs give significantly more attenuation (about 15 dB, $p < .05$) than the muffs (about 4 dB). The Willson plugs

are significantly better than the custom plugs, 18 dB compared with 9 dB ($p < .01$). The attenuation provided by muffs increases dramatically between 500 and 6,000 Hz. In this range the muffs provide similar attenuation to Willson and EAR plugs, but the custom molded plugs provide significantly less attenuation than any of the foregoing ($p < .01$), across frequencies the difference being about 10 dB.

The distribution of individual scores at 500, 1,000, and 3,000 Hz is shown in Figure 3 for three types of plug. They are compared with the scores obtained for a group of 102 plugs, comprising the 88 plugs studied together with an additional 14 plugs of assorted types. The distribution curves indicate that at each frequency attenuation scores cover a broad range, from 0-40 dB. For the group of 102 plugs, there is a clear trend toward higher scores with an increase in frequency. A comparison of the curves for the three main protector types indicates that at all frequencies the attenuation scores for custom molds are largely concentrated between 0 and 15 dB. At 1,000 Hz 50 per cent of the EAR and Willson plugs give 20 dB or more attenuation, and at 3,000 Hz only 5 per cent of these two plug types give less than 20 dB. The average attenuation and standard deviation for the group of 102 plugs is shown in Figure 4 for the eight frequencies tested. The distribution of attenuation scores of plugs and muffs is shown in Figure 5. Both groups

Table 1. Attenuation Scores* for Four Protector Types

Type	Frequency Hz							
	125	250	500	1,000	2,000	3,000	4,000	6,000
Custom	8.9 ± 8.8	8.8 ± 8.3	7.3 ± 6.3	9.1 ± 7.2	14.8 ± 9.2	16.8 ± 9.3	15.2 ± 9.1	13.2 ± 8.9
EAR	11.2 ± 9.1	12.7 ± 9.1	15.2 ± 7.3	18.2 ± 7.2	26.4 ± 6.9	28.3 ± 7.7	27.1 ± 8.9	21.7 ± 7.5
Willson	17.3 ± 11.1	17.4 ± 9.3	17.9 ± 9.3	20.0 ± 9.4	23.3 ± 8.6	27.6 ± 8.3	25.7 ± 9.5	22.4 ± 9.7
Muff	4.2 ± 5.4	6.4 ± 7.7	15.3 ± 8.7	24.1 ± 6.2	25.3 ± 8.4	22.6 ± 12.4	22.9 ± 10.9	19.4 ± 9.3

*Mean ± 1 standard deviation.

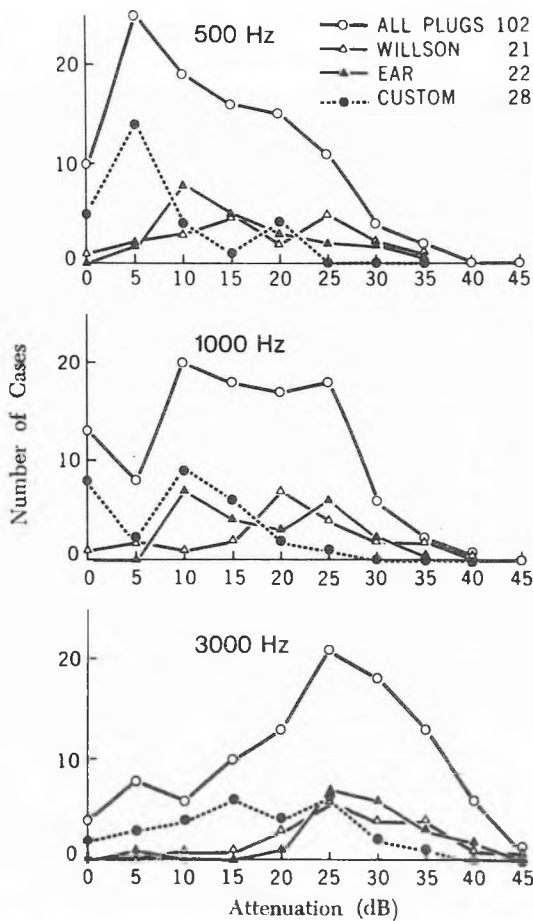


Fig. 3. Distributions of attenuation score.

cover a broad range. At 1,000 Hz half the plugs but 82 per cent of muffs provide 20-35 dB of attenuation, but at 3,000 Hz the distribution of the two groups is similar.

The degree of relationship between the amount of hearing loss and the attenuation scores was investigated. Using these two measures for each subject, correlation coefficients were computed for each type of protector at each frequency. Only two cases were significant at the .05 level. At 125 and 250 Hz with a custom plug, the attenuation score decreased as the free-field hearing threshold increased.

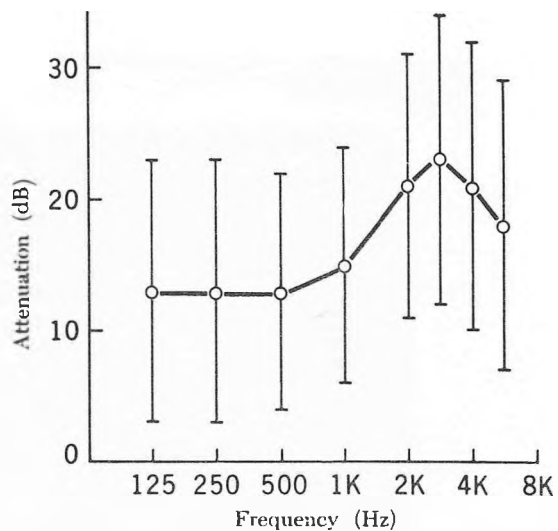


Fig. 4. Average attenuation for 102 plugs (mean \pm 1 S.D.).

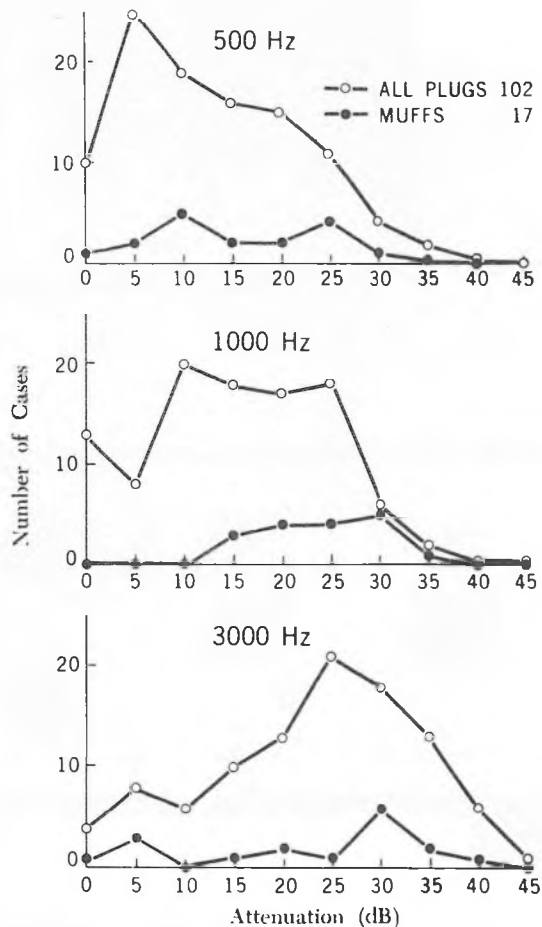
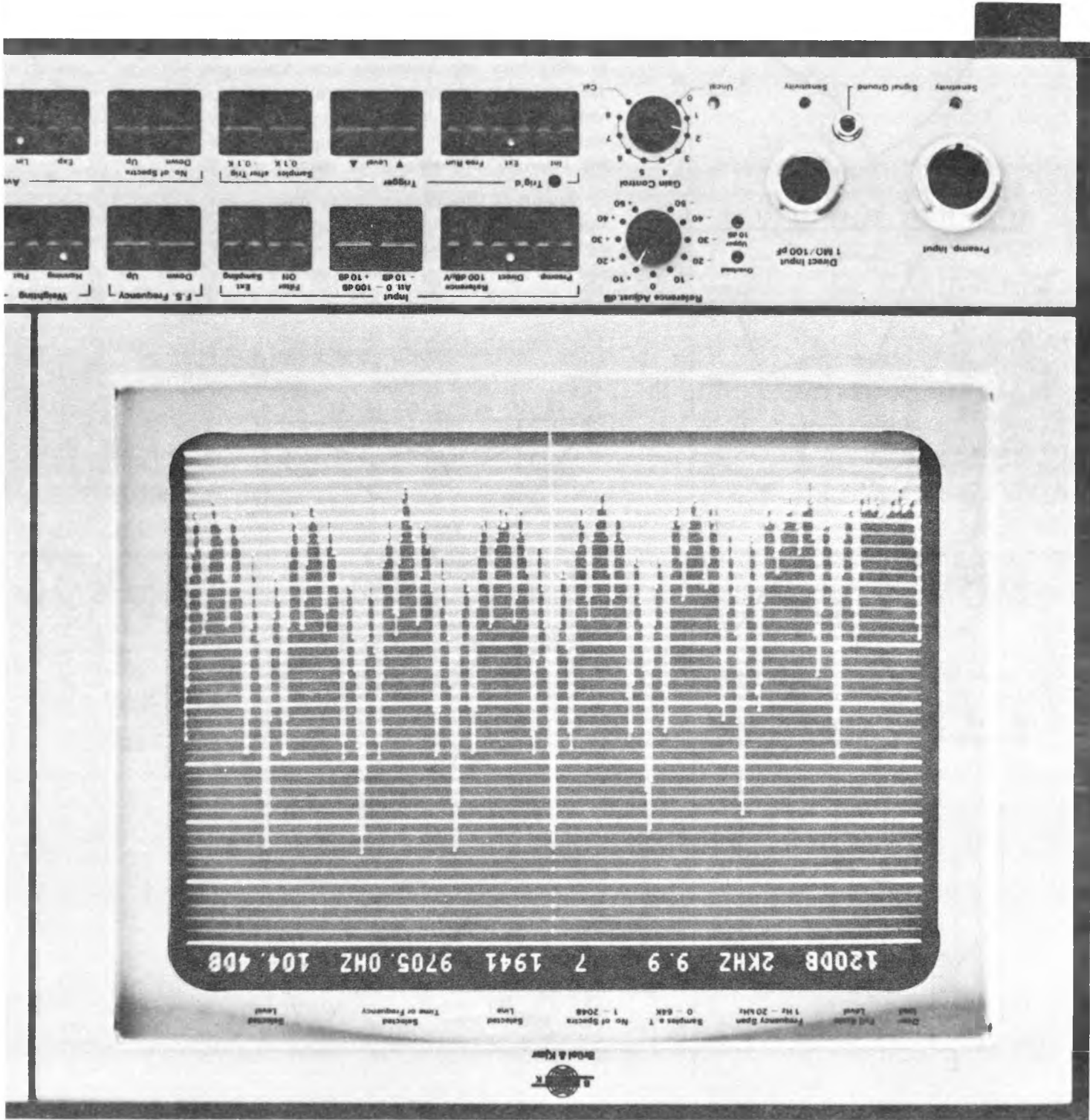
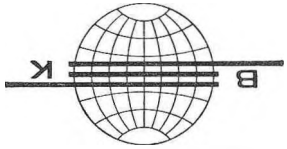


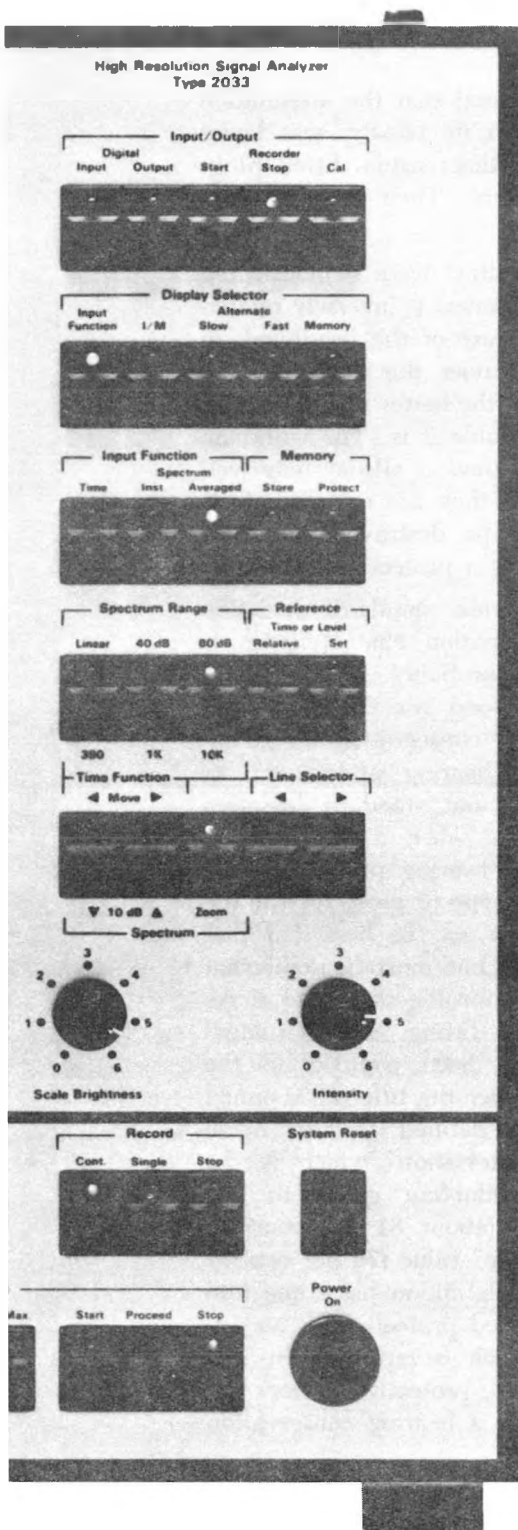
Fig. 5. Distributions of attenuation score.

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DISCUSSION

The mean attenuation figures found in this study were lower than the figures generally accepted for both plugs and muffs. This is a reflection of the difference between optimum laboratory methods and real life practice. Our own observations suggest that the poor low frequency attenuation of earmuffs could be accounted for by long hair, inadequate pressure from springs, poor seals between the muff and the head; leaks between the temple of eye glasses, the muff and the head, and poorly maintained muffs. For plugs some idiosyncrasies were noted in fitting related to size of ear canal and the technique for inserting them, including inadequate insertion of the plug into the ear canal and inadequate holding in of sponge plugs while they expand. Nevertheless the plugs protected as well as the muffs, and thus, in this sample at least, belie the belief that muffs are a more effective method of hearing protection in real life than plugs.

Custom molded plugs have had a considerable vogue. They are attractive to those initiating hearing conservation programs. Their use demonstrates interest in the individual worker, by provision of a specific customized device; although they are more expensive than most plugs they theoretically last a considerable period of time and thus in the long run are cheaper than many disposable plugs and they cost less than most muffs. At their best they are excellent, but they are difficult to fit exactly and the fitting is critical. Some of the plugs we saw had been tampered with by the workman to make them more comfortable, thereby destroying their seal, in others the external coating had worn off, some were actually cracked. In this group of workmen, they did not stand up to use as well as any of the other devices tested. In practice we are not alone in criticizing the attenuation which they provide⁷. Our findings in general are similar to those of Regan¹², and Edwards

*et al*³, who also found that the attenuation of hearing protectors in industry was lower than expected and that custom fitted plugs gave least attenuation. Their samples were however, small.

Flugrath and Wolfe¹⁴ have demonstrated that earmuff effectiveness is inversely related to weight and pressure of the headband, in other words the heavier the muff and the tighter the spring – the better its attenuation but the less comfortable it is. The workmen having to use these devices all day may well adjust them so that they are more comfortable, thereby perhaps destroying some of their effectiveness as a protective device.

The extremely wide standard deviation found in the attenuation characteristics is disappointing but probably realistic, and gives considerable food for thought about programs of hearing conservation based entirely on personal hearing protectors. As Martin¹⁰ has pointed out, standard deviation is important because when dealing with a total workforce the hearing protection provided by a specific type of protector for the population at risk is not the best that that device can produce, but must be somewhat less than the mean for the device to make allowance for poor fitting and individual variation. This has been codified in the United Kingdom under the title of “assumed protection” which is defined¹⁵ as the “mean minus 1 standard deviation” which is the minimum sound reduction given to the “majority of users” (about 84 per cent) or as the “lower quartile” value (75 per cent of users). The former definition has come into general use. “Assumed protection” is an important concept which is rarely taken into account when specific protective devices are being considered for a hearing conservation program.

Thus in this study the mean attenuation of 102 plugs is at all frequencies better than 12 dB and in the higher frequencies 20 dB, whereas the mean minus 1 standard deviation

— the *assumed protection* — is no more than 5 dB up to 1 kHz, and at the best frequency of 3 kHz is only 12 dB. Certainly in this study we have found a large gap between the theoretical attenuation which hearing protectors should be able to provide under optimum conditions, and the practical protection provided by the devices as worn by workmen. This outlines the need for considerable education of safety personnel and workers in how to fit and how to take care of protective devices. It also suggests

that those responsible for applying hearing conservation programs must be realistic in suggesting the potential protection that can be expected from a program based upon personal hearing protection.

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Résumé. Une étude de l'atténuation sonore fut effectuée sur les protecteurs d'oreilles employés par une série d'ouvriers réclamant de dommage auditif causé par un traumatisme acoustique industriel. Les cache-oreilles et les bouchons produisent la même atténuation des hautes fréquences mais les caches-oreilles atténuent moins les basses fréquences. Dans tous les cas, l'atténuation moyenne était moins bonne que le suggère la littérature. Les bouchons moulés étaient moins efficaces que les autres bouchons. Nous avons discuté des raisons qui expliquent les piètres performances de ces divers appareils et le concept de la protection assumée: la moyenne moins une déviation standard. Il est nécessaire de bien démontrer comment employer les protecteurs pour qu'ils soient vraiment efficaces.

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