HEARING PROTECTORS

11th October, 1971.

METHODOLOGY OF THE MEASUREMENT OF THE ATTENUATION OF HEARING PROTECTORS

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For hearing protectors to be used to the greatest advantage in a particular noise environment, two types of information are required: the sound level-frequency characteristics of the noise and the sound attenuation properties of the hearing protectors. Of the several methods available for determining the latter, the technique most widely used at the present time is the real-ear free-field threshold shift method. Basically this depends upon determinations of the threshold of hearing of a number of subjects with and without the hearing protectors being worn. The difference between the occluded and unoccluded thresholds is the real-ear attenuation of the protectors. This technique has been standardized by a number of countries (but not so far by Britain) and the detailed procedures are usually similar to the American Standard (A.S.A. Z24.22 - 1957). Briefly, this specifies that the occluded and unoccluded thresholds of 10 subjects should be measured 3 times using pure tones as the test signal produced by a single loudspeaker under anechoic conditions.

However, it has been found that measurements carried out by different laboratories on the same hearing protector, following the same procedures, can produce widely differing results. For example, Table I compares the means and standard deviations of the attenuation provided by V51-R earplugs, as measured once for 10 subjects by two workers using similar procedures and equipment. It is apparent from the table that the two sets of data are significantly different. The object of this paper is to discuss some aspects of the problems of reducing such discrepancies and improving the reliability of the measurement techniques.

TABLE I
Attenuation in dB of V51-R earplugs

	Frequency kHz	.250	.500	1	2	3	4
Piesse 1962	Mean	11	13	19	27	30	25
	St.dev.	7	9	10	9	6	5
Hanson and Blackstock 1958	Mean	23	26	29	35	37	27
	St.dev.	3.6	3.0	3.2	4.2	3.9	4.5

An improvement in the uniformity of attenuation results may be achieved by specifying more detailed measurement procedures which also reduce the uncertainty associated with the results.

1. Audiometric Test Signal

The test signal which has usually been used to determine thresholds of hearing up to the present time, and has also been specified by some standard methods, consists of pure tones; thus following accepted audiometric techniques. However, their use in free-field threshold determinations has certain drawbacks. Owing to diffraction effects at the subject's head, the sound level at the ears may vary considerably, particularly at the higher test frequencies and if the subject is wearing earmuffs. Also in the case of earmuffs a pure tone test signal may well excite resonances within the muff. So that at, or near to, any of these resonant frequencies, small changes in absolute frequency of the test signal may produce disproportionately large changes in the apparent frequency curves.

Both these effects may be diminished to a certain extent by the use of narrow bands of random noise as the test signals; such as ⅓-octave bands of random noise centred on the frequencies 63, 125, 250, 500, 1k, 2k, 3k, 4k, 6k, and 8k Hertz. According to Wheeler(1971), subjects found that test signals of narrow bands of random noise enabled a more rapid discrimination of the threshold level to be made than with pure tones.

2. Sound Field

Inaccuracies caused by the use of a single loudspeaker to generate the sound fields at the subject's head may be reduced to a certain extent if random noise is used as the test signal, as discussed above. However, the production of a more diffuse sound field at the subject's head would further reduce such diffraction effects. At the same time it would also provide a test environment that is nearer to the sound field likely to exist in practice, when the hearing protector will be worn.

One method of providing a more diffuse sound field is to carry out attenuation measurements under reverberant conditions. However, practical difficulties such as the need for the low ambient sound levels required for these tests, external subject noise and the difficulties involved in specifying the rise and fall times of the test signal make such an environment undesirable.

An alternative method of producing a more diffuse and consistent sound field under anechoic conditions is the use of a number of loudspeakers situated around and orientated towards the subject. Whittle (1971) has reported that four loudspeakers arranged in a tetrahedral formation, and acting as non-coherent sources facing the centroid, produce a sound field which varies by less than ± 3dB as measured at 27 points within a 30cm. cube at the centroid, for ⅓-octave bands of random noise at frequencies up to 8kHz. Such an array of sources would provide a more consistent test signal at the subject's head and therefore would probably reduce diffraction effects and associated sources of uncertainty due to the sound field.

3. Fitting Hearing Protectors

The choice of procedure involved in the fitting of hearing protectors to subjects taking part in attenuation measurements is important. This is particularly so in the case of earplugs. Table II compares two sets of mean and standard deviation figures for the attenuation of V51-R earplugs as measured on two groups of 10 subjects during the same experimental series by the same experimenter and equipment. However different fitting procedures were employed.

TABLE II
Attenuation in dB of V51-R earplug

	Frequency kHz	.250	.500	1	2	3	4
Procedure A	Mean	25.1	25.8	29.1	34.1	38.6	34.7
	St.dev.	4.3	4.9	3.7	4.3	5.6	5.7
Procedure B	Mean	16.9	16.4	18.8	24.0	30.0	28.4
	St.dev.	9.3	12.1	8.4	7.8	9.9	8.1

In procedure A, subjects were instructed in the method of fitting the plugs and this was followed by a close visual inspection by the experimenter. If it was apparent that the fit was not good, or initial measurements indicated abnormally low values of the attenuation, the earplugs were refitted. In procedure B the subjects fitted the earplugs after instruction, and, apart from obvious errors such as extreme discomfort or very loose fits, measurements were carried out without further corrections to the fit. It can be seen from the table that significantly different results were obtained. Owing to the fact that the presence of leaks in a protector-ear system has the greatest effect at low frequencies, the discrepancy between the two sets of data increases as the test frequency decreases.

Such results indicate the possible extreme variation in apparent attenuation which may be caused by relatively minor changes in experimental procedure. In the case of earplugs, it is probable that differences in fitting technique may be a major cause of the different attenuation figures reported by different laboratories for the same protector. However, it is also probable that such effects are not so marked in the case of ear muffs. Nevertheless, it would appear desirable for a detailed description of the protector fitting procedure to be specified in a standard method in order to improve uniformity of attenuation results.

The choice of fitting technique is governed by two main considerations. The required proximity of the results to the attenuation likely to be provided in practice and the degree of variability in the results that can be tolerated. Both considerations are conflicting in their requirements. For example, if it is required that attenuation data should represent as near as possible the protection afforded in the practical situation, procedure B described above would appear to be the correct one. However, as is illustrated in table II, the standard deviation of the results is likely to be greater than if more stringent precautions were taken as regards fit.

It is apparent that it is necessary, first of all, for the degree of variability that can be tolerated in such measurements to be specified. Fitting procedures and other factors which may be varied, such as the number of subjects and replications, should then be adjusted so that these specifications are met.

4. Number of Subjects

The number of subjects and replications that are required in attenuation measurements is governed by the variances associated with the results and the confidence limits that may be set. As the variance will vary not only with different types of hearing protectors but also with test frequency and the number of replications, the optimum number of subjects that may be recommended is necessarily only an estimate. For example, Table III compares the number of subjects required, with three replications, to satisfy a confidence level of 95% and a confidence interval of ± 3dB at each test frequency, for the V51-R earplug and the "Peacekeeper" personalized earmould plug.

TABLE III

Predicted Number of subjects

Frequency kHz	.250	.500	1	2	3	4
V51-R, (Hanson & Blackstock, 1958)	3	5	8	7	6	7
"Peacekeeper", (Martin, 1971)	25	14	13	12	13	16

It is apparent that the number of subjects required to achieve these confidence limits is different for the two types of earplug. This is to be expected as the variances associated with the respective attenuation data are also different. These variances in turn will be governed by the different experimental procedures employed.

It would also appear that the reliability of attenuation measurements could be improved by increasing the number of measurements made on each subject and the number of subjects. However, owing to the fact that the data are not normally distributed, the decrease in variance associated with an increase in the number of replications or the number of subjects is not as great as would be expected.

It is hoped that this brief discussion has indicated some of the problems associated with the measurement of the attenuation of hearing protectors. A standard method of measurement is required that will deal with these and other problems and hence ensure that reliable and consistent results are obtained.

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