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EVALUATION OF LINEAR AND NON-LINEAR (AMPLITUDE-SENSITIVE) MUFF ATTENUATION DURING GUNFIRE

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1. INTRODUCTION

The Noise at Work Regulations [1] specify that the unprotected ear should not be exposed to an instantaneous unweighted peak pressure greater than 200 Pascals (140 dB re 20 μPa). The peak pressure at the ear of a person firing a gun often exceeds this level and hearing protection is required to reduce the peak level. Although BS 5108 [2] data is used to calculate the attenuation of a hearing protector there is no standard method for using this data to estimate the attenuation of peak levels.

A further problem arises when non-linear (amplitude sensitive) hearing protectors are used. These hearing protectors are designed to give increased attenuation as the ambient sound pressure level increases. They have the advantage of allowing the wearer to hear external noise during quiet periods while ensuring they are protected during high sound pressure levels. Because these hearing protectors give different levels of protection depending on the level of the external noise, BS 5108 data cannot be used to determine the attenuation provided by non-linear hearing protectors at high noise levels.

Measurements of the attenuation provided by linear and non-linear hearing protectors during gunfire have been made by the Noise and Vibration Section at the Health and Safety Executive's Research and Laboratory Services Division in Buxton. This work has included measurements with handguns on indoor ranges, shotguns outside and proof-firing of shotgun cartridges.

A practical method of measuring the attenuation of hearing protectors (muffs) during gunfire is described here. Also included in this paper are some of the problems that can arise during field measurements of muff attenuation.

2. MEASUREMENT METHOD

2.1 Transmission loss measurements

Muff attenuation is generally taken as the difference between the sound pressure level (SPL) at the ear with and without the muffs. This is the insertion loss. However, in the high SPLs generated during gunfire it is not safe to make measurements at the unprotected ear. An alternative method of measuring muff attenuation is to measure the transmission loss which is the difference between the SPL outside and under the muff.

An ideal transmission loss measurement will give a result that is close to the insertion loss value. However the transmission loss is affected by the measurement position for the inside and outside SPLs. The outside SPL is affected by the proximity of the subject's head and the inside SPL by the microphone position on or in the subject's ear.

Laboratory measurements, by the Noise and Vibration Section, with third octave bands of random noise have shown that transmission loss measurements using a miniature microphone in the cavum of the concha, and a microphone 15 cm from the side of the head, are within 2 dB of the insertion loss up to and including 1 kHz. Above 1 kHz large variations (up to 10 dB) occur. Better agreement up to and including 2 kHz is obtained by measuring the outside SPLs with a miniature microphone fixed on the outside of the muff cup.

The differences between the insertion loss and transmission loss at high frequencies are less significant with broadband noise (such as with gunfire) and also where the muff attenuation is high at the higher frequencies. Non-linear muffs often amplify the frequencies between 1 and 4 kHz, at moderate levels of ambient noise, and so the transmission loss measured will be significantly different to the insertion loss. However at the peak SPLs generated during gunfire the reproduced high frequency sound is negligible and the expected difference between the insertion loss and transmission loss is likely to be less than 2 dB for both linear and non-linear muffs.

2.2 Measuring the SPL outside the muff

During gunfire high peak SPLs will occur. Table 1 shows the peak levels from a range of firearms measured by the Noise and Vibration Section. A low sensitivity microphone is needed to measure these peak SPLs such as the Brüel and Kjær Type 4135 quarter-inch microphone which is capable of measuring up to 164 dB with less than 3% distortion. The microphone is either mounted on a tripod close to the ear (within 20 cm) or hand-held close to ear where the person firing the gun moves around during shooting.

2.3 Measuring the SPL under the muff

The SPL under the muffs is measured with a miniature microphone. This microphone should have a flat frequency response, be small and fitted with cables that do not disturb the muff seal. The microphone is positioned in the cavum of the concha of the ear and the cable from the microphone is taped to the side of the firer's face.

3. ANALYSES

3.1 Measured peak attenuation

The peak attenuation of a muff is calculated by subtracting the measured peak SPL under the muff from the peak SPL measured outside the muff.

The peak SPL measured outside and under the muff can be simply measured with a sound level meter. Alternatively the pressure waveforms can be recorded and then displayed on a frequency analyser and the peak SPLs measured directly. The benefit of using this method is that any problems with the recorded signals (eg electrical noise or movement of the microphone under the muff) can be identified and these results discarded.

3.2 Estimation of peak attenuation using BS 5108 data

There is no standard method for predicting the peak attenuation of a muff using BS 5108 data. An estimate of the peak attenuation can be made using the following method: The first half-second of the shot measured outside the muff is analysed into octave bands. The BS 5108 mean attenuation is then subtracted from the unweighted octave band levels. The estimated peak attenuation is taken as the difference between the summed octave band levels outside the muffs with and without the BS 5108 mean attenuation subtracted.

In general, the predicted peak attenuation for all the different types of muffs is close to or lower than the measured levels. Although the differences between the measured and predicted attenuation can be large (up to 10 dB), the predicted attenuation gives an underestimate of the likely protection provided by the muff. Therefore people will be overprotected rather than underprotected if this method is used to estimate the performance of a muff against peak SPLs. The method described will only give an estimate of the optimum attenuation and so it will not reflect the effects of muff movement or environmental conditions. This has been illustrated in some of results where the measured peak attenuation is lower than the predicted attenuation.

BS 5108 data is not provided with electronic non-linear muffs. For the non-linear muffs that are based on a linear muff, the Noise and Vibration Section have used the BS 5108 data provided with the linear muffs to give an estimate of the optimum protection that is possible when the non-linear muff is fully attenuating sound. The peak attenuation of the electronic non-linear muffs estimated using this method is generally close to or lower than the measured levels.

4. PRACTICAL PROBLEMS WITH HEARING PROTECTORS DURING GUNFIRE

Field measurements of muff attenuation have been made by the Noise and Vibration Section with a range of different firearms (including shotguns, rifles, pistol and proof-firing of shotgun cartridges) fired outside in open spaces and indoor firing ranges. From these measurements several practical problems associated with both the use of hearing protectors and the measurement of muff attenuation during gunfire have been identified. These are discussed briefly below.

4.1 Movement of the muffs during gunfire

The attenuation of the muffs, with shotguns and rifles, is reduced by movement due to recoil and possibly direct physical contact of the butt of the firearm with the muff cup. Filming, using a high speed video camera, of a shotgun being fired showed the muff lifting from the head as the shot was fired. This movement was also apparent as an additional low frequency component, between 20 and 40 Hz, recorded under the muff. The filming of the muff movement also showed that after the initial peak pressure from the gunshot, the muff lifted from the marksman's head enabling sound to enter the ear unprotected. This results in low values of the A-weighted attenuation of the rms level (attenuation as low as 5 dB(A) was measured). This movement has not been observed during the use of smaller firearms (eg pistols and revolvers) which are held in both hands with the arms extended from the body to shoot.

4.2 Environmental conditions

Similar measurements of muff attenuation using shotguns were made on two different days; on a cold and windy day and on a warm still day. The results from the two sets of measurements were very different. The peak attenuation values measured on the warm day were consistently higher than those measured on the cold day by at least 8 dB (average difference 10 dB). It is possible that in warm weather the muff seal is more flexible and gives a closer fit.

4.3 Positioning of the outside microphone

In general muffs do not give high levels of attenuation at low frequencies. However when measurements are made close to the ground (this would be necessary if the firer was shooting from a prone position which is typical on a practice range), the low frequencies measured outside the muffs are amplified by reflection from the ground. This leads to apparent high levels of attenuation at these low frequencies which do not reflect the true performance of the muff.

4.4 Effect of individuals on measured muff attenuation

The Noise and Vibration Section have measured muff attenuation on a large number of individuals under similar conditions and the results clearly show that the performance of muffs can vary significantly depending on the fit of the muff on the individual, on their method of firing and on whether measurements are made at the left or right ear. Differences between individuals can lead to differences in measured attenuation of up to 12 dB (average difference 7 dB).

5. CONCLUSIONS

There is no standard method of measuring the peak attenuation of muffs in impulsive noise. The simple method of measuring the peak attenuation of muffs during gunfire described in this paper could also be used to measure muff attenuation in industrial impulsive noise (eg drop forging, hand hammering, stapling).

Field measurements have shown that in impulsive noise muff attenuation is affected by a wide range of factors - some due to the measurement method and some due to the behaviour of the muff on people. It will be impossible to incorporate the influence of some of these factors (eg recoil and environmental conditions) into a standard test method. Therefore results obtained using a standardised laboratory test can only be used as a guide to the actual performance of the muffs in impulsive noise.

6. REFERENCES

[1] The Noise at Work Regulations 1989, Statutory Instrument 1989 No 1790, Health and Safety
[2] British Standards Institute, British standard method for measurement of sound attenuation of hearing protectors, BS 5108: 1991

TABLE 1
Measured and predicted peak attenuation of muffs during gunfire

Type of firearm	Peak SPL dB	Muff attenuation dB					
		Linear muffs		Non-linear muffs			
				Electronic		Mechanical	
		Measured	BS 5108	Measured	BS 5108	Measured	BS 5108
12-bore shotgun	151-153	35	28	31	28	23	22
410 shotgun	147-149	19	25	25	31	12	23
rifle	153-158	37	20	36	20	28	16
.38 calibre revolver (with high velocity ammunition)	154-160	29	25	28	-	20	21
semi-automatic pistol	143-146	34	30	30	-	16	22
semi-automatic pistol	156-158	23	-	23	24	8	18
proof-firing 12-bore cartridges	135-143	33	23	27	25	17	20