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THE ACOUSTICAL ATTENUATION OF EARPLUGS AND EARMUFFS WORN SINGLY AND IN COMBINATION

R.D. Rawlinson (1) and P D Wheeler (2)

(1)Salford University Business Services Limited, Salford, UK.
(2)Racal Acoustics Limited, Wembley, London, UK.

INTRODUCTION

The Code of Practice for reducing the exposure of employed persons to noise (1) gives a method for estimating the noise levels at the ears of a person wearing hearing protection in noise. But in some high noise environments the wearing of a single hearing protector may not provide sufficient protection to the wearer. Combinations of earplugs and earmuffs are then provided although there is very little guidance available on the additional benefits of combinations of hearing protection.

This paper gives the results of two separate studies that were carried out on various combinations of protectors when assessed according to BS 5108 (2).

THE TEST METHOD

The test method, BS 5108, requires at least 10 subjects to be tested wearing the protectors. The subjects must be otologically normal and must be experienced in the test procedure. The subject is exposed to 1/3 octave filtered pink noise played through four loudspeakers. The level of the signal is controlled by the test subject. He depresses a switch when the signal is audible then releases the switch when he can no longer hear the signal. The mean signal level indicates the subjects threshold of hearing.

The subject is tested wearing the protector, or combination, and also in the unoccluded state. The difference in the mean threshold values is an indication of the protector, or combination, performance.

In the first study two muffs and two plugs were tested in particular combinations which were currently being used in industry. In the second study the choice of devices was intended to reflect the range of protectors available on the market. The devices were as follows:

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Study	Earmuffs	Earplugs
1	Racal Auralgard	Custom Moulded
	Racal Sonomuff	EAR foam
2	Safir Junior	Bilsom Soft
	Racal Sonomuff	Hearguard V51R
	Bilsom Viking	EAR foam

Only the Hearguard V51R earplug was available in several pre-formed sizes. All the subjects were measured using a proprietary ear guage. Two of the subjects were sized for an extra-large plug which was no longer made so they were given the large size instead.

Where possible test conditions were randomised across subjects. For some combinations this was impracticable because the combination test had to follow the earplug alone test.

The aim throughout the studies was to determine the typical performance likely to be found in industry rather than the optimum performance.

RESULTS

The group mean attenuation values for each device when worn alone are given in tables 1 and 2 and figures 1 and 2. Table 3 contains the manufacturers published data. Table 4 gives the attenuation results for the combinations that were tested. These results are shown graphically in figure 3.

DISCUSSION

A comparison of the single device results with the manufacturers published data shows reasonably good agreement. Only the Hearguard V51R earplug had substantially lower performance than the manufacturer indicated which is probably due to poor fitting.

Since the Racal Auralgard and Bilsom Viking earmuffs were not tested alone in these studies the attenuation values plotted in figures 1 and 2 are those published by the manufacturers.

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The group mean attenuations for the combinations, shown in figure 3, show considerable variation in performance of up to 29dB below 2kHz. Above 2kHz the attenuation values are very similar and are in close agreement with the various estimates of the bone conduction limits shown in figure 4 (3).

The results of each family of protectors are shown in Figure 5. Here the combination performance is compared to the performances of the protectors worn singly. In each case the combination gave better results than the earplug alone over the whole frequency range. But in some cases the earmuff alone was better than the combination at some frequencies.

It is apparent that the combinations' acoustical performances devices are less than the arithmetic sum of the devices' individual decibel attenuation values.

When comparing the combinations' performances for the same earplug the differences in performance do not relate to the differences in performance of the individual muffs. At 500Hz all the earplug combinations for the Racal Sonomuff gave less attenuation than for corresponding combinations with a lower volume muff. A t-test (for related samples) was carried out on the combination data for each plug at 500Hz. For the V51R earplug combinations there was no statistically significant difference in the two attenuation values. For the Bilsom soft plug the difference was significant at the 1% level and for the EAR plug and Custom moulded plug the differences were significant at the 0.1% level. No satisfactory explanation for this can be given but it clearly illustrates the unpredictability of combination performance when considered in detail. It is essential, therefore that combinations of protectors are selected by reference to BS 5108 data on actual combinations.

CONCLUSION

1. All combination attenuation results were better than the performance of the earplugs, when worn alone, but were less than the arithmetic sum of the attenuation for each device worn alone.

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2. When worn alone the Racal Sonomuff gave comparable performance at mid-frequencies to some protector combinations.

3. All the combinations gave similar results at 2kHz and above, which agree with published estimates of the bone conduction limits.

4. Below 2kHz the performance of combinations varied by up to 29dB at some frequencies.

5. All combinations using the Racal Sonomuff gave worse results at 500Hz than combinations using the same plugs with small volume earmuffs. The differences were statistically significant at the 1% level for the Bilsom Soft earplug and at the 0.1% level for the EAR and Custom Moulded earplug.

6. Where combinations of protectors must be worn, the choice of combination must be based on test data obtained for that particular combination and not on modifications to single protector test results.

ACKNOWLEDGEMENTS

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Device			Octave Band Centre Frequency, Hz									
			63	125	250	500	1k	2k	3.15k	4k	6.3k	8k
Plug 1	Custom Moulded Earplug	Mean	19.0	14.4	13.6	11.0	11.8	21.7	29.1	27.9	26.9	27.5
		SD	9.1	6.6	5.9	5.1	5.5	6.1	7.1	7.5	8.8	10.0
Plug 2	Hearguard VSIR Earplug	Mean	17.4	16.8	16.1	15.1	17.3	24.3	26.6	22.5	20.5	23.9
		SD	11.0	11.6	10.9	11.0	10.6	8.6	8.5	7.5	10.0	9.6
Plug 3	Bilsom Soft Plug	Mean	17.5	17.8	19.2	19.8	21.1	27.2	33.4	33.8	34.6	32.3
		SD	8.8	8.8	8.5	7.2	6.7	4.3	6.9	7.1	7.8	9.3
Plug 4	EAR Foam Plug - Study 1	Mean	27.5	27.8	28.0	29.3	29.6	32.1	40.2	41.4	43.8	44.7
		SD	6.9	6.4	6.6	8.0	7.2	5.2	4.0	3.4	4.3	6.0
Plug 4	EAR Foam Plug - Study 2	Mean 2	23.1	25.3	27.0	29.6	30.5	31.6	38.5	39.0	41.0	38.8
		SD	11.0	11.4	10.1	9.7	7.6	4.5	2.9	4.3	6.0	7.0

TABLE 1: Real-Ear Attenuation of Individual Protectors According to BSS108 (1983): Earplugs

Muff	Device		Octave Band Centre Frequency, Hz									
			63	125	250	500	1k	2k	3k	4k	6k	8k
1	Racal Auralgard		Not Tested Alone									
2	Racal Sonomuff	Mean	19.2	21.0	27.0	30.1	37.9	37.3	39.4	39.7	36.7	38.3
		SD	3.4	3.4	3.6	4.6	3.2	3.2	3.5	4.1	5.4	5.0
3	Sefir Junior	Mean	9.3	8.3	9.0	15.7	25.4	29.9	36.1	36.8	30.8	30.2
		SD	5.2	5.4	4.2	4.7	4.7	5.0	4.9	6.1	7.5	5.0
4	Bilsom Viking		Not Tested Alone									

TABLE 2: Real-ear Attenuation of Individual Protectors According to BS 5108 (1983): Earmuffs

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	Device		Octave Band Centre Frequency, Hz									
			63	125	250	500	1k	2k	3.15k	4k	6.3k	8k
Plug 1	Custom Moulded Earplug		Not Available									
Plug 2	Hearguard V51R Pre-moulded Earplug	Mean	22.2	22.7	21.7	22.1	24.6	28.5	33.4	30.4	28.8	30.2
		SD	8.0	7.5	7.2	8.4	8.5	5.8	5.1	4.8	8.8	6.6
Plug 3	Bilsom Soft Earplug	Mean	19.8	19.9	20.0	22.2	24.1	30.7	38.8	41.4	41.5	40.8
		SD	7.5	7.8	6.4	4.9	3.5	4.3	4.5	4.7	4.5	5.9
Plug 4	EAR Foam Earplug	Mean	27.2	27.9	28.3	30.4	30.8	32.5	40.6	41.3	42.2	41.4
		SD	8.6	9.2	8.1	8.5	7.4	5.3	4.2	4.2	5.4	8.2
Muff 1	Racal Auralgard	Mean	18.3	16.9	15.6	22.6	34.4	33.5	41.0	40.3	33.6	34.7
		SD	4.1	2.9	2.0	2.5	2.9	3.4	3.8	4.5	3.0	3.2
Muff 2	Racal Sonomuff	Mean	18.0	19.0	21.0	28.0	35.0	35.0	38.0	39.0	35.0	36.0
		SD	5.1	4.3	3.9	4.9	4.2	3.6	3.3	4.3	3.9	4.7
Muff 3	Safir Junior	Mean	-	8.5	9.8	16.8	26.7	33.0	38.8	38.3	34.8	32.7
		SD	-	3.4	3.8	3.1	3.3	4.7	5.5	4.4	5.8	6.2
Muff 4	Bilsom Viking	Mean	14.5	13.5	20.5	33.0	34.1	35.9	37.1	36.7	36.7	33.0
		SD	4.8	3.9	4.2	5.4	5.1	4.4	4.2	5.3	6.0	6.4

TABLE 3: Manufacturers' Published Attenuation Data According to BS 5108

Device		Octave Band Centre Frequency, Hz									
		63	125	250	500	1k	2k	3.15k	4k	6.3k	8k
EAR Plug: Safir Junior	Mean	28.8	33.5	38.3	46.0	41.9	38.2	44.4	46.5	45.5	46.1
	SD	8.9	10.0	8.3	7.6	4.9	3.8	4.1	4.3	4.6	4.1
EAR Plug: Racal Auralgard	Mean	30.5	33.3	36.1	43.0	41.7	39.9	46.2	48.6	48.0	44.0
	SD	6.2	8.2	8.4	9.0	6.4	4.0	2.6	3.8	4.7	5.7
EAR Plug: Racal Sonomuff - Study 1	Mean 1	32.9	35.0	36.2	35.9	40.7	39.9	45.5	49.0	48.5	48.4
	SD	7.4	5.8	7.2	10.1	6.7	4.3	2.6	2.8	4.2	5.5
EAR Plug: Racal Sonomuff - Study 2	Mean	29.2	36.3	38.3	38.1	42.1	37.2	43.6	46.0	45.5	46.5
	SD	8.3	7.6	7.4	10.1	4.5	3.0	2.6	3.6	4.6	4.5
EAR Plug: Bilsom Viking	Mean	27.3	30.6	41.0	47.9	43.0	38.7	42.5	47.6	46.3	47.8
	SD	4.9	6.6	5.9	7.0	6.0	3.5	3.7	3.5	4.0	4.0

TABLE 4: Real-Ear Attenuation of Combinations, According to BS 5108 (1983)

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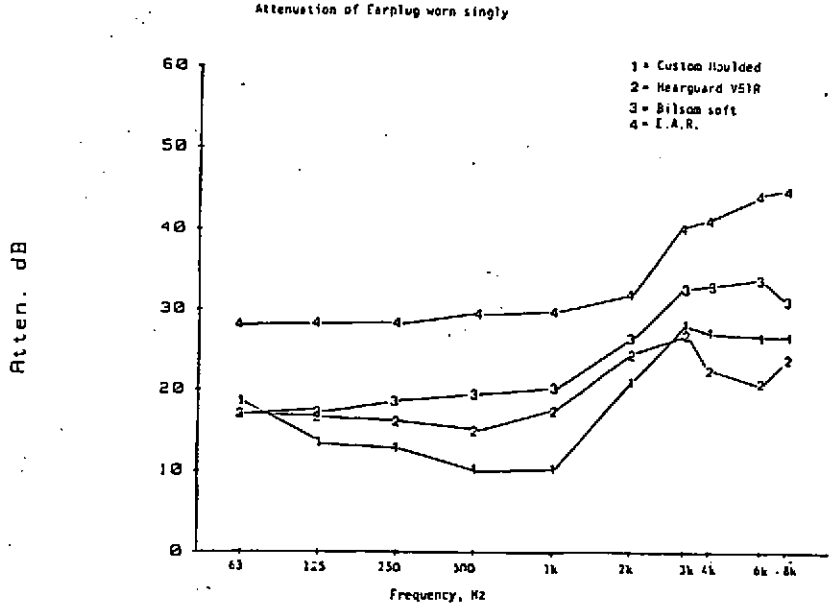

Fig. 1

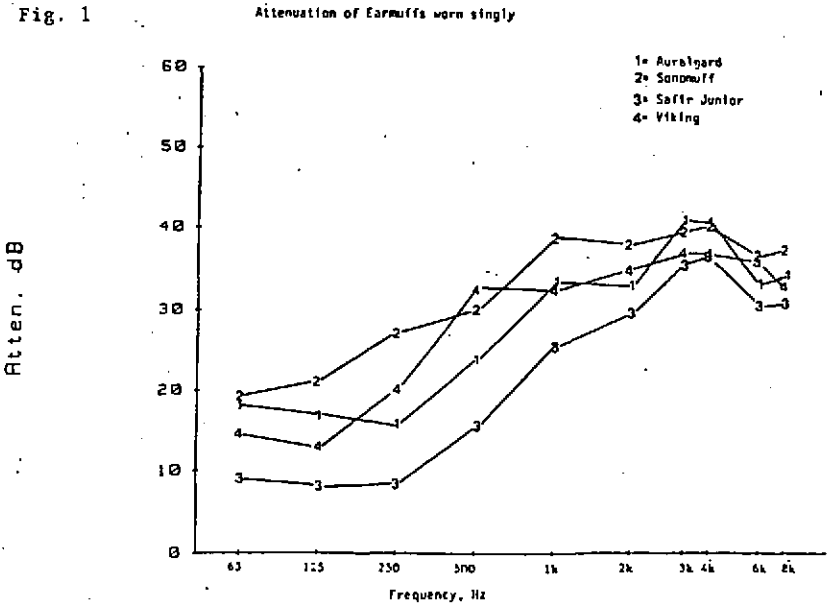

Fig. 2

THE ACOUSTICAL ATTENUATION OF EARPLUGS AND EARMUFFS WORN SINGLY AND IN COMBINATION

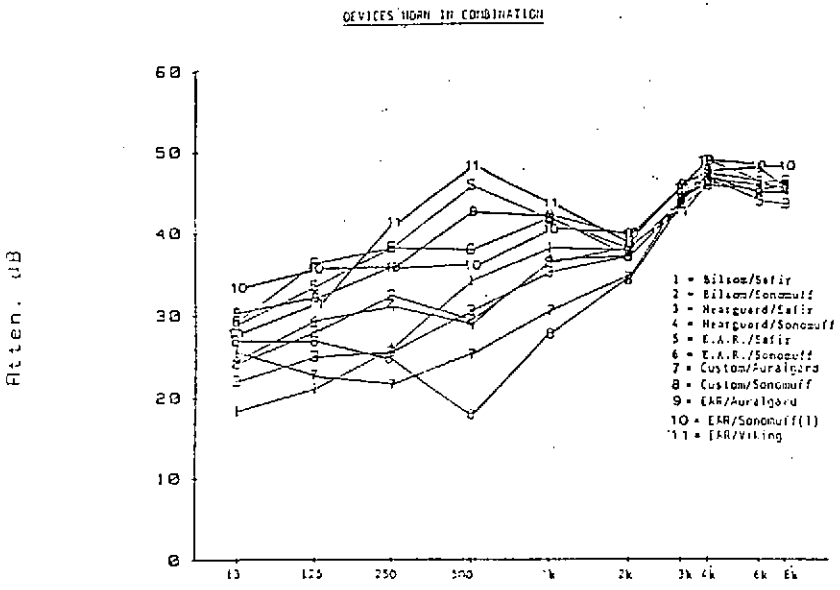

Fig. 3

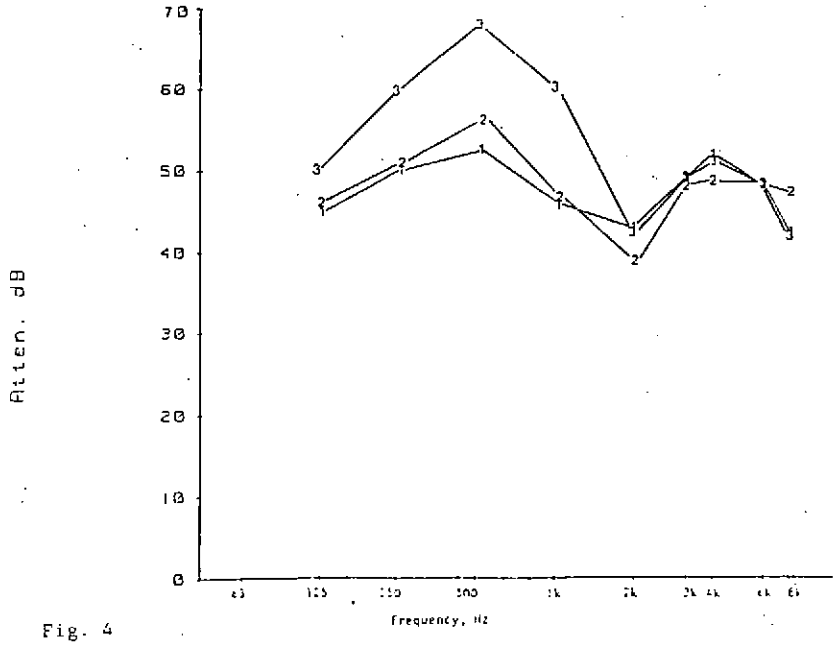

Fig. 4

THE ACOUSTICAL ATTENUATION OF EARPLUGS AND EARMUFFS WORN SINGLY AND IN COMBINATION

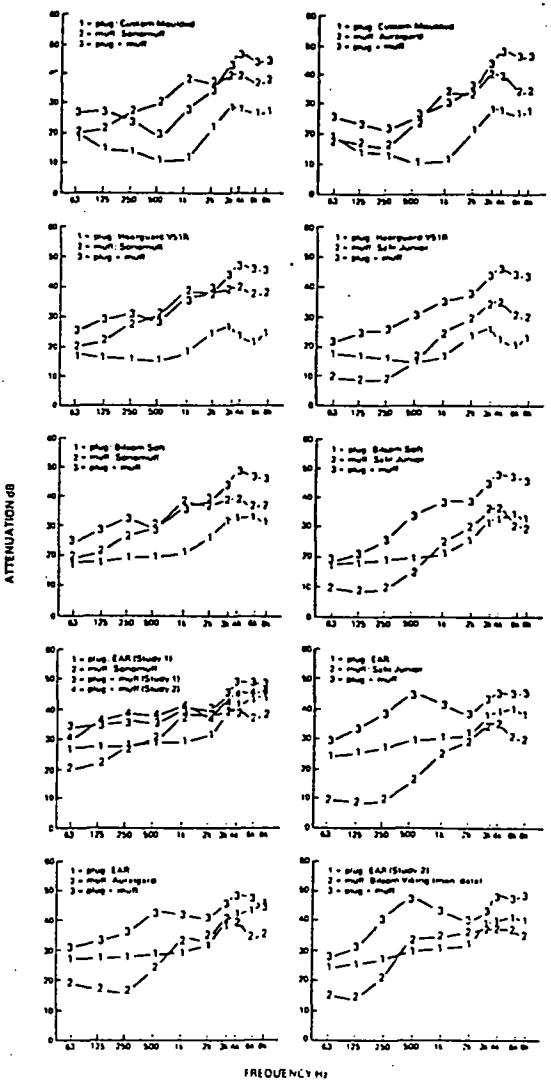

FIG. 5. Attenuation of plugs, muffs and plug/muff combinations.