# AN EXPLANATION FOR THE APPARENT POOR PERFORMANCE OF SOME HEARING PROTECTORS

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Abstract: Hearing protectors do not always perform as well as manufacturers and distributors would wish. Sometimes the attenuation ratings fall well below what was expected. On close examination of the test data it can sometimes be seen that the results are spread over a very wide range thus producing a lower than anticipated mean value and a large standard deviation. In Australia and New Zealand the rating of a hearing protector depends on the value of the mean attenuation minus one standard deviation at seven octave band centre frequencies of one-third octave wide filtered pink noise. A low mean and large standard deviation can reduce the hearing protector rating significantly. Recent work indicates that present methods of analysing data may not always be satisfactory. Perhaps bimodal or other analysis techniques are more appropriate.

## 1. INTRODUCTION

It sometimes happens that when hearing protectors are tested in accordance with the requirements of combined *Australian/New Zealand Standard AS/NZS 1270:2002 Acoustics – Hearing protectors* [1] and its precursors, that in the view of the manufacturer/distributor/supplier, unexpected results are obtained.

Sometimes the test results conclude with an unexpected high attenuation. Though this is not the usual case. The most common difficulty for laboratories is when an unexpected low attenuation results from the testing of a device when the manufacturer was expecting to achieve a high attenuation. Frequently this will be a 'new' or innovative device on which great hopes and expectations were placed for competitive entry into a new market segment. The company who requested (and paid for) the testing wants an explanation from the testing laboratory as to why the device has not performed up to their expectations.

This "low attenuation" performance is not limited to any particular device type or style. It occurs across the board with ear plugs, ear muffs, canal caps, helmet mounted muffs, corded and uncorded plugs. The precise reason for this 'underperformance' is currently unclear.

## 2. BACKGROUND

In a recent paper Murphy and Franks [2] have suggested that the modelling of hearing protector attenuation test results through the accepted procedure of using a normal distribution and applying the associated statistics may be flawed. The reason for the low attenuation was not addressed but rather they suggested that the traditional method of 'processing' the experimental results may be inappropriate.

Murphy and Franks analysed the ANSI [3] and ISO [4] test results from several sets of ear plugs and one set of earmuffs using statistics for a normal Gaussian distribution and for a bimodal distribution. They found that in many cases bimodal data fit was much more appropriate than a normal distribution. Their conclusion was that "*standards could be based on empirical quantiles which do not assume any particular attenuation distribution*" (p 2115) rather than specific assumptions and that perhaps a bimodal fit would be most appropriate.

In Australia and New Zealand acoustic testing of hearing protectors is carried out using a "subject fit" methodology. This is where the test subject is allowed to fit the hearing protector using the instructions supplied by the manufacturer but the tester is not allowed to interfere in this fitting process. To assist the test subject to produce the maximum attenuation 'fitting noise' the subject is supplied with an instruction from the tester "*so that you can adjust the protectors for good noise reduction*" [1, p. 26].

The argument has been made [5] that without the experimenter (tester) being able to be directly involved in the hearing protector fitting the results that are obtained may be sub-maximal. Conversely others argue that the subject fit method more realistically approaches what can be expected in the workplace when individuals are provided hearing protectors as part of an occupational noise management program. At the present time in Australia and New Zealand the second argument holds sway. The subject fit procedure is gaining credence internationally with discussions underway for an International Standard [4] utilising a subject fit protocol very similar to that of AS/NZS 1270.

## 3. THEORY

Currently the suggestion of Murphy and Franks [2] to use a bimodal model appears to fit the available data. Very simply, this model assumes that the measured test data arises from two separate and distinct causes that are indistinguishable during the course of testing.

The two sets of data are able to be described by normal Gaussian distributions, $N_1$ and $N_2$, respectively. Thus the overall distribution of test data can be described using a distribution function that is simply a linear combination of the two normal distributions. This combined distribution function $N_{1+2}$ can be written as,

$$N_{1+2} = k\,N_1 + (1-k)\,N_2.$$

The distribution functions $N_1$ and $N_2$ can be found using cluster analysis and $k$ is a proportionality constant, directly related to the number of sample points from each cluster, ranging between 0 and 1. The more the two distributions overlap, ie the closer the two means and more similar the standard deviations, the more the combined distribution resembles a single normal distribution.

## 4. ANALYSIS OF SPECIFIC DATA

When a hearing protector is acoustically tested, attenuation is determined for each of seven test signals. These test signals consist of one-third octave bands of noise, filtered from a pink noise source and centered on octave band center frequencies. The seven attenuations along with their respective standard deviations are combined as described in AS/NZS1270, Appendix A, to give the $SLC_{80}$ rating and subsequent Class of the hearing protector.

The data on which the statistical analysis is carried out is the attenuation at each one-third octave band. Thus it is here that the test of bimodality is applied. Several examples of octave band data have been chosen from tests recently carried out at the National Acoustic Laboratories.

For commercial-in-confidence reasons the particular devices that were under test have not been specified. Also it should be noted that a hearing protector that performs poorly in one particular test band does not necessarily perform poorly over all test bands. However, poor performance in one test band can markedly affect the overall rating of a device.

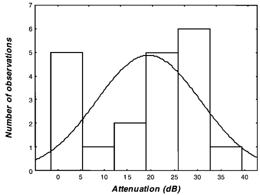


Figure 1: Attenuation results (dB) at 125 Hz for ear plug A, with superimposed normal distribution.

Consider the test results from ear plug A. The attenuation of this particular device in the 125 Hz band for each test subject was given in Table 1.

If this data is treated as being normally distributed it has a mean of 19.5 dB and a standard deviation of 11.1 dB. This distribution of data is illustrated in Figure 1. As can be seen from the superimposed normal Gaussian curve the distribution of the data is far from normal showing two distinct peaks.

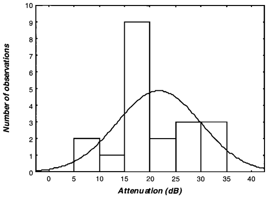


Figure 2: Attenuation results (dB) at 125 Hz for ear plug B, with superimposed normal distribution.

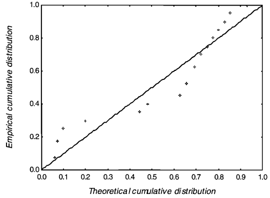


Figure 3: Probability – Probability plot for the attenuation of earplug A at 125 H

However, if the data is regarded as being distributed in a bimodal manner the result is two independent, normal distributions, $N_1$ and $N_2$, with means and standard deviations of 4.2, ±3.1 dB and 26.1, ±4.7 dB respectively, and $k = 0.30$. For this ear plug a mean attenuation of 4.2 dB would be regarded as a 'poor fit' while 26.1 dB would be seen as an 'acceptable' value. For these results it is clearly demonstrated that the results from the 'poor fit' subjects draw down the results of the 'acceptable fit' subjects.

Table 1: Individual attenuation in dB obtained by 20 test subjects for ear plug A at 125 Hz.

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| dB | 24 | 5 | 10 | 27 | 28 | 36 | 24 | 18 | 25 | 25 | 19 | 30 | 2 | 29 | 26 | 23 | 2 | 3 | 3 | 31 |

Table 2: Individual attenuation in dB, 20 test subjects, for ear plug B at 125 Hz.

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| dB | 18 | 24 | 10 | 19 | 35 | 16 | 19 | 7 | 16 | 19 | 30 | 25 | 30 | 18 | 13 | 35 | 17 | 35 | 26 | 20 |

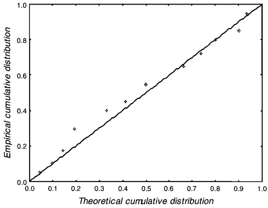


Figure 4: Probability – Probability plot for the attenuation of earplug B at 125 Hz

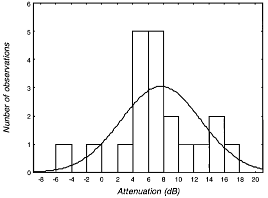


Figure 5: Attenuation results (dB) at 125 Hz for helmet mounted ear muff, with superimposed normal distribution

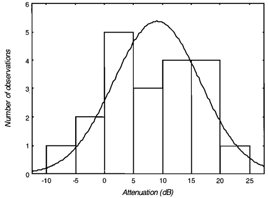


Figure 6: Attenuation results (dB) at 250 Hz for helmet mounted ear muff, with superimposed normal distribution

In the particular example cited above there are approximately six test results that could be interpreted as being due to 'poor fit'. It would be tempting to put forward an argument that under the guidance of some declared criteria test subjects with a "low" and "high" attenuation results be respectively divided into two groups and the data processed separately. However, it must be remembered that attenuation is tested at seven one-third octave bands and subjects that record a low attenuation in one particular one-third octave band do not necessarily record low attenuation results in other one-third octave bands.

Compare the above results for ear plug A with those for ear plug B tested at 125 Hz in Table 2. Here the mean attenuation is 21.9 dB with a standard deviation of 8.1 dB. The distribution of the data is illustrated in Figure 2 with the accompanying expected normal curve. It can be seen that this distribution is much better approximated by a normal Gaussian curve. Hence normal statistics can adequately describe the characteristics of this device.

The tendency to normal distribution is better described through the use of a *probability – probability* plot where, by definition, a normal Gaussian distribution is defined by a straight line. This is shown in Figures 3 and 4 for earplugs A and B respectively where ear plug B conforms to the straight line fit of a normal distribution as compared to ear plug A.

Consider now difficulties exhibited with the same hearing protector (a helmet mounted ear muff) at adjacent test frequencies from the same test population. The protector has not been removed or in anyway adjusted between these two test frequencies and the resulting attenuation is an average of three measured thresholds out of five, the first two being discarded as they are considered to be practice runs at the particular one-third octave band.

Figures 5 and 6 show the distribution of attenuation test data for the helmet mounted ear muff at the two adjacent test frequencies of 125 Hz and 250 Hz and their respective suggested 'normal' distribution curves. The actual distribution of the data indicates that there is a great deal of difference in both the spread and the concentration of the results. The degree of kurtosis exhibited by both curves is very different with the kurtosis of Figure 5 being 0.27 and Figure 6 –0.90.

## 5. DISCUSSION

As can be seen from the above analysis of a limited number of test results the assumption that hearing protector test data is normally distributed may lead to conclusions that do not accurately represent the true performance of the hearing protector in question. Although analysis was only demonstrated on a limited number of data sets the general principle of different possible distributions is clearly illustrated.

As proposed by Murphy and Franks [2] the use of a bimodal distribution describes many data sets that are not well described by normal statistics. However, the question arises "are there only two factors governing the attenuation test data – normal and bimodal?" With relatively limited data points from standard test procedures some further "attenuation" factors could be overlooked. Situations could exist where not only are there 'poor fits' and 'acceptable fits' but there may also be some intermediate results arising from other various causes. Thus there may be a variety of distributions involved.

Possibly what statistics to apply will not be known until what is causing the attenuation that is being measured is more fully understood. 'Poor' fit could be caused by behavioural or educational difficulties such as individuals not following the fitting instructions; unclear fitting instructions; or intentional poor fitting for whatever reason. However, the poor fit could also be caused by physical constraints such as poor design or some anatomical feature of the head, ear or ear canal that has yet to be fully considered.

Further investigation into the causes of significant steps in the attenuation of some hearing protectors needs to be carried out.

## 7. ACKNOWLEDGEMENTS

I would like to acknowledge the assistance of Geoff Colin-Thome at NAL for his assistance in gathering the test data and Richard Fraccaro from StatSoft Pacific for his assistance in analysing the bimodal data.

## 8. REFERENCES

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