Improved calculation for hearing protector performance

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ABSTRACT

A variation in the method of calculating the attenuation performance of hearing protectors can produce a simple relationship between overall performance and a single standard deviation. This outcome facilitates easier comparison of the statistical performance between hearing protectors and allows for a less complex error analysis procedure. For example, one such comparison reveals a strong negative correlation between attenuation and standard deviation which has important implications on the perceived performance of hearing protectors for the end user and may partially explain why, particularly in 'low' noise environments, hearing protector programs are not as successful as they should be. This method of analysis is compatible with any single number rating such as NRR, SNR or SLC_{80}.

INTRODUCTION

Current subjective test methods for hearing protector attenuation determination in use around the world follow a similar procedure with the main differences being in the individual detail and not the overall philosophical concept (EN 458: 1993; ISO 4869-2: 1994; ANSI S12.6 – 1997; AS/NZS 1270: 2002; CSA Z94.0 – 02). Suitable, individual test subjects have their binaural hearing threshold levels determined for un-occluded and occluded ears under specified free field listening conditions using an acceptable psychoacoustic test method. The hearing threshold test levels are determined at recognised octave band frequencies using either pure tone or 'filtered' pink noise. The differences between the un-occluded and occluded threshold levels are then used to determine the attenuation of the device.

The attenuation figures for each octave band frequency are calculated statistically, producing a mean value and standard deviation. These attenuation figures are then either used individually as in the case of an Octave Band specification or they may be combined to produce a single figure (NRR, SNR, SLC_{80}), or several figures (HML, HML-check). The details provided to the end user depends on many factors but are usually governed by the occupational health and safety requirement under which it is anticipated the hearing protectors will be used.

Even under ideal conditions not all individuals will receive the same attenuation for the same device under what would be regarded as the same conditions. Variations arise due to personal characteristics, variations in test procedures and test-retest variability. These variations are expressed in the standard deviations of the test results.

These variations mean that different individuals receive different levels of attenuation both simultaneously and from time-to-time. To date these variations in the test attenuations have been incorporated in the resulting overall attenuation specification through various methods. Commonly this is done by subtracting a multiple of the standard deviation from the mean attenuation at each octave band based on the assumption that, statistically, a predictable number of individual end users will receive a minimum attenuation. For example, SNR and SLC_{80} both use the mean minus one standard deviation in order to adequately specify the attenuation performance for approximately 80% (more exactly 84%) of the end users at any one time, while NRR utilises the mean minus two standard deviations to cover approximately 98% of end users.

This mean minus a multiple of the standard deviation procedure is applied at each octave band. Difficulties arise when trying to determine the overall performance of a device. For example, when using a single number rating procedure attenuations from the each respective octave band must be combined using a prescribed method to result in the single rating (EN 458: 1993; ISO 4869-2: 1994; ANSI S12.6 – 1997; AS/NZS 1270: 2002). A statistical decision is made that, for example, in the case of NRR, 98% of the population is covered by each mean minus two standard deviations of attenuation and that mean attenuations and their respective standard deviations are independent. This is not necessarily the case and the use of the means and standard deviations in this manner inhibits further simple comparison of performance data and makes unnecessarily difficult error analysis.

METHOD

For this paper we will utilise the calculation of SLC (Sound Level Conversion) (Botsford: 1973) and the SLC_{80} as described in AS/NZS 1270: 2002. The octave band test data from the AS/NZS 1270 test procedure is analysed as demonstrated in *Table 1*.

There are n test subjects, S_n, each tested at m octave bands, B_m, resulting in a mean attenuation at each octave band, M_m a standard deviation at each octave band, SD_m, and a *'performance attenuation'* at each octave, A'_m. The overall performance attenuation is a function of the mean attenuation and in the case of SLC is calculated using the formula:-

$$SLC = 100 - 10 \log_{10} (\Sigma_{fj} 10^{0.1(Rfj - Mfj)}), \quad (1)$$

where R_{fj} = reference octave band spectral levels;

(71, 81, 89, 93, 95, 93 & 86 dB)

M_{fj} = mean attenuated level at f_j Hz; and

f_j = octave band centre frequencies @

125, 250, 500, 1k, 2k, 4k & 8k Hz.

This SLC is the mean performance of the device or the attenuation that can be expected to be experienced by 50% of the users at any one time. This can be thought of as an SLC_{50}.

Table 1

Data for the calculation of SLC and SLC_{80}

Subject number	Attenuation at Octave Band Centre frequencies (dB)			
	B_1	**B_2**	**…**	**B_m**
S_1	A_{11}	A_{21}	…	A_{m1}
S_2	A_{12}	A_{22}	…	A_{m2}
…			…	…
S_n	A_{1n}	A_{2n}	…	A_{mn}
Octave Band Mean	M_1	M_2	…	M_m
SD	SD_1	SD_2	…	SD_m
Mean-SD	A'_1	A'_2	…	A'_m

However, in the practical situations where these devices are meant to be used we wish to ensure that more than half of the wearers are adequately protected. To do this we use the SLC_{80}. The calculation of the SLC_{80} involves the substitution of the (mean – one standard deviation) rather than the mean attenuation in equation (1). This is then the performance that can be expected to be experienced by approximately 80% of the users at any one time.

Complications now arise when we wish to calculate the standard deviation of the final performance figure for the device. There are several standard deviations that need to be combined. These standard deviations are not necessarily independent just as the attenuations at adjacent (and further) octave bands are not necessarily independent. Conventionally, however, any interdependency has been ignored. Inter-comparison of hearing protector performance has also been difficult as we do not end up with a single performance figure and an associated standard deviation or error indicator, rather just a single performance figure effective for a given proportion of the population. Some users have tried to use an average of the octave band standard deviations as an error performance measure but this has not been satisfactory.

We can now look at a variation to the calculation applied in this case to the SLC process, demonstrated through the use of *Table 2*.

This time the same equation (1) is used but the individual performance of the device is calculated for each subject, the $iSLC_n$. The mean of these individual performance figures gives the *mi*SLC, while the *mi*SLC minus the standard deviation gives the $miSLC_{80}$ for the population.

This variation in procedure results in a transparent process for end users in that they can apply simple statistical theory in order to understand why, say, 80% of the population is covered by a particular attenuation.

Table 2

Data for the calculation of miSLC and $miSLC_{80}$

Subject number	Attenuation at Octave Band Centre Frequency (dB)				***i*SLC (dB)**
	B_1	**B_2**	**…**	**B_m**	
S_1	A_{11}	A_{21}	…	…A_{m1}	$iSLC_1$
S_2	…A_{12}	A_{22}…	…	A_{m2}	$iSLC_2$
:	…	…	…	…	
S_n	A_{1n}	A_{2n}	…	A_{mn}	$iSLC_n$
				Mean	*mi*SLC
				SD	*i*SD
				Mean - SD	$miSLC_{80}$

Confirmation of the direct correspondence between the existing and the proposed new calculation procedure is simply made by a direct comparison. In the case of the combined *Australian/New Zealand Standard AS/NZS 1270: 2002* which specifies the SLC_{80} procedure, the results of the comparison of 115 hearing protectors tested at the National Acoustic Laboratories over the last two years including ear plugs, ear muffs and helmet mounted ear muffs is shown in *Figure 1*. The correlation between the old and new is seen to be excellent considering that mathematically the two performance figures are not the same.

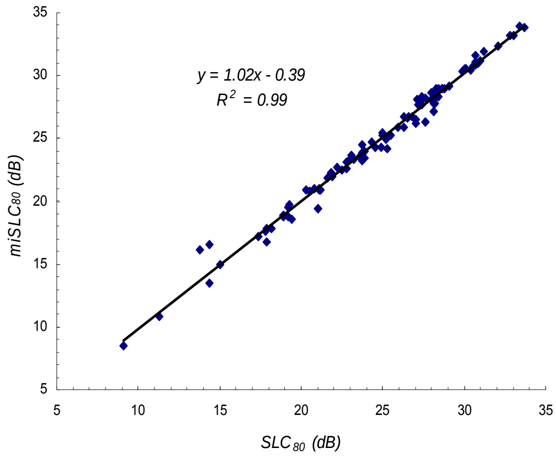

Figure 1: Comparison of hearing protector performance calculated by the conventional method, the standard SLC_{80}, versus the new calculation, in this case the mean individual SLC_{80} ($miSLC_{80}$), using the suggested variation showing the close correlation between the two figures.

A comparison of the relationship between the average octave band standard deviation and the single standard deviation is illustrated in *Figure 2*. As can be seen the average octave band standard deviation tends to be larger than the individual standard deviation. This is an indication of possible non-independence.

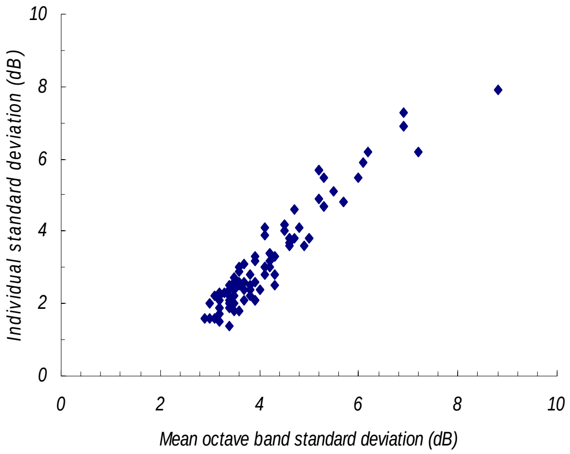

Figure 2: The relationship between the mean of the individual octave band standard deviation and the standard deviation of the overall attenuation performance.

The fact that the mean standard deviation is, in general, larger than the individual standard deviation implies that the *mi*SLC_{80} tends to be greater than the SLC_{80}.

DISCUSSION

Now that we have achieved a single standard deviation it is easier to determine such parameters as confidence intervals or expanded uncertainties and to carry out an error budget analysis. Perhaps more importantly direct comparisons of parameters can be made across hearing protectors.

Using the same 115 hearing protectors from above it is constructive to plot the standard deviation of the hearing protector against the attenuation performance. This is displayed in *Figure 3*.

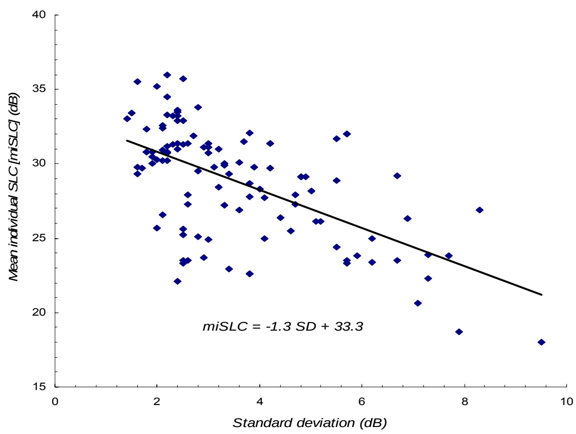

Figure 3: A plot of hearing protector performance calculated by the suggested variation in the method, the mean individual SLC (miSLC), versus the standard deviation for all tested hearing protectors showing a strong negative correlation.

From *Figure 3* the line of best fit shows that there is a strong negative correlation displayed between hearing protector performance and standard deviation, something that with the current method of calculation would be difficult to display quite so clearly. The relation between the two values can be expressed as,

$$miSLC = 33.30 - 1.26\ SD,\ (R^2 = 0.36).$$

The coefficient of determination, R^2, implies that a large proportion of the variation of the performance of the device, approximately 36%, is explained by the standard deviation. This means that as device attenuation becomes less, the distribution of the results becomes much broader in character (platykurtic). Ideally hearing protector attenuation should not show any correlateion with standard deviation.

The presentation of test results as per *Figure 3* can allow us to interpret hearing protector use in a different light. For example, we can readily see that as the value of the rating of the hearing protector decreases there is a general corresponding increase in its standard deviation. This means that for users of hearing protectors with low attenuation there is a much broader spread in performance compared to users of high attenuation devices. Hence, those who use hearing protectors in low noise environments requiring less attenuation will experience a wide range of attenuation and may find such a variation annoying. This could then lead to inconsistent hearing protector use, an undesirable outcome.

The experience of overprotection that many users may experience could also be a significant factor operating against the success of hearing protector programmes.

A further relationship that can be displayed is that between the clamping force and attenuation (excludes ear plug data).

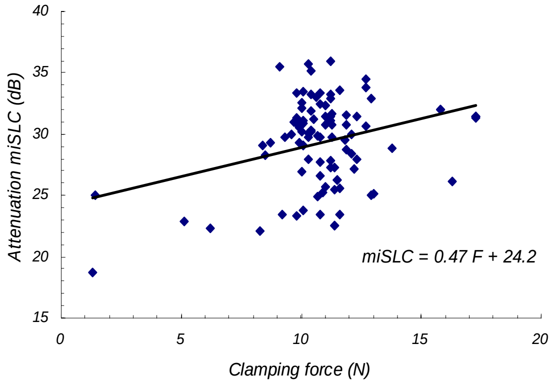

Figure 4: The relationship between clamping force and attenuation

The line of best fit (*Figure 4*) shows a general tendency toward an increase in attenuation with increasing clamping force. Intuitively this is a reasonable result. However, there is a large cluster of devices that have a clamping force in the range of 10 to 13 Newtons with a spread of attenuation values from 22 to 31 dB, indicating an influence of factors other than clamping force alone that need to be more fully explored.

A further relationship for examinination is that between clamping force and the *mi*SLC standard deviation (*Figure 5*). This shows that there is a small overall trend for the standard deviation to decrease as the clamping force increases, again a reasonably intuitive result, but the wide scatter of results shows that there is obviously a large dependency on other factors that require greater examination.

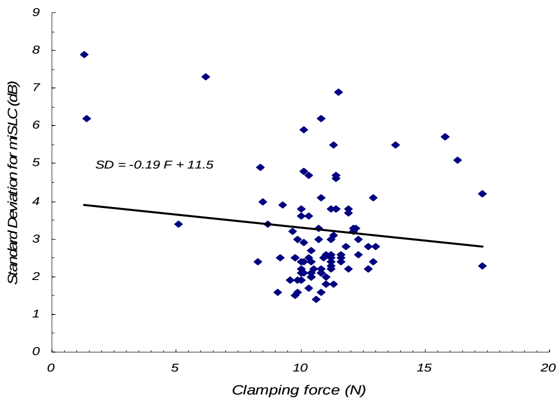

Figure 5: The relation between clamping force and the overall standard deviation of the attenuation of the device

If we wish to carry out an error calculation or determine an uncertainty budget for the measurement of attenuation we would normally use, in the case of SLC_{80}, all seven standard deviations arising from the attenuation measurements at the seven octave bands. However, with the improved method we need use only the one standard deviation produces, simplifying the process considerably.

CONCLUSION

The improved method for calculating the attenuation performance of hearing protectors results in an individual performance figure for each test subject followed by averaging across subjects. This is in contrast to the current methods which use the averaging of attenuation performances at specified octave bands followed by the calculation of an overall performance figure. There would be no real advantage if we only required an average performance. However, we usually wish to improve on hearing protector effectiveness by doing better than average, for example, by protecting at least 80% or more of the users and this is when difficulties arise.

The suggested variation in the analysis of hearing protector test data provides a significant advantage when examining the general performance of hearing protectors and provides an opportunity to compare the overall performance of individual devices. The use of a single standard deviation simplifies the error calculation process required for the presentation of the reliability and validity of attenuation test data by reducing the number of standard deviations.

By adopting the improved method of analysis we provide the same overall objective and a tool that permits simple inter-comparisons of performance parameter for suppliers of hearing protector with no apparent change for the end user.

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