A VARIATION TO THE SOUND LEVEL CONVERSION MEASURE OF HEARING PROTECTOR PERFORMANCE

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Abstract This work looks at a variation in the method of calculating the single number rating of hearing protector attenuation performance, the SLC_{80}. The resulting figure has a slight variation from the current method of calculation but comparison with 111 devices that had recently been tested shows that in practice this difference is minimal. The advantage of the variation in the method is that the uncertainty in attenuation performance is reduced to one standard deviation replacing the conventional seven standard deviations. This makes for easier error analysis and future statistical analysis of the relative performance of different devices.

1. INTRODUCTION

For many years in both Australia and New Zealand the Sound Level Conversion (SLC) method (Botsford: 1973) and in particular the SLC_{80} method (Waugh: 1973, 1976) has been used to estimate the effective at ear noise level of individuals who are wearing hearing protectors in noisy situations. Currently the SLC_{80} figure is also the basis of the simplified classification system (Williams: 1999) for the specification of hearing protectors as detailed in combined *Australian/New Zealand Standard AS/NZS 1269.3: 2005 Occupational noise management Part 3 – Hearing protector program*.

The SLC_{80} is more closely defined in *AS/NZS 1270: 2002* and represents the minimum attenuation provided to approximately 80% (strictly 84%) of the users of a hearing protector when wearing the protector appropriately. The intention of the SLC_{80} is to provide a realistic figure for the attenuation of a hearing protector when used in a real life situation. It is intended to provide neither an overestimate nor under estimate of attenuation performance.

The SLC_{80} is one of a number of single number rating systems currently in use around the world for specifying the attenuation of a hearing protector. It is very similar in character to the North American NRR (Berger: 1986, p 329) and European SNR (EN 458: 1993). Being single number rating systems based on the work by Botsford (1973) the discussions that are presented in this paper in relation to the SLC_{80} can apply to both NRR and SNR.

2. METHOD

The method of calculating SLC_{80} is based on the experimental procedure detailed in *AS/NZS 1270: 2002*. This involves a subject-fit test whereby the occluded and un-occluded hearing thresholds of the volunteer test subjects are measured. This is done at seven octave band centre frequencies by exposure to one-third octave band width, filtered pink noise. The attenuation is calculated from the occluded – un-occluded difference in hearing threshold level. In the case of ear muffs there are a minimum of 16 test subjects required while for ear plugs the number is 20. For the SLC_{80} calculation at each octave band a mean attenuation and standard deviation is determined. *(Note: For the requirements of AS/NZS 1270: 2002 a calculation of the SLC of a hearing protector is not necessary)*

From a predefined reference spectrum[1], the mean attenuation of the device at each octave band is subtracted in order to get the attenuated spectrum under the device. The difference between the overall value of the reference spectrum and the attenuated spectrum provides the single figure performance or SLC of the device. This is summarised in the formula:-

$$SLC = 100 - 10\log_{10}\left(\Sigma_{fj}10^{0.1(R_{fj} - M_{fj})}\right), \tag{1}$$

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 value is the SLC of the device experienced by the average user and exceeded by 50% of the users. This value could be thought of as the average SLC or the SLC_{50}. In order to calculate the SLC_{80} instead of using the mean attenuated level the mean minus one standard deviation attenuated level is employed. So

$$SLC_{80} = 100 - 10\log_{10}\left(\Sigma_{fj}10^{0.1(R_{fj} - M'_{fj})}\right), \tag{2}$$

where M'_{fj} is now the mean attenuated level minus one standard deviation at octave band f_j Hz. Strictly speaking in statistical terms we should refer to this as the SLC_{84}, however, for simplicity SLC_{80} is used.

This method of calculating the SLC_{80} has served well for many years. However, it does suffer from one serious drawback in that it contains seven standard deviations from

1. This spectrum is 'defined' in AS/NZS 1270 as being 100 dB overall with components of 71, 81, 89, 93, 95, 93 and 86 dB at Octave Band centre frequencies of 125, 250, 500, 1k, 2k, 4k and 8k Hz respectively

Table 1 Attenuation test results for a typical set of ear muffs

	Octave Band centre frequency (Hz)								
Subject	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz	iSLC	
S1	15	18	35	37	35	45	46	33.9	
S2	2	10	22	35	35	25	31	24.7	
S3	11	25	33	41	39	36	41	35.4	
S4	13	20	28	32	35	37	38	32.3	
S5	8	15	30	34	35	38	32	30.4	
S6	11	23	27	34	35	33	41	32.2	
S7	4	16	22	23	27	30	30	25.0	
S8	20	20	26	27	25	29	36	27.0	
S9	-1	13	18	32	23	33	38	22.8	
S10	8	15	25	38	33	35	32	29.5	
S11	13	18	28	38	31	39	37	31.6	
S12	18	24	31	35	40	37	28	34.8	
S13	8	18	33	33	31	33	38	30.5	
S14	12	13	18	32	33	37	22	25.9	
S15	10	21	31	33	34	34	43	32.2	
S16	2	3	13	23	25	24	21	18.5	
Mean	**9.6**	**17.0**	**26.3**	**32.9**	**32.3**	**34.1**	**34.6**	29.2	***miSLC***
SD	**5.8**	**5.6**	**6.2**	**5.0**	**5.0**	**5.3**	**7.1**	4.7	***SD***
Mean - SD	**3.8**	**11.4**	**20.0**	**27.9**	**27.3**	**28.8**	**27.5**	24.5	***miSLC*$_{80}$**

SLC	30.2
SLC_{80}	24.6

the seven octave band attenuations and any error analysis of the result must use the seven standard deviations. The seven octave band attenuations are required for the Octave Band method for hearing protector selection.

An alternative procedure is to calculate an individual SLC (*i*SLC) for each test subject using equation (1) by substituting the individual attenuated level at each octave band. An average of the *i*SLCs then produces a mean *i*SLC (*mi*SLC). By subtraction of the standard deviation we have an *mi*SLC_{80}. The total error for *mi*SLC_{80} is calculated using the single standard deviation.

Since the introduction of the current method of attenuation testing in *AS/NZS 1270:2002* in 2002 there has been a total of 111 devices (98 ear muffs and 13 ear plugs) tested at NAL that were suitable for inclusion in this analysis. Two methods of analysis were applied to these 111 devices for comparison.

3. RESULTS

Table 1 shows the attenuation results and calculations for SLC_{80} and *mi*SLC_{80} as an example for one particular set of ear muffs.

For the standard SLC_{80} process the results are calculated vertically for mean attenuations and standard deviations followed by a horizontal calculation for the final SLC_{80}, while an initial horizontal calculation of an individual SLC (*i*SLC) is carried out followed by a vertical calculation of the *mi*SLC_{80}.

By way of example the calculation for the SLC_{80} and miSLC_{80} can be followed from *Table 2*.

Using equation (2) we get,

$$SLC_{80} = 100 - 10\log_{10}(10^{0.1(71-3.8)} + 10^{0.1(81-11.4)} + \ldots + 10^{0.1(93-28.8)} + 10^{0.1(86-27.5)}),$$

$$SLC_{80} = 100 - 10\log_{10}(10^{6.72} + 10^{6.96} + 10^{6.90} + 10^{6.51} + 10^{6.77} + 10^{6.42} + 10^{5.85}),$$

thus SLC_{80} = 24.6 dB.

Note: SLC_{80} is normally rounded to the nearest integer. However, in this case it has been left unrounded for analysis and demonstration purposes

For the *i*SLC value equation (1) is used by substituting the attenuated spectrum level at each octave band for each test subject. For example, for the first subject the *i*SLC calculation would be,

$$iSLC = 100 - 10\log_{10}(10^{0.1(71-15)} + 10^{0.1(81-18)} + 10^{0.1(89-35)} + \ldots + 10^{0.1(93-45)} + 10^{0.1(86-46)}),$$

Table 2 Example of the calculation of SLC_{80} from data supplied from Table 1

Octave band centre frequency (Hz)	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Reference band level (dB) (equivalent to 100 dB)	71	81	89	93	95	93	86
Mean – SD attenuation of protector (dB)	3.8	11.4	20.0	27.9	27.3	28.8	27.5
Attenuated spectrum level (dB)	67.2	69.6	69.0	65.1	67.7	64.2	58.5

$iSLC = 100 - 10 \log_{10} (10^{5.6} + 10^{6.3} + 10^{5.4} + \ldots + 10^{4.8} + 10^{4.0}),$

or $iSLC = 33.9$ dB

The mean of the *i*SLCs are calculated (*mi*SLC = 29.2 dB) and the standard deviation (4.7 dB) subtracted to result in an $miSLC_{80}$ of 24.5 dB.

As demonstrated in *Table 1* the SLC_{80} and the $miSLC_{80}$ are very close in value and, in general, this does seem to be the case. Mathematically the two processes are not the same and should not necessarily conclude with the same result. When the results of the SLC_{80} and the $miSLC_{80}$ for a mixture of the 111 devices (plugs and muffs) tested are compared there is high correlation ($r^2 = .99$) as shown in *Figure 1*. The two points {(13.8, 16.1) & (14.4, 16.6)} that appear to be well above the possible line of best fit are corded and un-corded versions of a new design of ear plug. This poor performance could be explained through the relatively large standard deviation for both devices of 7.7 and 7.3 dB respectively compared to their $miSLC_{80}$ values of 17 and 16 dB.

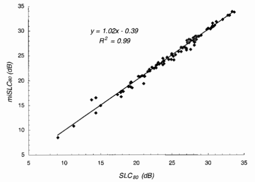

Figure 1: The mean individual SLC_{80} ($miSLC_{80}$) versus standard SLC_{80} demonstrating the close relationship between the two figures

As a further comparison of results *Figure 2* shows the relation between SLC and the *mi*SLC. The correlation shows that the SLC tends to be, on average, about 1 dB greater than the *mi*SLC.

The summary of results of the overall statistical analysis is presented in *Table 3*. This gives, for the indicated group of devices, the average SLC_{80} as calculated by the *Australian/New Zealand Standard* method; the average *mi*SLC followed by the average standard deviation of the *mi*SLC for the group; the average $miSLC_{80}$, calculated by subtracting the standard deviation from the *mi*SLC.

4. DISCUSSION

The original impetus in the method of calculating the SLC_{80} utilising the mean attenuations arose during a time when computers and calculators had a much more limited capability to carry out complex processes. It was an historical process. With the use of contemporary computing capabilities, calculation using the traditional method or the suggested variation is easily achieved. The advantage of the new variation comes with the production of a single standard deviation. For an error analysis and a simple relationship between the *mi*SLC and the $miSLC_{80}$ the advantage of the existence of one standard deviation is obvious.

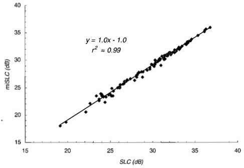

Figure 2: The relationship between miSLC and SCL. On average SLC is 1 dB greater than miSLC

Table 3
Summary of test results for ear plugs, ear muffs and all devices for the main parameters discussed

Device(s)	*Average SLC_{80} (dB)*	*Average miSLC (dB)*	*Average SD (dB)*	*Average $miSLC_{80}$ (dB)*
ear plugs (N = 13)	18.9	25.2	6.2	19.0
ear muffs (N = 98)	25.9	29.2	3.3	25.9
all devices plugs & muffs (N = 111)	25.0	28.7	3.6	25.1

Figure 1 shows a comparison between SLC_{80} and $miSLC_{80}$ and presents an argument that the two values are comparable on a practical basis. *Figure 2* shows the consistent relationship between *mi*SLC and SLC with the latter usually being a little larger than the former, in the order of one decibel.

It is now time to look at reasons why it may be of advantage to use this method of $miSLC_{80}$ calculation in preference to the traditional method. Using the same 111 hearing protectors from above that demonstrated the correlation between old and new methods of calculation of the performance parameter, it is constructive to plot the standard deviation of the hearing protector against the attenuation performance. This is displayed in *Figure 3*.

From *Figure 3* we can see 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,

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

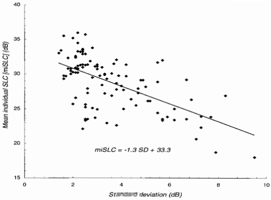

Figure 3: A plot of hearing protector performance calculated by the suggested variation in the method, the mean individual SLC (miSLC), versus the standard deviation for all tested hearing protectors showing a strong negative correlation

This indicates that there is a close correlation between the attenuation performance of the device and the standard deviation. Ideally the standard deviation should be independent of the device attenuation and vice-versa.

Previously the presentation of such data would have been difficult as in the case of SLC_{80} for example there would be seven standard deviations involved from each of the seven octave bands. One way could be to use an average of the individual octave band standard deviations but the relation between this average and the standard deviation of the overall attenuation performance parameter is not as regular as would be desired. The relation between the average octave band standard deviation and the single standard deviation is illustrated in *Figure 4*.

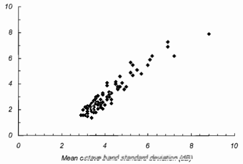

Figure 4: The relationship between the mean of the individual octave band standard deviations and the standard deviation of the overall attenuation performance.

The presentation of test results as per *Figure 3* can allow us to look at hearing protectors and hearing protector use in a different light. For example, it is clear that as the value of the rating of the hearing protector decreases there is a 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 individuals who use hearing protectors in low noise areas, where less attenuation is required, will experience a wider range of attenuation. Users who experience too much attenuation may find this over-protection annoying and decrease their hearing protector use. This is an undesirable outcome.

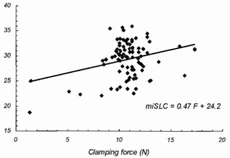

Figure 5: The relationship between clamping force and attenuation

A further relationship that can be displayed is that between the clamping force and attenuation (excludes ear plug data). These results (*Figure 5*) show a general tendency toward an increase in attenuation with increasing clamping force. Intuitively this would seem to be 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.

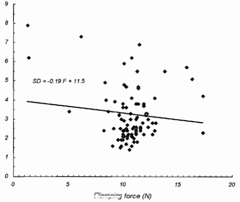

Figure 6: The relation between clamping force and the overall standard deviation of the attenuation of the device

Another relationship is that between clamping force and the standard deviation for the overall attenuation figure (*Figure 6*). This shows that there is an 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 dependency on other factors.

5. CONCLUSION

The suggested variation in the analysis of hearing protector test data provides a significant advantage when examining the general performance of hearing protectors and when comparing individual performance. The use of a single standard deviation also simplifies any error calculation process that may be required for the presentation of the reliability and validity of attenuation test data.

Some examples of the advantage of using the suggested variation in analysis have been illustrated with brief discussions. Detailed discussion of these points is a topic for further research.

6. REFERENCES

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