A COMPARISON OF TONAL NOISE REGULATIONS IN AUSTRALIA

Tom Evans[1] and Jon Cooper[2]

[1]Resonate Acoustics, Level 4/10 Yarra St, South Yarra VIC 3141, Australia
Email: tom.evans@resonateacoustics.com

[1]Resonate Acoustics, Level 1/23 Peel St, Adelaide SA 5000, Australia
Email: jon.cooper@resonateacoustics.com

Abstract

Tonal noise, or tonality, as a component of environmental noise can be an important factor in the annoyance of people listening to that noise. Environmental noise with audible tonal components generally results in higher levels of annoyance than broadband noise at a similar level. To reflect this, specific assessment methodologies are applied to tonal noise in environmental noise regulations around Australia as well as internationally. Typically these assessment methodologies seek to determine whether a peak in a frequency spectrum exceeds a criterion level and, if so, what penalty should be added to the measured noise level such that it better reflects the likely annoyance.

While tonal regulations are in place throughout Australia, there is a significant variance in the level of tonality at which they require a penalty to be applied. The differences can be particularly significant for tonal frequencies lower than 200 Hz. In many cases, the level at which a penalty applies does not accurately reflect the findings of dose response studies into tonal noise. Additionally, the standard application of a flat 5 dB penalty in many cases, regardless of the amount by which the tonal component exceeds the criterion, makes the regulations relatively inflexible. This paper reviews tonal noise criteria applied throughout Australia and compares them to each other as well as to international criteria and the findings of dose response studies to tonal sources. The tonal assessment criteria are used to assess examples of tonal noise from some sources to review the difference in outcome between the regulations.

1. Introduction

Tonal noise, or tonality, as a component of environmental noise can be an important determinant of annoyance. It is well documented that noise with a strong tonal component typically results in significantly higher levels of annoyance than broadband noise at the same overall level [1]. Indeed in some cases, tonality could be the primary determinant of annoyance with one study into the perceived annoyance of workers to air-conditioning noise finding that the correlation between noise level and annoyance was weak but that there was a significant relationship between annoyance and the presence of tones [2]. This could lead to problems where environmental noise from a source that would otherwise be compliant, and not expected to result in annoyance based on the A-weighted noise level, could result in a marked community reaction.

While environmental noise regulations in Australia do define tonal assessment criteria for noise sources and apply penalties in an attempt to reflect increased annoyance, it is interesting that no two States impose the same tonal assessment criteria. This raises questions as to whether all States apply appropriate assessment criteria and penalties for tonal noise.

This paper compares the tonal assessment criteria imposed in the various environmental noise regulations in Australia against international criteria and against subjective studies into tonal noise. The different criteria are also applied to different examples of tonal noise to compare the penalty that would apply in each case.

2. State Regulations

Each Australian State provides assessment criteria for tonality from industrial noise and noise regulations require the application of a penalty where it occurs. However, the criteria differ significantly between States, as can the penalties applied.

2.1 New South Wales

The *NSW Industrial Noise Policy* uses the simplified tonality assessment criteria from ISO 1996-2 [3]. The presence of tonality is assessed using one-third octave bands with a tone deemed to be objectionable if the level of a one-third octave band exceeds that of both adjacent bands by:

- 5 dB or more if the centre frequency of the tonal band is greater than 400 Hz
- 8 dB or more if the centre frequency of the tonal band is between 160 and 400 Hz inclusive
- 15 dB or more if the centre frequency of the tonal band is below 160 Hz.

If an objectionable tone is detected, the INP requires the application of a 5 dB penalty to the measured A-weighted noise level.

2.2 Queensland

The Department of Environment and Heritage Protection *Noise Measurement Manual* [4] specifies the procedure for the assessment of tonality in Queensland. The Manual makes reference to AS 1055.1 [5] but specifies a different procedure to the Standard.

Where the A-weighted level in a one-third octave band exceeds both neighbouring bands by 5 dB, a 5 dB penalty is added only to the tonal one-third octave band. The overall A-weighted noise level is recalculated and the overall penalty is the difference between the overall A-weighted levels before and after application of the tonal penalty to the one-third octave band.

The Manual also allows for the application of a subjective penalty between 0 and 5 dB to the overall noise level where a tone is detected, depending on the perceived audibility of the tone.

2.3 South Australia

The SA *Environment Protection (Noise) Policy 2007* [6] states that a 5 dB penalty is applicable to the measured A-weighted noise level where tonality is part of the noise. The *Guidelines for the use of the Environment Protection (Noise) Policy 2007* [7] state that tonality is deemed to exist if the level of one-third octave band exceeds that in each of the adjacent one-third octave bands by 5 dB. Unlike the NSW INP, the 5 dB limit also applies at lower frequencies.

2.4 Tasmania

The Tasmanian *Noise Measurement Procedures Manual* [8] specifies a somewhat different procedure for the assessment of tonality. A tonal band adjustment (TBA) is determined for each one-third octave band where the A-weighted level exceeds the arithmetic average of the two adjacent one-third octave bands by more than 3 dB.

For the frequencies of 1-5 kHz, the TBA is determined as:

$$TBA = 0.35(Tonal\ Band\ SPL - Average\ Adjacent\ Band\ SPL) + 4.31 \quad (1)$$

For frequencies less than 1 kHz and greater than 5 kHz, the following applies:

$$TBA = 0.26(Tonal\ Band\ SPL - Average\ Adjacent\ Band\ SPL) + 2.49 \quad (2)$$

The tonal penalty is the difference between the overall A-weighted noise level with and without any applicable TBAs up to a maximum of 10 dB.

2.5 Victoria

With regards to tonality assessment, State Environmental Protection Policy (SEPP) N-1 [9] differentiates between major scheduled premises and other minor premises. For major premises, a tonal penalty is applied in a similar manner to Tasmania, although with the equations to determine the TBA differing slightly.

For the frequencies of 1-5 kHz, the TBA is determined as:

$$TBA = 0.34(Tonal\ Band\ SPL - Average\ Adjacent\ Band\ SPL) + 4.5 \quad (3)$$

For frequencies less than 1 kHz and greater than 5 kHz, the following applies:

$$TBA = 0.25(Tonal\ Band\ SPL - Average\ Adjacent\ Band\ SPL) + 2.75 \quad (4)$$

For minor premises, a subjective tonality assessment is undertaken:

- when the tonal character of the noise is just detectable then the tonal penalty is 2 dB
- when the tonal character of the noise is prominent then the tonal penalty is 5 dB.

2.6 Western Australia

The WA *Environmental Protection (Noise) Regulations 1997* [10] also require assessment of tonality based on one-third octave band levels. However, the tonality criteria applied are more stringent than in NSW, Queensland and SA. The WA Regulations specify that if the A-weighted level in a one-third octave band exceeds the arithmetic average of the two adjacent bands by more than 3 dB, then tonality is deemed to be present. If a tone is detected, a 5 dB penalty is applied to the measured A-weighted noise level.

2.7 Summary

Table 1 summarises the objective tonal assessment criteria and resultant penalties applied within the various Australian States.

It is apparent from the summary that, while objective tonal assessment criteria in Australia are all based upon one-third octave band levels, there is a considerable variation in the level at which tonality is deemed to occur and the penalty that should be applied to correct the measured level to reflect the subjective response. For example, at low frequencies, there may be more than a 12 dB difference in the level of a tone between the point at which a 5 dB penalty would be applied when assessed in WA and NSW.

It is not unusual for Australian State-based environmental noise regulations to differ, although generally this difference is reflected in the overall A-weighted noise limit applied to an area to reflect planning priorities. Despite this, it would normally be expected for tonality assessment criteria to be relatively consistent as the intention is simply to assess the character of environmental noise.

Table 1. Australian objective tonal assessment criteria

State	Assessment methodology	Penalty
NSW	If A-weighted 1/3 octave band exceeds each adjacent band by: • 5 dB or more for > 400 Hz • 8 dB or more for ≥ 160 Hz and ≤ 400 Hz • 15 dB or more for < 160 Hz.	+5 dB
Queensland	If A-weighted 1/3 octave band exceeds each adjacent band by 5 dB or more, regardless of frequency.	+5 dB to 1/3 octave band only
SA	If A-weighted 1/3 octave band exceeds each adjacent band by 5 dB or more, regardless of frequency.	+5 dB
Tasmania	Calculated Tonal Band Adjustment (TBA) applies to each A-weighted one-third octave band which exceeds arithmetic average of two adjacent bands by more than 3 dB.	Variable based on TBA up to maximum +10 dB
Victoria	Calculated TBA applies to each A-weighted one-third octave band which exceeds arithmetic average of two adjacent bands by more than 3 dB.	Variable based on TBA
WA	If A-weighted 1/3 octave band exceeds arithmetic average of two adjacent bands by more than 3 dB, regardless of frequency.	+5 dB

3. International Guidance

3.1 ISO 1996-2

ISO 1996-2 includes both a narrowband objective method (the reference method) for assessing tonality and a simplified one-third octave band method. The one-third octave band method is the same as that applied in NSW, although the Standard suggests this method is only for detecting "prominent, discrete tones".

The narrowband assessment method is equivalent to the Joint Nordic Method Version 2 and involves the determination of tonal audibility, ΔL_{ta}, which is a measure of the audibility of a tone. A tonal audibility of 0 dB indicates a tone is just detectable to the average listener, with higher levels indicating progressively more audible and prominent tones.

The narrowband methodology is based around the theory of a critical bandwidth, centred around a potential tonal peak. The critical bandwidth is the frequency range within which noise may exist to mask the tone, and is variable depending on the frequency of the tone. The ISO 1996-2 methodology uses a simplified method of determining the critical bandwidth, with tones below 500 Hz having a bandwidth of 100 Hz and tones above 500 Hz having a bandwidth of 20% of the tonal peak. Each line within the critical bandwidth is classified as tone, masking or neither depending on the shape of the peak and the proximity of each line to the maximum level.

Tonal audibility is determined as the difference between the A-weighted energy sum of the tonal lines and the A-weighted energy sum of the masking lines, adjusted by a frequency dependent audibility criterion. The audibility criterion is -2 dB at low frequencies, gradually decreasing to -6 dB at greater than 16 kHz. This effectively means that tones may be just detectable when the tonal energy does not exceed the masking energy within the critical bandwidth.

One significant difference between the narrowband reference methodology and most other methodologies is the application of a sliding tonal penalty rather than a fixed penalty. The tonal penalty can range up to 6 dB and the Standard specifies that the penalty is not restricted to integer values. It is defined based on the tonal audibility as follows:

- for $\Delta L_{ta} < 4$ dB, the tonal penalty is 0 dB
- for 4 dB $\leq \Delta L_{ta} \leq$ 10 dB, the tonal penalty is ΔL_{ta} – 4 dB
- for $\Delta L_{ta} > 10$ dB, the tonal penalty is 6 dB.

The ISO 1996-2 reference and simplified methodologies are used in other jurisdictions. The most relevant to Australia is NZS 6808:2010 [11], which includes both methods but gives preference to the narrowband reference methodology. NZS 6808 is the Standard used for the assessment of wind farm noise in both New Zealand and Victoria, and therefore the ISO 1996-2 tonal assessment methodology is used for wind farms in Victoria instead of the SEPP N-1 methodology.

BS 4142 [12] was also recently updated to include the same reference and simplified tonal assessment methodologies as ISO 1996-2.

3.2 IEC 61400-11

IEC 61400-11 Edition 3 [13] is the Standard used for the measurement and assessment of sound power levels for wind turbines. It includes a narrowband tonality assessment procedure that is similar to the ISO 1996-2 reference methodology, but with the following differences that result in differences in the calculated tonal audibility:

- IEC 61400-11 does not use a simplified procedure for calculating the critical bandwidth as ISO 1996-2 does. The IEC Standard calculates the critical bandwidth based on the original work undertaken by Zwicker [14], which could result in tonal audibility values up to 0.7 dB higher than the ISO 1996-2 procedure.
- There are differences in how tonal, masking and other noise is classified for the assessment of tonal audibility.
- The IEC Standard assesses tonal audibility over 10-second periods, averaging the tonal audibility of each period to obtain a final value. ISO 1996-2 does not specify an assessment period but determines tonality over the whole measurement, the period of which is not defined other than to say that it should generally be at least one minute.

The IEC Standard does not specify an acceptable level of tonal audibility or recommend the penalty that should apply. It only states that detected tones with audibility greater than -3 dB must be reported following any test.

Although the IEC narrowband assessment methodology is typically applied during a test at the turbine, it can be applied at residences if adapted slightly [15]. The SA EPA has recommended it for assessing tonality at wind farms [16] and, although it is not formalised in the guidelines, has previously advised that tonal audibility should not exceed 0 dB.

3.2 ANSI S1.13

ANSI S1.13 [17] provides a different procedure to assess tonal noise, with the quantification of Tone-to-Noise Ratio (TNR) and Prominence Ratio (PR). One important difference with the other narrowband procedures is a linear spectrum is used to assess tonality rather than an A-weighted spectrum.

The TNR is determined using a narrowband procedure with the critical bandwidth around the tone being calculated using the same procedure as in IEC 61400-11. The tone level and the masking level are calculated in a similar manner to that Standard although there is no specific guidance on the tonal bandwidth and noise is either tonal or masking, there is no option to classify noise as neither. The TNR is the difference between the tonal and masking noise levels, without the audibility criterion used to calculate tonal audibility in ISO 1996-2 and IEC 61400-11.

A tone with tonal frequency f_t is classed as "prominent" where:

$$TNR \geq 8 + 8.33 \times \log(\frac{1000}{f_t}) \text{ for } f_t \leq 1000 \text{ Hz or TNR} \geq 8 \text{ dB for } f_t > 1000 \text{ Hz} \quad (5)$$

The PR is a different method of assessing the prominence of a tonal peak. The theory of the PR is somewhat similar to that of the one-third octave band simplified method except based on critical bands. The total sound pressure in the critical bandwidth containing the tone (L_M) is compared to the total sound pressure in the immediately lower (L_L) and higher (L_U) critical bands. PR is then calculated according to the following:

$$PR = 10\log(10^{L_M/10}) - 10\log(1/2 \times (\frac{100}{\Delta f_L} \times 10^{L_L/10} + 10^{L_U/10})) \text{ for } f_t \leq 171.4 \text{ Hz} \quad (6)$$

$$PR = 10\log(10^{L_M/10}) - 10\log(1/2 \times (10^{L_L/10} + 10^{L_U/10})) \text{ for } f_t > 171.4 \text{ Hz} \quad (7)$$

A tone with tonal frequency f_t is classed as "prominent" where:

$$PR \geq 9 + 8.33 \times \log(\frac{1000}{f_t}) \text{ for } f_t \leq 1000 \text{ Hz or TNR} \geq 9 \text{ dB for } f_t > 1000 \text{ Hz} \quad (8)$$

4. Subjective response

The primary purpose of any tonality assessment procedure and penalty should be to accurately reflect individuals' subjective response to tonal noise. Therefore, it is important to understand how the different tonal metrics relate to annoyance.

4.1 One-third octave bands

Studies into the subjective performance of one-third octave band tonal assessment methodologies are not readily available, with identified subjective studies typically focussing on narrowband assessment methodologies.

One study into tonal components in high-speed trains progressively introduced tonal noise into relatively broadband noise, with tones being assessed in both the 630 Hz and 1250 Hz one-third octave bands [18]. Only a 2 dB increase was required from the base sound for a difference to be noted by approximately 50% of subjects. A 6 dB increase resulted in almost all subjects noting a difference with 10-20% describing it is as a "big difference".

An Australian study of tonal transformer hum in the low frequency region found the audibility of the hum was still clearly audible even where the 15 dB level difference, required for a 5 dB penalty in NSW at low frequencies, was not achieved [19].

4.2 Joint Nordic Method Version 2 (ISO 1996-2)

Detailed subjective listening tests have been undertaken for the Joint Nordic Method Version 2 [20], the narrowband reference method documented in ISO 1996-2. The subjective tests undertaken for the Joint Nordic Method showed good correlation (R^2 = 0.91) between the calculated tonal audibility and the subjective response for both synthesised and recorded stationary and varying real tones in the range 70 – 7000 Hz.

As shown in Figure 1, the subjective response was classified as "prominent" for a tonal audibility of approximately 10 dB and "prevalent" for a tonal audibility of approximately 20 dB. It is interesting to note that, in the subjective tests, tones with an audibility of less than 0 dB could still elicit a small subjective response.

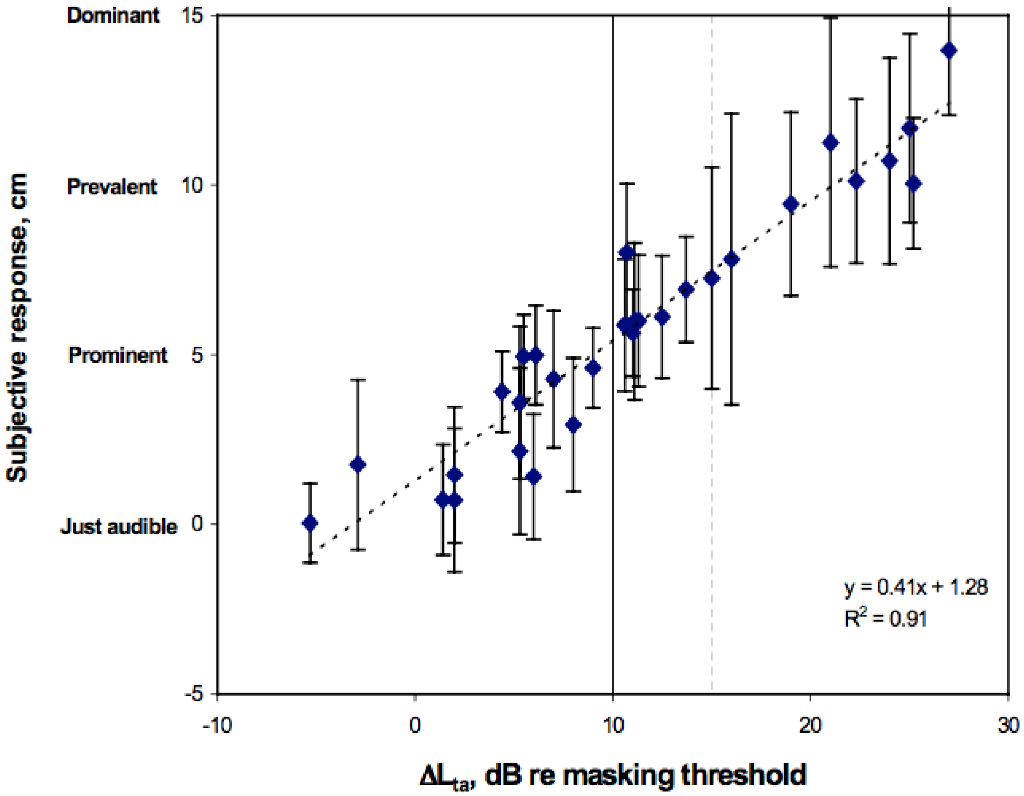

Figure 1. Subjective response versus tonal audibility determined using Joint Nordic Method Version 2, from Pedersen, Søndergaard and Andersen [20].

A more recent study [21] into wind turbine tones compared the Joint Nordic Method to the tonality methodology from IEC 61400-11. Relatively good relationships between subjective perception and tonal audibility were found for both methodologies although the Joint Nordic Method performed slightly better. The level of tonal audibility under IEC 61400-11 required to obtain a similar subjective reaction to that obtained under the Joint Nordic Method was approximately 1 to 2 dB lower.

4.3 Kobayashi et al Study

As part of a recent significant study into wind turbine noise in Japan, a subjective assessment of steady constant tones assessed using IEC 61400-11 was undertaken [22]. A tone at varying frequency was added to synthesised wind turbine noise and the tonal audibility gradually increased in 3 dB steps.

At levels of tonal audibility below 0 dB, there was some reporting of slight perceived differences relative to the base scenario (without tone) at frequencies of 50 Hz and 400 Hz but not at other frequencies. At an audibility of 0 dB, typically 50% of subjects identified a slight difference in noise, which is to be expected if an audibility of 0 dB is taken to be the level at which the average listener would just detect a tone. Tonal audibilities of 6 dB and greater typically resulted in relatively strong reactions. The study found a particularly strong response to the tone at 400 Hz, even at low audibility, which could not be explained, particularly as no similar reactions occurred at either 200 or 800 Hz.

4.5 Mechanical equipment in buildings

A recent study into the dose response of noise-induced annoyance by tones in building mechanical systems [23] compared the subjective response to tones from the methodologies in ISO 1996-2, ANSI S1.13 as well as a one-third octave band method used to assess aircraft noise (Tone Corrected Perceived Noise Level). It concluded that tonal audibility as defined by ISO 1996-2 was the most reliable tonality assessment procedure, but that loudness was also important with tones becoming more annoying as the loudness level increased.

4.4 Beating tones

It is important to note that the majority of studies referenced above are relevant to steady tones, and this is an assumption that underlies most assessment criteria, yet tonal noise may not always be steady in level or frequency. Some methods, such as the ISO 1996-2 narrowband methodology, are designed to address tones that may vary in frequency but do not provide specific procedures for assessing tones that vary significantly in level. Salford University carried out a comparative study between steady and beating low frequency tones [24] and identified that beating tones at 40 and 60 Hz resulted in an increase in annoyance of 3 to 5 dB. This suggests that unsteady tones (with regards to tonal audibility) may need to be considered differently to steady tones in any assessment.

One method that is designed to consider tones that vary in level is the tonality assessment procedure used in the UK ETSU-R-97 guideline for wind turbine noise [25]. This method, based on the original Joint Nordic Method, calculates the tone level as the arithmetic mean of the top 10% of tone levels from short-term spectra (0.29 – 0.4 s) comprising a two-minute measurement. While not considered further in this paper, this method may be worthy of consideration where the level of tonal noise modulates significantly.

5. Assessment of tonal samples

To compare the relative tone detection and penalty applied by the various tonal assessment methodologies, six different measurement samples have been assessed. The six samples are:

- Sample A: an outdoor night-time measurement at a residence near a wind farm. In this instance, the wind turbines at the wind farm are known to exhibit an audible low frequency tone in the 100 Hz band at times in accordance with IEC 61400-11.

- Sample B: a measurement of low frequency noise within an apartment, produced by mechanical equipment elsewhere within the building, with the noise annoying the resident. The low frequency noise was also present at 100 Hz.

- Sample C: an outdoor measurement conducted at a distance from an electrical substation for a passenger train line located in a residential area. The substation noise at the residence included tonal noise at a frequency of 200 Hz.

- Sample D: an outdoor measurement of construction noise with a mulcher and skid steer loader with tonal reversing beeper operating intermittently. A number of low level tones were present in the noise in the 80, 160, 500 and 1250 Hz bands.

- Sample E: an outdoor measurement near a plant room with VSD motors producing a high frequency tone at 4000 Hz.

- Sample F: an outdoor measurement near a pedestrian rail crossing warning alarm. While this source is intentionally tonal at the crossing as a warning device (with strong tones in the 630, 1600 and 3150 Hz bands), it was also audible at nearby residential locations.

In all cases, the tonal noise was resulting in a level of annoyance for a nearby receiver of the noise. Based on the overall noise level, it is more likely due to the tonal nature of the noise rather than the overall noise level although other non-acoustic annoyance factors are not able to be discounted.

An assessment has been carried out on each sample using the objective methodologies recommended in each State, as well as the international narrowband methodologies identified above. Table 2 presents the tonal penalties applicable to the samples using each of the methodologies as well as additional information where relevant. For a number of samples, some procedures identify multiple tones in the samples in which case the overall penalty for all tones is presented, along with the highest applicable individual TBA or tonal audibility.

Table 2. Comparison of tonal penalties

Methodology	Overall tonal penalty applied, dB					
	Sample A 100 Hz	**Sample B 100 Hz**	**Sample C 200 Hz**	**Sample D 80 Hz 160 Hz 500 Hz 1250 Hz**	**Sample F 4000 Hz**	**Sample E 800 Hz 1600 Hz 3150 Hz**
NSW	0	0	0	0	0	5
Queensland	0	3.6	1.4	0	0	4.5[a]
SA	0	5	5	0	0	5
Tasmania (TBA)	0.6 (4.4)	4.2 (5.4)	1.4 (4.5[b])	2.5 (5.6[b])	0	9.1 (10.2[b])
Victoria (TBA)	0.7 (4.6)	4.3 (5.5)	1.4 (4.7[b])	2.6 (5.8[b])	0	9.2 (10.3[b])
WA	5	5	5	5	0	5
ISO 1996-2 (ΔL_{ta})	3.5 (7.5)	6 (13.0)	1.8 (5.8)	2.0 (6.0[c])	1.5 (5.5)	6 (24.1[d])
IEC 61400-11 (ΔL_{ta})	n/a (7.6)	n/a (9.9)	n/a (6.5)	n/a (4.6[c])	n/a (6.2)	n/a (22.6[d])
ANSI S1.13 Prominent? (TNR)	No (3.4)	No (4.9)	No (2.4)	No (-5.5)	No (-1.0)	Yes (14.5)
ANSI S1.13 Prominent? (PR)	No (8.6)	No (10.1)	No (1.2)	No (4.7)	Yes (3.3)	Yes (12.4)

a. Based on 5 dB penalty being applied in both 1600 Hz and 3150 Hz one-third octave bands.
b. Tonal band adjustment shown based on most prominent tone.
c. Audibility of most prominent 500 Hz tone shown.
d. Audibility of most prominent 800 Hz tone shown.

5.1 Australian State methodologies

From Table 2, it is clear that there can be significant differences in penalties applied not only between one-third octave band and narrowband methodologies, but also between the one-third octave band methods applied within each State. The same tonal noise source in various states could attract a wide range of penalties.

The NSW methodology performs poorly, applying a penalty to the noise resulting in complaint in only one of the six cases. This reflects the large difference that is present between the ISO 1996-2 simplified methodology (the same as the NSW methodology) and narrowband methodology. Only Sample F attracts a penalty under the NSW methodology and this corresponds to mid-frequency tones with a significant tonal audibility of more than 20 dB. For Sample B, the 100 Hz tone has an audibility of 13 dB but would not qualify as tonal in NSW, despite the 100 Hz one-third octave band having an A-weighted level of 26 dB(A), as part of a total noise level of 28 dB(A) in this sample.

The Queensland methodology is more stringent than the NSW methodology at lower frequencies but fails to apply penalties to three samples, including Sample A which has a tonal audibility of 7.5 dB. While this would not attract a full 6 dB penalty under ISO 1996-2, it still suggests that some people could be considerably annoyed by the tonal nature of the noise. The simple SA methodology has the same tone detection method as Queensland but applies the 5 dB penalty to the overall noise level rather than the individual one-third octave band. The results of the comparison suggest that the SA and Queensland methods are suitable for detecting prominent tones but may not be suitable for detecting tonal noise that may still increase annoyance albeit by a smaller degree. This inflexibility is common to any methodology that applies a fixed overall penalty as soon as a criterion is exceeded regardless of the level of exceedance.

Of all the methods employed within various States, that employed in Tasmania and Victoria appears to result in the best agreement with the ISO 1996-2 narrowband methodology with regards to tone detection and application of penalties. The fact that the penalty is able to vary with the relative strength of the tonal frequency results in better agreement with the narrowband ISO methodology than methods that apply fixed penalties. However, the 3 dB average band difference screening criterion for a TBA used in both Tasmania and Victoria is simplistic and can miss low level tones (Sample E) but can also result in the application of tonal penalties to noise sources that would not otherwise be tonal. For example, both methodologies would result in a 3.7 dB TBA being applied at 100 Hz to the substation noise in Sample D, even though the 100 Hz tonal audibility determined using the ISO 1996-2 method (-2.1 dB) indicates inaudibility of this tone to a typical listener.

Additionally, the application of a penalty to the one-third octave band only (as employed in Queensland, Tasmania and Victoria) can result in the application of penalties that are not necessarily in agreement with that recommend by psychoacoustic theory. The theory suggests that it is primarily the frequencies immediately around a tone, the critical bandwidth, which are important for masking, yet these three methodologies effectively allow masking noise to be present at much higher or lower frequencies than the tonal frequency. For example, a low frequency tone may not end up in the application of an appropriate penalty if there is high frequency noise in the measurement despite this being well outside the critical bandwidth which provides masking.

Unsurprisingly, the more stringent WA methodology provides the most conservative tonal assessment method, applying a 5 dB penalty to all but one of the samples. However, this methodology is simplistic and, in the same manner as the Tasmanian and Victorian methodologies, also applies this penalty to frequencies within the various samples that would not be considered tonally audible.

5.2 Narrowband methodologies

Comparing narrowband methodologies in Table 2, it can be seen that there is relatively good agreement between then ISO 1996-2 (Joint Nordic Method) procedure and the IEC 61400-11 methodology applied for wind turbines. As identified in previous studies [21], the tonal audibility determined using the ISO 1996-2 methodology is sometimes marginally higher than that determined by the IEC methodology but, broadly speaking, both methods would apply similar penalties if the ISO 1996-2 penalty scheme was applied to the IEC 61400-11 results.

The ANSI S1.13 methodologies, however, do not provide a consistent result. Both the Tone-to-Noise Ratio and Prominent Ratio do not class tones as prominent that many other methodologies would consider annoying, particularly at low frequencies. This is not surprising due to the strong frequency correction used in these methods to determine what the required TNR or PR would be. For example, a tone at 100 Hz would require a TNR of 16.3 dB and PR of 17.3 dB to be considered "prominent".

6. Discussion

It is clear from the comparisons between the narrowband and one-third octave band methods, that considerable differences arise, even between the various methodologies employed in Australian States. Of the one-third octave band tonality assessment procedures, the most stringent procedure is used in WA, with the NSW methodology the least stringent. At low frequencies, a tone could exceed the WA criterion by more than 12 dB and still be considered non-tonal in NSW. This results in a wide variety of tonal penalties applicable depending on which State a noise source is located.

Of the one-third octave band procedures, the objective methods employed in Tasmania and Victoria come closest to approximating the ISO 1996-2 (or Joint Nordic Method) narrowband methodology. The variable penalty applied by these methods displays relatively good consistency with the narrowband method for the six samples considered in this paper. Despite this, there are still concerns with these methods around the application of penalties to samples that may not be tonal and with respect to the methods allowing noise at significantly different frequencies to effectively reduce the applicable tonal penalty.

One additional potential concern with one-third octave band procedures, not addressed in the samples considered here, is that they could be inaccurate where a tone occurs at the band limit between two bands. Not all tones are pure tones at the centre of a band, and if the tonal energy is spread across two one-third octave bands, there is a potential that there will be no difference between the two adjacent bands. The narrowband assessment procedures would not be affected should this occur.

For the narrowband methodologies, the ISO 1996-2 narrowband approach appears to be a reasonable standard for future consideration due to the supporting subjective annoyance studies, although we note the classification of tonal and masking noise in IEC 61400-11 is slightly easier to undertake. The adoption of the ISO approach by Australian regulatory authorities would provide a number of benefits including:

- Recommending a tonal assessment procedure on a methodology supported by subjective annoyance studies [20], [23].

- More accurate quantification of potential tonal annoyance.

- Application of a variable penalty to tonal noise that reflects the relative prominence of the tonal signal within the relevant masking noise.

- Potential standardisation of approaches between States.

Despite the above, it is recognised that the simplified one-third octave band methods do have some advantages. Notably, it is rare to obtain suitable narrowband tonality data for potential noise sources during a planning stage acoustic assessment meaning that a detailed tonality assessment may not be possible, although often one-third octave band data is not available either. Additionally, the narrowband assessment procedures can be difficult to implement and perform even for people with experience in acoustics, and the one-third octave band procedures provide a simpler assessment less prone to error. This could perhaps be addressed via standardised narrowband assessment tools approved by regulatory authorities.

It is worth noting that wind turbine acoustic assessments in both Victoria and South Australia are required to consider narrowband tonality assessments and therefore there is experience in this area within the acoustic consultant industry within Australia. Additionally, wind turbine suppliers are required to provide narrowband tonality information during planning stage assessments, a result of tests being carried out on wind turbines internationally in accordance with IEC 61400-11.

6. Conclusion

In Australia, no two States employ the same objective tonal assessment methodologies in their environmental noise assessment procedures. While all States use simplified one-third octave band procedures rather than narrowband procedures, there can be a wide variation between what is considered a tone and the penalty that is applied where a tone occurs. For example, a low frequency tone can exceed the criteria in WA by more than 12 dB before it is considered tonal in NSW.

A comparison of various samples of tonal noise found that the NSW tonal criteria failed to identify tones in the majority of cases, whereas the WA criteria applied a 5 dB penalty in the majority of cases but also in some where no tone was audible. Of all the State-based methodologies, the Tasmanian and Victorian methods were found to be most consistent with the narrowband methodology specified by ISO 1996-2 but were not consistent in their application of penalties to low level tones.

It may be worthwhile for States considering the adoption of narrowband assessment procedures in the future, such as that defined by ISO 1996-2 or IEC 61400-11. While this would introduce additional technical difficulties into the assessment of tonal noise, it would standardise assessment procedures against one that has been found to have a consistent relationship with the typical subjective response to tonal noise.

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