PREDICTING BS 4142 CHARACTER CORRECTIONS AT THE PLANNING STAGE

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1 ABSTRACT

This paper presents a method for environmental noise practitioners to estimate tonal and impulsivity corrections for sources that do not yet exist as part of a BS 4142 assessment. Whilst BS 4142 does provide objective measurement-based methods for determining graded corrections to the specific sound level for impulsivity and tonality, these require specific sound sources to be installed and operating. In planning applications where the sources are proposed, or the propagation path is intended to change significantly, only the professional judgement of the acoustics practitioner can be relied upon to determine the likely prominence/audibility of these features at a remote assessment location. To address this gap, simplified auralisation ('auralisation-lite') has been used to estimate the character corrections using the calculation method from ISO 9613-2: 1996. The initial results suggest that objective evaluation can offer an improvement over the current approach of subjective evaluation. The findings have practical implications for environmental agencies, industrial settings, and other fields where accurate prediction of sound level impacts are crucial.

2 INTRODUCTION

The tonality and impulsivity character corrections used to derive the rating level from British Standard 4142: 2014 + A1: 2019 ('BS 4142')[1] may be up to 15 dB, which can make a critical difference to the outcome of the numerical 'initial estimate'. This total is the combination of maximum character corrections for both tonality and impulsivity, which are added arithmetically based on Note 2 of subclause 9.2 of the standard. BS 4142 provides subjective and objective methods for evaluating character corrections for these two acoustic features.

The character correction for tonal content, K_T, is a graded scale from 0 to +6 dB. A 0 dB correction is applied to the specific sound level for sound that does not contain perceptible tones, +2 dB for 'just perceptible' tones, +4 dB for 'clearly perceptible' tones, and +6 dB for 'highly perceptible' tones. The graded scale was established in the original work for the tonality reference method.[2]

The character correction for specific sound containing impulsive content, K_I, is a graded scale from 0 to +9 dB. The graded subjective descriptions for impulsivity are described in BS 4142 as 0 dB for sound that does not contain perceptible impulsivity, +3 dB for 'just perceptible' impulsivity, +6 dB for 'clearly perceptible' impulsivity, and +9 dB for 'highly perceptible' impulsivity. The graded scale was established in the original work for the impulsivity reference method.[3]

The reference methods may be applied to measurement data; however, there are no objective methods for estimating the character corrections for the specific sound at the assessment location in the presence of other residual sound at the planning stage. This means that environmental noise practitioners must rely on subjective character corrections for new or modified sources, or in situations where the propagation path may undergo significant change; this would be typical in a planning scenario. The subjective approach relies heavily on the knowledge of the environmental noise practitioner and their experience of similar situations.

This paper presents a method that uses simplified auralisation ('auralisation-lite') to create syntheses of the ambient sound at the assessment location to aid the practitioner in their assessment.

3 AURALISATION-LITE

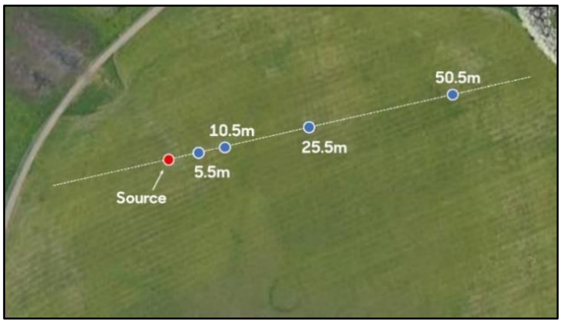
Environmental noise practitioners are directed to use ISO 9613-2 (or similar) for calculating sound levels for a BS 4142 assessment.[4,5] This allows calculated specific sound levels to be established for new or modified sources where source level information is known. The path attenuation is calculated from the sound power level of the source to the specific sound level at the assessment location. The attenuation is calculated in octave bands. This same octave band attenuation may be used to filter audio recordings of the specific sound and, when combined with a recording of the residual sound, results in a synthesis of the ambient sound at the assessment location. This synthesis may either be listened to by the environmental noise practitioner to aid in subjectively evaluating the character corrections, or these corrections may be evaluated by applying the reference methods to the same synthesis. An infographic describing this procedure has been provided in Figure 2.

Three controlled situations were created to test the effectiveness of auralisation-lite, each tested with a tonal and then an impulsive specific sound source:

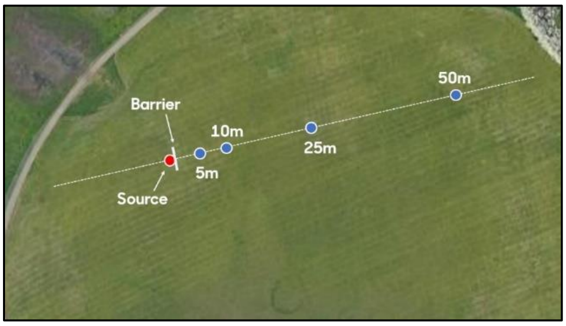
- Situation 1 - Simple situation - with a specific sound source in an open field;
- Situation 2 - Simple situation + barrier - adding an intervening barrier between the source and receiver positions; and
- Situation 3 - Realistic situation - using the same specific sound sources as the first two situations but in an industrial estate, with multiple reflecting surfaces and barrier objects.

The contrived situations have been illustrated in Figure 1.

(a)



(b)



(c)

Figure 1: Plans illustrating the source locations (red) and the measurement locations (blue) for the:

(a) simple situation;

(b) simple situation + barrier; and

(c) realistic situation.

3.1 Specific Sound Source Characterisation

Two sound sources were created that had deliberately prominent features: one a highly tonal source and the other a highly impulsive one. The aim was to create sources that would not cause debate as to their character. To characterise the sources and make recordings that could be used for auralisation-lite, the sources were measured in hemi-anechoic conditions using a 90º measurement arc, rotating the sources to obtain the directivity characteristics.

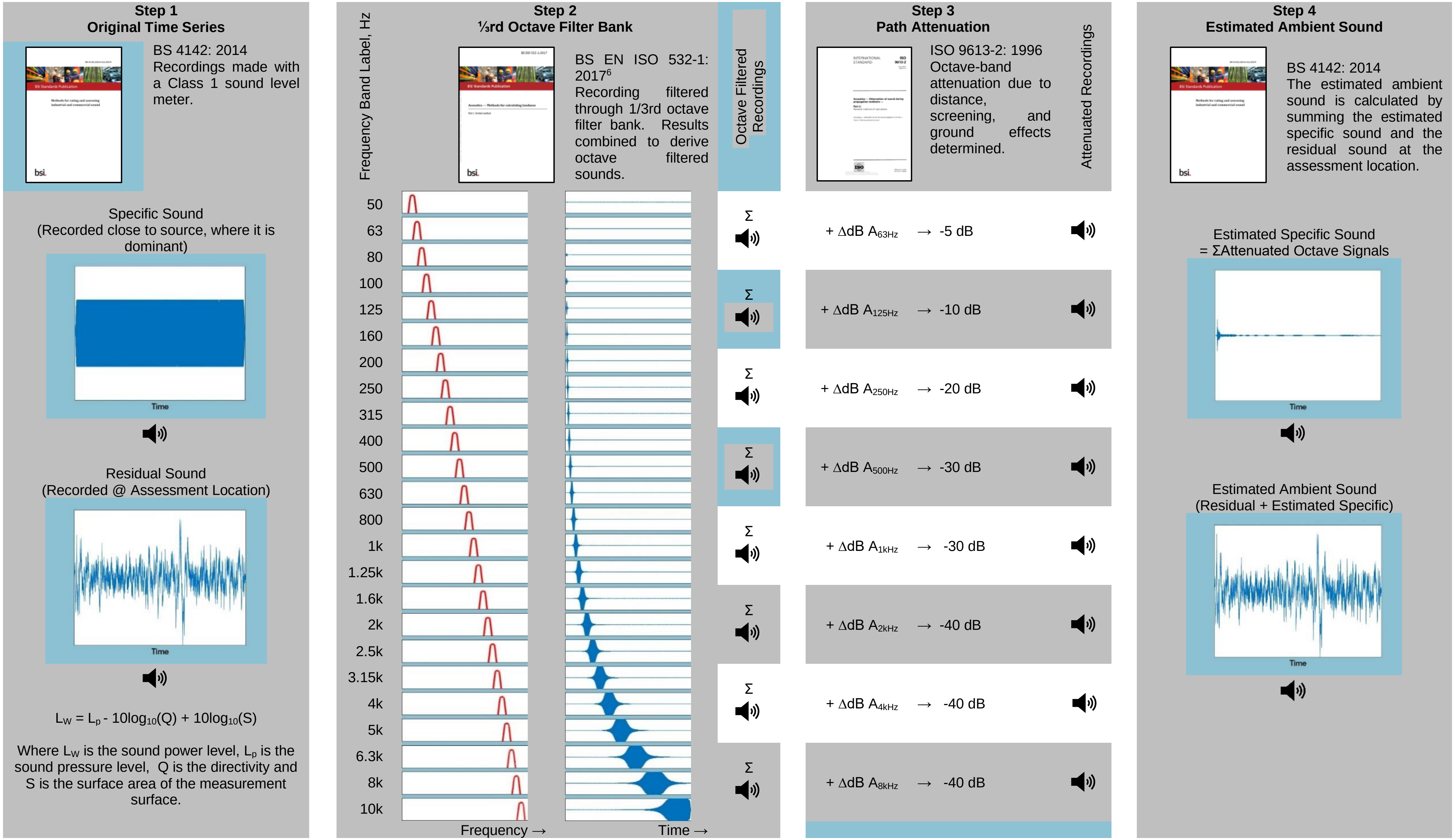


Figure 2: Illustration showing how the estimated ambient sound recordings were created using speech as an example, evaluated with arbitrary attenuation for effect.

The tonal specific sound source was created using a piezo electric sounder (a buzzer) driven by a regulated 12V power supply that could be powered by a battery. The buzzer's frequency and level are dictated by the voltage of the supply; therefore, a regulated voltage supply was essential, with the battery enabling the system to be operated in the field. To allow the system to be used in the field, the electrical components were housed inside a weather resistant case, with the buzzer glued to the top surface. Details of the tonal source are given in Figure 3.

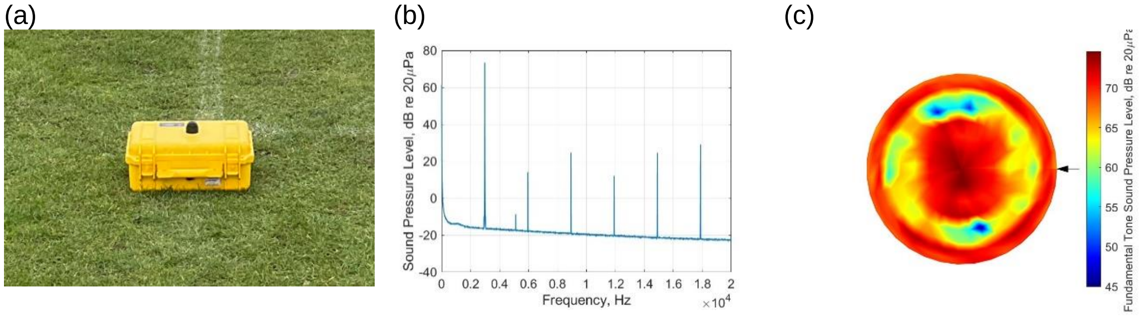


Figure 3: The tonal specific sound source (b) example autospectrum; (c) plot of the measured tone level at each microphone.

The measurements made in the laboratory showed the sound power level of the tonal source to be 86 dB(A) re 1pW. This is based on an average of 350 microphone positions, normalised for measurement area as prescribed by ISO 3745.[7] The autospectrum in Figure 3 was created using a sample rate of 48 kHz, 2^{14} FFT points, and a Hann window with 50% overlap. The source did include harmonics of the fundamental at 2980Hz, but these were at least 40 dB lower in magnitude and would not be included in the critical band of the fundamental in the assessment method. The tonal sound source was, therefore, considered to be a pure tone sound source for the purposes of this study. The directivity plot, which shows the interpolated level over the hemispherical measurement surface as viewed from above, clearly illustrates large variation in sound pressure radiated by the tonal sound source. The directivity was included in the source data used in the modelling. The tonal sound source generated a high enough sound pressure within a narrow enough range to be considered tonal in most residual sound environments. It was sufficiently stable over time to be used in the field experiments.

The impulsive source was created by dropping a 50mm steel ball bearing onto a 150mm x 150mm x 1.5mm steel plate from a height of 950mm. The steel plate was suspended on rubber cord to allow it to radiate sound effectively. To allow remote activation, the ball bearing was released from height by an electromagnet that was powered by the same battery circuit as the tonal sound source. A photograph of the impulsive sound source is shown in Figure 4(a). The sound power level of the impulsive sound source, calculated using L_{AFmax}, was 113dB(A). This is based on an average of 350 microphone positions, normalised for measurement area as prescribed by ISO 3745. Sample spectra measured in the laboratory are shown in Figure 4(b).

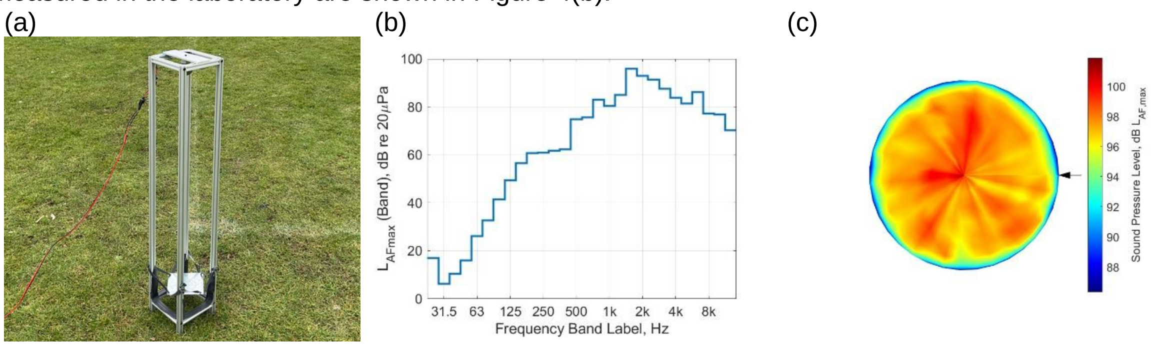


Figure 4: Impulsive sound source (a) photograph, (b) example 1/3rd octave spectrum, and (c) L_{AFmax} at each microphone.

The directivity plot, which shows the interpolated level over the hemispherical measurement surface as viewed from above, demonstrates that most of the sound is radiated vertically, which is expected from a flat rectangular plate. The impulsive sound source generates a high enough sound pressure level over a short enough time period to be considered impulsive in most residual sound environments. Despite impacts being relatively difficult to replicate, the range of L_{AFmax} values measured in the laboratory was small, as shown in Figure 4(c).

3.2 Field Measurements and Recordings

The field recordings had two purposes:

1. residual sound recordings were required for addition to the specific sound recordings that had been attenuated for the calculated propagation path. This combination would create the ambient sound syntheses; and
2. ambient sound recordings for a comparison to be made with the syntheses.

Four class-1 sound level meters were used to make the recordings simultaneously at the positions shown in Figure 1. The recordings were made at 24-bit depth and 48kHz over the full dynamic range of the instrument (up to 130 dB), the latter being required due to the high sound pressure levels at close proximity to the impulsive source. The meters were synchronised and set to start simultaneously so that recordings from each meter could be readily compared with another.

Single one minute excerpts were identified during post-processing that excluded non-stationary residual sound and included clean examples of the specific sound. Recordings of the tonal specific sound were analysed for the full one minute of recorded data. Recordings of the impulsive specific sound source were truncated to 10 seconds with five seconds pre-trigger for ease of identifying the source.

3.3 Online Survey

An online survey was created to gather information to investigate whether subjective evaluation from syntheses delivered via headphones better estimated character corrections than relying on professional experience of similar situations alone (the typical planning control situation). The remaining question is whether objective evaluation of syntheses offers an additional improvement. The invitation to participate in the study was sent to members of the Association of Noise Consultants in the UK, the membership of which is likely to have experience of subjectively evaluating character corrections for BS 4142 assessments. The survey had the following structure:

- **About you** - to gather information about the participants' level of experience and any hearing impairments (4 questions);
- **Introduction** - describing the purpose of the survey and the types of questions that will be asked;
- **Section 1** - where the participants are asked to evaluate character corrections from information about the source and the situation being assessed. This covers the three situations that were described in 7.2 (24 questions); and
- **Section 2** - where participants evaluate character corrections from audio recordings, including synthesised sounds (12 questions).

The 40 questions took the participants about half an hour to complete. They were encouraged to take the survey in a quiet office environment using headphones to listen to the audio recordings. In addition to the procedure outlined in Figure 2, recordings were also truncated to 10 seconds for playback to participants, with fading added to the start and end of the recordings to avoid artifacts.

4 RESULTS

4.1 Survey Results – Section 1

Ideally, the reference methods would be applied to the auralisation-lite syntheses; currently, at the planning control stage, environmental noise practitioners are asked to evaluate the character subjectively based on their own experience of similar situations. A comparison of these two approaches for all 12 of the situations (four assessment locations for each of the simple, barrier and realistic situations) based on the survey results is shown in Figure 5. The reference method results have been presented to a single decimal place between the K_T = 0 → 6 dB or K_I = 0 → 9 dB.

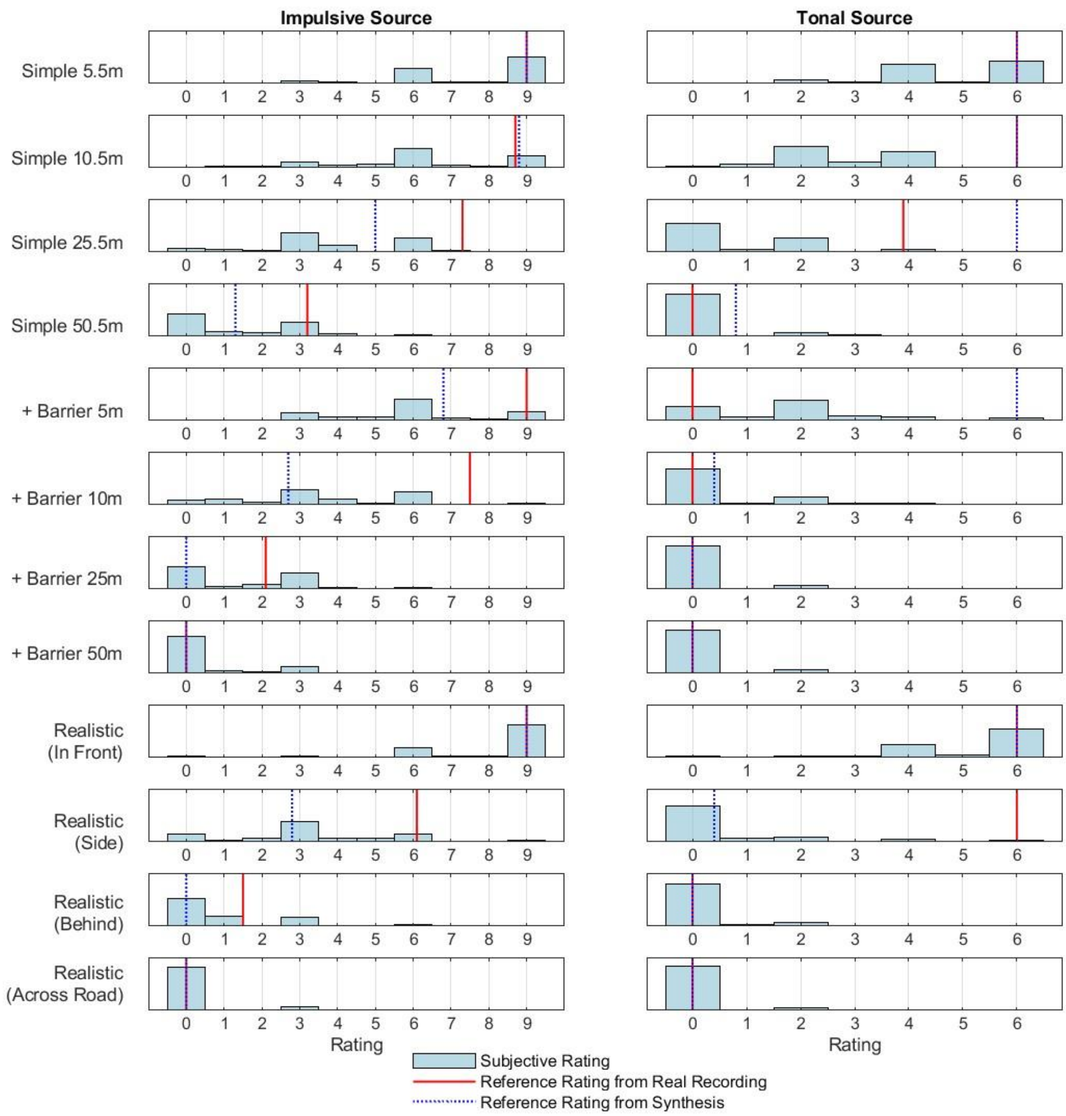


Figure 5: Comparison of the purely subjective responses (based on plans) and the reference method results for real recordings and syntheses.

4.2 Survey Results – Section 2

Auralisation-lite provides the facility to listen to the sound at the assessment location as well as enabling the synthesis to be analysed using the reference methods. In section two of the online survey, participants were asked to rate 12 recordings, six of them being real and six of them having been created using auralisation-lite. These were paired sounds for the simple situation with assessment locations 10.5m, 25.5m and 50.5m from the tonal and impulsive sources.
The subjective and reference ratings have been presented in Figure 6.

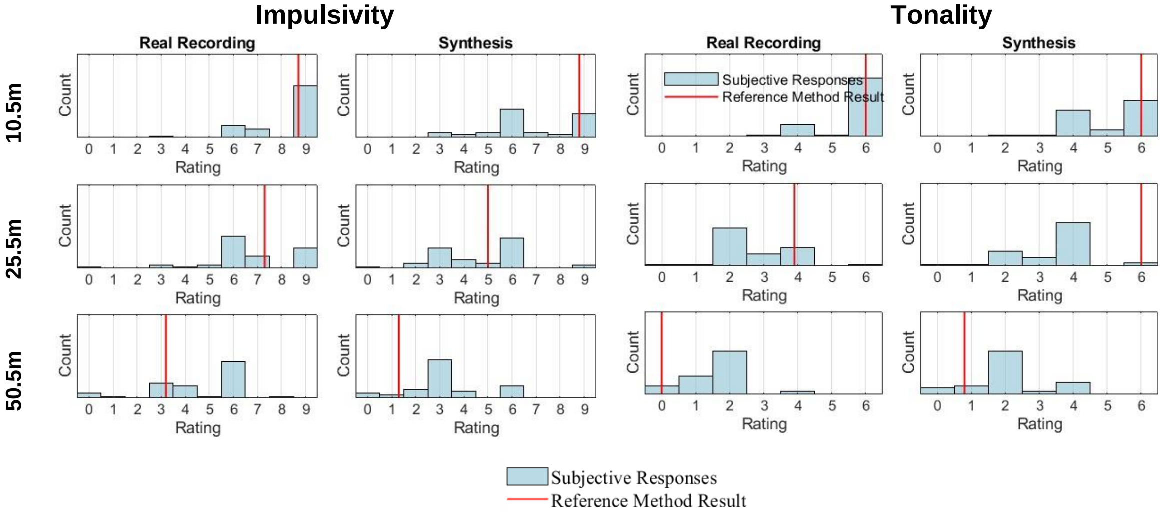


Figure 6: Comparison of the subjective and objective ratings for real recordings and syntheses.

5 DISCUSSION

In this section, the independent variable has been taken to be the result for the reference method for the real recordings. Whilst there is legitimate debate about whether the reference methods are appropriate in all cases,[8] for the deliberately simple impulsive and tonal sources that have been created for this study they adequately capture the acoustic features. The decision to use simple sources was to increase the reliability of the reference methods; however, it will also have increased the reliability of the subjective methods as well. When it is known that 100% of the specific sound is due to a pure tone at approximately 3kHz, the difference between the specific sound level and the residual sound level provides a crude but reliable indicator of tone audibility.

5.1 General Performance of Auralisation-Lite

The magnitude of the ground attenuation calculated using ISO 9613-2 depends on the height of the source, height of the measurement point and the distance separating source and measurement positions. These factors are considered band-wide by ISO 9613-2, however narrow band attenuation will vary significantly within each of these bands. The estimated specific sound levels were shown to be affected by this limitation, particularly for the tonal source.

Figure 7 was created using 50% overlapped Hann windows comprising 2^{14} datapoints. It shows that there is more variability in the real recordings than in the syntheses, considered to be due to turbulence. Small changes in meteorological conditions are assumed to be the cause of time-varying features being imposed on continuous sources as heard remote from the source. This is currently not accounted for in ISO 9613-2, which is only concerned with the calculation of equivalent continuous levels over extended periods of time.

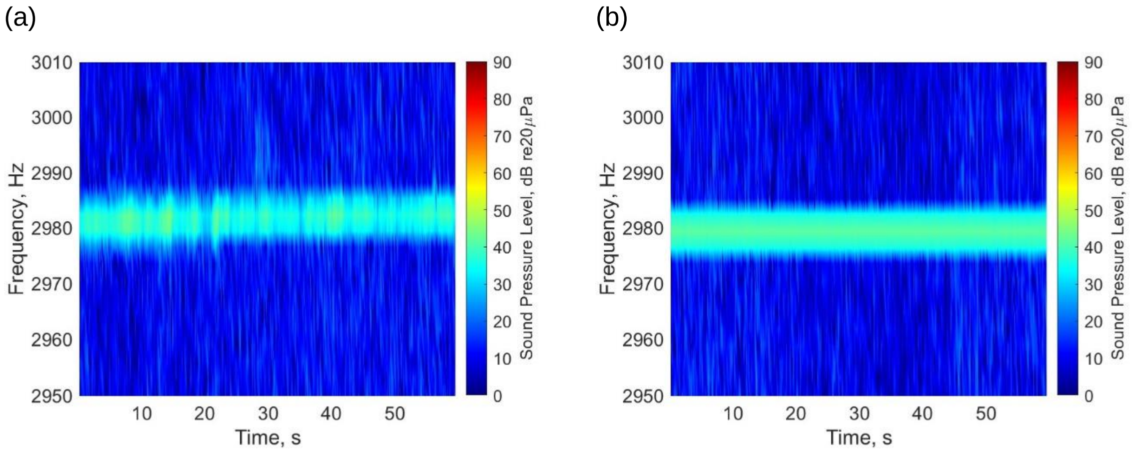


Figure 7: Spectrograms illustrating how the tonal source was audibly affected by meteorological conditions. (a) Real recording for the simple situation with the measurement location 25.5m from the source (b) equivalent synthesis.

The ISO 9613-2 calculation method is entirely in the frequency domain, which means this reverberant characteristic is not captured. Where there is no direct line-of-sight to the specific sound source from the assessment location, the onset rate may be overestimated from a synthesis of the ambient sound because reverberation is not accounted for. This is clearly visible in both the onset and decay in Figure 8.

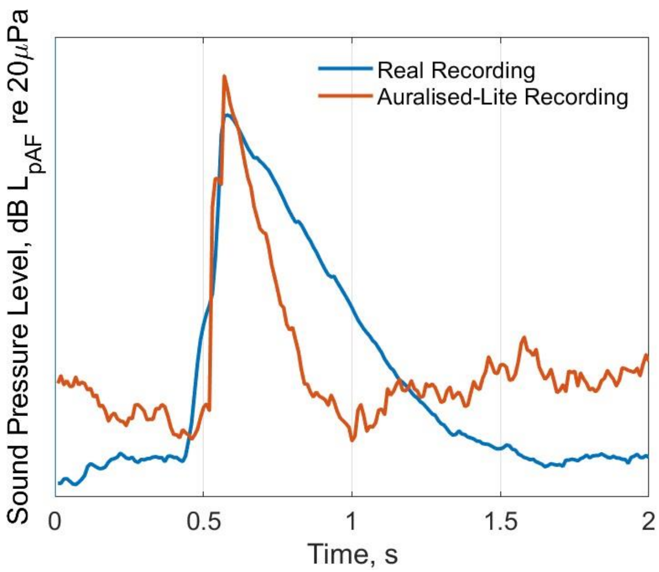


Figure 8: L_{pAF} time-series for the impulsive source in a realistic situation.

5.2 Purely Subjective Analysis of Situations Vs. Auralisation-Lite

It is clear from Figure 5 that neither method exactly reproduces the character corrections that would have been applied using the reference methods for sources measured in-situ. Equally, it is also clear that neither the purely subjective nor the auralisation-lite approach was a particularly poor indicator, if the sample population of participants were taken as a whole. However, the range of results provided by participants means that, for every environmental noise practitioner that rates the character close to the reference result for sound measured in-situ, there is a significant proportion that rate it very differently. This means that one could ask two environmental noise practitioners to provide a subjective judgement about a proposed specific sound source and receive two results that are 6 or 9 dB apart, for tonal or impulsive sounds respectively.

The performance of auralisation-lite has been plotted directly against the average subjective response in Figure 9.

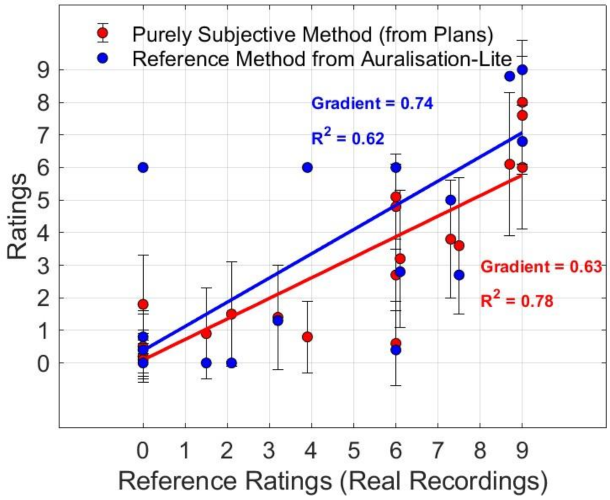


Figure 9: Direct comparison of the purely subjective method (based on plans) and the use of auralisation-lite.

The error bars in Figure 9 indicate the standard deviation of the participants responses from the mean. The poor fit of the linear regression is due to the uncertainty in the measured and calculated outdoor levels, which has been discussed previously. The crucial feature of Figure 9 is that the gradient of the regression line is closer to the expected 1:1 for the auralisation-lite approach than the purely subjective approach. This is considered to result from the general reluctance of the participants to subjectively rate the situations as highly tonal or highly impulsive. It is important to stress here that, in many cases, the impulsivity correction was objectively rated as greater than K_I = +9 dB but was capped at that figure because of the subjective scaled provided in BS 4142. The gradient for the auralisation-lite approach would be closer to 1:1 if this were taken into account.

There are some known biases in the results. A scale of $K_T = 0 \rightarrow 6$dB or $K_I = 0 \rightarrow 9$dB in 1 dB steps was provided for respondents. However, BS 4142 only provides subjective descriptions in 2dB and 3 dB increments for tone audibility and impulsivity respectively (‘not’, ’just’, ’clearly’ or ’highly’ perceptible tones or impulses). Overall, 87% of responses corresponded to one of the descriptions, which increases the standard deviation of the responses and may either exaggerate or minimise the observed effect.

5.3 Subjective Analysis (Via Listening) Vs. Auralisation-Lite

In the investigation, auralisation-lite provided the facility to listen to the sound at the assessment location as well as enabling the synthesis to be analysed using the reference methods. In section two of the online survey, participants were asked to rate 12 recordings, six of them being real and six of them having been created using auralisation-lite. These were paired sounds for the simple situation with assessment locations 10.5m, 25.5m and 50.5m from the tonal and impulsive sources.

The subjective and reference ratings have been presented in Figure 6 and have been further summarised in Figure 10. These figures show that there is a general cluster of subjective responses around the results from the reference method; the same range of results is seen as in section 1 of the survey.

Comparing the ratings for the real recordings against the syntheses in Figure 6, the participants tended not to rate the syntheses as either highly tonal or highly impulsive. The outcome is of interest because it suggests that, despite attracting similar ratings using the reference methods, the real recordings still sounded like they had more prominent acoustic features. This could be due to the lower absolute levels that were calculated, compared to those that were measured. For the tonal source it is possible that the real recordings were underrated by the reference method because of the effect that the small changes in meteorological conditions were having on the recordings. Small changes in the tone magnitude, shown in Figure 7 meant that the tone audibility, which is based on the average over 1 minute, would not have reflected the period where the difference between the tone magnitude and the masking noise was at its maximum. The variation of the tone magnitude may also have served to attract more attention: time-varying tones are poorly treated by the reference method. More advanced, fully psychoacoustic, measures of tonality and impulsivity do account for such level dependence.[9,10]

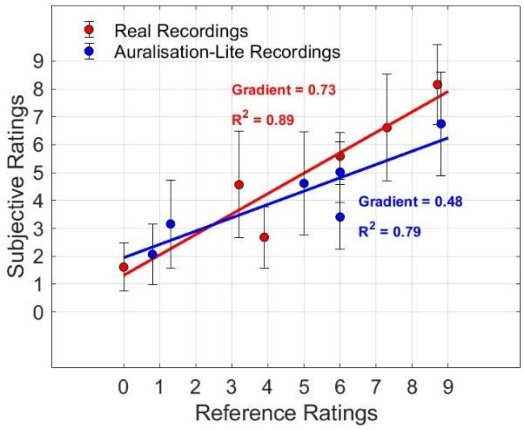


Figure 10: Comparison of the subjective and objective ratings for the real recordings and syntheses.

As seen in the previous section, Figure 10 shows that participants as a group tended not to rate the sounds they listened to as highly tonal or highly impulsive. When presented with recordings to listen to they also tended not to rate them as not tonal or not impulsive either, leading to clusters of responses in the middle of the range. This emphasises the participants' reluctance to evaluate character as being an extreme value.

6 SUMMARY

Currently, there are no published objective methods for estimating character corrections to the rating level used in a BS 4142 assessment for new or modified specific sound sources or propagation paths. Environmental noise practitioners must subjectively apply character corrections based on their experience of similar situations.

This study investigated the feasibility of using auralisation-lite syntheses to objectively evaluate character corrections used in a BS 4142 assessment. The results showed that this approach is promising and could offer improvements over the purely subjective methods that are currently available.

The study found that environmental noise practitioners in the UK tend to avoid rating proposed specific sound sources at the extreme ends of the subjective scales. This means that the specific sound sources in the study were rarely rated as not tonal or not impulsive, nor highly tonal or highly impulsive. The auralisation-lite approach was able to rate several of the artificial recordings at both extremes, which proved to be its main advantage.

Environmental noise practitioners typically use frequency-domain modelling, which does not account for reverberation and turbulence in meteorological conditions. This means that the calculated sound levels averaged over time may be correct, but the sounds themselves will be very artificial. Additionally, it was found in this study that the calculated specific sound levels in octave bands are not always equal to those that are measured. This was due to a combination of shortcomings in the ISO 9613 calculation procedure, which focusses on a time-averaged L_{Aeq}, as well as problems with the characterisation of the test sources.

The quality of the syntheses is only as good as the recordings of the specific sources and residual sound that were used to create them. Recording residual sound for a proposed new or modified specific sound source is straightforward, but making recordings of the specific sound sources, together with adequate directivity information, is not. Examples of the specific sound source to be installed, or examples like it, would be required.

7 CONCLUSIONS

Auralisation-lite provides an absolute result based on time averaged conditions. This means that auralisation-lite could be used to settle disagreements between environmental noise practitioners on opposing sides should they fail to agree on the character corrections to apply. It also avoids the need for previous experience of similar situations. In situations for which an environmental noise practitioner has little or no experience, auralisation-lite may be used as a way of gauging the ambient sound at a remote assessment location. Finally, it does not require additional time or equipment. Provided the environmental noise practitioner is using an instrument with the ability to record high-quality calibrated audio files, no additional time or equipment is required for measurement and modelling than is already invested to carry out the BS 4142 assessment.

It is concluded that there is a need for more objective methods for estimating character corrections at the planning control stage. Future research should focus on developing new assessment methods that incorporate both subjective and objective measures of sound character. The main implication of this work is that environmental noise practitioners should receive training on how to apply, and the limitations of, objective and subjective measures of sound character when conducting assessments in accordance with BS 4142.

8 FURTHER WORK

This study emphasises the critical role of character correction estimation tools in assessing sound within industrial and commercial settings. Further research is necessary to refine these methods and explore their potential applicability.

The main objectives of proposed further work are to:

- conduct a comprehensive international review of the scientific literature on psychoacoustics with respect to the human impacts of industrial and commercial sound;
- critically evaluate and interpret the existing body of evidence; and
- develop recommendations in a format that corresponds to the users' requirements of the BS 4142 standard.

This study recommends the following further work:

- collect a field trial database to capture the full range of human perception and tolerance to industrial and commercial sound;
- establish performance standards for the current noise metrics and the methods used to evaluate their adverse impacts; and
- incorporate psychoacoustic testing to identify the perceptual dimensions of different categories of noise and to devise innovative perceptual models for managing annoyance.

9 ACKNOWLEDGEMENTS

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