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A comparison of inaudible windfarm noise and the natural environment noise whilst monitoring brainwaves and heart rate.

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ABSTRACT
A pilot study undertaken in late 2017 using inaudible wind turbine noise and persons having a heightened sensitivity to turbine noise found the test subjects could detect the presence of the signal by way of feeling (rather than hearing) the signal. A control group that had not been exposed to wind turbine noise was unable to detect or sense the inaudible signal. A single case study as a precursor to a further pilot study utilised inaudible wind turbine noise, inaudible white noise, inaudible surf (ocean) noise and an inaudible ventilation fan, was undertaken in a 126 m^3 reverberation room and also in a 31^3 hemi-anechoic room, whilst monitoring of the test subject's heart rate and brainwaves was obtained. The results of that testing are discussed.

Keywords: Wind Turbine Noise, Brain Response

1. INTRODUCTION
A common complaint from residents in proximity to wind farms is one of sleep disturbance and waking up in an agitated state, where sometimes wind turbines may be audible and at other times the turbines are not audible.

Testing in 2017 [1] by the generation of inaudible full-spectrum signals of a high quality, high sample rate wave file recording of noise detected in the master bedroom of house 87 in the Cape Bridgewater study [2] was presented to 2 groups of nine test subjects. One group involved people who have been found to be sensitive to wind turbine noise who had either moved away/abandoned their homes or reside at a different place a number of times per week. The second group (control group) had never been exposed to wind turbine noise.

Monitoring of wind turbine noise (both external to premises and inside dwellings) has revealed the presence of a dynamically pulsed amplitude modulation [3] which involves a significant variation in the overall pressure level where that variation occurs at an infrasound rate, being identified as the blade pass frequency. One common description used to describe this modulation for wind turbines is “amplitude modulation” The pulsation affects all frequencies and is not necessarily amplitude modulation as defined in an electrical engineering sense (other than modulation of the tone associated with the gearbox output shaft) [4]. Utilising digital frequency analysis of the infrasound region reveals a signal at the blade pass frequency and harmonics of that frequency.

Leventhall [5] has suggested the modulation of the low frequency components of wind turbine noise may be the source of annoyance and not infrasound per se.

Basner and Greifhan [6] have suggested that monitoring of heart rate variability may be one tool for investigating sleep disturbance associated with wind turbines.

Due to relocation from premises containing the laboratory used for previous “wind turbine noise testing”, and the need to consider reconstructing laboratories in a temporary location, an experimental test of a one-person case study was undertaken to monitor the test subject's heart rate and brainwaves. Seven different signals were being applied in two test rooms.

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2. METHODOLOGY

The test signals that were utilised for the experiment involved:

- the Cape Bridgewater test signal (inside a dwelling) utilized in the previous study [1],
- surf noise at a headland above ocean cliffs,
- three different samples of wind turbine noise obtained in the outside environment involving different degrees of amplitude modulation,
- noise of a large exhaust ventilation fan for an underground coal mine,
- white noise, and
- ambient noise prior to and after the seven samples.

The monitoring of the test subject for the seven samples (and the ambient noise) utilised each sample having a time period of three minutes with all samples being inaudible to the test subject in both test rooms.

The first room that was tested was a 126m^3 reverberation room used in the previous studies where all the internal walls and the roof are lined with 50 mm thick medium density polyester and the noise emitter for the signal generation was twelve 15 inch 1000 watt (RMS) subwoofers fixed to a baffle of two layers of 38 mm craftwood and three layers of 16mm plasterboard mounted in the aperture of the reverberation room.

Figure 1: Test set up in Reverberation Room

The frequency response of the subwoofers falls off after 1 kHz and thereby provides an effective low pass filter to restrict the signal to the low/mid frequency bands and the infrasound bands. The system is able to generate a clear sine wave at 1 Hz at a level of 96 dB.

The second room was a hemi-anechoic room where all walls and ceiling are subject of seven layers of insulation, with the first three layers being a high-density polyester (50 mm thick), followed by 50 mm thick glass wool insulation and three layers of 50 mm thick low density polyester. The anechoic room as an empty room has a volume of 31 m^3.

The speakers in the anechoic room involved three 12 inch subwoofer speakers in a sealed enclosure and three (vertical) line array speakers (28^{o} beam width for each array) positioned across the short dimension of the room so as to create a uniform sound field with the capability of the line arrays to generate frequencies up to 16 kHz.

Figure 2: Speaker set up in hemi-anechoic room

The line array system in the hemi-anechoic room has been used for the evaluation of stereo versus mono signals [1]. For the purpose of this study all three sets of line array/subwoofers had the same signal (i.e. mono) generated across one end of the hemi-anechoic room.

The original signals for obtaining the sound files were recorded using a Bruel & Kjaer LANXI Pulse Unit Type 3050-B-040, using GRAS 40AZ microphones and B & K 2669 preamps. The recordings were obtained using B & K Pulse DATA Recording Module or B & K Connect with a sample rate of 51.2 kHz rather than the typical 44 or 48 kHz rate, which has been found to be lacking in terms of reproduction of the pulsations associated with wind turbine noise and other transient noises [7].

As the acoustic signature of wind turbines contains a time varying stream of pulses occurring at an infrasound rate, under the "fluctuation" definition from Zwicker & Fastl [8] the individual senses rather than hears the modulation with the degree of sensing dependent upon the rate of the pulse/modulation and the depth of the modulation. Leventhall [5] refers to Bradley [9] who investigated modulation at an infrasound rate of low frequency noise and found a similar result to Zwicker & Fastl, but expressed the impact in terms of annoyance.

The four wind turbine signals contain amplitude modulation to varying degrees. The ventilation fan has an infrasound pulsation whilst the surf noise and white noise have no periodic function.

The detailed narrow band and 1/3 octave band, time and frequency data for the seven signals (derived in accordance with the procedure in ref [4]) can be viewed from the following links (http://acoustics.com.au/media/ICA2019BW01 and http://acoustic.com.au/media/ICA2019BW02.pdf).

Figure 3 presents the A-weighted Leq spectra (including the modulation indices) for the wind turbine signals, whilst Figure 4 presents the ventilation fan (with modulation indices) versus the surf noise and white noise (that have no modulation indices).

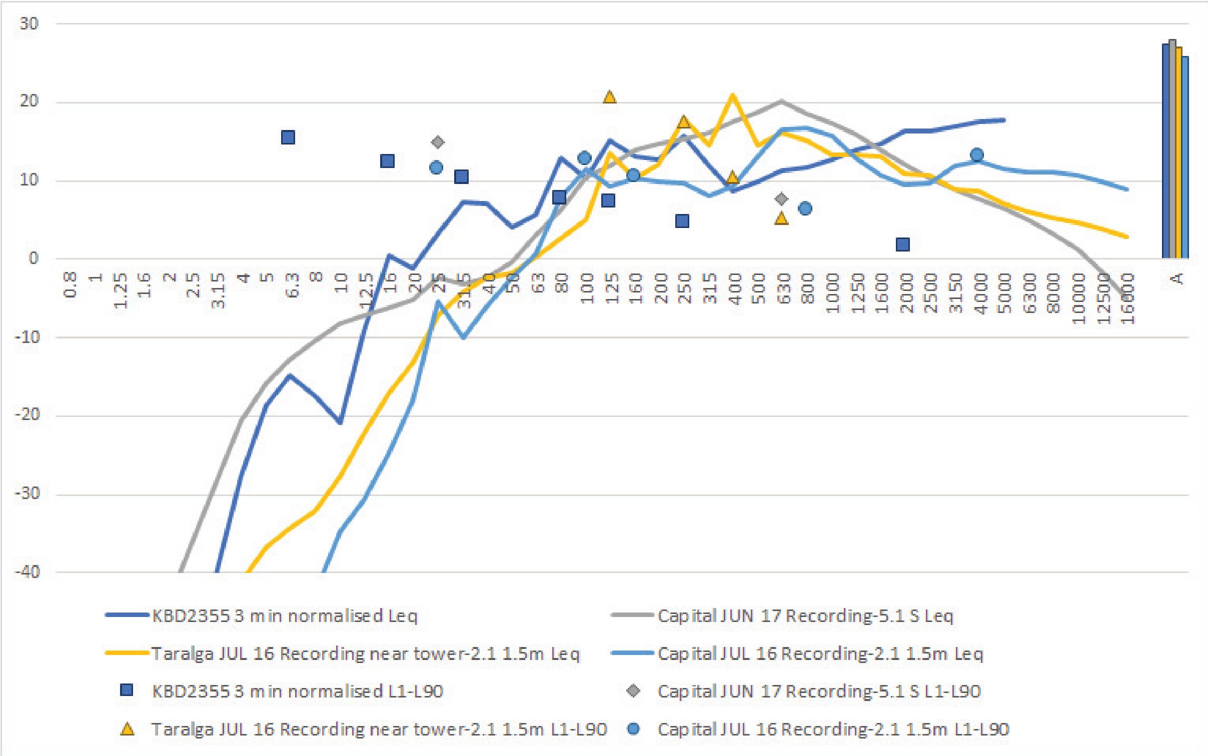

Figure 3 – A-weighted 1/3 Octave Bands and Modulation Indices for the 4 Wind Turbine Samples

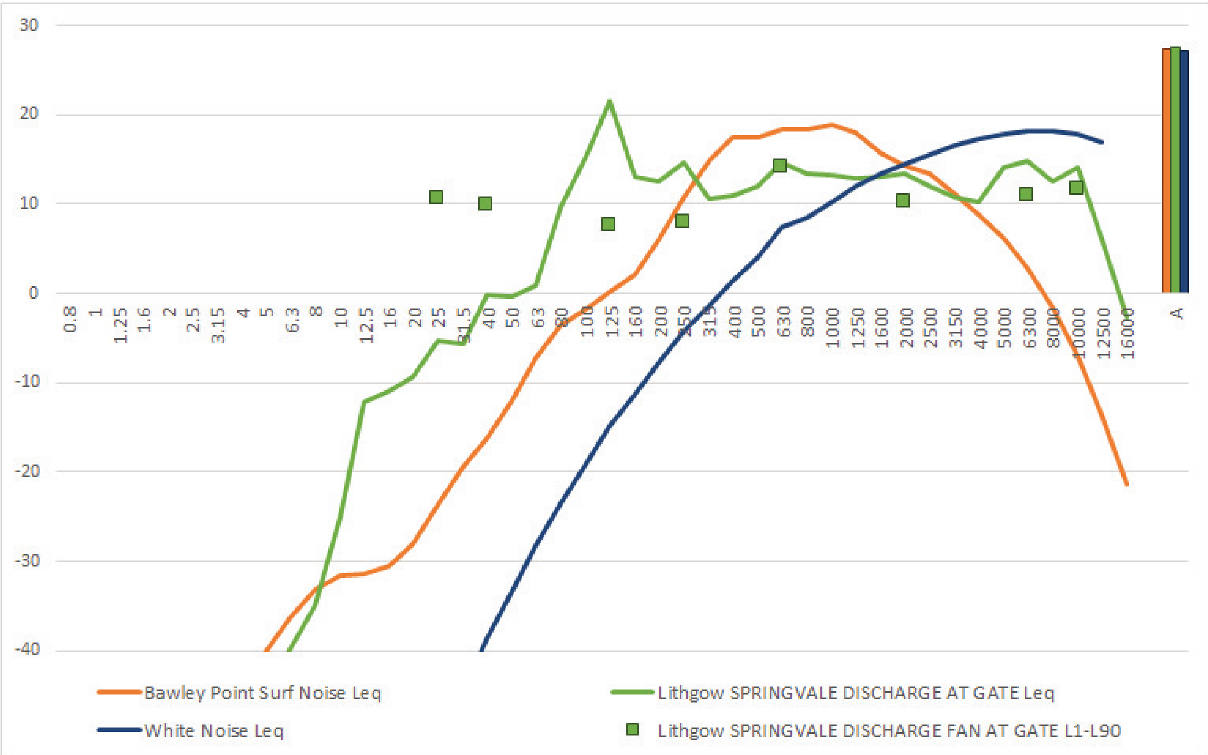

Figure 4 – A Weighted 1/3 Octave Bands an Modulation Indices Non-Wind Turbine Samples

However, in dealing with internal noise levels the attenuation of building elements renders the use of A-weighted spectra of little assistance. The use of Unweighted (linear) results (Figure 5) would appear to be more appropriate for assessing fluctuations where higher amplitude modulation indices can be seen.

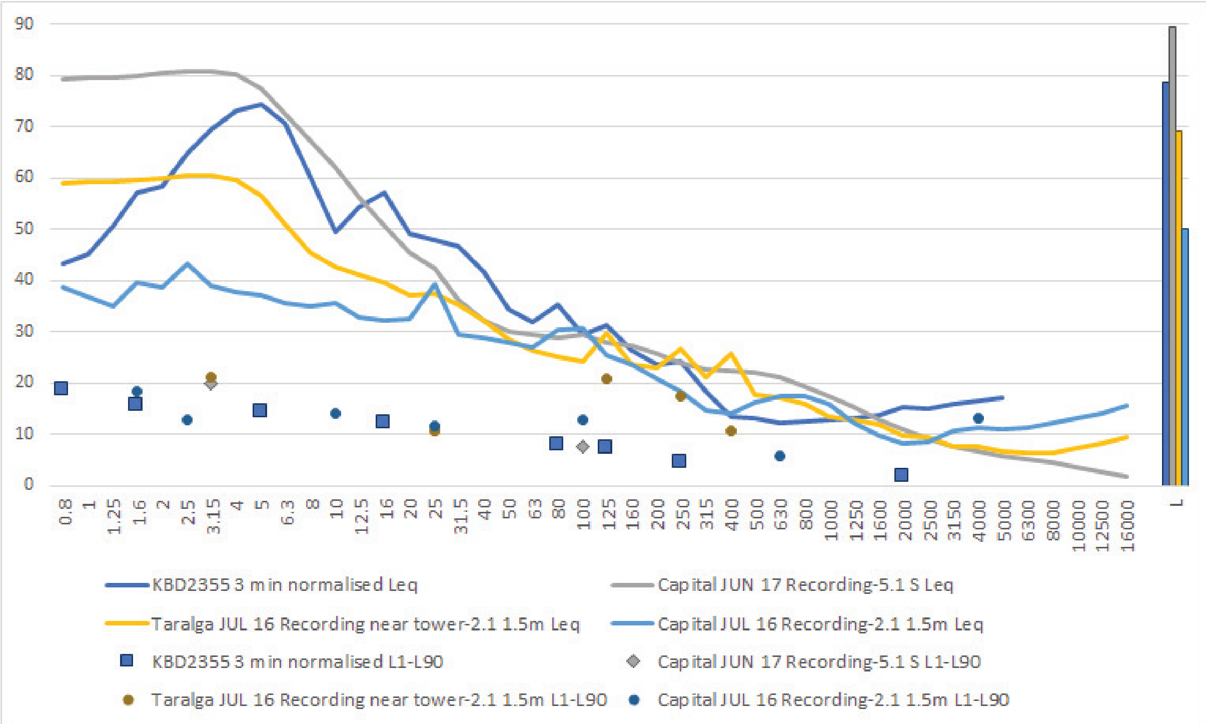

Figure 5: Figure 3 as Unweighted levels

The generated wave files were sent to multiple D Class 2000 watt amplifiers via a high-performance Schiit Gungnir DAC providing a 115 dB dynamic range analogue output from 1 Hz to 100kHz (-1dB). The D class amplifiers had input compensation capacitors to provide a frequency response from 0.5 Hz.

The audio signals were individually normalised to a 25 dB(A) source level then attenuated to achieve a contribution of 18 dB(A) for the reverberation room and 12 dB(A) for the hemi-anechoic room, to be inaudible in both rooms.

For the levels that were generated, the testing was undertaken in accordance with Australian Standard AS 1269.4 *Occupational Noise Management, Part 4: Auditory Assessment* [10] and the testing conducted in accordance with the ASA *Ethical Principles of the Acoustical Society of America for Research Involving Human and Non-Human Animals in Research and Publishing Presentations* [11]. An observer was present in each room during the testing.

The test subject was not aware during the testing of the type of noise source, or when the signals were applied. The psychologist was given a 1 minute count down to the application of the test signals but no information as to the content/type of the signals.

The heart rate monitoring used a Contec Medical Systems Dynamic EGG System Model TLC5000, with the setup of the monitor conducted by a Registered Nurse.

The brain wave monitoring was conducted by a Psychologist who is an accredited BCIA Certified Practioner using a J&J Neuronavigator. The test subject has been a patient of the psychologist for 11 years, is familiar with the conduct of brainwave tests and would not exhibit any anxiety associated with the EEG testing.

The EEG data was run through a normative database to evaluate the nature of the severity of deregulation in brain regions. The normative database used was the Dr Robert Thatcher Neuroguide database (Applied Neuroscience Inc).

The QEEG (Quantitative EEG) provides information on impaired conduction and connectivity between different areas and neural networks in the brain.

3. OBSERVATIONS

The first set of tests in the 126 m³ reverberation room [12] were undertaken with the test subject in the centre of the room in front of the sound field from the speakers, with eyes closed throughout the entire test.

The test subject was unable to detect any noise during the test program.

4. RESULTS

The subsequent post analysis of the data was examined with respect to the time of the applied signals noted by the acoustician controlling the signal generation.

The heart rate monitor revealed variations during the different test samples.

The details of the EEG results are outside our area of acoustic expertise and will be the subject of a separate paper by the psychologist. However, the results have been summarised for mere acousticians as follows:

- The monitoring of the brainwaves revealed for the reverberation room test a posterior dominated alpha frequency of 10 Hz with the overall amplitude remaining within two standard deviations of the norm, except for the ventilation fan test. In terms of individual brain monitoring sites, the Bilateral Medial sites (T3 and T4) were found to exhibit changes depending upon the different (inaudible) signals.
- The increase in T3 and T4 exhibited during the noise samples remained at a steady rate during the white noise and the baseline testing.
- Monitoring in the hemi-anechoic room after a 10 minute break for setting up equipment found at the commencement of the testing that the fundamental posterior dominate alpha frequency of the test subject had reduced to 9.5 Hz and that by the end of the testing had reduced to 8 Hz.
- For the same test signals in the hemi-anechoic room the EEG indicated levels exceeding 2 standard deviations with respect to the normative database. Noticeable increases in the Bilateral Medial sites (T3 & T4) were observed and a significant increase in the Central Midline site (i.e. Vortex Cz).

5. DISCUSSION

The consequence of having full-spectrum frequencies generated in the anechoic room revealed that on a dB(A) basis the levels in the anechoic room were actually lower than in the reverberation room, but the inaudible levels in the hemi-anechoic room had a significantly greater high frequency component by reason of the frequency response of the speaker system being used.

The increased frequency response for the hemi-anechoic room suggests that for the same dB(A) level the presence of inaudible frequencies above 1kHz is relevant.

Subsequent comparisons of the same signals in the reverberation room (limited to 1kHz) to observations in the hemi-anechoic room (by other test subjects) consistently gives rise to a greater level of annoyance in the hemi-anechoic room by persons having a sensitivity to wind turbine noise.

The results of this single case study, when added to the pilot study [1] referred to above, suggests that persons with a sensitivity to turbine noise can experience changes in the EEG during the presence of the signal or the operation of turbines, even when such noise is inaudible.

The changes in EEG and heart rate that were observed in the testing of the inaudible sound are an automatic response of the body and cannot be attributed to the false claim of nocebo and as such support the startle reflex concept previously considered [13].

6. CONCLUSION

Testing was undertaken as an extension of the 2017 double blind pilot study of inaudible wind turbine noise to investigate whether heart rate monitoring or brainwave monitoring could identify a response to the sample noise.

This one case experimental study is the result of six years of investigation into measuring and being able to accurately create wind turbine noise for laboratory study (by others).

The testing found that there was a measurable impact under EEG monitoring to the test samples, thereby supporting the hypothesis for undertaking further studies in this work for which funding is being sought.

From this testing it is proposed:

- The testing could be undertaken using the existing test samples for one case study, or in the resident's home and then repeated as on "on/off" test in the laboratory.
- The testing utilize one test sample spectrum in a session with a nominal exposure of 20 minutes. Then the exercise be repeated with a different test sample.
- A recovery time of not less than 30 minutes be applied if another sample signal is to be tested.
- The study team should be expanded to include appropriate medical experts to undertake additional testing to ascertain the components of the body responding to the test signal.
- The testing involved immersing the test subject into the entire sound field and not just headphones exciting the ears. Accordingly, testing of using just headphones could be of benefit in assessing whether the impact is a whole body experience or just the ears..

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