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VERIFICATION OF OBJECTIVE ASSESSMENT METHOD FOR TONAL NOISE FROM WIND FARMS

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1. INTRODUCTION

This paper forms the second half of a presentation of work carried out on the objective and subjective rating of tonal noise radiated from UK wind farms. It presents the results of subjective testing carried out to verify the objective assessment method proposed within the paper "Tonal Noise Imission from Windfarms" presented at this conference by Bullmore and McKenzie [1]. The whole of this work is an extension of the work carried out earlier by Bullmore & McKenzie [2].

This half of the presentation describes the recording and presentation of the test samples, the experimental procedure used to establish the subjective perception of any tonal features within them and comparison of the results with the objective assessment.

2. DATA COLLECTION

As described in Bullmore and McKenzie [2], noise recordings were carried out at typical residential distances from each of nine wind farm sites covering examples of various wind turbine types currently in use in the UK.

The proposed subjective tests required that the recorded samples were listened to in a way that resembled real life as closely as possible. The best approach for these tests, therefore, was recording using a pair of instrumentation microphones at a separation reproduction over a pair of high-quality, open-back headphones. In this way the path of sound to the ears is maintained and any effects of the listening room are excluded. Microphones were, however, mounted at the standard measurement height of 1.2m rather than typical ear height. Subsequent objective analysis was carried out in the normal way from one of the recorded channels.

All recordings were made on two channel digital audio tape (DAT) recorders using linear (un-weighted) signals which were passed through a 40Hz 24dB/octave high pass filter to minimize the effect of any low frequency wind induced microphone noise.

3. SUBJECTIVE TESTS

The aims of the subjective tests were to establish which of the recorded samples contained tonal components which were 'inaudible', 'audible but not prominent' or 'prominent' as judged by a panel of listeners; to establish a tone rating for each of the noise samples, based on a scale from 0 (not tonal at all) to 10 (very tonal); to establish the equivalent annoyance level for each noise sample relative to a reference noise with no tonal components; to compare the results with the results of the objective assessment.

The noise samples were re-recorded onto a demonstration tape in such a way that each sample played back with the same L_{Aeq} over the 40 second period. They were reproduced through a pair of Sennheiser HD480 open backed headphones at a level which produced 45 dB L_{Aeq} when coupled to a Brüel & Kjær Artificial Ear type 4152.

The 16 noise samples were presented to 32 subjects in turn according to a repeated 'latin square' design. This ensured that, over the 32 subjects, each sample was presented twice at each presentation number and followed every other sample twice and twice only.

The test subjects were volunteers between the ages of 18 and 55 with an average age of 32. Eighteen of the subjects were male and fourteen were female.

Subjects were played each sample in turn, according to the latin square design, and asked to indicate whether they considered any tones present in the sample to be 'inaudible', 'audible but not prominent' or 'prominent'. They were then asked to indicate how tonal they felt the noise sample was on a scale of 0 (not tonal at all) to 10 (very tonal). Subjects were then able to adjust the level of the reference noise signal to give the same subjective annoyance as that of the wind farm noise sample. The reference noise consisted of pink noise shaped to emulate a typical wind farm noise spectrum without any tonal content.

4. ANALYSIS OF RESULTS

The results of the objective and subjective tests are shown in Table 1. The tone sensation level (TSL) is the level of the most prominent tone or tone group as determined by the objective analysis procedure. The objective rating (OR) is the corresponding rating of A-Inaudible, B-Audible but not Prominent or C-Prominent, according to the Joint Nordic Method. The percentages (%A, %B, %C) are the number of subjective rating tones in the sample as A, B or C respectively. The majority subjective response (MSR) is the most common rating between A, B and C. Agreement is whether the MSR agrees with the OR. The subjective tone rating (STR) on the 0-10 scale and the equal annoyance level (EAL) relative to the broad band reference noise is shown averaged over all subjects.

Table 1 - Subjective and Objective Test Results

Sample	TSL	OR	%A	%B	%C	MSR	Agreement	STR	EAL
1	3.49	B	56	41	3	A	N	1.0	-2.1
2	17.36	C	0	19	81	C	Y	7.3	0.7
3	-	A	25	66	9	B	N	2.3	-1.8
4	2.04	B	13	53	34	B	Y	3.9	-0.9
5	9.47	C	6	47	47	B/C	Y/N	5.0	0.8
6	8.91	C	6	34	59	C	Y	5.8	0.4
7	-0.99	A	28	66	6	B	N	2.3	-2.6
8	-	A	22	53	25	B	N	3.3	-1.4
9	1.07	B	38	56	6	B	Y	1.9	0.3
10	-0.66	A	84	13	3	A	Y	0.5	-1.4
11	9.01	C	0	19	81	C	Y	7.3	0.2
12	-0.61	A	28	53	19	B	N	3.1	-1.8
13	5.95	B	3	44	53	C	N	5.1	-1.0
14	9.99	C	0	47	53	C	Y	6.0	0.7
15	2.55	B	9	75	16	B	Y	3.5	-3.3
16	-0.31	A	13	53	34	B	N	4.4	-1.5

The results show that out of the 16 samples, the objective analysis gives the same result as the majority of subjects in 8 cases.

Figure 1 shows STR plotted against TSL; Figure 2 shows %C against TSL; Figure 3 shows %C against STR; Figure 4 shows EAL against TSL. In all cases the solid line shows the best fit straight line through the data and the correlation coefficient is also shown.

Figure 1 - STR vs. TSL

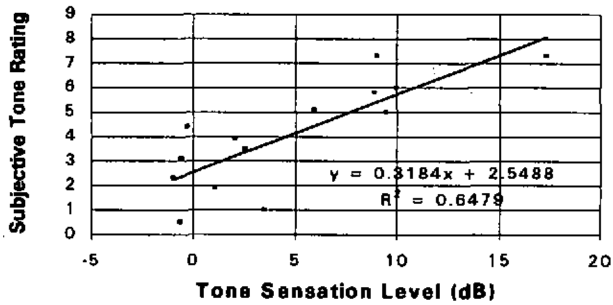


Figure 2 - %C vs. TSL

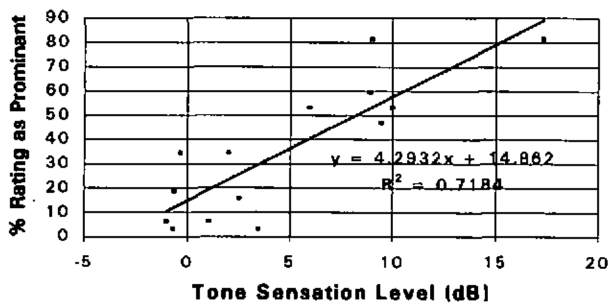


Figure 3 - %C vs. STR

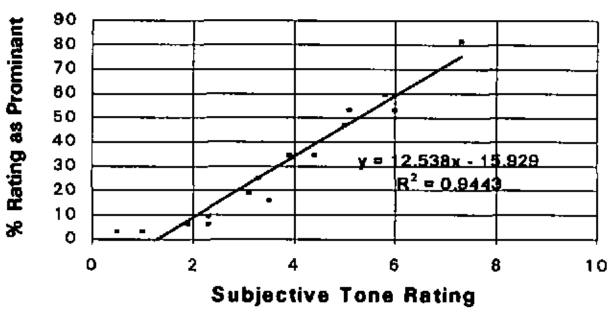
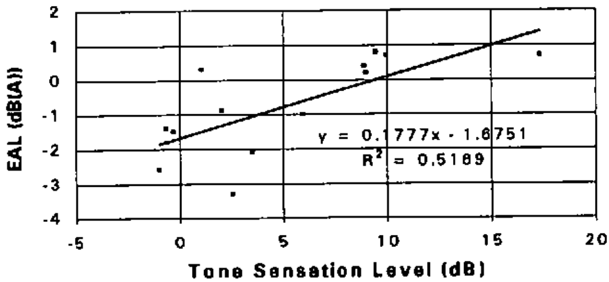


Figure 4 - EAL vs. TSL



5. DISCUSSION

Majority Subjective Response

The samples where the objective rating does not agree with the majority subjective response are numbers 1,3,5,7,8,12,13 and 16. Of these, the objective analysis only over rates the tone level in one sample, number 1, and it under rates it in sample numbers 3,7,8,12,14 and 16. For sample 5, 47% of subjects gave response B and 47% gave response C. In no instances does the objective analysis disagree with the majority subjective result by more than one level (ie. in-audible - prominent).

For samples 3 and 8, the objective tone identification procedure failed to pick the presence of a tone at all. On checking the levels, it appears that the tones in question both lie less than 0.5 dB below the criterion at which a tone is deemed to exist.

Of the remaining 5 samples, samples 1 and 13 are borderline cases only having a small majority subjectively. Samples 7, 12 and 16 are borderline cases objectively with tones lying less than 1 dB below audibility.

Plots of Subjective Response and Tone Sensation Level

These plots show considerable scatter of results in the relationship between subjective responses and objective analysis especially at low tone sensation levels. This suggests that perception of tones is particularly variable around the threshold of audibility.

There is however, a very good relationship between percentage of subjects finding tones to be prominent and subjective tone rating. It shows clearly that tone prominence occurs at different levels for different people.

Equal Annoyance Level Relative to Broad Band Reference Noise

Although the data would suggest that wind farm noise is less annoying than a featureless broad band noise, this hypothesis should be viewed with caution. Although samples were selected as carefully as possible, it is hard to overlook the auditory cues that show the recordings to have been made, in most cases, in a rural environment. It is considered that the results of these tests show that subjects found the binaurally recorded samples of wind farm noise, plus attendant rural environment, to be more pleasant to listen to than the monaurally presented shaped pink noise at the same level until the sensation level of any tones present exceeded a 9.5 dB sensation level.

6. CONCLUSIONS

The comparison between subjective judgments of audibility and prominence and the results of the objective analysis shows that the proposed objective analysis method generally either correctly rates or under rates tonal content relative to the majority subjective judgments.

The objective method failed to identify tones in two of the test samples which rated as audible according to the majority subjective response.

The subjective rating of tones that are close to the threshold of audibility is much more variable than those which are more prominent.

REFERENCES

[1] A J Bullmore & A R McKenzie, "Tonal Noise Imission from Windfarms", InterNoise 1996, Liverpool, UK

[2] A J Bullmore & A R McKenzie, "Objective & Subjective Assessment of Tonal Noise from Wind Turbines", IoA Acoustics '95, Liverpool, UK

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