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PLEASANT AND UNPLEASANT CHARACTERISTICS IN WIND TURBINE SOUNDS

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ABSTRACT

Background and aim: Noise annoyance in areas or at times when the background level is low, may be related to intrusive acoustical characteristics in wind turbine sounds. In this study one of the most noticeable and annoying [1] psycho-acoustical descriptors ”lapping” was evaluated. Methods: With the object to obtain a pleasant sound, a total of 24 subjects varied four parameters related to the perception of ”lapping”. The variations of the parameters were carried out with a constant dBA level using an interactive sound processing system. Results: The adjusted value of three of the four parameters was significantly different from the default parameters in the original sound. The changes of perceived pleasantness of the sound could not be detected by the frequency spectra analysis, but some differences were detected using psycho-acoustical analysis [2], especially specific loudness versus time.

1 - INTRODUCTION

Noise annoyance in areas or at times when the background level is low may be related to acoustical characteristics in the wind turbine sound that are easily perceived and considered unpleasant. Limited number of international studies indicate that the extent of annoyance is weakly related to the equivalent noise level (LAeq) [3, 4]. This may be due to the influence of other factors not related to the noise, such as attitude and visual intrusion. It is also possible that different acoustical factors in the noise not fully detected by the equivalent level, is of importance for annoyance and noise perception. Findings from a previous experiment [1] showed that wind turbines sounds were rated differently with regard to annoyance, time for awareness and intrusive acoustical characteristics, even though the dBA level was the same. Of those intrusive characteristics the psycho-acoustical descriptors of: swishing, whistling and uneven, were previously evaluated [5]. In this study the aim was to evaluate one of the most noticeable and annoying [1] psycho-acoustical descriptor ”lapping”. Lapping can be described as the sounds of moving water, like the sound of waves.

2 - METHODS

Sound generation and exposure: In order to change the psycho-acoustical perception of lapping, it was necessary to modify the sounds with a great degree of flexibility. A software for a parameter-controlled source filter modelling synthetic wind turbine sounds was therefore developed. In the current implementation, sounds from the wind, from the rotor blades passing the pole, sounds generated at the wing tips (physical factors) can be generated as well as acoustical factors, such as modulated noise and perceptual factors such as ”lapping”. The physical origin of the lapping characteristic is not known, but it probably corresponds to the sound generated when the wing tips or certain types of wing tips, pass through turbulence. The model was used in the interactive sound processing system Aladdin (Nyvalla DSP). Using this model a synthetic wind turbine sound was created. As we wanted to evaluate the lapping characteristic, we chose the sound that was given the highest rating of lapping in the earlier study [1]. Equivalent frequency analysis in 1/12 octave band levels as well as analysis of loudness, roughness, sharpness, and tonality showed that there was very good congruity between the synthetically created sound and a recorded sound. For the psycho-acoustical parameters the greatest difference was found for loudness (0.5 sone GF for the 50 percentage value). Perceptually there was also very good congruity between the two sounds and we were thus content with using a synthetic sound instead of a recorded sound for the experiment. The exposure sound level was 50 dB LAeq.

The exposure room was a 4 ×5 m large room furnished as an outdoor environment. On entering the room and always in the pause between the noises, recorded bird song was played as background sound. The sound exposure was emitted from two loudspeakers hidden behind thin curtains. The influence of the room acoustic was <±3 dB in the frequency range of 315 to 4000 Hz.

Interactive evaluations: With the object to make the sound as pleasant or as least unpleasant as possible, the subjects were asked to interactively vary a total of four different parameters in the exposure sound by turning a knob on a panel. The knob had no perceivable start or endpoints. The model was built up in such a way so the resulting sound always had a constant dBA level. The following parameters were varied: *The bandwidth of the lapping sound* (Hz), *the start frequency for the lapping sweep* (Hz), *the frequency range for the lapping sweep* (Hz) *and the gain of the lapping sound parameters* (dB). The lapping sound parameters were generated by amplitude and frequency modulated sounds. A sweeping resonance filter moved in the frequency domain and the centre frequency was the sum of a linear sweep and a random signal causing a frequency flutter. The four parameters changed the sound quality of parts of, or the total frequency range of 800 to 3500 Hz. The reliability of the method was tested in a previous study [5] where the design allowed repeated measures of the same parameter with an interval of 7 to 10 days. The analysis showed that the congruity between the two occasions was very good.

Figure 1 shows an equivalent frequency spectra of the original exposure sound and the same sound with the four lapping parameters adjusted to their minimal and maximal values.

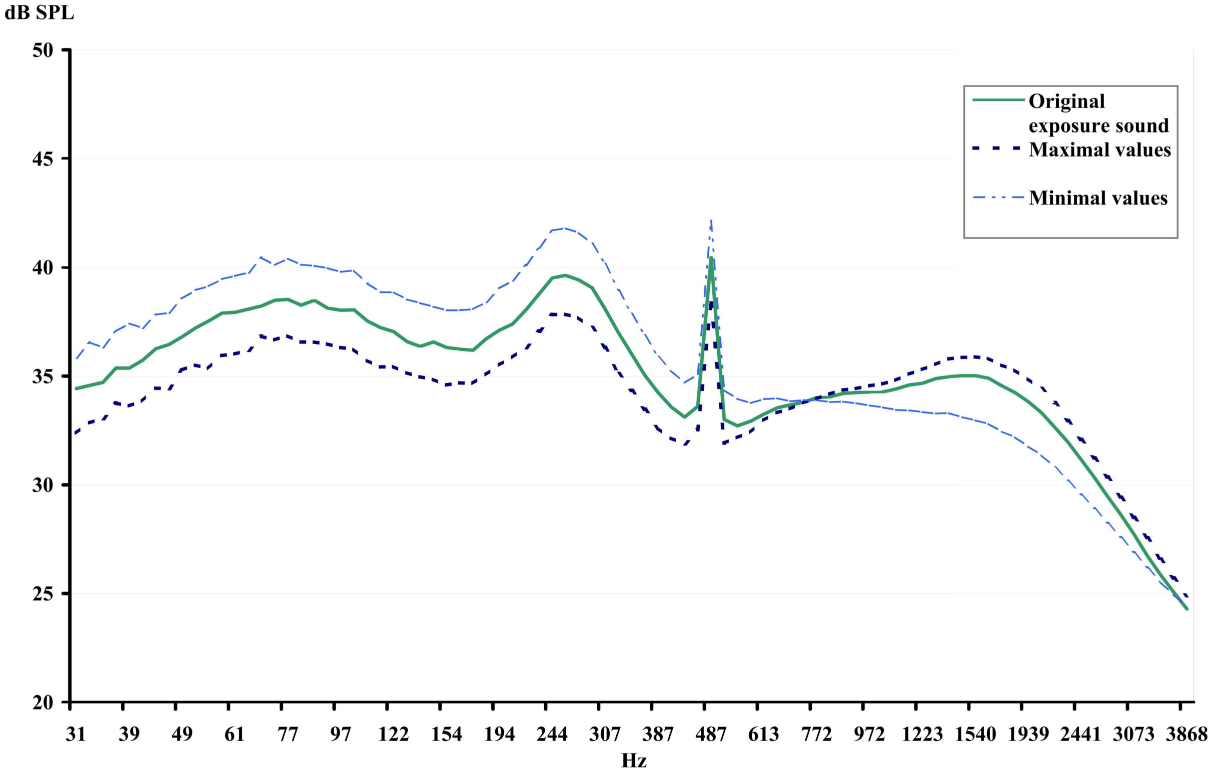

Figure 1: Frequency spectra of the original exposure sound and the same sound with the four lapping parameters adjusted to their minimal and maximal values.

Test subjects: The test subjects were 12 women and 12 men, with normal hearing < 20 dB HL and with an average age of 24 years (sd=5.43)

Design: Subjects adjusted the four parameters one at a time, at three sessions (A, B, C) during the experiment (table 1). The pre-adjustment value was the value that the subject was asked to vary. The first time (A) this value was adjusted twice, starting from its maximal and minimal value. After the subject's choice was made, the project assistant adjusted the parameter to post-adjustment value. The three occasions were thus not repeats of the same sounds.

Session	*Pre-adjustment value*	*Resulting values after adjustments by the test subject*	*Post- adjustment value*
A	Default value	A 1 och A 2	Default value
B	Average value of A 1 and A 2	B 1	Average value of A 1 and A 2
C	B 1	C 1	C 1 (no adjustment)

Table 1: Design for the experimental task.

On separate days, each subject took part in a learning session and an experimental session. The experimental session lasted about 1.5 hours. The order of the parameters were presented in a randomised design, with the exception of the gain parameter, which was during session B and C, presented at the end. This was done to avoid it influencing the other parameters.

3 - RESULTS

The results of the subjects adjustments in the different sessions are shown in table 2.

	Median	***Min***	***Max***	***p-values****
Bandwidth (Hz.)	**1710**	**375**	**5000**	
session A	1048	375	3452	0.067
session B	1085	375	4053	0.032
session C	794	375	2924	0.000
Frequency range (Hz.)	**43**	**25**	**1000**	
session A	96	25	774	0.001
session B	52	25	324	0.058
session C	28	25	363	0.310
Start frequency (Hz.)	**1499**	**400**	**4000**	
session A	1017	428	2441	0.015
session B	726	400	3915	0.001
session C	641	400	2214	0.000
Gain (dB)	**40**	**27**	**45**	
session A	30	27	41	0.000
session B	32	27	45	0.000
session C	33	27	45	0.000

Table 2: Results of the subjects adjustements of the four parameters (* Wilcoxon signed ranks test; analysis of the adjusted value in relation to the default value).

The default values and the maximal and minimal values of the three parameters are given in bold letters. It can be seen in table 2 that the subjects in relation to the original sound, chose a lower value for all the parameters except for frequency range. With this exception all the adjustments were significantly different from the default parameters in the original sound.
Based on the median value from the third session (C), a new sound was constructed. This sound was thus constructed based on the values that were judged to be most pleasant. An analysis of max, min and equivalent 1/12 octave band sound pressure levels of this new sound did not differ in any significant way from the original sound. The pleasant lapping characteristic could does not be found in a frequency domain analysis.
An analysis of loudness, roughness, sharpness, tonality and fluctuation level, showed that the only parameters that differed somewhat were roughness and possibly sharpness. The difference between the new sound and the original sound for roughness was 0.08 and for sharpness even lower 0.03, and it can therefore not be assumed that these differences could explain the difference in perception between the sounds.
An analysis of specific loudness over time between the sounds showed that in the region of 10 to 15 bark, the new sound had a specific loudness that was about 50 % of that of the synthetic sound.

4 - CONCLUSION

Conventional acoustical analysis were not sufficient to predict the subjects perception of intrusive and unpleasant characteristics in the wind turbine sound. Psycho-acoustical analyses, especially specific loudness versus time were found to be better descriptors. Further analysis should be pursued of how to best measure and acoustically describe unpleasant or pleasant sound characters. The relative importance of pleasant windturbine sounds are currently being evaluated.

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