inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 6.3

EXPERIMENTAL QUANTIFICATION OF ANNOYANCE TO UNPLEASANT AND PLEASANT WIND TURBINE SOUNDS

K. Persson Waye, A. Agge

Department of Environmental Medicine, Göteborg University, Box 414, 405 30, Göteborg, Sweden

Tel.: +46 31 773 36 04 / Fax: +46 31 82 50 04 / Email: kerstin.persson-waye@envmed.gu.se

Keywords:
SOUND QUALITY, WIND TURBINE, ANNOYANCE, ACOUSTICAL CHARACTERS

ABSTRACT
The aim of this study was to evaluate annoyance of a less intrusive/more pleasant wind turbine sound in relation to an original sound with a higher content of unpleasant/intrusive characteristics. Method: A wind turbine sound was modified in accordance with the knowledge of pleasant and unpleasant noise characteristics obtained from previous studies. In total 26 subjects were exposed to this modified sound with and without a tonal character and to the original wind turbine sound with a tonal character, at three sound levels, 40, 45 and 50 dBA. Subjective evaluations were obtained after the exposures using questionnaires. Results: Significant differences between the sounds were found for annoyance and awareness for each level, and for pleasantness for 45 and 50 dBA. The two modified sounds were regarded as least annoying, achieved little perceptual attention and considered most pleasant.

1 - INTRODUCTION

One requirement for extensive development of wind turbines near populated areas is a low degree of negative influences on the environment. Regarding noise perception and annoyance there is rather little information of factors influencing noise annoyance. Previous studies e.g. [1] indicated that the relationship between the Laeq value and annoyance was rather weak. Another study [2] showed that one of the more important risk factor is whether the noise can be perceived or not. Support for this latter finding was found in an experimental study showing that test subjects exposed to five different wind turbine sounds rated them differently with regard to annoyance and time for awareness, even though they were presented at the same Laeq value [3]. In following studies the more unpleasant or intrusive characters in wind turbine noise were evaluated by letting subjects vary different acoustical parameters [4,5]. In order to test the hypothesis, that less intrusive/more pleasant wind turbine sounds would be less annoying, a wind turbine sound was modified in accordance with the obtained knowledge of pleasant and unpleasant characteristics, and its annoyance evaluated in relation to the unmodified sound.

2 - METHODS

Sound generation and exposure: Using the knowledge of unpleasant and pleasant characteristics obtained in [4,5], a wind turbine sound was modified using a sound processing system (Aladdin, interactive work bench, Nyvalla DSP, Stockholm) and a software model described in [5]. The original sound (Orig) contained a tonal character and in order to evaluate the influence of a tonal character the modified sound was presented with (ModT) and without (Mod) a tonal character. The sounds were presented at 40, 45 and 50 dBA. The frequency spectra for the three sounds are presented in figure 1.
The modified sounds contained less of the unpleasant/ intrusive characters perceptually related to "swishing", "whistling" and "lapping" and more of pleasant characters related to low frequencies. From the frequency spectra it can be seen that the modified sounds accordingly contained less energy in the frequency area above 950 Hz. The evaluations of lapping was done in [5] and a low level of "lapping" was obtained in accordance with that study. The absence of this character could not be shown in a frequency analysis, but an analysis of specific loudness over time indicated that specific loudness was about 50% lower in the frequency range of 1270 till 3150 Hz [5].

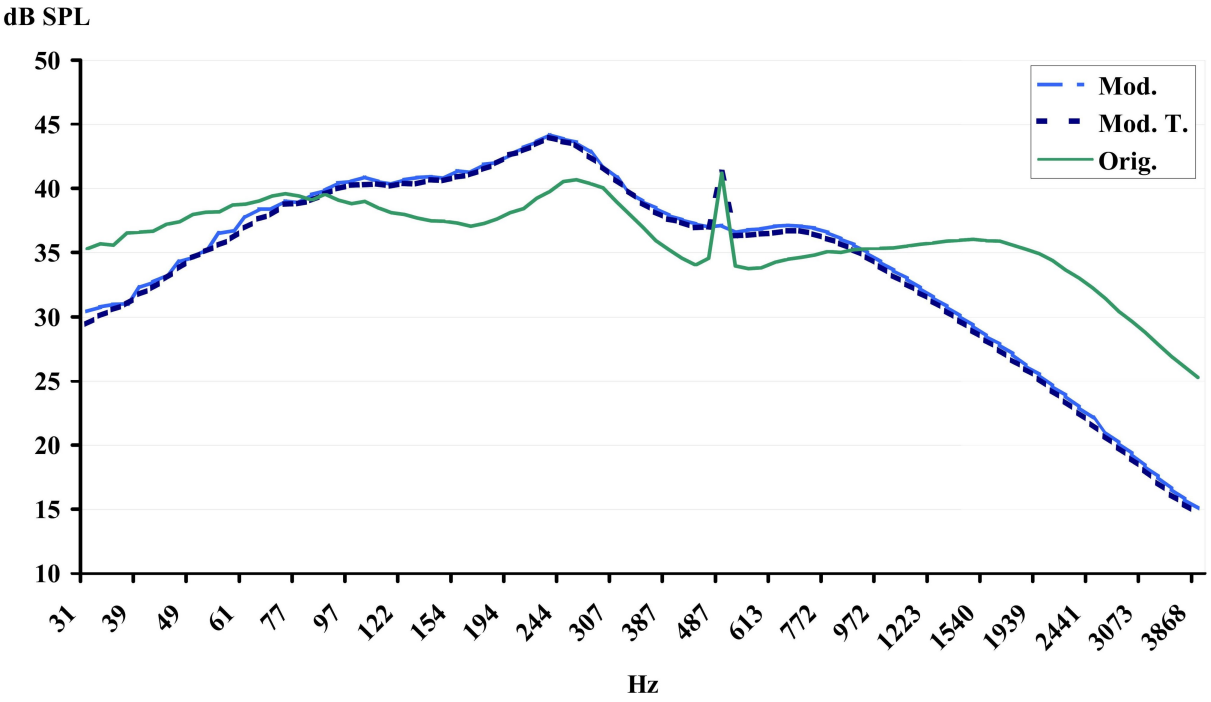

Figure 1: Equivalent 1/12 octave band sound pressure levels of the three exposure sounds.

The exposure room was a 4 ×5m 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 exposure sound was emitted from loudspeakers hidden behind thin curtains.
Test subjects: 15 women and 11 men, with normal hearing <20 dB HL and an average age of 25 years took part. Their subjective sensitivity to noise and attitude to wind turbine noise was evaluated using questionnaires at the end of the experiment. Of the subjects 81 % was positive or very positive to wind turbines, and about 75% were not or not especially sensitive to noise.
Experimental procedure: The design was a 3 (sounds) ×3 (levels) design. Subjects were exposed in groups of three to the three wind turbine sounds at three levels. The order of the sounds was randomised between the groups. In phase I subjects were relaxed reading books of their own choice during a 10 minute sound exposure. Annoyance and degree of pleasantness were then rated on scales from 0 (not at all) to 10 (very). Awareness of the sound, i.e. how long time the subjects had been aware of the wind turbine sound, was rated on a five degree verbal scale from 1 (not/nearly not/ aware of it at all) to 5 (aware of it all the time). In phase II subjects were during 3 minutes exposures to each sound at 45 dBA, asked to listen attentively and rate perception and annoyance of 14 psycho-acoustic descriptions on a scale from 0 (do not notice) to 5 (very annoying) (The results from these data will be reported later). At the end the subjects were asked to rate the relative annoyance of the three noises, from 1 (least) to 3 (most annoying). In total the experiment took about 2 hours and 40 minutes.
Statistical analysis: Analyses were performed using non parametrical statistical methods as the distribution of subjective ratings was skewed. Friedmans ANOVA analyses for repeated samples were performed to evaluate the influence of noise and level on the subjective ratings. Following analysis between each of the modified sounds and the original sound was done using Wilcoxson signed rank test. The statistical analyses were done using SPSS [SPSS base 7.5 for Windows. All tests were two-sided and p-values <0.05 was considered as statistically significant.

3 - RESULTS

Figure 2 shows the median values of rated annoyance for three sounds and levels.
As can be seen in Figure 2, the Orig was rated as most annoying at all levels. The rating of annoyance was significantly different at 40, 45 and 50 dBA (Chi-sq=8.91, df=2, p<0.012), Chi-sq=20,85, df=2, p<0.0001, and Chi-sq=32.01, df=2, p<0.0001). A following analysis of the modified sounds in relation to the Orig, showed that the Mod T was significantly different from the Orig at all levels, while Mod was not significantly different (p= 0.076) at 40 dBA.
The ranking of the sounds from least to most annoying followed the same pattern. The Mod was rated

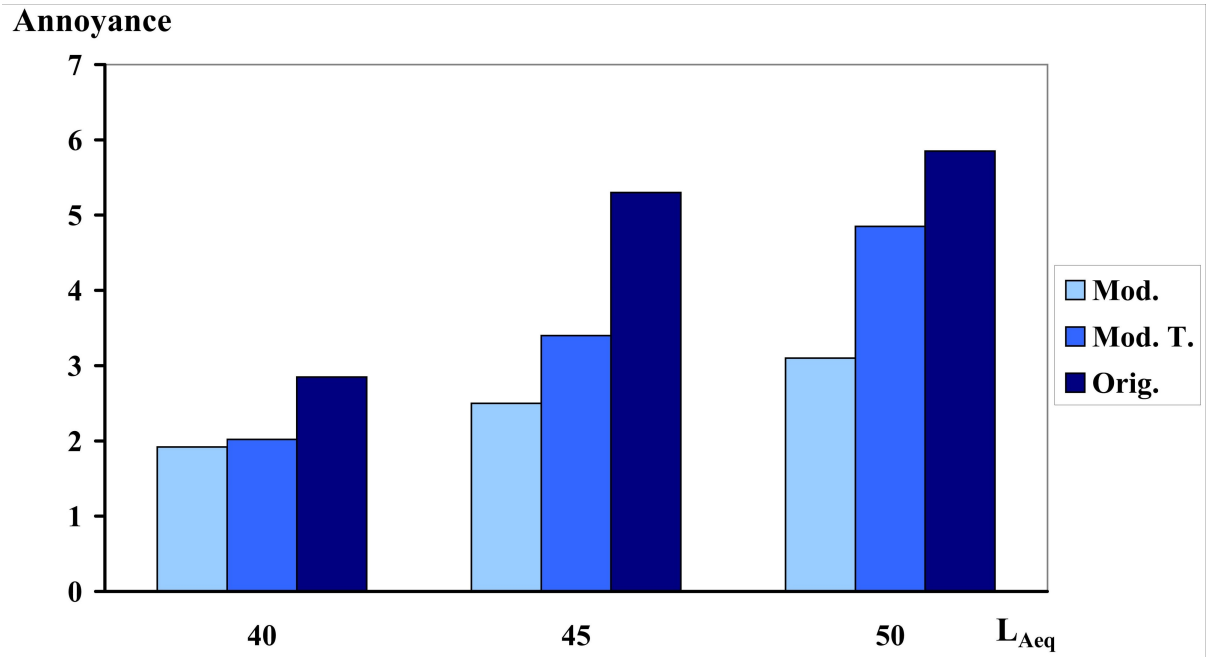

Figure 2: Median values of annoyance of the different sounds and levels.

as least annoying (median value 1.2), followed by ModT (median value 2.2) and Orig (median value 2.6). The difference was significant (Chi-sq=28.68, df=2, p<0.0001).
The median values for pleasantness is shown in table 1.

	Mod	***Mod T***	***Orig***
40 dBA	4.3	3.4	3.1
45 dBA	3.9	3.1	1.8
50 dBA	3.8	2.3	1.7

Table 1: Median value of pleasantness for the exposure sounds.

As can be seen from table 1, Mod was rated as most pleasant and Orig as least pleasant. Pleasantness was significantly different at 45 and 50 dBA (Chi-sq=20.35, df=2, p<0.0001, and Chi-sq=15.94, df=2, p<0.0001), while no difference could be detected at 40 dBA. A following analysis showed that the Mod, was significantly different from Orig at all levels, while the ModT was not significantly different at the level of 40 dBA.
An analysis of Friedman ANOVA showed that the difference for awareness between the sounds was significant at all levels (Chi-square= 8.71, df =2, p<0.02; Chi-square = 20.68, df=2, p<0.0001; Chi-square = 27.46, df=2, p<0.0001). In figure 3 is shown the percentage of subjects reporting awareness of the sound "often", "nearly all the time" and "all the time".
As can be seen in Figure 3, the percentage reporting a high degree of awareness was highest for the Orig and ranged from 40% at 40 dBA to 73 % at 50 dBA. The proportions of subjects reporting high awareness for the modified sounds were lower and ranged from 20% at 40 dBA to up to 40% at 50 dBA.

4 - CONCLUSION

The hypothesis that sounds with less intrusive and unpleasant acoustical characteristics would be perceived as less annoying was confirmed. The two sounds that contained a low degree of unpleasant characteristics were regarded as least annoying, achieved little perceptual attention and were also considered most pleasant. Attempts will be made to obtain a model for relating the difference in annoyance to number of dB.

ACKNOWLEDGEMENTS

The project was supported by funds from the Swedish National Energy Administration (grant no 5210-99-2113). We gratefully acknowledge the technical assistance of Dr Martin Björkman.

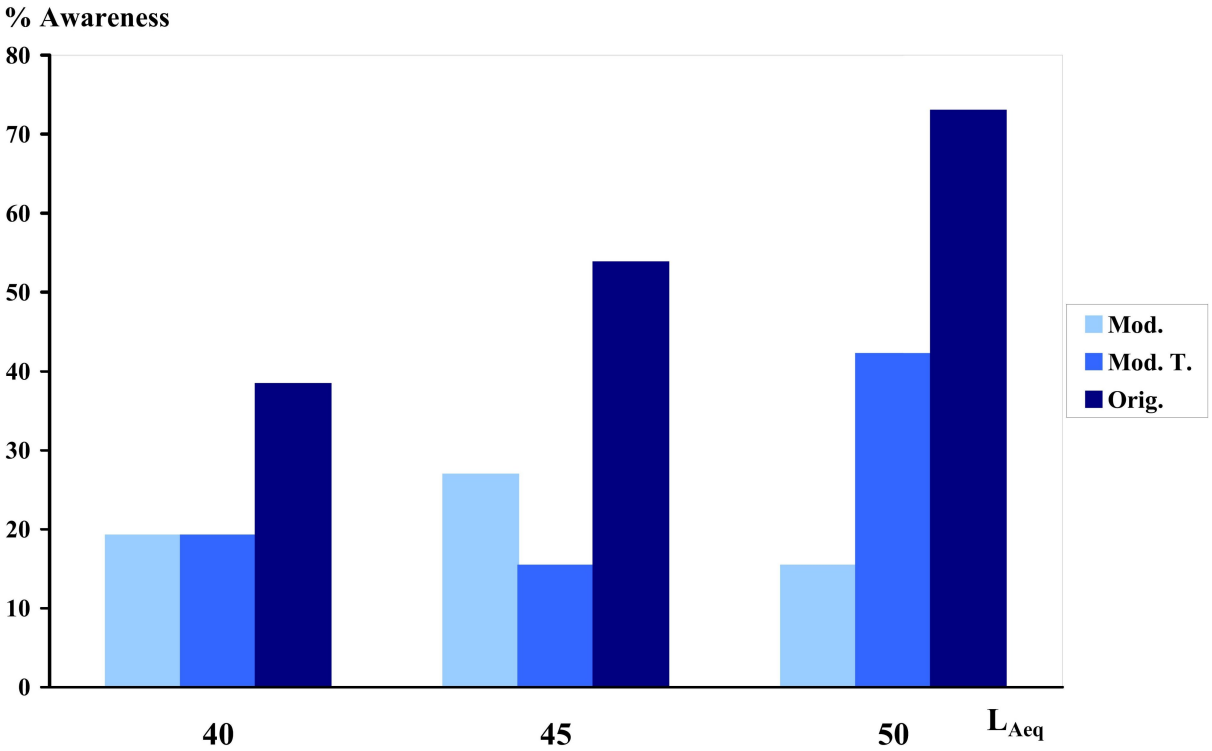

Figure 3: Proportion of subjects reporting awareness of the different noises "often", "nearly all the time" and "all the time".

REFERENCES

1. **Wolsink M, Sprengers M, Keuper A, Pedersen T H, Westra C A.**, Annoyance from windturbine noise in sixteen sites in three countries, In *European community wind energy conference* , pp. 271-276, 1993

2. **Holm Pedersen T och Skovgard Nielsen K.**, *Genevirkning af stöj fra vindmöller. (Annoyance from wind turbine noise)*, DELTA acoustic and vibration, Lydteknisk Institut, Danmark (in Danish). Report nr 150, 1994.

3. **Persson Waye K, Öhrström E.**, Psycho-acoustical characters of relevance for annoyance and perception of wind turbine noise, In *Inter-Noise Budapest, Hungary*, Aug 25-27, Vol III, pp1187-1190, 1997

4. **Persson Waye K, Öhrström E, Björkman M.**, Sounds from windturbines - can they be made more pleasant? In *7th International congress on noise as a public health problem*, Sydney, Australia 22-26 nov, N Carter and R F S Job (eds), pp. 531-534, 1998

5. **Persson Waye K, Agge A, Björkman M.**, Pleasant and unpleasant characteristics in wind turbine sounds, In *Proceedings Inter- Noise*, August 27-30, 2000, Nice France, Vol. 4, pp 2327-2330