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AUDIBILITY OF IMPULSIVE SOUNDS IN ENVIRONMENTAL NOISE

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ABSTRACT
This paper gives an introduction and some preliminary results. Final results and a measuring method may be found on http://www.delta.dk, search for "Impulsive". In the Danish guidelines for measurement of environmental noise it is stated that a penalty of 5 dB shall be added to the measured equivalent A-weighted sound pressures level if clearly audible impulses are present in the noise. As in ISO 1996-2 Amd.1 there is no definition of impulsive sound and no other guidelines for the administration of this 5-dB penalty than a number of examples. With the purpose of finding characteristics that can be utilized for a definition of impulsive sounds in environmental noise and with the hope of finding a practical measuring method that corresponds to the perception of impulses in the noise, a listening test was performed with environmental noise types. In the listening test the following definition was applied: Impulses are sounds with a sudden onset, which attracts attention through the continuous part of the noise, including the background noise. The test persons (12 "ordinary" people and 5 experts) were asked to judge the annoyance of the sound, the amount of impulse characteristic and the intrusiveness of the impulses. The types of noise and the results of the listening test will be presented. For the time being correlations between subjective data and objective measures are made. The results of these analyses will be presented.

1 - INTRODUCTION

Different objective measures for the prominence of impulsive sounds are tested against the average judgements of 17 listeners. A combined measure consisting of onset rate and level difference gave good correlation with the listening tests ($R^2 = 0.74$). This measure is transformed into an adjustment in the range of 0-12 dB to L_{Aeq}. Higher correlations were obtained with psychoacoustic-based measures, but these are still considered too advanced for practical use.

2 - DEFINITION OF IMPULSIVE SOUND

If we want to obtain systematic and objective judgements from listeners presented to various sounds, the listeners need a clear definition of the characteristic they shall evaluate. The following definition was given:

The sudden onset of a sound is defined as an impulse.

The penalty for impulses shall not depend on the type of sound source, but on how prominent this characteristic is perceived through the continuous part of the noise, including the background noise.

3 - RESULTS

The listeners (a test panel of 12 "ordinary" people and a group of 5 experts) were asked to judge the prominence of the impulses in the three groups of examples:

- Group L: L_{Aeq} = 40 dB of the noise samples. L_{Aeq} = 40 dB of background noise. 17 listeners (panel + experts). Artificial head recordings of "real sounds" presented on headphones. The sound samples were unknown to the listeners.

- Group H: L_{Aeq} = 60 dB of the noise samples. L_{Aeq} = 40 dB of background noise. Rest as group L.
- Group P: L_{Aeq} = 60 dB of the noise samples. No background noise. 5 listeners (experts). Mono recordings of artificial and "real sounds" presented on headphones. The listeners knew the sound samples from a laboratory proficiency test.

It is seen that the P-group differs from the L- and H-groups in several aspects. Therefore the main conclusions are based on the L- and H-samples, with additional analysis performed on all sound samples. The data analysis is mainly based on linear regression with the average of the listeners' judgements of "Prominent" as the Y-input and one or more objective measures or transformations of these as variables. Test for the significance of the variables was also made.
The following measures based on the A-weighted sound pressure levels were tested: $L_{AmaxF} - L_{Aeq}$ in one-second periods, $L_{A,F} - L_{A,S}$ as a running measurement, and $L_{AmaxF,30sec.}$, $L_{AmaxF} - L_{Aeq,30sec.}$, and $L_{AmaxF} - L_{A95}$ in 30-second periods. Onset rate (dB/s) and level difference (dB from background SPL to 90% of max. SPL). F and S denote time weightings F and S, respectively. Furthermore the A-, B-, C-, and D-weighted L_{eq}-values were tested.
The following psychoacoustic measures were tested: Loudness (sone), sharpness (acum), roughness (asper), fluctuation strength (vacil), onset rate (sone/sec.) and level ratio (sone/sone) from background level to 90% of max. level.
Good correlations were found between "Prominent" and the logarithm of the onset rate and the logarithm of the level difference. The best results of the A-weighted variables were obtained with the following combination: 2.41 ×log(onset rate) + 3.43 ×log(level difference); R^2 = 0.74 for L- and H-samples and R^2 = 0.57 if P samples were included.
For a similar combination of psychoacoustic data R^2 = 0.75 was obtained for L- and H-samples and R^2 = 0.60 if P samples were included. If also sharpness was included, the R^2-values increased to 0.78 and 0.61. The highest R^2-value was 0.83 obtained with a combination of several psychoacoustic parameters.

4 - OPTIMISATION

A result based on a combination of the psychoacoustic-related measures for level difference (sone ratio: $sone_{backgr.}/sone_{max.}$), onset rate (sone ratio/s), and sharpness are shown in Figure 1. Although this seems promising, an A-weighted measure was preferred for practical reasons.
As mentioned a linear combination of log (onset rate) and log (level difference) gave the highest R^2-value, but the constants were not critical. These were optimised with regard to: a high R^2-value both with and without the P samples, low values for slow (50 km/h) car passes-by and high values for sharp and loud artificial pulses. The measure was furthermore designed to give a maximum around 15.
The optimised formula which gave an R^2-value of 0.73 is:

$$\textbf{Predicted prominence}: \ \mathbf{P = 3 \times log\,(onset\ rate) + 2 \times log\,(level\ difference)} \qquad (1)$$

where the "onset rate" in dB/s and the "level difference" in dB are defined in Section 5. Log is the logarithm with base 10. The correspondence with the listeners' judgements is shown in Figure 2.
From the definition in Section 2 it seems reasonable to express the impulsiveness of an event as a combination of onset rate (how sudden the sound starts) and the level difference (how much the level increases). Although psychoacoustic measures for these characteristics give the best results, the A-weighting and the time weighting F for this purpose seem to give an acceptable and practical approximation to the characteristics of the hearing.

5 - ADJUSTMENT TO L_{Aeq}

Many researchers (e.g. References in [1]) have found that impulsive sounds are more annoying than other sounds with the same L_{Aeq}. Therefore there is a need for an adjustment or penalty to the measured L_{Aeq} for impulsive sounds. For sounds with onset rates larger than 10 dB/s the following adjustment K_I, based on the predicted prominence P, may be applied:

$$\textbf{Adjustment to } \mathbf{L_{Aeq}}: \ \mathbf{K_I} = \begin{cases} 1.8 \times (P-5)\,, & \text{for } P > 5 \\ 0, & \text{for } P \le 5 \end{cases} \qquad (2)$$

It is suggested that this adjustment is made to $L_{Aeq,30min}$ on the basis of the one event with the maximum value of P in the 30-minute period.

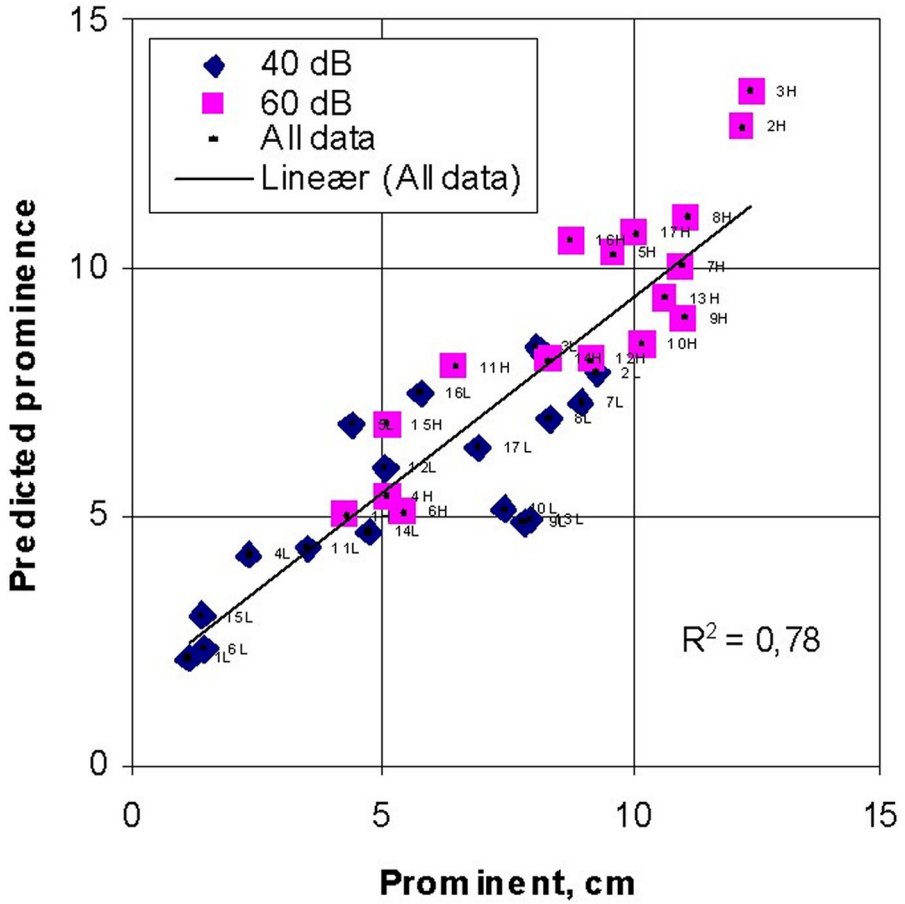

Figure 1: The listeners' judgements of "Prominent" and the prominence predicted from psycho-acoustic measures based on sone and sharpness.

The constants "1.8" and "5" in Equation (2) and the period for adjustment to L_{Aeq} have been set based on general experience with industrial noise types, the sound examples in this study and a few references only. A more thorough study is desirable.

6 - DEFINITIONS AND MEASURING METHOD

Measurements for this purpose shall be made on the basis of the A-weighted sound pressure level with time weighting F. If digital sampling is involved, the output of the F-detector shall be sampled at least every 25 ms.
Definitions:

- The level difference for an event is the difference in dB between the background level just before the event and the maximum level during the event.
- The onset rate is the rate of change in dB/s of the signal. The change shall be measured from the time where the signal first exceeds the background level by more than 10% of the level difference to the time where it first reaches 90% of the level difference above the background level (i.e. 10% below the maximum).
- For passes-by of vehicles, trains or flights the onset rates are defined similarly between the 50%- and the 95%-values of the level difference.

The values of level difference and onset rate may be found from analogous or digital level recordings. The results may also be found by measuring the reverberation time T of the reversed events. In this case the onset rate is 60/T. (Some systems are capable of measuring T of the onset without reversing the signal).

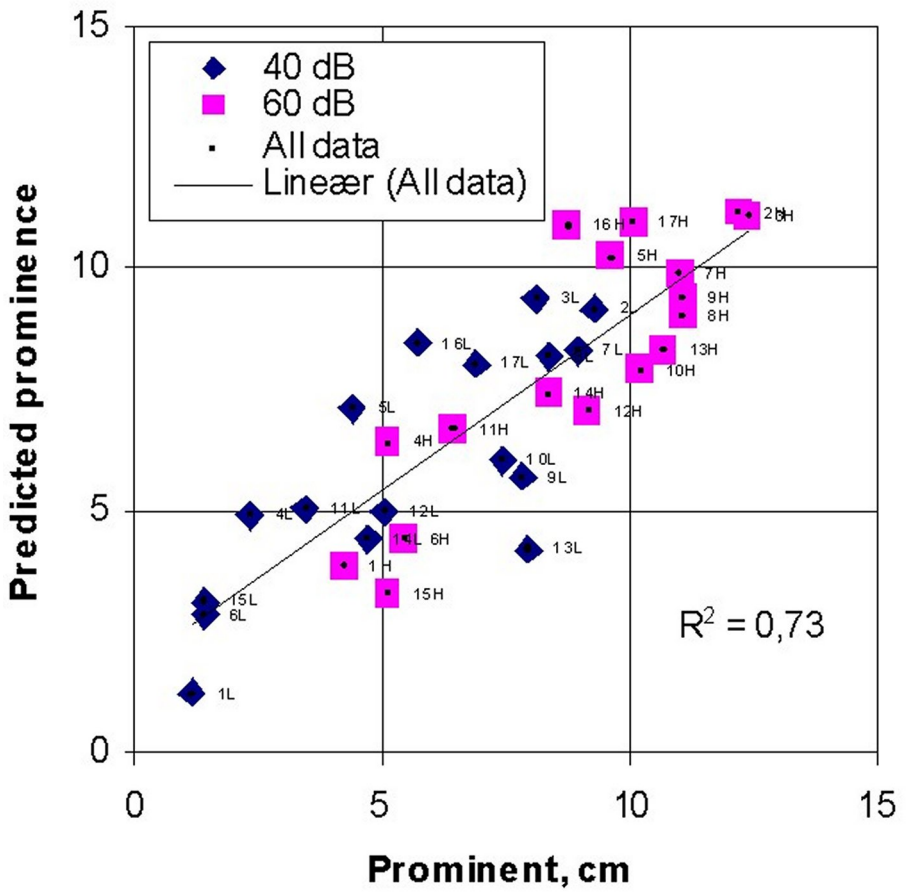

Figure 2: The listeners' judgements of "Prominent" and the prominence predicted from A-weighted measures with time weighing F.

REFERENCES

1. **ISO 1996-2 Acoustics**, *Description and measurement of environmental noise. Part 2 Acquisition of data pertinent to land use*, Amendment 1, 1998-09-15

2. **B.F. Berry**, Towards a Standardised Descriptor of the Impulsive Noise Caused by Low Altitude Military Aircraft, In *Inter-Noise 95 Proceedings*, pp. 879-884, 1995

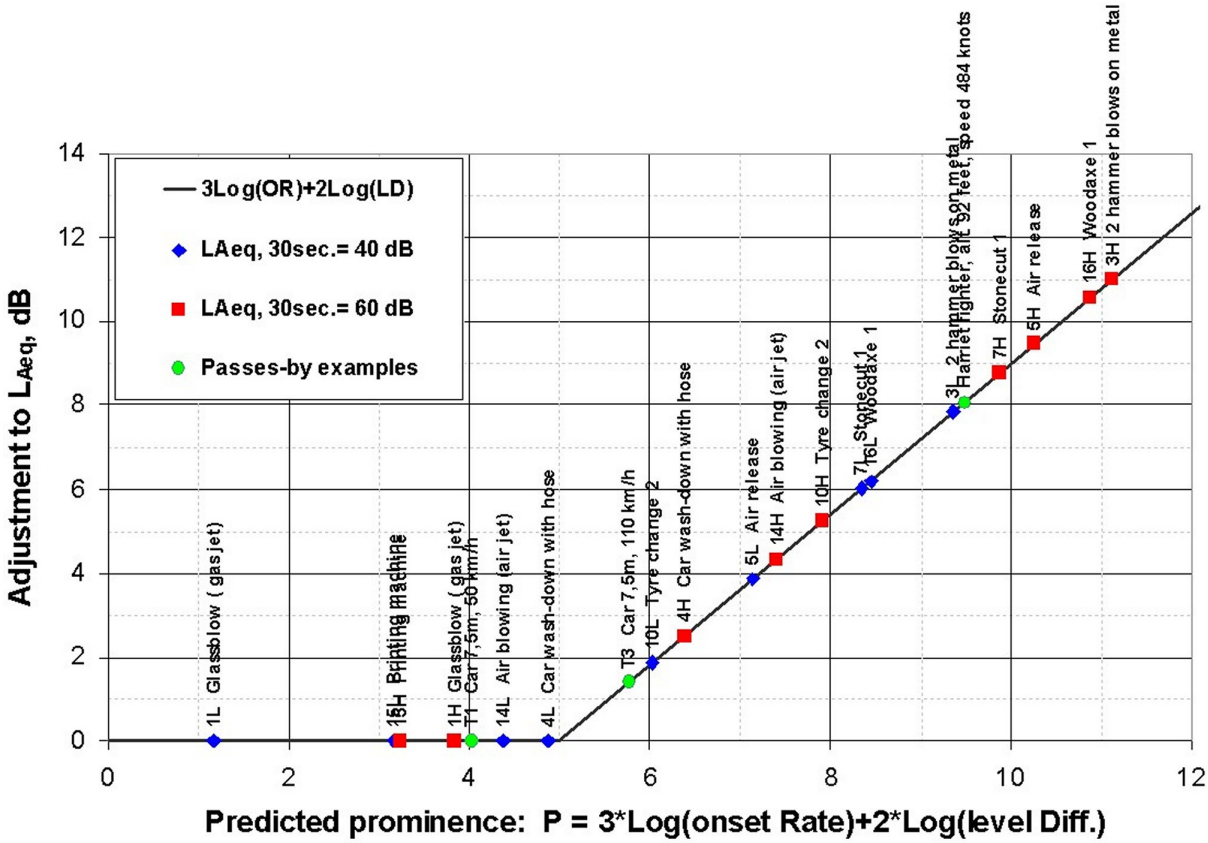

Figure 3: The penalty (Y) as function of the prominence (X), Equation (2), with noise examples (data for Harriet Fighter from [2]).