# COMPARISON OF SUBJECTIVE RATINGS OF TONAL COMPONENTS WITH MODEL PREDICTIONS WITH SPECIAL CONSIDERATION OF TONE TO NOISE PROCEDURES AS PROPOSED IN E DIN 45681 AND ANSI S1.13

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## ABSTRACT

In the last years there have been controversial discussions about the assessment of audibility and prominence of tones in noise. It is often criticized that the subjective impression is not in accordance with the predictions by the standards. Due to this reason new or revised procedures for the evaluation of tonal components have been proposed. In parallel, new measurement methods have been developed allowing a more precise determination of the subjective perception. In this contribution, the results of current models for the identification, audibility and prominence of tonal components are compared with subjective ratings of several investigations. The extent of validity is derived for the different models.

## INTRODUCTION

The correct estimation of perceived prominence of tonal components is an important parameter for the measurement of environmental noise and for sound quality assessment. There are two well known methods for the determination of tonal components: the **Tone-to-noise ratio (TNR)** and the **Prominence Ratio (PR).** Both methods are however restricted to clearly audible, non harmonic and non time varying tonal components above 100 Hz.

In the field of environmental acoustics this is often sufficent as measurements shall be applied on clearly audible tonal components. Therefore a discrete tone is often defined as being prominent if the sound pressure level of the tone exceeds the sound pressure level of the masking noise in the critical band centered on the tone by 6 dB. A pure tone however becomes already audible at about 4 dB below the sound pressure level of the masking noise in the critical band. In sum this means a level difference of **10 dB between detection and prominence of a tone** in noise.

On the other hand sound quality assessment often requires the detection of just audible and time varying components.

In this contribution the extent of validity of TNR and PR models shall be derived for the different applications and an alternative method for the assessment of just audible tonal components is proposed.

The **Tone-to-noise ratio (TNR)** is defined as the ratio of the power of a tone under investigation to the power of the critical band centred on that tone excluding the tone power. Masking effects by components outside the critical band are not taken into account.

The new draft of the E DIN 45681 – 2002 and ANSI S1.13 - 1995 for example are using the TNR-method. The results of these two methods differ significantly from each other and from subjectice data as will be discussed.

### E DIN 45681-2002

Tones are automatically identified as local maxima in an A-weighted power level spectrum where the TNR is greater than the masking index $a_v$, which is the TNR of a just audible tone. The masking index depends on the frequency of the tone. It amounts to –2 dB around 200 Hz and decreases to –6 dB for frequencies up to 16 kHz [7].

The noise power is computed by an iterative procedure that excludes **all** tonal components in the critical band. If there is more than one tone within a critical band, the critical band is centred symmetrically between the highest and lowest frequency of the detected tones. The noise power and masking index $a_v$ are recomputed. The powers of all tones within the critical band are added to the total tone power. The maximum level difference $\Delta L = \textbf{\textit{TNR - a}}_\textbf{\textit{v}}$ for all detected tones is taken as the result. A tone penalty between 0 and 6 dB can be computed from $\Delta L$. The maximum penalty of 6 dB is given for $\Delta L$ greater than 12 dB.

### ANSI S1.13 1995: TNR-method

A tone is classified as prominent when the **TNR** exceeds 6 dB. The TNR does not include the masking index $a_v$. If there is more than one tone within a critical band, the critical band is centred on the tone with the highest level (primary tone). The power of the tone with the second highest level (secondary tone) is added to the total tone power if its frequency is close enough. The noise power is the power in the critical band centred on the (primary) tone excluding the tone power and the power of a secondary tone if it exists. No frequency weighting is applied to the power spectral density. The maximum TNR for all detected tones is the result.

### ANSI S1.13 1995: PR-method

The Prominence Ratio is defined as the ratio of the power in the critical band centred on the tone under investigation to the mean power of the two adjacent critical bands. A tone is classified as prominent when the PR exceeds 7 dB.

## Application to Environmental Acoustics

2 studies from the literature were selected in order to compare the three methods for environmental applications. All maximum level differences $\Delta L$, TNR and PR are computed with the software VIPER, based on FFT analysis of the sounds with a maximum frequency resolution of 4 Hz according to E DIN 45681-2002 and a window overlap of 50%. The average time is equal to the signal length ranging from 4s to 20s. The computation of TNR and PR was carried out for all tones detected by the E DIN 45681 – 2002 procedure, with the maximum TNR, PR as the result.

### Study of Pompetzki

The study of Pompetzki [1] from the Office for the Environment in Essen provided the basic data for the development of the new draft E DIN 45681 –2002. 14 examples of typical industrial noises were recorded and sent on CD to 30 offices for environmental noise and consultants for subjective evaluation by experts. Pompetzki found significant differences and in general an overestimation by

the old draft  E DIN 45681 – 1992 in comparison to the subjective tone penalties given by the 114 subjects. Therefore the revision E DIN 45681-2002 (Sagemühl [2]) incorporates several modifications in order to meet the subjective penalties for environmental noises with tonal components.

Figure 1 shows the results for draft E DIN45681 –2002 and for TNR and PR according to ANSI S1.13 – 1995.
The two TNR-methods show a good correlation of r=0.88 with subjective data. Tone penalties calculated by draft E DIN 45681-2002 increases the correlation slightly to r=0.89. Correlation of PR is worse with r=0.63. Subjective ratings range e.g. from 1 to 4 dB tone penalty for same PR of about 6 dB. (lower part in Figure1)
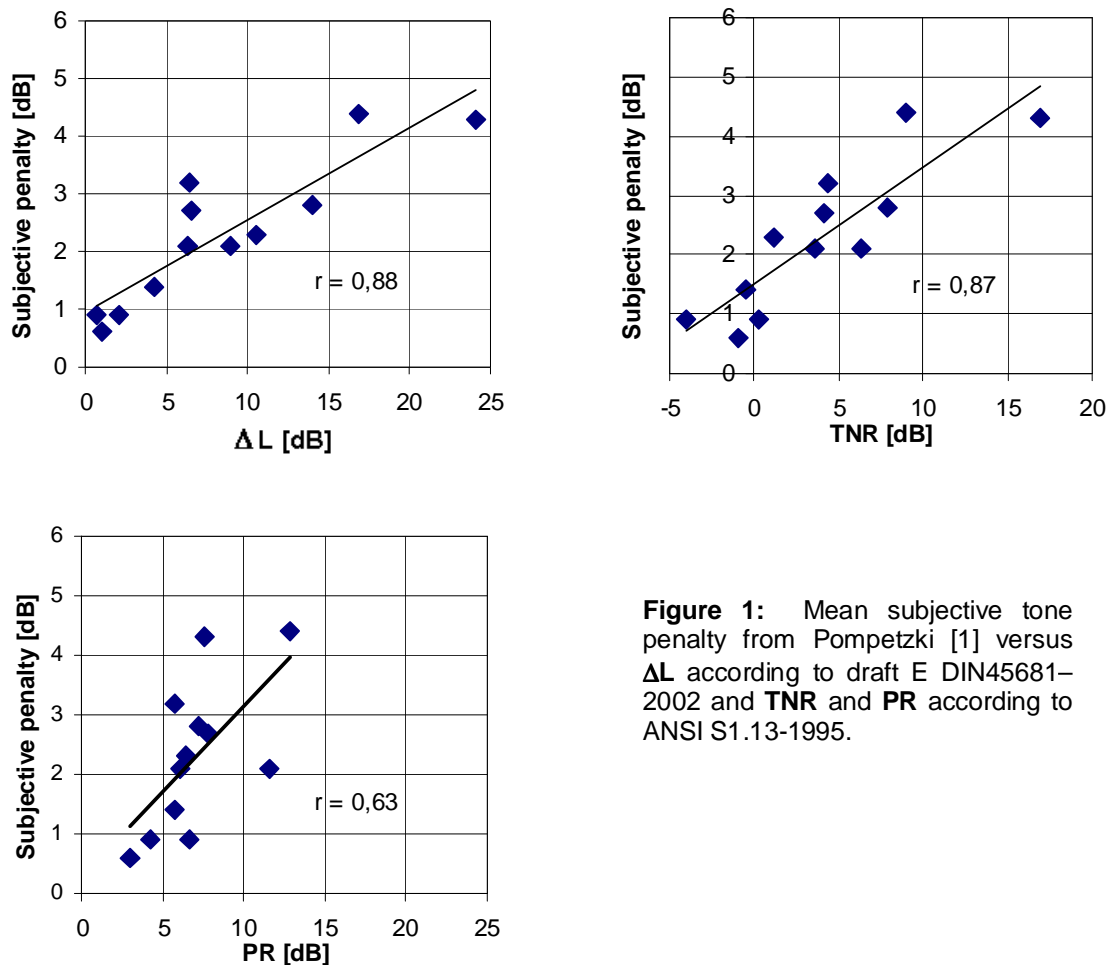


**Figure 1:**  Mean subjective tone penalty from Pompetzki [1] versus **ΔL** according to draft E DIN45681–2002 and **TNR** and **PR** according to ANSI S1.13-1995.

**Study of Dreesen and Weber**
Two experiments from Dreesen and Weber [3] are used to validate the new draft E DIN 45681 - 2002. The subjects had to judge the prominence of tonal components by adjusting a slider on an "analog" Rohrmann-category scale ranging from "not" via "little", "medium" and "rather" to "very" prominent.
**Experiment 1** investigated the influence of one tone (at 500 Hz) and two tones (at 500 and 530 Hz) in pink noise with increasing TNR between 7 and 33 dB and of 8 environmental sounds with subjective ratings between "not" and "very" prominent. 15 subjects took part in this experiment. All sounds were presented via headphones (STAX) at about the same level of 61 dB(A). Figure 2

shows the results for draft E DIN45681 –2002 and for TNR and PR according to ANSI S1.13 – 1995. Sounds with two tones are marked pink, sounds with one tonal component are marked yellow. All three methods predict the prominence of the synthetic signals quite well, prominence of the two tone components however is slightly overestimated by all three methods. The environmental sounds are better assessed by ∆L than by TNR or PR leading to the best overall correlation of r=0.85 with subjective data for the new draft E DIN45681 –2002.
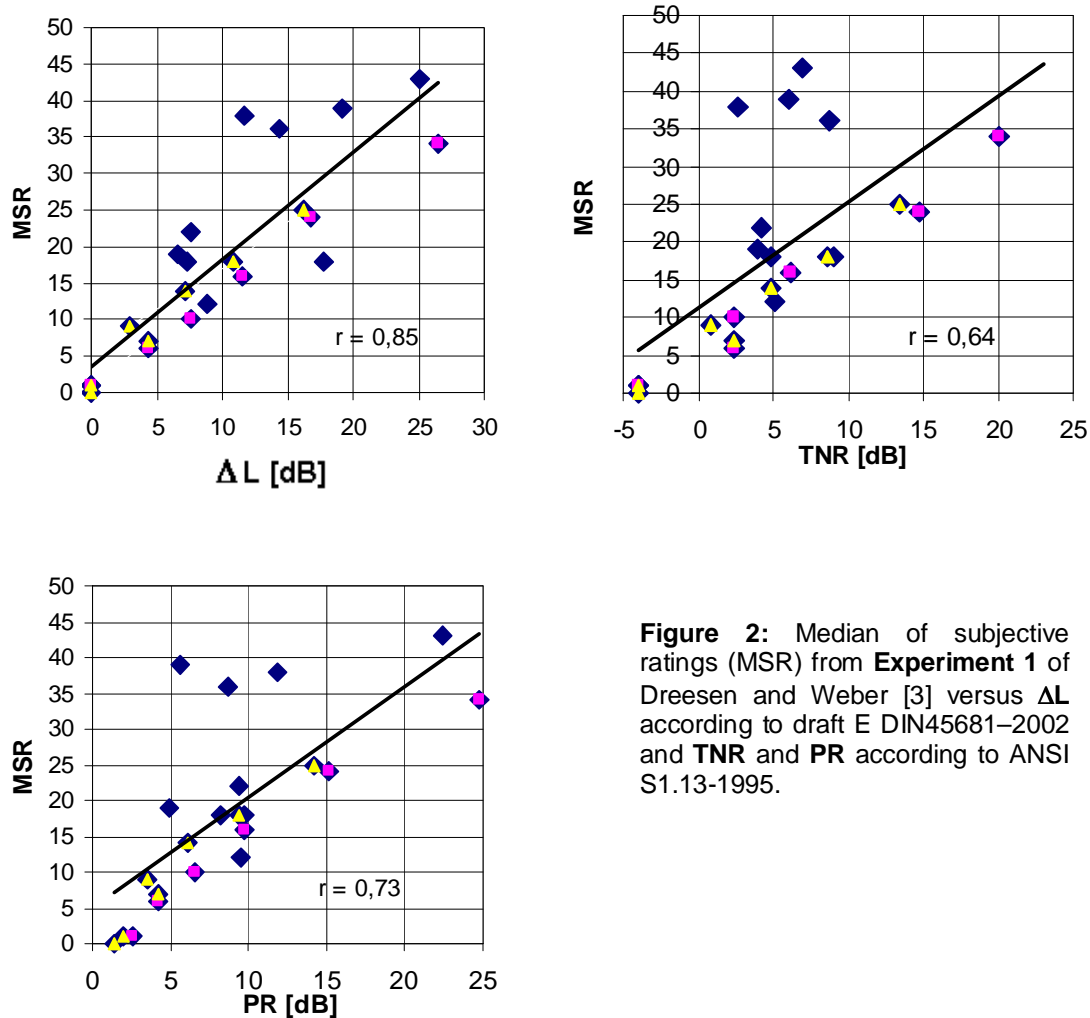






**Figure 2:** Median of subjective ratings (MSR) from **Experiment 1** of Dreesen and Weber [3] versus **∆L** according to draft E DIN45681–2002 and **TNR** and **PR** according to ANSI S1.13-1995.

In **Experiment 2** the influence of frequency on prominence was investigated. Dreesen and Weber [3] found subjective differences in prominence of up to 15 category units or about 1.5 categories. depending on the frequency of the signal. The same effect was observed by Balant et al [4] proposing a frequency correction in ANSI S1.13-1995. Dreesen and Weber varied the frequency of the tonal components in pink noise between 66 to 8000 Hz having TNR between 0 to 25dB. 10 subjects took part in this experiment. Sounds were presented via headphones (STAX) at about the same loudness of 17 sone. The results for draft E DIN45681 –2002 and for TNR and PR according to ANSI S1.13 – 1995 are shown in Figure 3. For better visibility only the representative results for 125, 500 Hz, 2 kHz and 4 kHz are shown. Overall correlation is best for ∆L with r=0.96. TNR and PR have similar correlations of 0.94 and 0.93. However the frequency effect can still be observed. Especially the prominence of low frequencies are overestimated by all three methods. For frequences above 500 Hz the use of the masking index $a_v$ reduces the frequency effect for ∆L compared to the results of TNR and PR.
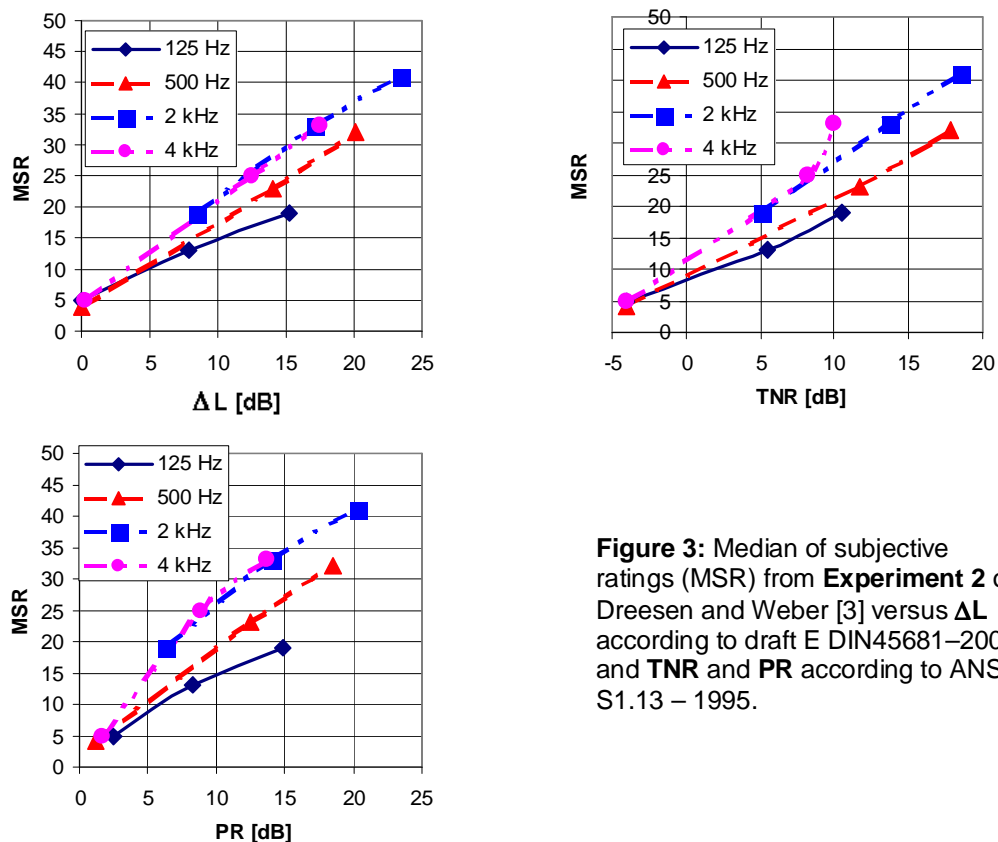
**Figure 3:** Median of subjective ratings (MSR) from **Experiment 2** of Dreesen and Weber [3] versus $\Delta$**L** according to draft E DIN45681–2002 and **TNR** and **PR** according to ANSI S1.13 – 1995.

## Application to Sound Quality

All three methods are not defined for the assessment of weak time varying tonal components as they often occur in sound quality problems. The correct estimation of such components should take into account the time and frequency resolution as well as masking properties of the human ear.

Prominence is closely related to the sensation of spectral pitches which depend upon the sensation level, bandwidth, duration and frequency of the tonal components present [7]. In [5,6] we proposed a pitch model in order to take these properties into account. From an auditory analysis candidates for tonal components are derived in the frequency domain. In the time domain components lasting long enough to be detected by the human listener are connected to form tracks out of which the prominence is calculated.

### Study of Daniel, Ellermeier and Leclerc

An original tire sound recorded in the laboratory with a dummy head sitting at the drivers seat served as "background-noise". Pure tones of 500 Hz with T/N-ratios of 3, 6, 9, 12, 18 dB and narrow-band noises (NBN) centered around 500 Hz having bandwidths of 10, 50, 100 and 200 Hz were added to this "background". The total power of the narrow-band noises was kept constant at the level of the pure tone having a T/N-ratio of 12 dB. All sounds were rated by 25 observers on a six point category scale ranging from "not tonal" to "very tonal".

The perceived prominence of the inserted tonal components is rather low due to spectral masking by components around 300 Hz in the background tire noise, which itself was rated slightly prominent (category 3). $\Delta$L is dominated by the prominence of this "background" sound with a maximum of 17 dB. The maximum TNR of the background sound is about 2 dB. The maximum TNR is the TNR around 500 Hz. $\Delta$L, PR and TNR overestimate the perceived low prominence of the components around 500 Hz since spectral masking is not taken into account and do not properly model the perceived differences in prominence for the added NBN. Correlations for the three method are in the range of 0.7 in contrast to the good prediction by the pitch model with correlation

r=0.94. Thus the new approach seems to provide a useful method in order to measure the tonalness of non-time-varying as well as time-varying sounds.
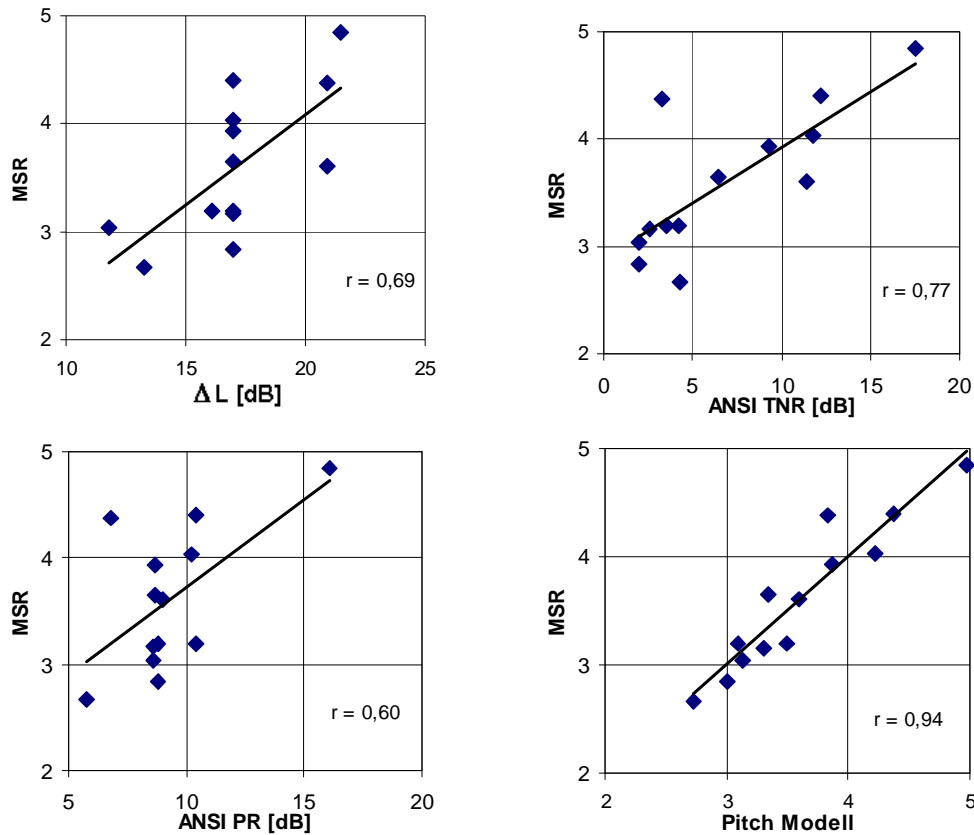


**Figure 4:** Mean of subjective ratings (MSR) from [6] versus ∆L according to draft E DIN45681–2002, TNR and PR according to ANSI S1.13-1995 and data from Pitch Modell [5,6].

**Summary:** The new draft E DIN45681–2002 performs better than ANSI S1.13-1995 (TNR and PR) for the assement of prominent tones in environmental sounds and improves significantly the old draft E DIN45681–1992. Frequency dependence of prominence is slighty improved by using the masking index $a_v$ in E DIN45681-2002, tonal components with low frequencies around 125 Hz however are still overestimated. All three methods are not adequate for the assessment of weak time varying tonal components as they often occur in sound quality problems. For the correct assessment of such components a pitch modell is proposed taking into account the time and frequency resolution as well as masking properties of the human ear.

**References**
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