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ADVANCED PROCEDURES FOR PSYCHOACOUSTIC NOISE EVALUATION

Hugo Fastl

AG Technische Akustik, MMK, TU München
Arcisstr. 21, D-80333 München, Germany
fastl@mmk.ei.tum.de

ABSTRACT

In addition to traditional, purely physical noise measurements, psychoacoustic metrics are used more and more for the assessment of noise problems. Within the psychoacoustic procedures, some already have become "classic" like e.g. Zwicker's loudness for stationary sounds as described in DIN 45 631 and ISO 532 B or algorithms for sharpness, fluctuation strength, roughness, and so forth.

Recently, new results of basic psychoacoustic research have been adapted for practical applications.

In the domain of loudness, a new model called Dynamic Loudness Model (DLM) was proposed, which accounts for the loudness perception of stationary and in-stationary sounds in normal hearing as well as hearing impaired persons. The latter is of particular relevance for questions of sound engineering of high quality products, since many customers already show slight hearing losses. For elder persons this can be the "normal" presbycusis; younger persons (e.g. Yuppies) increasingly also show hearing impairments because of extremely loud leisure pastimes.

In practical noise evaluation, cognitive effects (e.g. if we like or dislike a sound source) can play an important role. Therefore, to get a handle on the magnitude of possible cognitive effects, a procedure was developed, which largely keeps dominant psychoacoustic magnitudes the same, but obscures the information about the sound source.

It is well known that noises with tonal components can be pretty annoying. Therefore, in many countries "tone penalties" are added to the measured values. However, frequently the magnitude of the tone penalty is a matter of discussion or law suits. In extended psychoacoustic experiments, the "pitch strength" of various sounds was evaluated and a model was developed. These data can serve as a basis for the quantitative assessment of tonal components.

1 INTRODUCTION

Applications of psychoacoustic knowledge in noise evaluation have a long tradition. For example, the A-weighting curve is derived from an equal loudness contour, i.e. a standard for noise measurements used worldwide since decades is based on features of the human hearing system. However, in the meantime psychoacoustic research discovered many more aspects of human hearing. For example a drawback of A-weighting is that it simulates the human hearing system only for sounds with small bandwidths and low levels. In real life, however, most sound sources produce broadband spectra at mid or high levels. Nevertheless, the underlying concept that noise measurements should be based on features of the human hearing system deserves our appreciation and is still valid.

Since the last twenty years or so, psychoacoustically based metrics are used more and more for the assessment of noise problems and reviews were given e.g. by Zwicker (1978) or Fastl (1988, 2000). In this paper, more recent trends from the last five years are addressed.

2 DYNAMIC LOUDNESS MODEL

Based on the classic loudness model proposed by Zwicker (1960), a new loudness model, called Dynamic Loudness model (DLM) was developed (Chalupper and Fastl 2002). The main feature of the new loudness model is that it can predict loudness perception for stationary and in-stationary sounds not only for normal hearing persons but also for persons with hearing deficits. A block diagram of the model is given in figure 1.

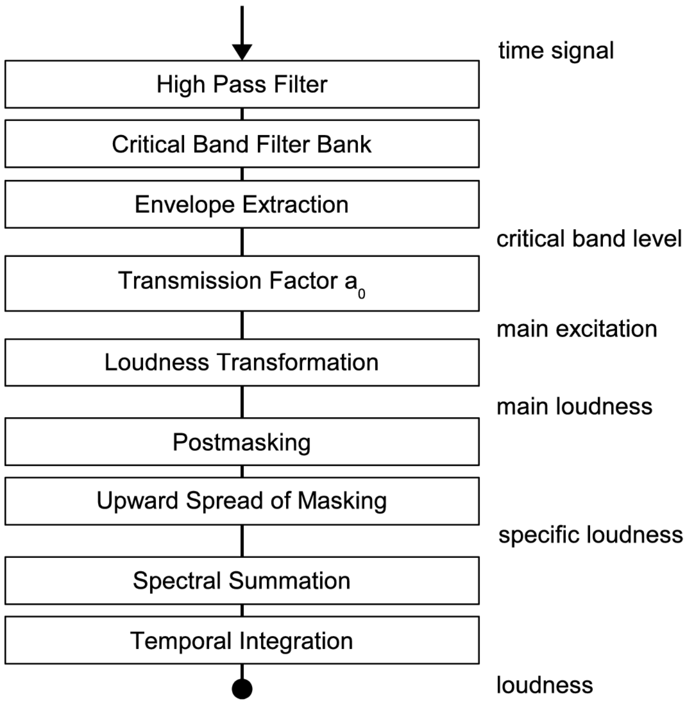

Fig. 1. Block diagram of the Dynamic Loudness Model DLM (after Chalupper and Fastl 2002).

As can be seen in figure 1, the basis for the DLM is a typical Zwicker-type model with spectral analysis in critical bands, including the upward spread of masking, and spectral summation. In addition, temporal features like post-masking or temporal integration are taken into account. Most important is the block “loudness transformation”: when considering normal hearing persons versus persons with (slight) hearing deficits, only this block has to be changed! In contrast to elder models (e.g. Florentine and Zwicker 1979, Florentine et al. 1980), where also the upward spread of masking and the post-masking had to be altered to account for data of persons with hearing deficits, in the DLM only one block, the loudness transformation, has to be modified. This advantage is due to the fact that in the DLM hearing deficits are modelled in the loudness domain, and not in the level domain as usual so far.

Figure 2 shows as an example the loudness transformation, i.e. the relation of level and specific loudness, for normal hearing persons (dashed) and a person with 50 dB hearing loss and recruitment (solid).

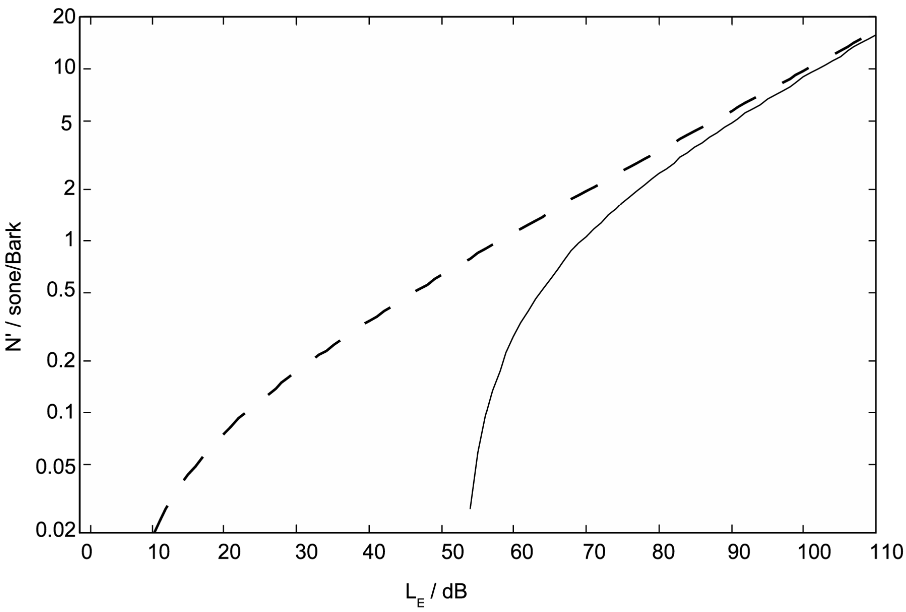

Fig. 2. Loudness transformation for normal hearing persons (dashed) and a person with 50 dB hearing loss and recruitment (solid) (after Chalupper 2002)

The data displayed in figure 2 clearly show that because of the recruitment phenomenon, the loudness perception of the person with hearing deficit (solid) “catches up”, i.e. some 20 dB above the threshold around 75 dB the magnitude of the loudness is almost normal!

For the evaluation of sounds and in particular for the understanding of speech it is necessary to follow loudness fluctuations in great detail. The data displayed in figure 3 allow a comparison of psychoacoustical measurements with predictions by the DLM for both normal hearing and hearing impaired persons (Chalupper 2000, 2002).

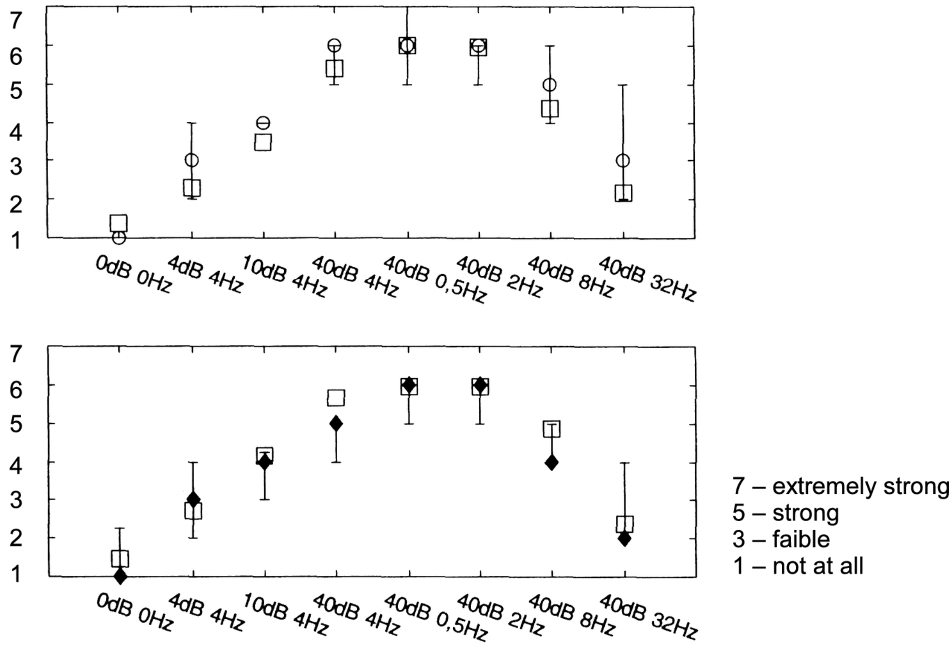

Fig. 3. Rating of loudness fluctuations by normal hearing (upper panel) and hearing impaired persons (lower panel). Comparisons of data from psychoacoustic experiments (symbols with interquartiles) and predictions by the DLM (squares)(after Chalupper 2002).

As expected, sounds with 0 dB modulation depth and 0 Hz modulation frequency, denoted 0dB 0Hz in figure 3, elicit no perception of loudness fluctuation. On the other hand, for 40 dB modulation depth and modulation frequencies between 0.5 and 4 Hz, strong loudness fluctuations are perceived by both normal hearing and hearing impaired persons. If the modulation frequency is increased to 32 Hz, the perceived as well as predicted loudness fluctuation decreases significantly since the hearing sensation roughness comes into play. Loudness fluctuation and roughness are widely used in sound engineering and sound quality design: while loudness fluctuation is indispensable for the engineering of warning signals, roughness can substantially enhance the sportiness of car sounds.

3 OBSCURING OF THE SOUND SOURCE

Among other things, the knowledge that a sound stems from a specific sound source may influence the rating of sound quality or annoyance. In order to study possible influences of such “cognitive” factors, a procedure was developed which keeps the dominant psychoacoustic magnitudes as far as possible the same, but largely obscures the information about the sound source (Fastl 2001). In particular, the loudness-time function of the signals is the same, but the spectral detail is blurred. The procedure is illustrated in figure 4.

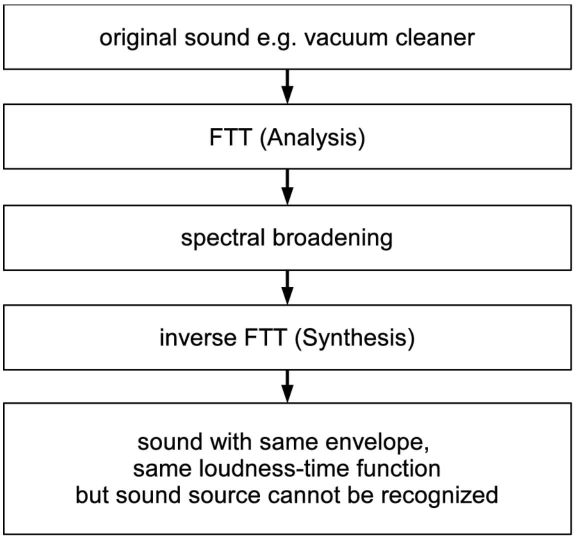

Fig. 4. Illustration of the procedure to largely obscure the information about the sound source despite keeping the loudness-time function the same.

For the procedure to obscure the information about the sound source, the original sound, e.g. the sound of a vacuum cleaner, is first analyzed by FTT (Terhardt 1985). By spectral broadening, the spectral detail is lost and after re-synthesis by inverse FTT, usually it is not easy to name the sound source (Zeitler et al. 2003, 2004, Ellermeier et al. 2004a, 2004b). Nevertheless, the resulting signal has the same spectral envelope and the same loudness-time function, i.e. shows much the same psychoacoustic features relevant for sound evaluations (e.g. Hellbrück et al. 2002). Therefore, using the procedure, psychoacoustic aspects and cognitive aspects can be sorted out: if original and processed sound get the same evaluation e.g. in annoyance ratings, the information about the sound source seems not to influence the rating considerably (see Hellbrück et al. 2004). If on the other hand, despite largely similar psychoacoustic features the rating of original and processed sound differ considerably, this can be an indication that the information about the sound source, i.e. a cognitive effect, may play an important part.

As an example for the quality of the procedure, results displayed in figure 5 enable a comparison of the loudness-time functions of original (upper panel) versus processed sounds (lower panel).

When comparing the upper and lower panel in figure 5, no differences can be distinguished. This means that despite the spectral broadening which obscures the sound source, the loudness-time functions are identical. Since these functions play a dominant role in the psychoacoustic evaluation of sounds, residual differences could be attributed to cognitive effects.

Results displayed in figure 6 allow a closer look on the effects of the procedure illustrated in figure 4. As an example for the practical application of the procedure, the sound produced by a vacuum cleaner is treated.

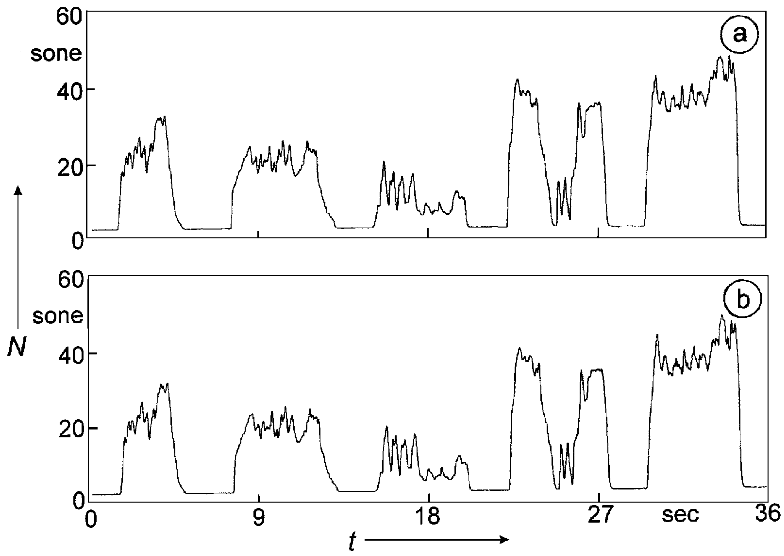

Fig. 5. Comparison of the loudness-time functions of original sounds (upper panel) and sounds processed according to the procedure illustrated in figure 4.

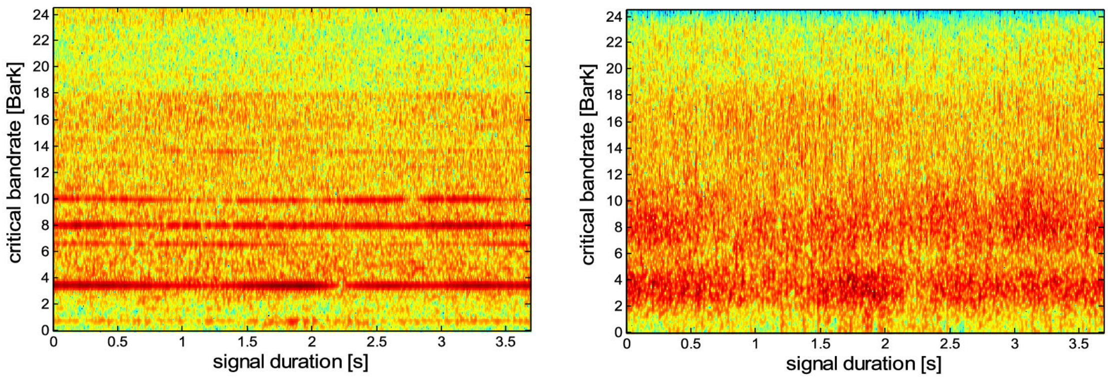

Fig. 6. Example for obscuring the information about the sound source. FTT-spectrum of the original sound of a vacuum cleaner (left) and after processing according to the procedure illustrated in figure 4 (right).

The FTT-spectrum in the left part of figure 6 clearly shows (as horizontal lines) tonal components of the vacuum cleaner sound around 4, 8 and 10 Bark which are typical for this family of vacuum cleaners. Regarding the FTT-spectrum in the right part of figure 6 it becomes clear that because of the processing with spectral broadening, the tonal components are no longer visible and also no longer audible. Therefore, the information about the "signature" of the specific product is lost and positive or negative attitudes towards the product – if any - can no longer influence its evaluation. Hence the procedure illustrated in figure 4 is meant to offer a handle to distinguish psychoacoustic and cognitive aspects of noise evaluations.

4 PITCH STRENGTH

From a psychoacoustic point of view, pitch can be scaled along at least two dimensions: pitch height and pitch strength. Pitch height arranging pitches along a scale low/high of course has a tradition of several thousand years. In contrast, pitch strength arranging sounds – irrespective of height – along a scale faint, weak versus definite, strong pitch is a more recent psychoacoustic magnitude (Fastl and Stoll 1979).

In practical questions of noise evaluation, in particular of industrial noises, pitch strength plays an important part, since in many countries tonal noises get a "tone penalty". Another example are noises of business machines including PCs, where manufacturers try to avoid tonal components because of their annoyance rating.

In order to introduce a psychoacoustically based tool for rating tonal components, a model of pitch strength developed by Fruhmann (2005) is illustrated by means of the block diagram displayed in figure 7.

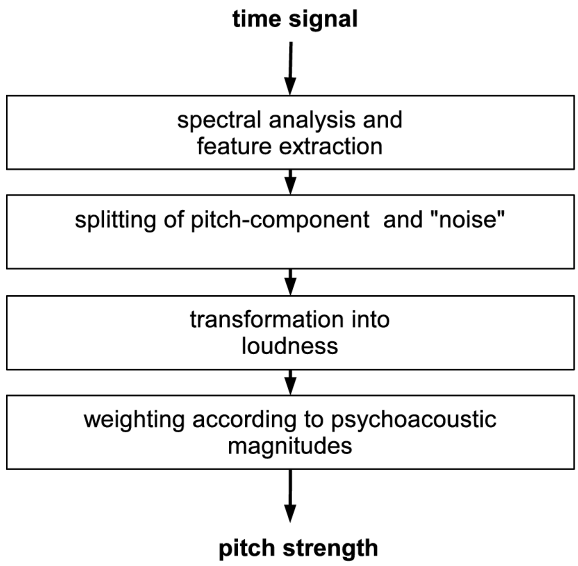

Fig. 7. Block diagram of a model of pitch strength (after Fruhmann 2006).

After using modified FTT algorithms for spectral analysis and feature extraction, the tonal "signal" part and the residual "noise" part are split. Then follows a loudness transformation similar to the procedure illustrated in section 2 of this paper. After weighting according to psychoacoustic magnitudes like roughness, a value proportional to pitch strength is obtained.

In order to illustrate the present status of the pitch strength model, psychoacoustic data are compared to model calculations. Figure 8 allows comparisons of data (Fastl 1989) and predictions.

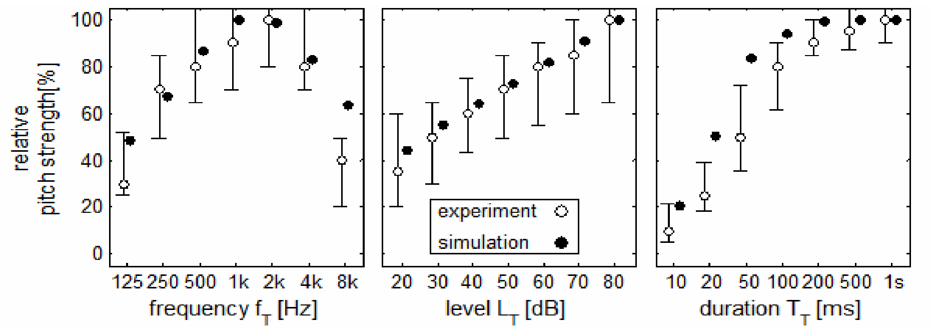

Fig. 8. Comparison of psychoacoustic data (Fastl 1989, circles) with model predictions (Fruhmann 2006, dots) for the dependence of pitch strength of pure tones on frequency, level, and duration

The data displayed in figure 8 indicate that pitch strength of pure tones increases with level and duration and shows a band-pass characteristic as a function of frequency. The calculated values (dots) usually are in line (at least within the interquartiles) with the psychoacoustically measured data (circles) indicating the quality of the model.

In addition, the model can predict the pitch strength of virtual pitches (Fruhmann 2006). In this case, a pitch is assessed which has no representation in the spectrum but is "calculated" by the human hearing system on the basis of higher harmonics (Terhardt 1979). A typical practical example for the perception of a virtual pitch is a telephone conversation: Although the fundamental frequency of a male voice at e.g. 100 Hz is not transmitted over stationary or mobile phones, where the frequency range usually is restricted to about 300… 3400 Hz, nevertheless instantaneously we can decide, whether a male or a female person is at the phone.

Despite the fact that virtual pitch is a phenomenon which occurs frequently in daily life, in questions of sound evaluation or sound quality design it is not yet common practice to look for (virtual) pitches which exist without direct spectral representation.

In practical applications, tonal components frequently comprise not only just a single frequency, but show more band-pass like characteristics. Therefore, the predictive value of the model was also challenged with respect to the pitch strength of band-pass noises. The related data are displayed in figure 9.

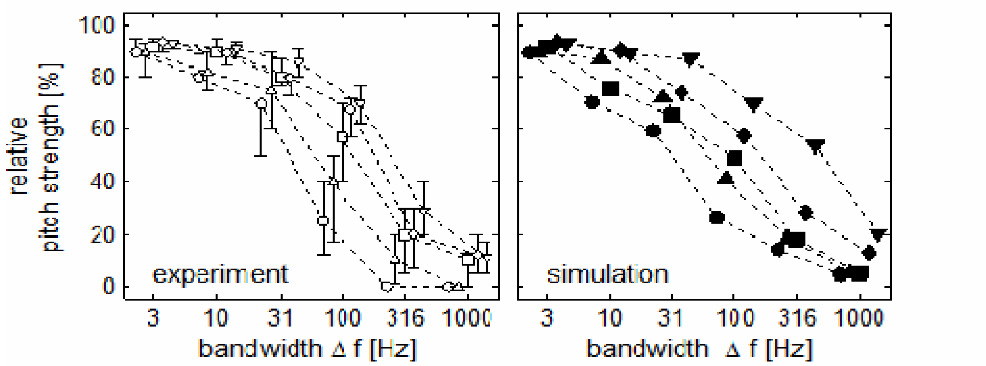

Fig. 9. Pitch strength of band-pass noises as a function of bandwidth. Psychoacoustic data (left, Fastl 1998) and model predictions (right, Fruhmann 2006). Center-frequencies in octaves from 250 Hz (circles) up to 4000 Hz (downward pointing triangles).

The data displayed in figure 9 show that with increasing bandwidth of band-pass noises, their pitch strength decreases. The magnitude of this decrease depends crucially on the center-frequency of the band-pass noise. For example, at a bandwidth of 100 Hz, band-pass noise centered at 250 Hz (circle) produces a relative pitch strength of some 20 %, whereas at 4000 Hz center-frequency (despite the same bandwidth) a relative pitch strength around 70 % is reached. The model can describe the decrease of pitch strength with increasing bandwidth as well as the dependency of pitch strength on center-frequency for constant bandwidth.

5 CONCLUSION

The concept that metrics for noise evaluation should be based on features of the human hearing system has proven successful from its humble start with A-weighting to present day psychoacoustic metrics like loudness, sharpness, roughness and so forth. In this paper, an overview of recent trends is given concerning in-stationary loudness, relevance of cognitive effects, and pitch strength. While the advantages of the Dynamic Loudness Model DLM are already used in practical applications, the brand new pitch strength model is in the process of refinement, including challenges in new practical applications. The procedure allowing to obscure the information about the sound source for the same dominant psychoacoustic parameters of course can not account for *all* cognitive effects. Rather it is meant as a starting point to try to sort out when dealing with noise evaluations the magnitude of effects which can be assessed by purely acoustic engineering means and a “residuum” which is in the focus of other disciplines like psychology or sociology.

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