COMPARISON OF DIFFERENT PROCEDURES FOR TONALITY CALCULATIONS.

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ABSTRACT The presence of distinct tones in environmental noises leads to an increasing annoyance especially if the tones are of long duration. Before 1992 in Germany the tonal content of noises had to be subjectively estimated by the acoustic consultants and up to six dB could be added to the measured L_{eq} depending on the tonality content of the noise under consideration. In order to give an objective basis for tonality estimates a DIN norm proposal for tonality evaluations was introduced in 1992. This proposal is compared with two different procedures: the prominence-ratio calculation which was proposed by Bienvenue and Nobile /4/ and the proposal of Aures /5/. The output of the three models is contrasted with subjective tonality judgements. It turns out that the prominence ratio model yields the best agreement with the subjective tonality assessments od the sound set chosen.

1. INTRODUCTION

The presence of tones or tonal components in environmental noises usually leads to a distinct increase in the perceived annoyance of those noises. That is one reason why an sensation-adequate valuation of the tonality plays an important role in noise assessment. In this paper three different methods of tonality calculation procedures are compared according to their agreement with results from subjective tonality assessments.

In January 1992 a recommendation of the German industry norm DIN 45681 /1/ was published where the tonality of noises have to be calculated on the basis of a tone-to-noise (T/N) relation. The aim of the norm is to introduce an objective procedure in tonality assessment. The norm implies additional charges of 0-6 dB to the L_{eq}. Till then the additional tonality charges were determined according to the subjective impression of the consultant after TA Lärm /2/, DIN 45645 Part 1 or VDI-guidelines 2058 /3/.

A second tonality calculation algorithm is given by the prominence-ratio (PR) procedure /4/, which relates the level of the 'tonal' critical band to the level of the neighbouring bands. Thus masking effects are better taken into account and further this algorithm gives the opportunity of calculating the tonality of more than just one tonal component within one critical band.

Aures /5/ has proposed a psychoacoustically motivated algorithm for the determination of the content of complex tones within a noise. The tonality contributes positive to the Sensory Pleasantness of sounds.

2. SUBJECTIVE TONALITY ASSESSMENT

15 male normal hearing test persons from 23 to 46 years old took part in the experiment. They have to judge by category the tonality of 22 sounds (13 artificial and 9 environmental sounds). The categories *not -*, *a bit -*, *medium -*, *rather-* and *very tonal* are chosen after a proposal of Rohrmann /6/ who found that the distances between theseitems are about equal in German.

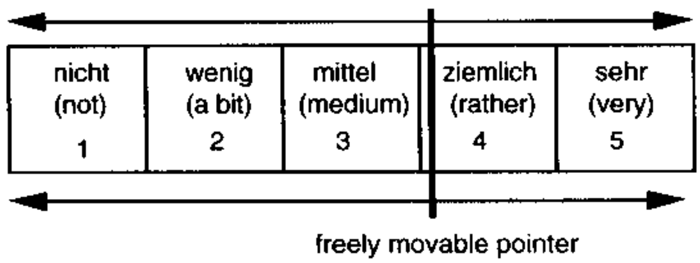

Fig. 1: 'Analog' category scale with freely movable pointer

The subjects indicate the strength of the perceived tonality by the position of a pointer, which can be freely moved along the category scale (Fig.1) so that any subdivision of the categories is possible. The position of the pointer is registered and used for subsequent evaluation. The sounds last for six seconds each and are separated by pauses of four seconds. They possess a common level of 62 dB(A) and are presented via headphones (Stax) to the test persons who are seated in a sound proof room.
For orientation purposes some selected sounds are presented before the judgement procedure starts. During the valuation phase the 22 sounds are presented three times. The whole sequence of sounds is subdivided into three parts with pauses of 20 seconds between them. In order to avoid serial order effects the sequence of the sounds is chosen at random.

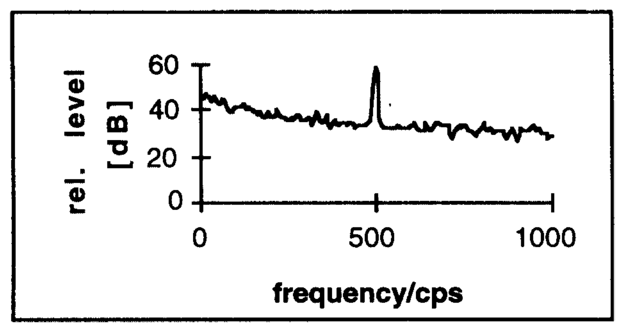

Fig 2.1: Pink noise with one tonal component

Sound selection

Sounds 1-7 consist of pink noise with one tonal component at 500 cps the level of which is varied between the sounds (Fig 2.1). The variation steps are 3-5 dB so that the excess of the tonal component is 7 to 26 dB over the 480 cps-component in the noise spectrum.The sounds are generated with analog equipment and stored on DAT.
Sounds 8-13 consist of pink noise with two equally strong tonal components at 500 cps and 530 cps the levels of which are equally varied between the sounds (Fig.2.2). The variation steps are 3-10 dB so that the excess of the tonal component is 9 to 33 dB over the 480 cps-component in the noise spectrum.The sounds are

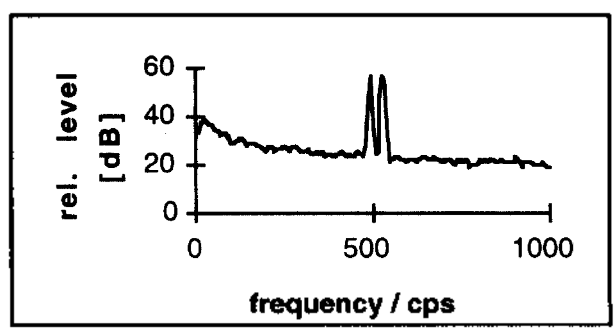

Fig 2.2: Pink noise with two tonal components

generated and stored as described above.
Sounds 14-22 are environmental sounds : air conditioner, electric drill, whistling kettle, vacuum cleaner, grinder, wind power stations and an lectric grinding wheel. The sounds from the wind power generators are free field recordings, the other sounds are taken from a sound-CD /7/. The sounds are selected to cover the whole range from *not tonal* to *very tonal* after a first inspection. Care is taken that the tonal components have different frequencies.

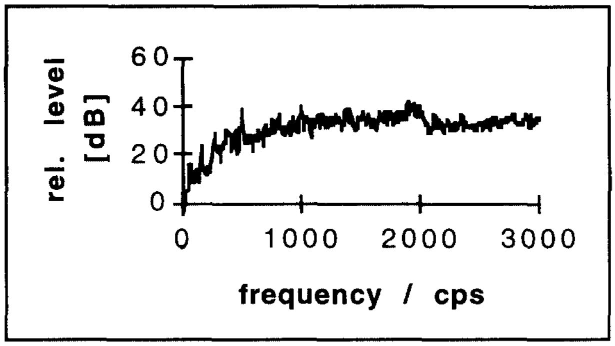

Fig 2.3: The spectrum of an electric drill as an example for the environmental sounds used

3. RESULTS

Fig. 3.1 shows the median values (of three judgements per sound) of all fifteen subjects for the different 22 sounds. 10 categorical units on the y-axis cover one category.The judgements of the test persons are highly correlated. The mean value of the rank order correlation coefficient after Spearman /8/ is 0.87 .

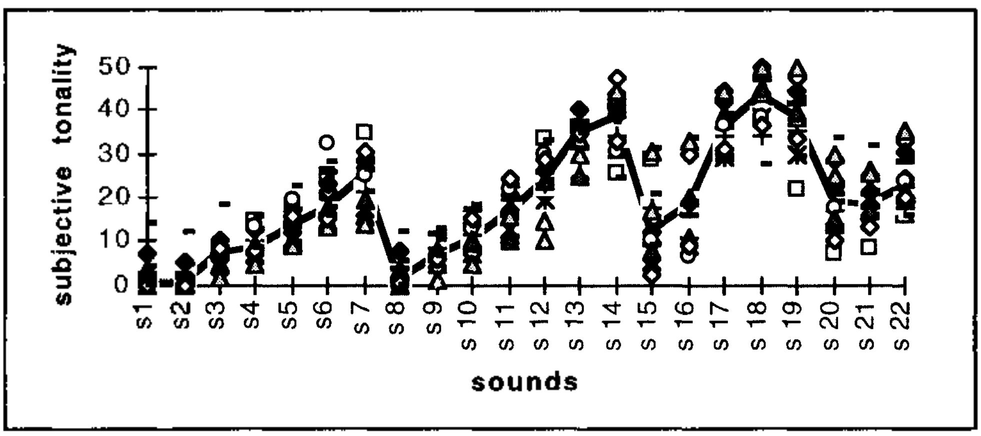

Fig. 3.1: Subjective tonality judgements: Each symbol is the median of the three judgements of a test person for the same sound. The seven artificial sounds at the left have one tonal component. The next eight sounds possess two tones and they are followed by the set of the environmental noises.

The correlation between the test persons is 0.86 on average and is significant at a 0.1 % level. The correlation between the judgements of individual test persons and the medians of all judgements (thick line in Fig 3.1) is as high as 0.93 on average.
The high agreement between the subject justifies to take the subjective data as a reference for the validation of the objective tonality calculation algorithms.

4. COMPARISON OF CALCULATED TONALITY WITH SUBJECTIVE DATA

The three different objective methods for tonality assessment are used to calculate the tonality of the twenty two sounds and the results are compared with the medium answer of the test persons.
In fig. 3.2 to 3.4 these calculated tonalities are shown as a function of the subjective judgements, differentiated after the three different methods and within the figures

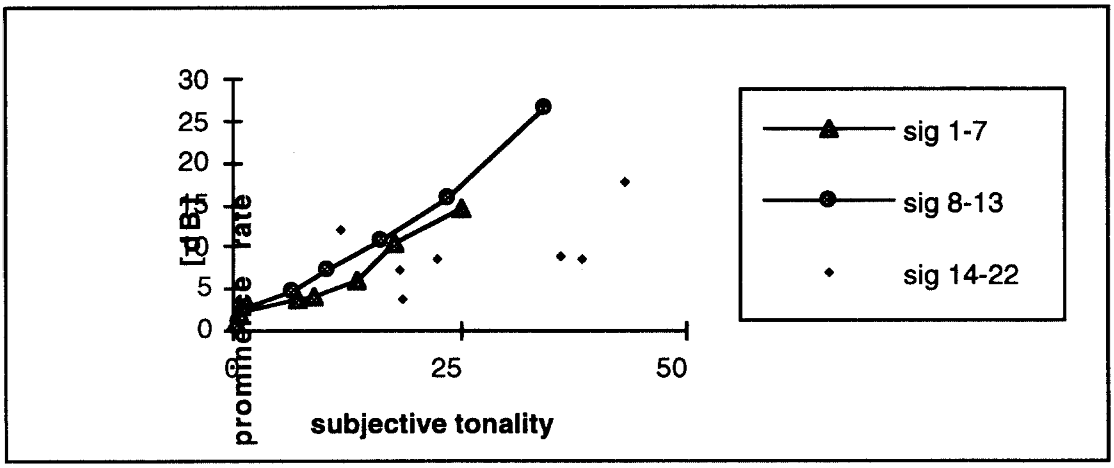

Fig 3.2: The prominence rate after Bienvenue and Nobile /4/ (y-axis) plotted against the subjective tonality judgements (x-axis).

separated after the three different types of sounds.

Objective method 1: Prominence ratio method:

The results obtained by this method are given in fig. 3.2 as a function of the subjective tonality. In the application of this method a tone is called prominent if the prominence ratio exceeds 7 dB. The tonalities of the sounds exhibit a linear relation between the objective and subjective data in a first order approximation. For the artificial noises (sounds 1-7 and 8-13) equal subjective tonalities posses also (nearly) equal prominence rates as the output of this objective method. This does not hold for the environmental noises (sounds 14-22). The results differ according to the frequency of the tonal components. The sounds with subjective ratings higher than 25 possess dominant tonal components at frequencies higher than 600 cps. Here the prominence ratio gives too small values compared to the artificial noises. On the other hand the agreement with the artificial sounds is better for those environmental sounds that possess prominent tonal components below 600 cps like all the artificial ones do. There is obviously still a frequency dependence which has to be explained in future work.

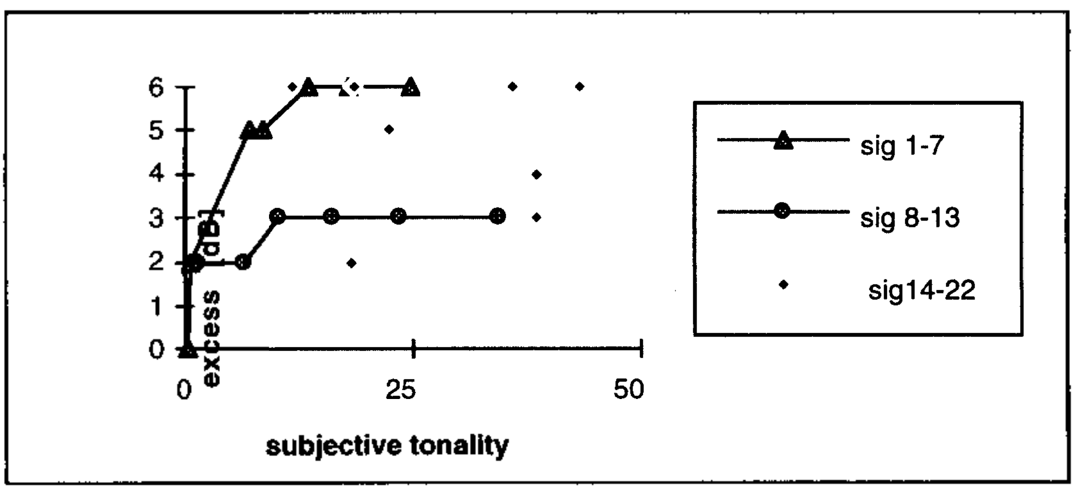

Fig. 3.3: Objective tonality calculated after DIN recommendation 45681 /1/ and plotted against the subjective tonality assessments

Objective method 2: DIN 45681

Fig. 3.3 gives the extra charge in dB which has to be added to the L_{eq} because of the sound's tonality again as a function of the subjective tonality data. The excess of 5-6 dB is reached very quickly for the first group of sounds (1-7) at subjective tonalities from only *a bit tonal* to *medium tonal* whereas the second set of sounds (8-13) only reach a maximal excess of 3 dB for the same subjectively judged tonalities. For the environmental sounds the excess may vary by as much as 4 dB for equal subjective judgements.

Objective method 3: tonality after Aures /5/

Fig 3.4 shows the objective data obtained after Aures' method /5/ which allows a maximum reachable value of 1. No linear dependency on the subjective tonalities can be seen for the sounds 1-7. Aures' method does not detect any tonality if there are more than one component in a critical band. For the environmental sounds no systematic

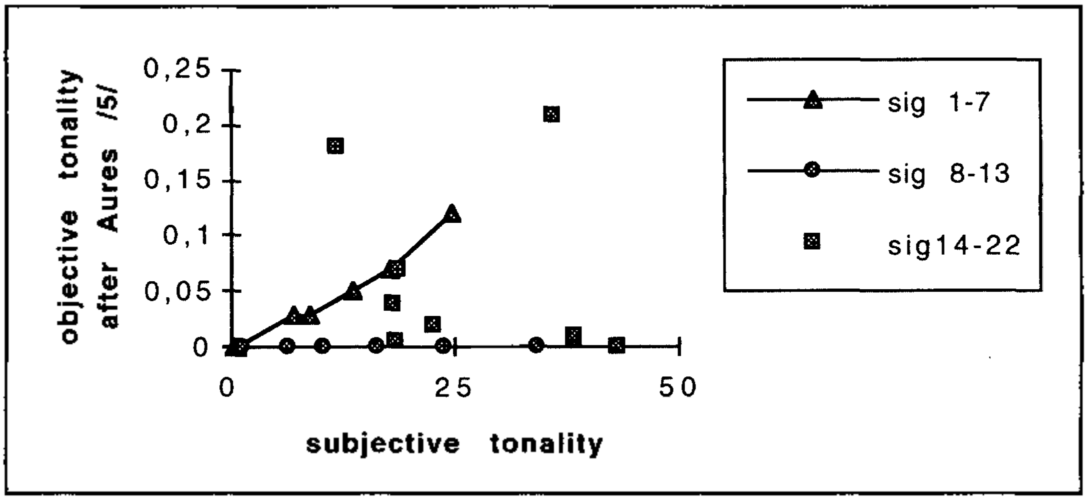

Fig. 3.4: The objective tonality values calculated after Aures /5/ does not exhibit a clear relation to the subjectively assessed tonality for the majority of the judged sounds with exception to those which only contain one tonal component

dependency between objective calculations and subjective data can be detected. It should be noted that Aures developed his method preferably for complex tones and not especially for randomly distributed separate tonal components.

5. COMPARISON OF THE METHODS AND DISCUSSION

The objective measures are best at sounds which only possess one tonal component (sounds 1-7). The prominence-ratio procedure after Bienvenue and Nobile /4/ here exhibits a clear functional approximately linear dependency on the subjectively assessed tonality. The DIN-recommendation tends to overestimate the tonality for small subjective tonal impressions for these one component tonal noises.
On the other hand it only concedes 3 dB excess when 2 components are present (sounds 8-13) which evoke high subjective tonality judgements. The underestimation of the DIN is due to the procedure which focusses only on one component at a time and adds the other component to the 'background'. A modification of the tone-to-noise method will be necessary to avoid this problem.
For the latter sounds the prominence-ratio procedure is the best choice of the three methods under investigation. The tonality calculation procedure after Aures /5/ has a too small frequency resolution to detect the two tones with their small frequency spacing.

For the environmental noises (sounds 14-22) it is difficult to establish a clear functional relation between the prominence-ratio values and the subjective data. But it is striking, that the sounds with dominant tonal components above 600 cps are underestimated by the prominence-ratio, whereas those sounds with low frequencies components (below 600 cps) fit rather well into the scheme found for the artificial sounds. The introduction of a suitable frequency weighting into the objective tonality calculation methods is expected to improve the poor correlation between the subjectively assessed and calculated tonalities.
Another problem occurs, if the tonal components show some fluctuations in frequency. As the methods perform an averaging process in the frequency domain, this may wipe out the distinct tonal impression which can be actually perceived

6. CONCLUDING REMARKS

Subjective tonality judgements by category of artificial and environmental sounds show low inter individual differences. The validation of three different objective tonality calculation procedures with these subjective data gives differently good results.
The prominence ratio procedure after Bienvenue and Nobile /4/ reproduces the subjective tonality judgements for the artificial noises best. The calculation of the environmental noises with tonal components above 600 cps underestimates the subjective tonality.
The recommendation for the norm DIN 45681 /1/ overrates the tonality of the signals with only one tonal component at low subjective tonality judgements. For signals with two tonal components and an equal subjective tonality the calculated excess is halved to three dB. For the same subjective tonality impression the excess may vary up to 4 dB in the case of the environmental sounds used.
The tonality calculation method after Aures /5/ shows a monotonic relationship for the artificial sounds with one tonal component only. This method is obviously not suited for this kind of investigation.

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