Quantitative determination of the sound character for multi-tone sounds and its relation to psychoacoustic metrics

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Introduction

The assessment of the unpleasantness or annoyance of a sound is often dominated by the loudness of a sound. The results then typically exhibit high correlation coefficients between the loudness and the unpleasantness judgments. The method illustrated here succeeds in separating the contribution of the loudness and the sound character to a preference judgment. In this way it also facilitates a quantitative determination of the sound character.

Method

In seperate experiments the loudness and the preference of multi-tone test sounds are evaluated. The method is based on the underlying assumption that a reduction in dBA-level renders a sound less loud and makes it also less unpleasant. Based on this assumption it is possible to determine the points of subjective equality (PSEs) for preference and loudness between a test and a reference sound with a level varying paradigm.

Procedure

In an adaptive paired comparison of a test and a reference sound participants are asked to decide which sound they prefer and which sound is louder. Depending on the answer of the participants the level of the test sound is varied until it becomes equally preferred/equally loud as the reference sound which is kept constant in level. Thus the judgments are given as test sound levels which reflect the PSE for preference/loudness, illustrated in figure 1.

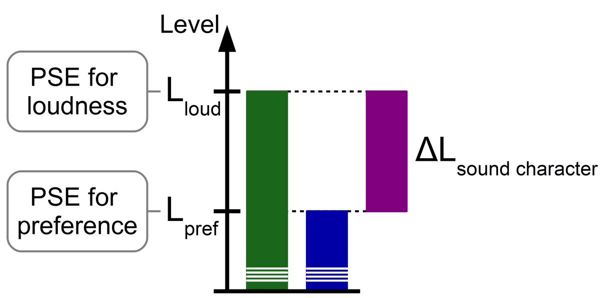

Figure 1: Level scheme: The test sounds are varied in level with an adaptive paradigm until they become equally loud (loudness experiment) or equally preferred (preference experiment). The subjective judgments are then expresse as levels and the level difference between the preference and the loudness judgments is attributed to the sound character of the test sound.

The additional level difference to make an equally loud sound equally preferred is attributed to the sound character. It can be calculated for from the raw judgments by the difference:

$$\Delta L_{sound\ character} = L_{pref} - L_{loud} \tag{1}$$

Stimuli

Synthetic multi-tone sounds consisting of up to 460 superposed partials composed of two complex tones (CX1 and CX2) and additional combination tones are used as test sounds. All partials are based on two fundamental frequencies $f_{10} = 100$ Hz (CX1) and $f_{01} = 132.66$ Hz (CX2). The frequency components in detail are given by:

$$f_{i,j} = i \cdot f_{10} + j \cdot f_{01} \tag{2}$$

The starting phases for all partials are taken from one set of equally distributed random values between zero and 2π. To determine the relationship between subjective judgments and psychoacoustic metrics overall 25 different multi tone test sound varying in the proportion of the complex tones and combination tones and with modifications of the spectral envelope are prepared. The reference sound is a noise signal with a spectral slope of approximately -6 dB per octave up to 1 kHz and -12 dB per octave above 1 kHz. It has a constant level of 74 dBA.

Relationship between loudness, preference and sound character judgements

Figure 2 shows the relationship between the results from the loudness and the preference assessments. A statistically significant correlation coefficient of $r_{mean} = 0.82$ is found between the mean values, which is well in line with other studies incorporating the assessment of loudness and other evaluative aspects (e.g. unpleasantness, annoyance) for sounds[1, 2].
On the other hand figure 3 demonstrates the rather weak relationship between the sound character measure $\Delta L_{sound\ character}$ and the loudness judgments L_{loud}. The participants seem to be able to use level differences to express their preference judgment and clearly differentiate it from the loudness judgments even though the loudness of the sounds is varied throughout the adaptive method for the preference judgment.

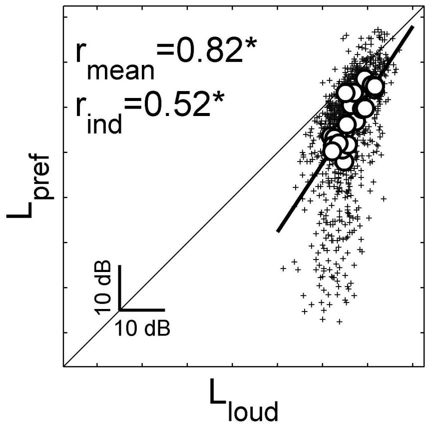

Figure 2: Relationship between L_{pref} and L_{loud}. Individual data (crosses) and mean values of the 25 sounds (open circles). A statistically significant correlation coefficient between the preference and the loudness measure is found.

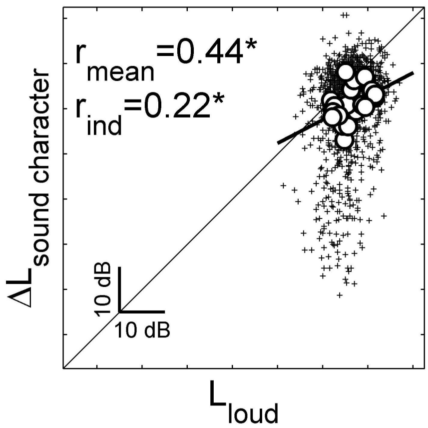

Figure 3: Relationship between $\Delta L_{soundcharacter}$ and L_{loud}. Individual data (crosses) and mean values of the 25 sounds (open circles). A shared variance of 20 % between the mean values and even less for the individual data demonstrates the rather weak relationship between the sound character and the loudness measure.

Relationship between subjective judgements and psychoacoustic metrics

Psychoacoustic metrics are calculated for the 25 test sounds with a commercial acoustic software (HEAD Acoustics, Artemis 11). All calculations are based on sound samples with durations of five seconds and only the last second of the samples (4s-5s) is evaluated, due to some overshoot effects in some of the metrics. The metrics are calculated for an absolute level of 74 dBA, the equally loud level and the equally preferrred level. In the following two examples are presented.
Figure 4 shows the values of L_{loud} for the 25 test sounds at the point of subjective equality for loudness plotted over calculated values from a loudness metric (DIN 45631). The vertical line indicates the expected position of the markers if the loudness calculated by the DIN standard would suit the equal loudness judgments perfectly. However a considerable gap between the reference sound and the test sounds as well as a considerable spread in between the test sound with respect to the loudness metric (x-direction) can be seen.
It turns out that the preference judgments are well reflected by the sharpness metric after the DIN standard while the level independency of this metric inhibits intrinsic correllations between the metric values and subjective judgments expressed as level differences. The level independency makes the sharpness metric also especially useful as a correlate for $\Delta L_{sound\ character}$ which is not linked to an absolute sound pressure level (see fig. 5). A statistically significant correlation coefficient of $r = -0.91$ between $\Delta L_{sound\ character}$ and the sharpness values is found for this set of sounds.

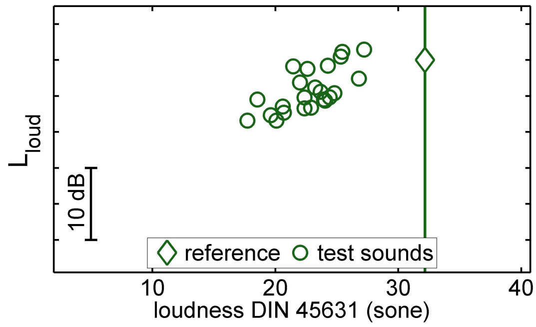

Figure 4: L_{loud} plotted over loudness values calculated after the DIN Standard (DIN 45631). The vertical line indicates the expected position of the data points if the loudness calculation would match the equal loudness judgments perfectly. However the subjective equal loudness judgments are not well reflected by the loudness metric.

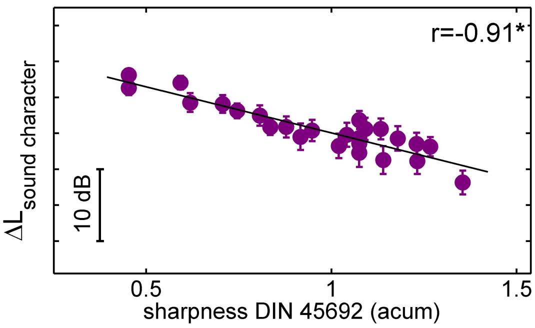

Figure 5: $\Delta L_{sound\ character}$ plotted over the sharpness values (DIN 45692, calculation based on a level of 74 dBA). The rather level independent sharpness metric reflects the sound character measure very well with a shared variance of $r^2 = 83$ percent.

References

[1] B. Berglund, U. Berglund, and T. Lindvall: Scaling loudness, noisiness, and annoyance of community noises. The Journal of the Acoustical Society of America 60, 1119–1125 (1976)

[2] K. Hiramatsu, K. Takagi, and T. Yamamoto: A rating scale experiment on loudness, noisiness and annoyance of environmental sounds. Journal of Sound and Vibration 127, 467 – 473 (1988).