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Loudness of pink noise and stationary technical sounds

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ABSTRACT

Although their basic concept is similar, the current standards for the calculation of loudness, ANSI S3.4-2007 and DIN 45631 (1991), produce significantly different results for many kinds of sounds.

While their values for pure tones can be explained by the equal loudness contours of their times, they also show huge discrepancies for broadband sounds.

For this reason, extended psychoacoustic experiments were made in order to find target values for the loudness of pink noise at various levels. Furthermore, the performance of the algorithms was investigated by subjective tests on several technical sounds at a large scale of loudness levels. In all cases, the method of adjustment was used.

The results suggest that DIN 45631 (1991) predicts loudness very well. Its estimations are within the interquartile range of the subjective evaluations.

Keywords: Loudness, Pink Noise, Method of Adjustment

1. INTRODUCTION

Pure tones are the probably most studied artificial sounds and targeted by many psychoacoustic experiments. Although broadband noise is more important for real problems, there exists comparatively few data about its loudness. Especially, there are few experiments where the loudness judgment was made by directly comparing complex sounds with 1 kHz pure tone.

At first glance, this lack does not seem to be disturbing as loudness can be calculated by several procedures, namely DIN 45631 (1991), which is a refinement of ISO 532 B (1975), and ANSI S3.4-2007. All are based on the same model, however, the first and the third differ in their implementations. They target different versions of the equal loudness contours caused by a revision of ISO 226. Moreover, while DIN 45631 (1991) uses the Bark scale for critical bands, ANSI S3.4-2007 realizes them with equivalent rectangular bandwidths (ERB) resulting in different models for masking and influence of bandwidth. This leads to significant discrepancies in their outcomes for broadband sounds. In the case of pink noise it is a shift of as much as 5 dB [1].

That’s why 20 participants were asked during this work to adjust the loudness of pink noise to the reference one of a 1 kHz pure tone in order to find clear target values according to the definition. Further subjective tests scrutinize the validity of the loudness algorithms with respect to technical sounds whereupon this work focuses on stationary ones.

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2. EXPERIMENTS

2.1 Equipment and stimuli

The diotic sounds were reproduced via PC and fed via audio interface, amplifier and free-field equalizer [2] to Beyer dynamic DT-48 (5 Ω) headphones. The transfer function of the first part of the setup, measured at the input of the equalizer, is flat up to 10 kHz and shows an attenuation of less than 1 dB at 20 kHz. The experiments took place in a sound-proof room of approximately 17 square meters.

Pink noise was produced by HEAD acoustic's Artemis, covering 30 third octaves with cut-off frequencies of 20 Hz and 20 kHz. Technical sounds were recorded with the binaural system Squadriga and filtered to get a monaural free field equivalent recording that can be judged by the algorithms. A frame that is as stationary as possible without distortions was chosen. All stimuli had a duration of 1 second with a fall and rise time of 5 ms.

2.2 Procedure

The method of adjustment was used. The standard stimulus (Ss) and comparison stimulus (Sc) were separated by 1 second with a silent time of 3 seconds until the pair started again. The participant could adjust the level of the Sc via the mouse while it was played and one second after. He or she could listen to the pair as often as needed until he/she thought that Sc and Ss were equally loud.

The described procedure was repeated eight times whereas the adjustment started from the sound pressure level of Sc obviously louder or softer than that of Ss. The order of ascending (A) and descending (D) was as following: ADDADAAD. Before experiments, two trials of training were made, one ascending and one descending.

In order to be permitted to the experiments, each participant had to pass an audiometry test, checking the hearing capability at frequencies from 125 Hz to 8 kHz in octave steps according to the JIS [3].

2.3 Methods of computation

The calculated loudness of pink noise was obtained with software provided by the group for technical acoustics of TU München (www.mmk.ei.tum.de/~kes/LoudnessMeter) respectively the Cambridge University Hearing Group (hearing.psychol.cam.ac.uk/Demos/demos.html).

Calculations for technical noises were done by own Matlab code, fulfilling all examples of the appendix of ANSI S3.4-2007 and also performing correctly for DIN 45631 (1991). Under assumption of stationarity, the input is a fast Fourier transformation (FFT) of a windowed frame in the middle of the signal. For DIN 45631 (1991), third octave levels were gained by summing all samples within its limiting frequencies and adding levels reduced by 20 dB to the neighboring third octaves as suggested by DIN 45631/A1 (2010) because the FFT is much steeper than real third-octave filters.

2.4 Loudness of pink noise

The loudness of pink noise was studied using the 1 kHz pure tone at 9 loudness levels from 43 to 83 phon at a spacing of 5 phon and in quasirandom order, whereas 73 phon always served as the first and tenth level. After that, pink noise was used as Ss at levels of 43 and 63 and the 1 kHz pure tone should be adjusted. As these 12 series altogether took between one and three hours, the participant took some breaks between.

The 20 participants were aged 21 to 26 with a median of 22.5, 5 of them female and 15 male. They were familiar with the method because they had completed a similar preliminary experiment.

Figure 1 illustrates the results with the abscissa showing sound pressure levels of the pink noise and the ordinate its loudness level as determined by the corresponding 1 kHz pure tone. Interquartile ranges are approximately 5 dB, which is in the same order of magnitude as that of a similar experiment done by Zwicker for uniform exciting noise [4]. Intraindividual differences, which are not shown at the figure, are typically around 2 dB and seldom significantly larger.

As shown by the horizontal red line, which is shifted slightly upwards and represents the second run of 73 phon, participants were able to reproduce their results very well. This is not only true for the average but also for most individuals. The vertical black line with the pure tone as Sc is lower than expected. A psychological reason could be the fact that the participant concentrates more on the adjustable stimulus and in this case focuses on frequencies around 1 kHz.

DIN 45631 (1991) does not meet the target values exactly but its calculations always are within

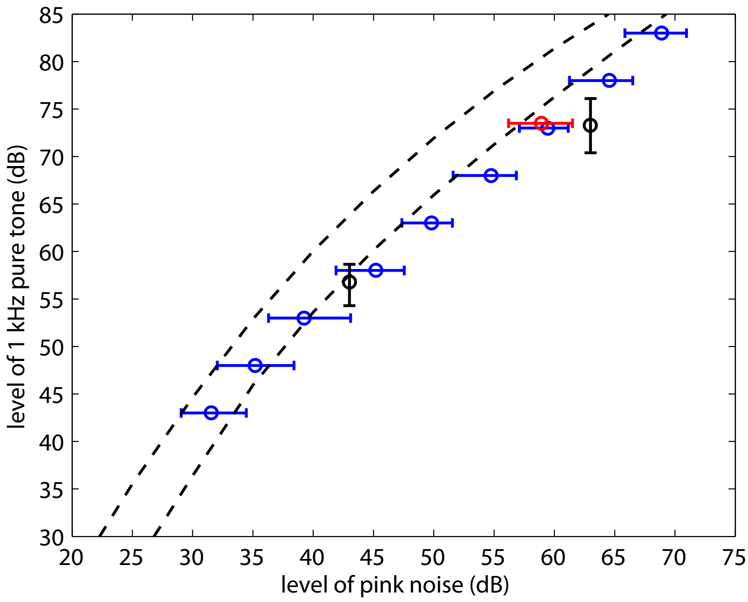

Figure 1 – Level of a 1 kHz pure tone that is as loud as a pink noise of 30 third octaves. Circles indicate medians, whiskers the interquartile range, the upper dashed line values as calculated by ANSI S3.4-2007, the lower that of DIN 45631 (1991)

the interquartile range. This means that at least 25 % of the evaluations lie on the other side than the remaining 75 %. It works best around 3 sone and again good at very high loudness.

By contrast, ANSI S3.4-2007 performs worse. It is always higher than the other standard which already predicts too loud in a wide range. However, it must be mentioned that its output becomes better for low levels and it cannot be excluded that it is very good for faint sounds that have not been part of the experiment. This is notably because ANSI S3.4-2007 pays much attention to the absolute threshold of quiet.

2.5 Loudness of technical sounds

A second experiment investigated the loudness of stationary technical sounds. They were chosen to cover a large extent of the audible range as well as various possible sources of annoyance. They go from a notebook fan noise at medium rotation and 1.8 sone to a hair dryer of almost 25 sone and are listed at Table 1.

Table 1 – Technical sounds of the second experiment

no.	sound	LL (phon)
1	Notebook fan, medium	48.8
2	Notebook fan, high	58.9
3	Sedan gasoline interior	63.0
4	Hatchback gasoline interior	68.9
5	Urban ambient noise at night	68.9
6	Sedan diesel interior	73.0
7	Vacuum cleaner	78.9
8	Hair dryer	86.2

Because of the results of the previous experiment, the technical sound was chosen as Sc and the 1 kHz pure tone as Ss. Each sound was reproduced at a typical loudness level. The 8 trials of

12 participants yield 96 evaluations per sound. All participants took part in the pink noise experiment before.

The results are represented by Figure 2, with the ordinate showing the real loudness as given by the 1 kHz pure tone, which the noise was adjusted to, and the abscissa showing the point of subjective equality (PSE) as it would be calculated by the algorithms. The diagonal line marks a perfect computation. Inter- and intrapersonal differences are in the same range as at the previous experiment.

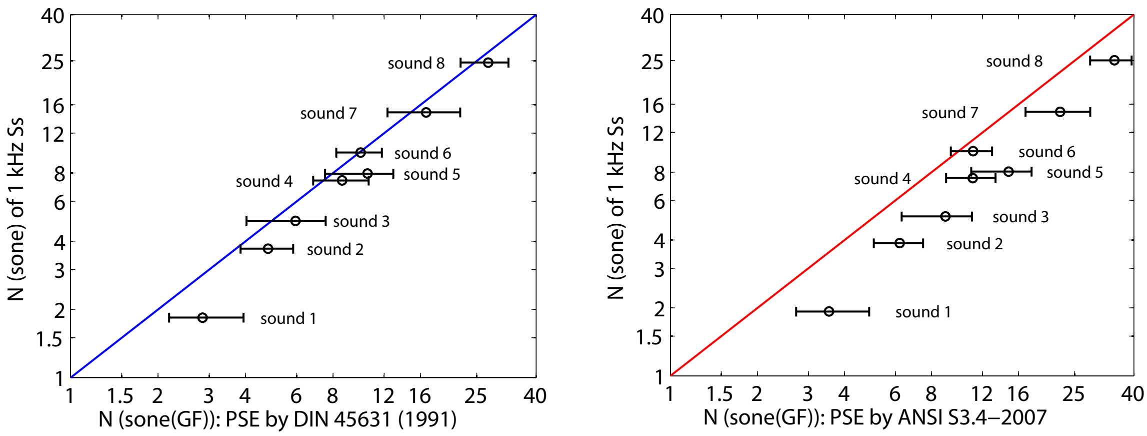

Figure 2 – Loudness of technical sounds: The ordinate shows the loudness as given by the fixed 1 kHz pure tone, the abscissa the PSE as calculated by DIN 45631 of 1991 (left) and ANSI S3.4-2007 (right). Circles and whiskers indicate medians and interquartile ranges, respectively.

Both standards predict the loudness of all sounds higher than it actually is. Their performance is in accord with that found for pink noise, meaning DIN 45631 (1991) is closer to the results. Furthermore it estimates the values of the vehicle interior noises, vacuum cleaner and hair dryer very well and is almost all times within the interquartile range. This accuracy is remarkable because the input was based on a rather simple FFT and in terms of DIN 45631/A1 (2010) most of the sounds would be considered just almost stationary. Although ANSI S3.4-2007 suggests higher values, the relations among its calculations are correct.

The notebook fan noises are overestimated most. A reason could be that they show strong spectral components, in particular the medium one has got a dominant one at 1.1 kHz. As it is very close to the reference stimulus, the participant could tend to not evaluate the total loudness but that of the component masked by noise. The urban ambient noise is judged a bit irregularly. It may be caused by the most difficult recording conditions, neither in laboratory nor at least a closed car which in turn could lead to more time variance.

3. CONCLUSIONS

Extended psychoacoustic experiments, which have found target values for the loudness of pink noise at various levels, have shown that the estimations of DIN 45631 (1991) are close to the subjective evaluations. It is always within the interquartile range. This is still true for many technical sounds which are only almost stationary.

As the standard meets the experimental output for that many sounds, it can be expected that it also determines specific loudness very well. Its graphical diagrams seem to represent a good model for the main loudness within a critical band.

By contrast, the outcomes of ANSI S3.4-2007 are too high for all tested sounds, indicating that it needs further refinement. Nevertheless, the algorithm is an interesting approach as it provides many details at intermediate steps.

Pure tones are adequate to show many aspects of loudness, for example frequency dependency. However, it is also very important to consider the psychoacoustic facts of broadband noises which are more similar to environmental sounds.

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