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RE-DETERMINED EQUAL LOUDNESS LEVEL CONTOURS ACCORDING TO THE NEW FINDINGS OF CONTEXTUAL EFFECTS

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ABSTRACT
Equal-loudness level contours (ELLCs) are subject of repeated attempts to standardize the results of thorough measurements of several laboratories world-wide. However, numerous findings indicate considerable deviations from the "old" contours in ISO 226. One reason is the influence of the psychoacoustic procedure on the determination of the points of subjective equality (PSE) of the sensation "loudness". The other is the influence of the individual threshold of hearing − at least for low-level ELLCs. An interleaved adaptive two-alternative forced-choice procedure (2-AFC) allows for a considerable reduction of the influence of the psychoacoustic procedure on the results. Additionally, equal-loudness sensation-level contours (ELSLC) can reduce significantly inter-individual differences observed in ELLCs.

1 - INTRODUCTION
Considerable differences exist in the literature on data of ELLCs. These differences are partly explained by the experimental context, e.g. using the method of constant stimuli for the determination of the PSE, shifts of up to 13 dB are observed when changing the absolute position of the presented test tone levels about 30 dB [1], [2]. The influence of the experimental set-up on the results can be reduced using an adaptive procedure. By enhancing the complexity of the adaptive strategy, it is possible to minimize the effects of starting level, frequency span, and interval steps on the resulting PSE. In [2] and [4] it is demonstrated that a procedure of four interleaved tracks is sufficient to gain reproducible and parameter-independent results: The shift of the range of the starting levels has an effect on the PSE-results of less than 2 dB, making it possible to determine practically unbiased ELLC with the proposed interleaved adaptive 2-AFC procedure.
The new method was developed and proved under laboratory conditions with headphone presentations. Now, experiments are conducted under controlled free-field conditions as specified in ISO 226, and first results are presented in this paper.

2 - EXPERIMENTAL SET-UP
Measurements are performed in a large anechoic chamber, which provides free-field conditions down to 50 Hz. This room, which is additionally highly isolated against structure-born vibrations ($>$ 3 Hz), was used in former experiments for the re-determination of the average threshold of hearing [3]. A high-quality one-system loudspeaker (JBL 2235H) is currently used for the presentation of the (low-) frequency tones 100, 160, 250, 315, 400, 630, 800 and 1000 Hz. The test-person listens to the presentation while sitting in 4 m distance on a simple chair, which has negligible effects on the sound field properties. The radiated wave fronts are plane in good approximation, as certified in [3].
The interleaved 2-AFC procedure is controlled by a Silicon Graphics workstation: The test and the reference tone (duration 1 s) are presented as pairs in random order. The test-person presses the button, which indicates the subjective louder signal. The strategy of the psychoacoustic procedure to determine a PSE is illustrated in Fig. 1a and 1b.

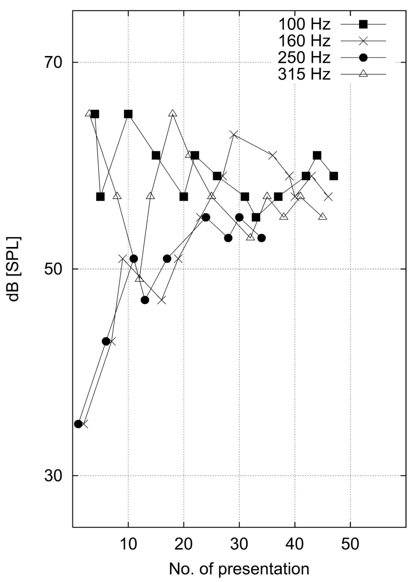

Figure 1(a): Tracks of a test-person of the interleaved 2-AFC procedure; high starting levels for 100 Hz and 315 Hz, low for 160 Hz and 250 Hz.

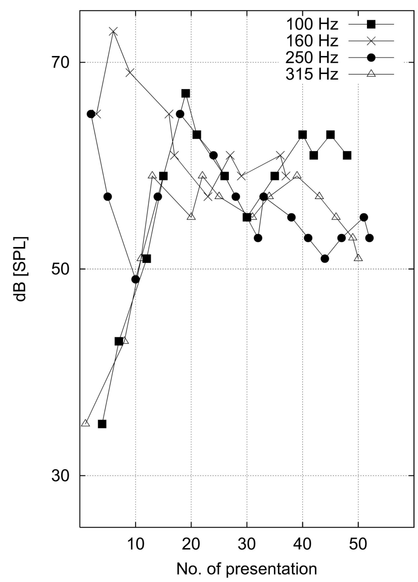

Figure 1(b): Tracks of the same test-person as in Fig. 1a, but high starting levels for 160 Hz and 250 Hz and low for 100 Hz and 315 Hz.

Four test-frequencies are presented in random order with one track starting at a comparatively higher and one at a lower level. Each paired comparison answer is kept in the workstation and determines the following level of the test-tone on the specific track. The tracks are presented interleaved in random order. The level is shifted up or down depending on the answer of the test person. The level steps are 8 dB initially, and then reduced to 4 dB and finally 2 dB. The last turning points are evaluated. The final difference between "high-level" tracks and "low-level" tracks is a good estimate for the stability of the procedure regarding the influence of the contextual parameters. In the case of the arbitrary chosen test-person in Fig. 1, these differences are below 2 dB (average of all test-persons). The time for one measurement with four test-tones is in the order of 20 min.
The hearing thresholds of the test-persons are determined with a 3-AFC procedure.
Eight test persons participated in the experiments up to now.

3 - RESULTS: ELLC FOR 30 dB AND 50 dB

Fig. 2 shows the average ELLC of the 8 test-persons for a 30 dB reference tone of 1 kHz (curve "Reckhardt et al."). The ISO 226 contour and results from Betke [3] and Fastl [5] are plotted for comparison. The new unbiased measurements lie at even higher levels than the former measurements of Betke and Fastl, up to about 13 dB above the ISO contour (below 315 Hz).
The standard deviation well below the test frequency is considerable (about $7 - 9$ dB) and mainly determined by the inter-individual differences between the test persons. The test persons themselves have much higher intra-individual reproducibility in the order of the precision of the used measurement procedure (about 2 dB). The observed high inter-individual differences are of same magnitude as reported for similar investigations in the literature.
Fig. 3 displays the result for the 50 dB reference level. The measurements confirm the same tendency as observed in Fig. 2. The deviation from the corresponding ISO-contour is of similar order as for the 30 dB contour, and deviates in the same direction as already indicated in the cited former measurements. (Both new unbiased measurements in Fig. 2 and Fig. 3 exhibit a certain lack of "smoothness" around the 400 Hz measurement (less than 2 dB). It is not clear, yet, if there is an objective increase in the level of the 400 Hz test-tone caused by a disturbance of the free-field condition, e.g. by a reflection, or if there is an unrecognized mistake in the calibration of the experimental set-up at this frequency.)

4 - RESULTS: THRESHOLD OF HEARING AND ELSLC

The average threshold of the 8 test-persons is plotted in Fig. 4. The result is in general agreement with Betke's findings, and well below the old ISO-threshold. The "dip" at 630 Hz cannot be explained

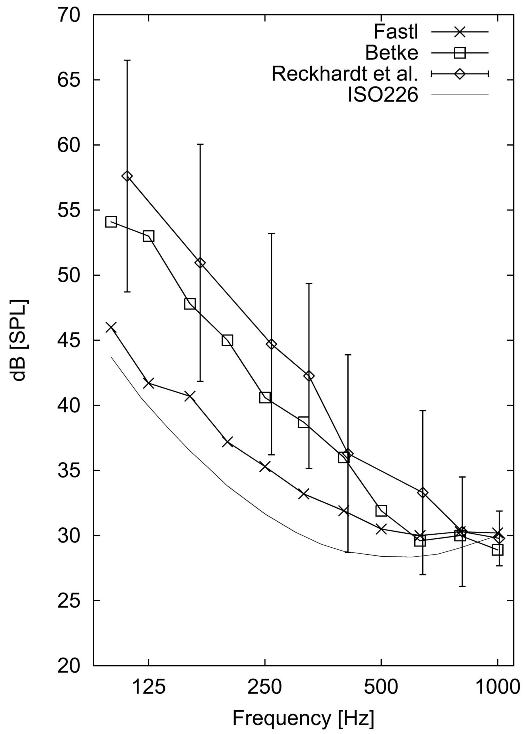

Figure 2: ELLC of 30 dB; new result "Reckhardt et al." – Betke [3], Fastl [5], and ISO 226 are plotted for comparison.

presently, but might be within normal fluctuation. It must be taken into account that the presented measurements are the average of only 8 persons, while Betke's results are based on 40 to 50 persons. Though the new results are gained with the fast converging 3-AFC procedure, the agreement with former measurements is remarkable.

As already reported in [2], the inter-individual deviations in the loudness sensation are reduced by taking the individual thresholds into account. Therefore, the 30 dB ELLC of each test person was transformed to a sensation level contour (ELSLC) by subtracting the threshold value from the corresponding ELLC-value. The averaged result for the 8 test-persons is depicted in Fig. 5. The ELSLC is obviously much less frequency dependent than a ELLC. The standard deviation is reduced from about $7 - 9$ dB (in the case of ELLCs) to $4 - 5$ dB, since deviations of individual hearing thresholds are eliminated.

The values at 400 Hz and of 630 Hz seem to deviate from an expected "smooth" course of the ELSLC. The reason for the shift at 400 Hz is already laid in the measured values of the ELLC at this frequency, as pointed out. The 630 Hz value reflects the dip, which was measured in the hearing threshold (Fig. 4). On the other hand, both values are still within the error bars and might line up for a larger ensemble of test-persons.

5 - PERSPECTIVES

The interleaved 2-AFC allows for unbiased determination of ELLCs. Up to date only a small section of the ELLC-area has been measured with this method. The frequency and level range must be extended, especially below 100 Hz and above 10 kHz there is a lack of measured data. The role of the fixed 1 kHz reference tone has to be investigated, since it becomes increasing difficult to perform the PSE determination with increasing frequency span. Perhaps it is possible to determine additional reference frequencies with the more reliable 2-AFC method, presented in this paper. Irregularities at certain frequencies might occur if the position of the test-person in the plane wave sound field is kept fixed, since reflection and bending is caused by the test-person acting as an obstacle in the sound field. In order to avoid this effect, a diffuse sound field condition should be used. The advantage of sensation level contours has to be discussed, which allows for a significant reduction of the inter-individual variance.

6 - SUMMARY

First results of a re-determination of ELLCs are presented. An interleaved 2-AFC method is capable to

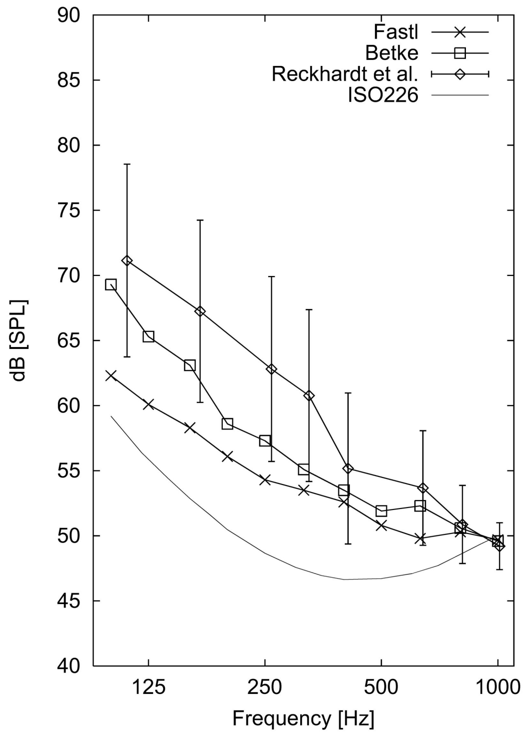

Figure 3: ELLC of 50 dB; new result "Reckhardt et al." – Betke [3], Fastl [5], and ISO 226 are plotted for comparison.

reduce contextual impacts on the PSE determination. The unbiased ELLCs are even more deviating from the ISO 226 guideline than measured in former investigations. For frequencies well off the reference of 1000 Hz, the unbiased ELLC lies about 13 dB higher than the ISO 226 − contour. Taking the individual hearing threshold into account reduces the inter-individual variation by about a factor of two (for the measured 30 dB contour).

ACKNOWLEDGEMENTS
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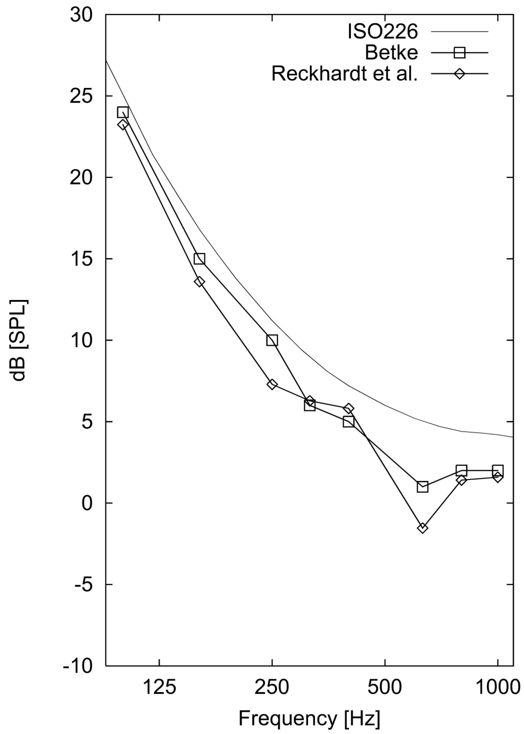

Figure 4: Hearing threshold of 8 test-persons ("Reckhardt et al.") in comparison to Betke's measurements and the ISO 226 threshold.

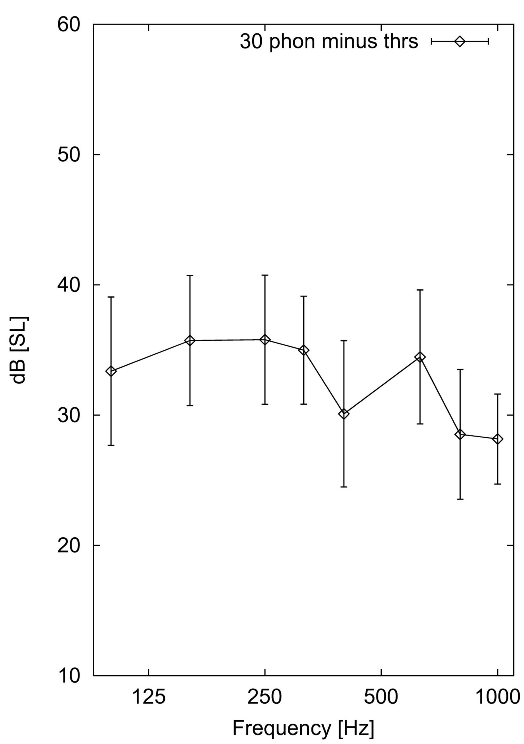

Figure 5: Equal-loudness sensation-level contour of 30 dB.