Calibration effects on optimal stimulus paradigms for measurement of distortion product otoacoustic emissions in humans

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Problem Distortion product otoacoustic emissions (DPOAEs) and therefrom derived input/output functions depend on inter-individual anatomical and physiological conditions as well as on technical side effects of calibration. Therefore, calibration methods have to be developed for yielding defined stimulus conditions for eliciting DPOAEs.

Goal of the study is to separate the impact of calibration errors from inter-individual anatomical conditions in humans and to evaluate a general, non frequency dependent stimulus paradigm for optimizing stimulus generation. Our ear simulator based calibration method (ECCC) is compared to the 'in-ear-calibration' method (ITE), which is most often used.

Methods

DPOAEs were measured at test frequencies f_2 = 1, 2, 3, 4, 6, and 8 kHz (fixed frequency ratio f_2/f_1 = 1.2) and at different combinations of primary tone levels L_1 and L_2. L_2 was varied from 25 to 75 dB SPL in steps of 10 dB. L_1 was varied in steps of 3 dB in a wide range around $L_{1,start} = 0.4\ L_2 + 39$ [dB SPL].

Subjects:

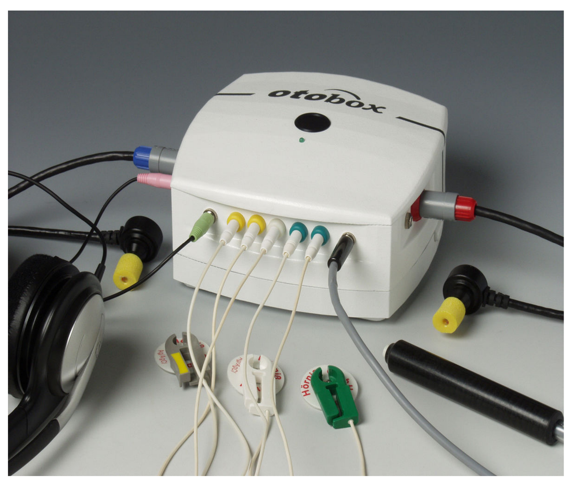
13 normal hearing subjects (7 female, 6 male; aged between 19 and 34 years) with pure-tone thresholds better than 20 dB HL. Middle ear function was normal proved by tympanometry. Measurement time per subject for acquisition of the whole L_1-L_2 space was approximately 90 minutes.

Data Acquisition:

Calibrations, stimulus generation and data collection was performed using a custom made device (otobox, Fig. below). Data analysis was done using Matlab.

Data processing:

DPOAEs with more than 6 dB SNR were considered as valid. SNR calculation was done by averaging the levels at 6 frequencies located around the DPOAE frequency $2f_1$-f_2 . For each individual and calibration method, DPOAEs were analyzed separately. An optimal stimulus paradigm was determined for each individual by using the projection of the maximum DPOAE levels on the L_1-L_2 space (Fig. 3).
The average of all optimal stimulus paradigms was called scissor-paradigm in analogy to [4].



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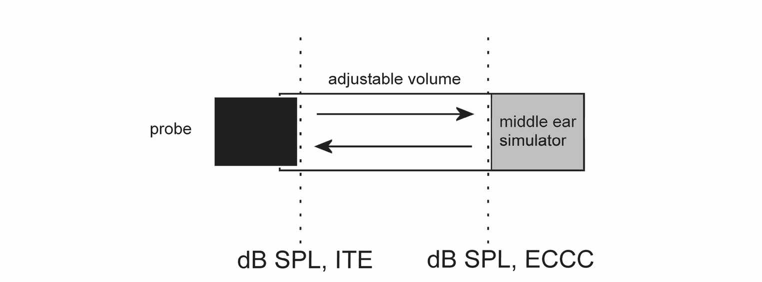
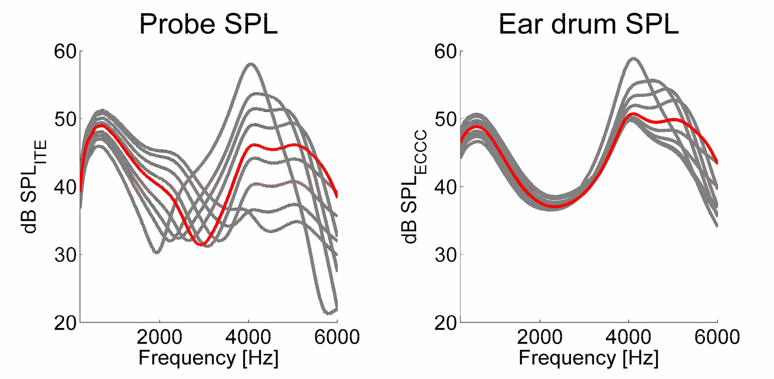
1 Basic principle of ECCC calibration (1)



- sound pressure levels are calibrated at simulated ear drum place
- calibration tables are recorded for different insertion depths and impedances

2 Basic principle of ECCC calibration (2)



the correct ear drum SPL curve is selected by matching the measured probe SPL curve to those in the database

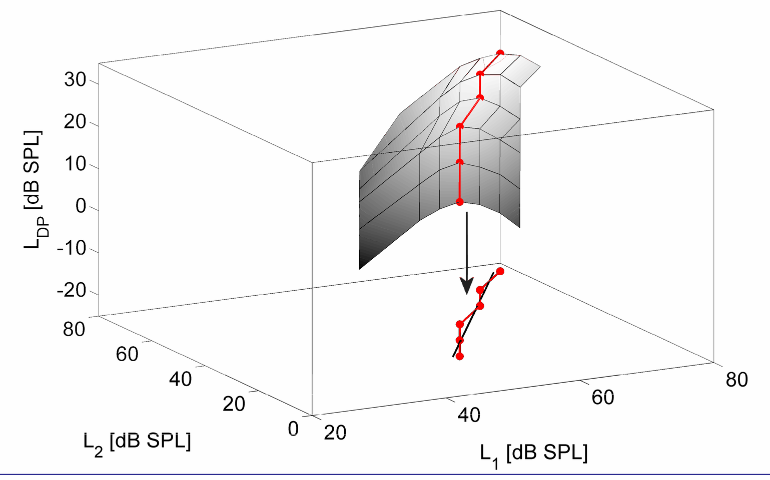
Calibration methods: ITE and ECCC

Our calibration method aims at compensating the standing wave effect in the outer ear canal [2,3] and is therefore referred to as Ear Canal Compensated Calibration (ECCC) in the following. The basic problem of ITE calibration is, that the sound pressure level at the ear drum (SPL_{ECCC}) is not the same as measured by the probe microphone (SPL_{ITE}) (Fig. 1). Therefore, stimulus level as well as DPOAE level differ between both locations:

"Calibration of the probe in an ear simulator at approximately the same distance from the eardrum as in the real ear, minimizes probe measurement errors of the eardrum SPL." [1]

Measuring the transfer function with SPL_{ITE} and SPL_{ECCC} in the Brüel&Kjær ear simulator B&K 4157 with different insertion depths, a database was generated and used for identifying the correct SPL_{ECCC} in the real ear by sophisticated curve matching (Fig. 2).

3 Optimal primary tone setting (one subject, one frequency)



4 Scissor paradigm: Optimal primary tone level pairs

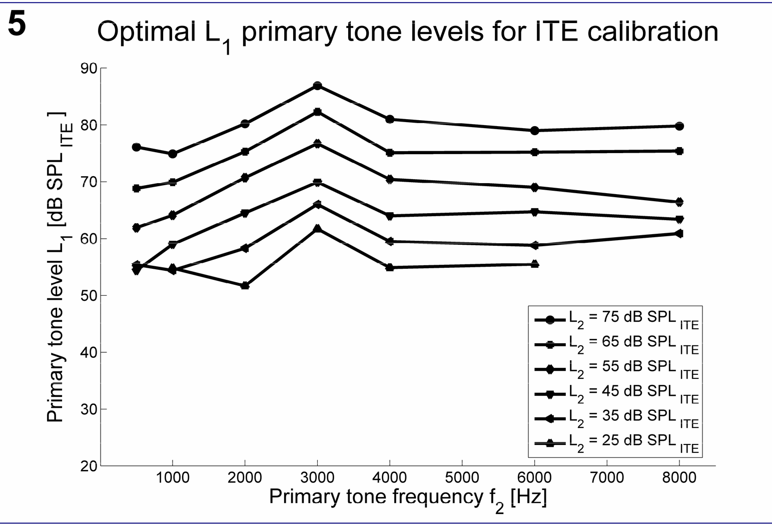
ITE (Kummer et al 2000 [4]) Levels [dB SPL]

L2	L1
65	65
60	63
55	61
50	59
45	57
40	55
35	53
30	51
25	49

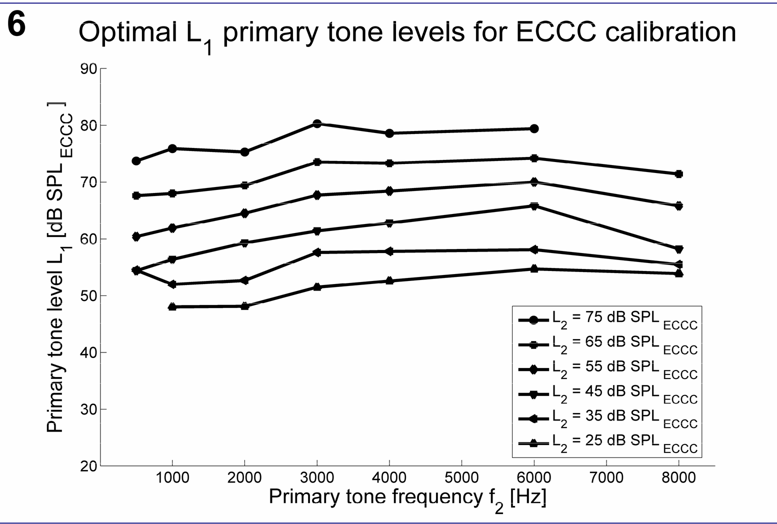
ECCC Levels [dB SPL]

L2	L1
65	72
60	69
55	67
50	64
45	62
40	59
35	57
30	54
25	52

5 Optimal L_1 primary tone levels for ITE calibration



6 Optimal L_1 primary tone levels for ECCC calibration



Results

ECCC proved to have less frequency dependent effects than ITE, as can be seen from Figures 5 and 6 in the 3 kHz region.

Table 1 lists the mean (± std.) of the optimal primary tone pairs averaged over all subjects and frequencies for each calibration method.

L2 [dB SPL]	L1 ± std [dB SPL]		
	ITE	ECCC	Kummer [4]
25	55.7±3.1	51.7±5.8	50.7±5.8
35	59.0±7.4	57.2±5.1	55.7±5.0
45	62.8±6.5	61.1±4.5	59.9±4.4
55	68.5±5.2	66.8±3.9	63.0±2.9
65	74.6±4.9	72.0±3.5	63.9±2.1
75	79.7±4.7	77.8±3.3	-

Table 1: Optimal primary tone pairs (avg.) and standard deviations for ITE and ECCC

Using ITE, the optimal setting over all subjects and frequencies was

$$L_{1,ITE} = 0.4\ L_{2,ITE} + 44 \text{ [dB SPL]}$$

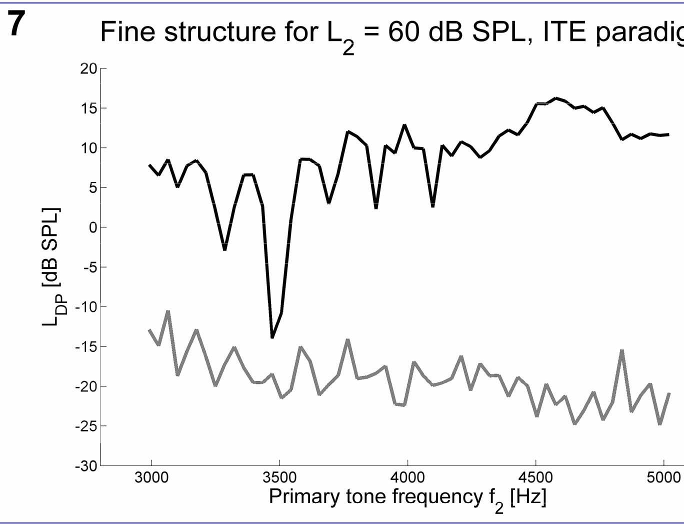
when restricted to stimulus levels L_2 < 65 dB SPL like in comparable studies in literature.

Using ECCC, the optimal setting was

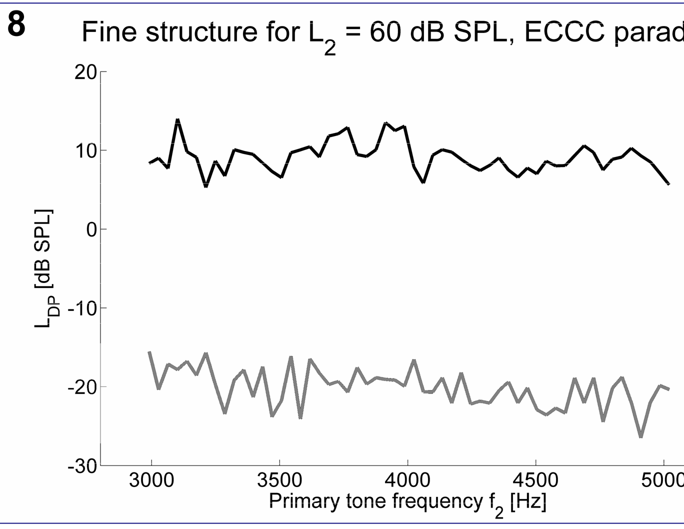
$$L_{1,ECCC} = 0.5\ L_{2,ECCC} + 39 \text{ [dB SPL]}$$

Figures 7 and 8 demonstrate to what extent the DPOAE fine structure can differ when using different calibration methods (one person, no further changes in setup).

7 Fine structure for L_2 = 60 dB SPL, ITE paradigm



8 Fine structure for L_2 = 60 dB SPL, ECCC paradigm



Conclusions

DPOAE levels vary depending upon calibration method, equipment and parameter setting used. This should be taken into account when interpreting DPOAE measurements.
Ear simulator based calibration methods with appropriate stimulus paradigm like ECCC yield less frequency dependent DPOAE measurements than the commonly used ITE calibration.

Literature:

[1] Gilman, S. and Dirks, D. (**1986**) "Acoustics of ear canal measurements of eardrum SPA in simulators" J. Acoust. Soc. Am. **80**, 783 – 793.

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[4] Kummer P, Janssen T, Hulin P, Arnold W (**2000**): "Optimal L1-L2 primary tone level separation remains independent of test frequency in humans." Hearing Research, **146** (1): 47-56.

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DFG