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Scientific Research

A Collection of Abstracts

- Auditory evoked potential (AEP)
- Oto-acoustic emission (OAE)
- Tympanometry & Reflexes

Content

Auditory evoked potential (AEP)

Intraoperative and postoperative measurement of brainstem responses through electrical stimulation of the auditory nerve via implantable neurostimulators

Polterauer, D. (Department ENT, LMU Hospital Munich, 2020)

Abstract

The recording of brainstem potentials is one of the most important methods currently employed in hearing diagnosis within audiological practice. Stimulation can be provided either acoustically or by means of an implanted neurostimulator, as in the case of electrically evoked auditory brainstem responses (eABR) when using neurostimulators, such as cochlear implants.

In theory, performing an eABR test is as easy as doing air conduction ABR. In practice the stimulus artifact is always a major problem. If this signal spreads too much into recording, the response waves are much more difficult to detect. This falsifies the amplitudes of the responses as well as their latency.

Postoperative examinations using eABR are very rare in everyday clinical practice. This is mainly due to the fact that a special electrically shielded room is required for the measurement, in which the measuring equipment, which is typically very large, is then installed on a trolley.

Avoiding disruptions as much as possible is extremely important, especially in an intraoperative scenario. Additional sources of interference can be present in the operating room. These interferences cannot be prevented and may also occur suddenly. Therefore, a small, portable, battery operated device provides a distinct advantage.

This report shows the practical application of such a device, the SENTIERO ADVANCED, in clinical practice, and demonstrates it to be a very valuable tool. The electrode positioning used was vertex or high-forehead for the non-inverting (active (+)) electrode, contralateral mastoid for the inverting (reference (-)) electrode and lower forehead for the ground electrode. To date, 46patients have been successfully tested and it was usually possible to perform the measurements in a simple doctor's examination room that was not electrically shielded.

Using a small, portable, battery operated device such as the SENTIERO ADVANCED certainly eases the daily work. The portability of the device and rapid test times are a real asset in everyday clinical practice.

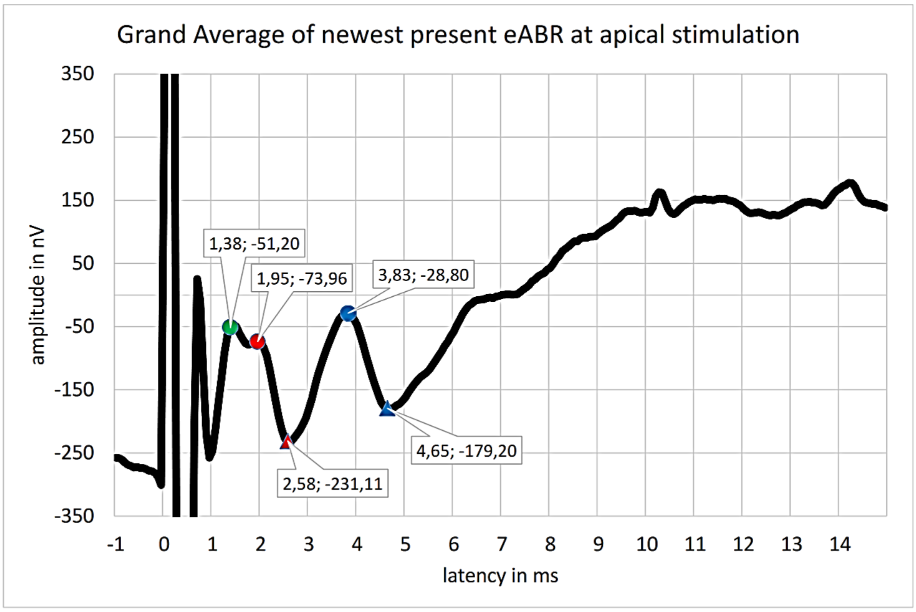

Figure 1: Grand average of first measurement over all tested patients at apical stimulation (i.e. electrode 1). Peak markers of waves (circle): eII (green), eIII (red) and eV (blue). Trough markers of waves (triangle): eIII (red) and eV (blue). Grand average latency: 1.38ms @ eII, 1.95 @ eIII and 3.83 @ eV. Grand average amplitude: 157,15nV @ eIII and 150,4nV @ eV.

Table 1: Mean latencies for apical, medial and basal stimulation for waves eIII and eV

	Latency eIII	**Latency eV**
Apical stimulation	2.45 ± 0.37 ms (n = 46)	3.88 ± 0.25 ms (n = 46)
Medial simulation	2.45 ± 0.37 ms (n = 46)	3.98 ± 0.24 ms (n = 46)
Basal stimulation	2.57 ± 0.35 ms (n = 32)	4.03 ± 0.21 ms (n = 32)

Literature (partly)

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Note: For original article visit: www.pathme.de/related-materials

Hearing Screening Test with Portable ABR in High Risk Newborn

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Background

Hearing loss is the most important problem. Approximately 1-2 children in every 1000 born has a hearing impairment in the well-baby nursery population. The incidence of such a hearing loss in babies admitted to the neonatal intensive care unit (NICU) is 20–40 times higher. The high incidence of hearing loss in NICU babies could be due to newborns with different etiologies such as utero infection, preterm, very-low-birth-weight (VLBW), hyperbilirubinemia, birth asphyxia, on mechanical ventilator > 5 days, ototoxic drug used, craniofacial abnormality and a family history of hereditary sensorineural hearing loss. Hearing loss is the most important cause of speech problem, impair development of language and learning disability which impact social and family especially before 3 year of life. Early identification and intervention before age of 6 months can improve the child's speech and language development. JCIH recommends using automate ABR for hearing screening in the NICU population since they are considered high risk for auditory neuropathy spectrum disorder (ANSD) Currently, there is new techniques for newborn hearing screening: portable auditory brainstem responses (portable ABR) which could be report hearing level, high sensitivity and specificity, short duration of test and less cost. This test could be appropriate for detecting hearing loss.

Objective

• Compare the hearing screening test between portable ABR and Conventional ABR

• To determine the incidence and risk factors of abnormal hearing test and auditory neuropathy spectrum disorder of neonate in NICU (Neonatal Intensive Care Unit) at Songklanakarin hospital.

Study design

Prospective cross-sectional study

Material and Methods

This cross-sectional study was conducted to assess the prevalence of hearing loss in neonates who were admitted to the NICU and followed up at high risk newborn clinic at Songklanakarin hospital, between July 2013 and January 2014 (N=64 eras). Auditory function was examined using otoacoustic emission (OAE) and Portable auditory brainstem response (Portable ABR) followed by conventional auditory brainstem response (ABR) tests. For statistical analysis the chi-squared test, and Fisher's exact test were used to identify significant risk factors with a significant level of $P < 0.05$.

Results

The thirty two high risk newborns (64 ears) included in this study. The incident of hearing loss in high risk newborns was about 18.7%. There were 2 newborns (6.25%) have severe hearing loss suspected auditory neuropathy disorder (AN). To determine high risk of newborn screening audiometer; the Portable auditory brainstem response (Portable ABR) was no different to the standard auditory brainstem response (Conventional ABR). The Portable auditory brainstem response (Portable ABR) used the significant less duration for hearing screening than the standard auditory brainstem response (Conventional ABR). The Portable auditory brainstem response (Portable ABR) can be used for newborn hearing screening for high risk newborn,the value of Sensitivity 80%, Specificity 78%.

Conclusions

Our study demonstrates the use of a Portable ABR testing ensures acceptable high sensitivity and specificity, and predict the AN profile in high risk newborns. Portable ABR used short duration of test and less cost for hearing screening. This test will benefit from early detection and remediation of hearing deficit.

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Chirp evoked ASSR on a handheld device

Rosner, Th. and Lodwig, A. (PATH MEDICAL GmbH)

presentation at IERASG, New Orleans, 2013 and printed in Book of Abstracts

2013, New Orleans

Auditory Steady-State Responses (ASSRs) are currently of great interest in clinical audiology, since they allow for a frequency-specific and quantitative evaluation of hearing impairment. In clinical practice it is important to have robust, reliable, and easy to use test equipment to perform the measurements.

An ASSR recording algorithm was implemented on a battery powered handheld device which allows flexible hearing threshold determination in various clinical environmental conditions. For eliciting ASSRs multiple narrow-band chirp stimuli (up to 4 in each ear, binaural stimulation) are presented to the ear with slightly jittered stimulus repetition rates (random change) to get maximum response amplitudes and resistance to interference. Multiple-frequency ASSRs are analyzed (i.e. averaged and detected) independently from each other to allow a stimulus paradigm which adapts quickly to the subject's individual hearing loss.

In a preliminary study the ASSR system was evaluated in adults with normal hearing and adults with sensorineural hearing loss. ASSR thresholds were determined at four frequencies at 500 Hz, 1 kHz, 2 kHz, and 4 kHz. Threshold differences between behavioral hearing thresholds and 40-Hz-ASSR thresholds ranged between -8 and 15 dB. Mean test duration was 22 minutes to estimate four thresholds in both ears. The results indicate the efficiency of the algorithm implemented on a mobile hand held device.

Tympanometry & Reflexes

An optimized protocol for acoustic impedance measurements: „Simultaneous multi component multifrequency tympanometry“

Kandzia, F. (PATH MEDICAL GmbH), poster presentation

Introduction

The most common probe tone frequency used in tympanometry is 226 Hz. Using 226 Hz, well known and categorized tympanogram shapes can be obtained, especially in adult patients. When testing infants younger than four months, a probe tone frequency in the range 660-1000 Hz is recommended (Baldwin et al., 2000). In many cases though, the optimal probe tone frequency is not a well established value. Multifrequency tympanometry is said to improve on middle ear diagnostics (e.g. Hunter and Margolis,1992). In practice however, the "standard" measurement is performed in the majority of cases.
The goal of the present study is to examine whether it is possible to record multiple tympanograms at once when presenting multiple probe tones at the same time.
This would allow to perform multi frequency tympanometry without increasing test duration.

Method

Tympanograms were recorded from 22 ears (of 11 adults). Five measurements were performed in a series. The test frequency was 226 Hz, 678 Hz, 800 Hz, and 1000 Hz for measurements one to four. For the last measurement, all four tones were presented simultaneously. The pressure range was -200 to 200 daPa (descending) for all measurements.

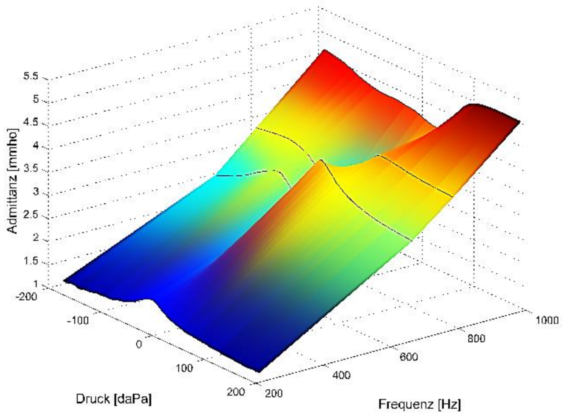

Figure 4: Multi frequency "3D-Tymp"[1]

Results

The average difference in admittance over the complete pressure range amounted to -0.05 ± 0.07 mmho (which is about 1.5% of the total amplitude). The other measures show similar deviations (see table1)[1]. The peak of the 226 Hz tympanogram was shifted by 1.5 daPa on the horizontal axis and 0.01 mmho on the vertical axis on average.

Discussion

Multifrequency tympanograms show little difference to tympanograms that are recorded with a single probe tone. These differences are within the expected test retest stability of tympanometry (Carazo and Sun, 2014; Wiley and Barrett, 1991) and within the accuracy limits of immittance instruments standards (IEC60645-5).
Tympanograms can be recorded for multiple probe tones at the same time, without influencing test results and without increasing test time. Compared to conventional tympanometry, multi frequency tympanometry can be performed without additional effort.

Literature

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▪Wiley TL, Barrett KA (1991) Test-retest reliability in tympanometry. J Speech Hear Res. 1991 Oct;34(5):1197-20

[1]Note: For original poster with all figures and tables visit: https://www.pathme.de/device-tutorials

Multi-Frequency Technology for acoustic Reflexes

Lodwig, A. (PATH MEDICAL GmbH)

Introduction

Tympanometry is a widely used objective method to assess the middle ear status. The basic idea is to measure the movability of the tympanic membrane as a function of static air pressure. Traditionally, a 226 Hz tone is used as a "probe tone" which is presented to the ear and recorded back with a microphone. Both speaker and microphone are located in a probe that needs to be sealed to the external ear canal and is connected to a pump that provides the static pressure. The movability is typically plotted as an equivalent air volume that changes with applied static pressure. It is a known fact that in certain middle ears, probe tone frequencies other than 226 Hz provide better information. Multi-frequency Tympanometry [1] and wide band tympanometry [2] have therefore been proposed to record tympanograms at more than one probe tone frequency simultaneously.

The acoustic reflex is the activity of the stapedius muscle and/or tensor tympani muscle of the middle ear, triggered by an auditory stimulus. The muscles apply force to the ossicle chain which stiffens middle ear mechanics, much like the static pressure in tympanometry does. It can therefore be measured with a similar setup as tympanometry, which is why both are often combined in one instrument.

An acoustic stimulus is presented to the ear in addition to the probe tone either ipsilateral or contralateral which triggers the stapedius muscle of the middle ear, while a compliance trace is recorded. The stimulus can also be provided electrically by a cochlea implant. Similar to tympanometry, the use of other probe tone frequencies than 226 Hz can help detecting the reflex in certain middle ears.

Since the sound level / phase change due to the reflex, as recorded by the probe microphone, is small, detecting the acoustic reflex is somewhat sensitive to artifacts. This includes both acoustic noise and test setup related effects, such as probe movement during recording. The use of more than one frequency to detect the reflex simultaneously should help making detection of the acoustic reflex more robust against artifacts. This paper therefore proposes a multi-frequency approach to the acoustic reflex.

Theory of operation

The main function of the middle ear is to transform the sound field from air conduction in the ear canal to fluid conduction in the inner ear. To deal with the different acoustic impedances of ear canal and cochlea, the area of the ear drum is much bigger than that of the stapes foot-plate. Additionally, the middle ear provides some protective mechanisms for the inner ear, including friction of ossicle joints and the acoustic reflex.

Like almost any mechanical system, the middle ear moving part has mass, compliance, and resistance. This means it can only work perfectly at one frequency, usually referred to as the middle ear resonance. Its resonance frequency typically is at about 1 kHz. The

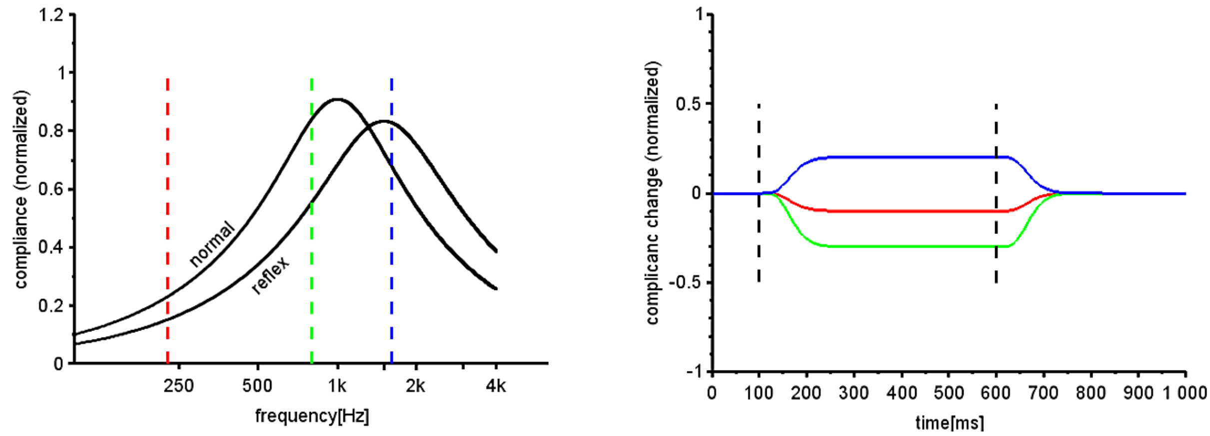

Figure 1: Left panel: General effect of the acoustic reflex on the middle ear's acoustic compliance. During the reflex, the resonance frequency moves up. This results in a compliance drop at lower frequencies and a compliance rise at high frequencies. Right panel: Expected reflex response at the 3 frequency marked in the left panel. The red trace represents traditional, 226 Hz recording. the traditional, 226 Hz recording.

acoustic reflex stiffens the middle ear mechanics, which also means it reduces its compliance and therefore moves its resonance frequency up. Figure 1 (left) illustrates the effect schematically.

The traditional probe tone frequency of 226 Hz will almost always be lower than the middle ear resonance frequency. Below resonance, the middle ear impedance acts as a spring, which means an added stiffness would reduce its compliance. This is what acoustic reflex testing observes. If plotted as an equivalent air volume, it will decrease during the reflex. Often, recording traces are inverted to produce a positive effect in the displayed trace.

However, if the probe tone frequency is higher than the middle ear resonance, the effect can be reversed, which means the recorded compliance (or equivalent air volume) can increase during the reflex period. At frequencies above resonance, the middle ear impedance acts as a moving mass, and added stiffness can increase movability. The blue trace in Figure 1 illustrates the effect. The simplified model data above is supported by measured data of real ears [3].

Methods

An existing acoustic reflex setup was modified in firmware to allow recording four different frequencies simultaneously. Since the original framing was optimized for a 226 Hz probe tone frequency, the additional frequencies were selected to be multiples of 226 Hz. This also avoids any beating issues, since the resulting waveform is periodic at 226 Hz. [A sample probe signal is shown in Figure 2 (left)][1].

Narrow band filters for each of the four frequencies were implemented digitally via a quadrature detection scheme. All filters use the same absolute bandwidth, which results in equal settling times for all filters. This is desirable to be able to compare response-traces of all frequencies later. Higher frequencies can be expected to be less impacted by environmental noise, since acoustic noise typically has a $\frac{1}{f}$ or $\frac{1}{\sqrt{f}}$ (aka "pink") spectrum.

In this study, stimuli were ipsilateral tone bursts of 1.5 s duration. Total recording frames were 7 seconds long. To avoid interference with the detection, stimuli were pulsed at a rate of 226 / 36 = 6.3 Hz and detection performed in pulse pauses. Contralateral stimulation does not need this provision.

Results

The simulations above suggest that for certain middle ears, other probe tone frequencies than the standard 226 Hz may be more effective to use. The multi-frequency approach allows doing so within one measurement, and responses can be compared directly under exactly equal conditions. [A result is shown in Fig. 2, right.][1] The response for the 452 Hz is lower, and from 904 Hz on a sign change can be observed, indicating the middle ear resonance in the relaxed state is between 452 and 904 Hz.

If the eardrum is pressurized at 100 daPa, the 226 Hz trace tends to provide a much smaller reflex response, while the other frequencies still perform well [(Figure 3, left)][1]. A sign-corrected sum (top trace) trace provides a stable response for both relaxed and pressurized situations. The effect of pressure expectedly is stronger at 200 daPa [(Figure 3, right)][1]. In this state, only higher frequencies provide significant responses.

Figure 4 illustrates the behavior of the proposed method if artifacts occur. Since all traces are recorded simultaneously, artifacts are also synchronous on all traces, which allows for a multi-channel analysis.

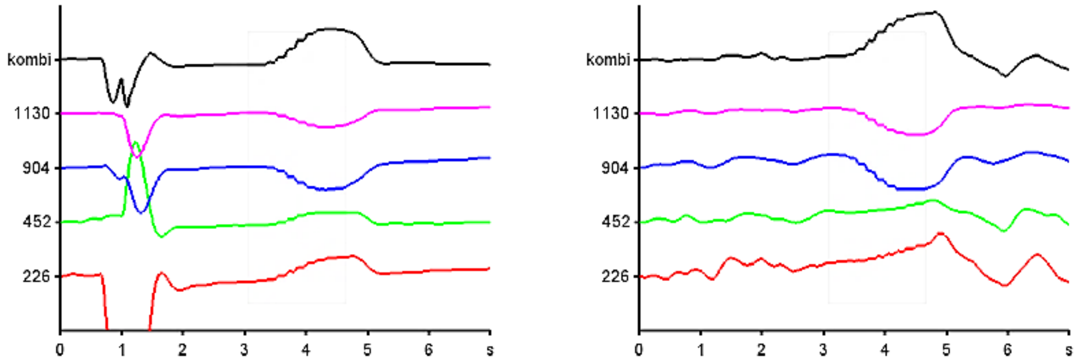

Figure 4: Multi frequency reflex recordings at 1 kHz, 95 dBHL ipsilateral. Left panel: Patient induced artifact (clearing throat) in the pre-stim period. The artifact is clearly reduced in the combination trace. Right panel: movement artifact (touching the probe cable) throughout the recording. The 226 Hz trace does not provide a clear response, while higher frequencies and the sum trace still do.

A very strong artifact was generated by the subject clearing his throat prior to the stimulus onset. The artifact is clearly strongest in the 226 Hz trace, which is an expected effect since the artifact mainly generates low frequencies. The other traces are still impacted, but much less intense. The combined trace shows a clear reduction of the artifact amplitude with a very stable reflex response.

An ongoing mechanical artifact was applied in the right panel by continuously touching the probe cable. Traditional recording alone would not have shown a clear response, while the combined one does. It is important to note that this type of artifact detection / suppression is only possible if all traces were recorded simultaneously.

Finally, combining data from multiple frequencies can also help performing reflex tests closer to threshold. Figure 5 shows an example. While the single traces do not show significant reflex responses, the summed trace still does. This indicates that multi-frequency detection of the acoustic reflex can provide more stable responses closer to threshold, compared to traditional recording.

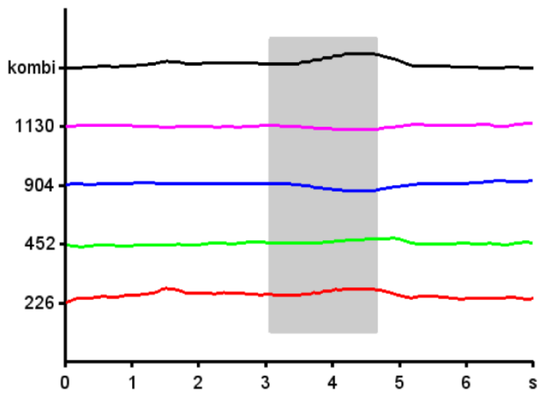

Figure 5: Recording close to threshold (1 kHz, 90 dB HL). The 226 Hz trace does not show a clear response, while the sum trace still does.

Conclusion

First experience with multi-frequency acoustic reflex recording indicates that it improves traditional acoustic reflex testing in several aspects:

- It allows reliable testing atypical middle ears without the need to search for an alternative probe tone frequency manually; it may make external pressure compensation obsolete.

- It provides more robustness against artifacts, such as external noise or subject related artifacts by aligning responses of the different probe frequencies.

- Reliable responses can be recorded closer to threshold by combining traces.

Since no additional test time is needed, the additional information comes at no "cost". Therefore, even if only the standard 226 Hz response is finally used for any reason, no extra test time has been spent.

Note: Patents are pending on the described method.

References

[1] Kandzia, F. An optimized protocol for acoustic impedance measurements: „Simultaneous multi component multi frequency tympanometry" DGA Tagungs-CD 2015

[2] Margolis, R. H.; Saly, G. L. & Keefe, D. H. Wideband reflectance tympanometry in normal adults The Journal of the Acoustical Society of America, ASA, 1999, 106, 265-280

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[1] Note: Figure can be found in the orginal article. For original article visit: www.pathme.de/whitepapers

OAE

Frequency Modulated DPOAE

Lodwig, A. (PATH MEDICAL GmbH)

presentation at IERASG, New Orleans, 2013 and printed in Book of Abstracts

2013, New Orleans

Background

When measuring DPOAE for screening or diagnostic purposes, usually only a few fixed frequencies are tested. However, a feature of DPOAE known as fine structure can interfere with such testing, if one of the test frequencies happens to hit a fine structure minimum. A so-called second source is widely accepted to be responsible for this interference pattern, located at the cochlear area which is tuned to the DPOAE frequency. Using a suppressor tones or pulsed DPOAE recording are known methods to overcome the fine structure. Both methods have certain disadvantages and are therefore not widely used in clinical settings.

Method

A different way of overcoming the DPOAE fine structure is presented here, using frequency modulated (FM) primary tones, resulting in a frequency modulated DPOAE response. We call this method FMDPOAE. Standard recording methods for DPOAE, usually based on Fourier transform or similar techniques, do not allow significant frequency modulation. Therefore, a different approach has been designed, making use of heterodyne filtering techniques. Modulation widths in the order of +-100Hz at modulation rates of 1 to 2 Hz can be applied, while still recording a stable DPOAE signal.

Results

Comparison tests between standard DPOAE and FMDPOAE indicate that fine structure is suppressed quite effectively. In contrast to known methods, FMDPOAE do not need any additional stimuli and do not extend the average test time. Measurements also show that DPOAE fine structure is level dependent. This can lead to higher DPOAE amplitude being recorded at lower stimulus levels and vice versa. This fact can impact DPOAE threshold estimation, based on so called DPOAE-growth functions. FMDPOAE are more robust in this aspect and can therefore improve average threshold estimation accuracy significantly.

Conclusion

FMDPOAE seem to have the potential to improve both screening and diagnostic DPOAE testing performance significantly.

Hybrid measurement of auditory steady-state responses and distortion product otoacoustic emissions using an amplitude-modulated primary tone

Oswald, J. A. (Lehrstuhl für Realzeit-Computersysteme, Technische Universität München, 2006);

Rosner, Th. and Janssen, Th. (Hals-Nasen-Ohrenklinik, Technische Universität München, 2006)

A maximum auditory steady-state response (ASSR) amplitude is yielded when the ASSR is elicited by an amplitude-modulated tone (f_c) with a fixed modulation frequency(f_m=40 Hz), whereas the maximum distortion product otoacoustic emission (DPOAE) level is yielded when the DPOAE is elicited using a fixed frequency ratio of the primary tones(f_2 / f_1=1.2). When eliciting the DPOAE and ASSR by the same tone pair, optimal stimulation is present for either DPOAE or ASSR and thus adequate simultaneous DPOAE/ASSR measurement is not possible across test frequency f_2 or f_c, respectively. The purpose of the present study was to determine whether the ASSR and DPOAE can be measured simultaneously without notable restrictions using a DPOAE stimulus setting in which one primary tone is amplitude modulated. A DPOAE of frequency $2f_1$-f_2 and ASSR of modulation frequency 41 Hz were measured in ten normal hearing subjects at a test frequency between 0.5 and 8 kHz (f_2= f_c). The decrease in the DPOAE level and the loss in ASSR amplitude during hybrid mode stimulation amounted, on average, to only 2.60 dB [standard deviation (SD)=1.38 dB] and 1.83 dB (SD=2.38 dB), respectively. These findings suggest simultaneous DPOAE and ASSR measurements to be feasible across all test frequencies when using a DPOAE stimulus setting where the primary tone f_2 is amplitude modulated.

[DOI: 10.1121/1.2197789]

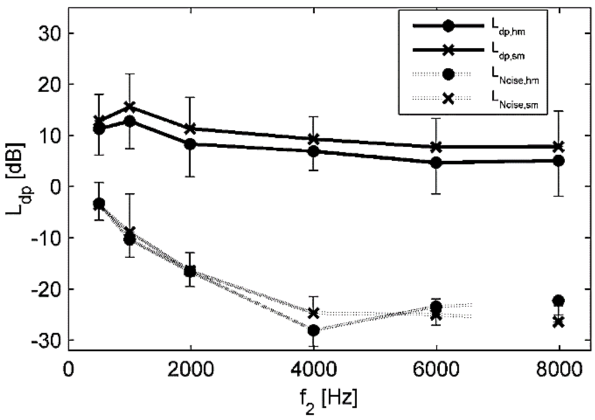

Figure 1: Mean and standard deviation of the DPOAE level (solid lines) and noise level (dashed lines) across test frequency f2 obtained in hm and sm in ten subjects. […] The decrease in DPOAE level during hm stimulation amounted to about 3 dB, nearly independent of test frequency.

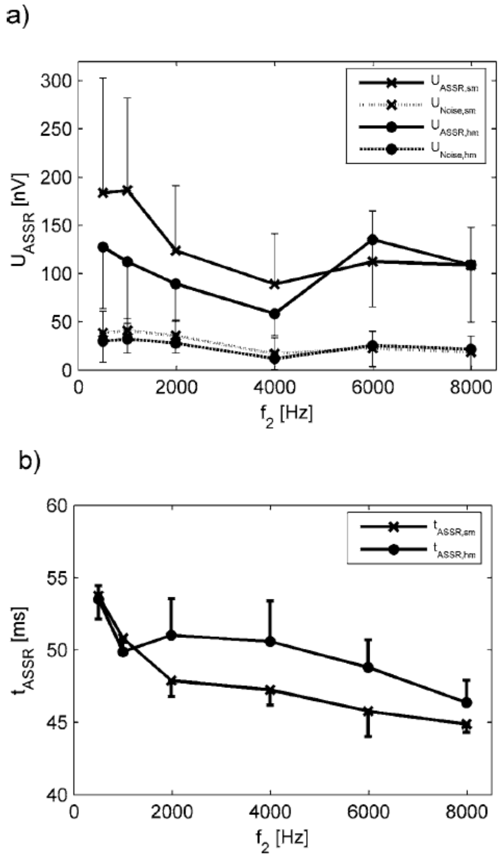

Figure 2: Mean and standard deviation of the ASSR amplitude (solid lines) and noise level (dashed lines) (a) and the ASSR latency (b) across test frequency f2= fc obtained in hm and sm in ten subjects. […]. Decrease in ASSR amplitude during hm stimulation occurred only at the lower test frequencies. Increase in ASSR latency during hm stimulation occurred only at the higher test frequencies.

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Problems with calibration of ear probes for measuring distortion product otoacoustic emissions

Mueller, J.; Oswald, J. A. and Janssen, Th. (Labor für experimentelle Audiologie, HNO-Klinik, Klinikum rechts der Isar der Technischen Universität München, 2004)

The intention of this article is to give a survey on ear probe calibration methods (Siegel 2002) and their fundamental problems. Moreover, the influence on the measurement of distortion product otoacoustic emissions (DPOAE) is described and ideas to improve calibration are presented.

The main goal of ear probe calibration is to generate a defined sound pressure level at the ear drum. Voltage at the loudspeaker is not functionally linked to sound pressure level at the eardrum due to the dependency of loudspeaker output level on the attached load impedance which differs individually. Main influencing factors are ear canal volume and ear drum impedance. Ear probe calibration is necessary to compensate for these impacts.

There are two major kinds of calibration methods (Whitehead et al. 1995). The most common calibration procedure is the in-the-ear adjustment strategy. Given a constant voltage at the loudspeaker, you measure the sound pressure at the ear probe microphone which is situated somewhere in the outer ear canal. The sound pressure level at the ear drum differs, dependent on the frequency, substantially from the measured sound pressure level at the microphone because of standing waves which result from the superposition of in-going and reflected waves. Especially at frequencies in the range of 3 to 7 kHz there could be fundamental deviations from the expected ear drum sound pressure level due to cancellations at the microphone place. These differences could exceed 20 dB SPL. Therefore, network models are useful to compensate for these effects. These models predict the differences between the sound pressure level at the microphone and at the ear drum on the basis of measurements of certain parameters as ear canal length and ear drum impedance. Indeed, the estimation of difference is very difficult, because the measurement of the required parameters is due to several side effects in the ear quite complex and thus imprecise. All in all, no complete correction will be possible.

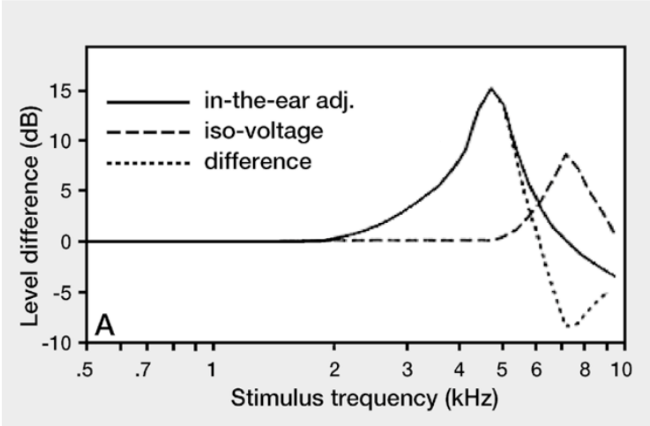

Figure 1: Schematic comparison of the deviation between actual and target sound pressure level for in-the-ear and constant-voltage calibration (Whitehead 1995)

Another calibration method is the constant voltage calibration, which measures the transfer function within a reference coupler and not within the ear. The sound pressure level is measured at the coupler microphone given a defined input voltage at the ear probe loudspeaker. This curve is used as reference transfer function and is shifted according to the individual ear canal volume. The advantage over the in-the-ear calibration is that the coupler microphone is located at the ›ear drum position‹, that means at the end of the coupler, so that there are no effects due to standing wave minima. Sources of error are deviations between the individual ear canal and the coupler transfer function. Further on, $\lambda/2$-resonances which are measured in the ear coupler could deviate from resonance frequencies in a real ear. Also, the amplitude of the resonance could differ enormously between coupler and ear.

The main advantage of this calibration strategy is the irrelevance of standing wave minima at the ear probe microphone place, so that the difference between assumed and real sound pressure level at the ear drum should be lower than with in-the-ear calibration in a frequency range up to about 5 kHz.

Considering all the additional undesirable effects in real ears, which were described above and which falsify the sound pressure level at the ear drum depending on the calibration method, it is apparent that calibration has a strong influence on DPOAE measurements, which are dependent on the primary tone level setting. The two primary tone levels L1 and L2 could deviate differently from their demand value, because they are located at different frequencies. Thus the optimal DPOAE amplitude, resulting from an ideal stimulus level setting (scissor paradigm: L1 = 0,4L2 + 39 – Janssen et al. 1995; Kummer et al. 2000) will be changed. This results in a calibration-dependent varying course of the DPOAE growth function. Therefore, the calibration strategy has to be improved in order to assure a reliable acquisition and evaluation of DPOAE data, which is important for further trustworthy diagnostic conclusions.

To improve the in-the-ear calibration strategy it is necessary to develop reliable compensation models and test their quality in real ears. Further on, constant voltage calibration could possibly be enhanced by using various reference curves and chose one of these dependent on ear canal length measurement. Moreover, it is important to think of methods for evaluating the quality of a particular calibration strategy when used in real ears, since it is not easily possible to measure the sound pressure level at the ear drum. Subjective comparative tests could be helpful to solve this problem.

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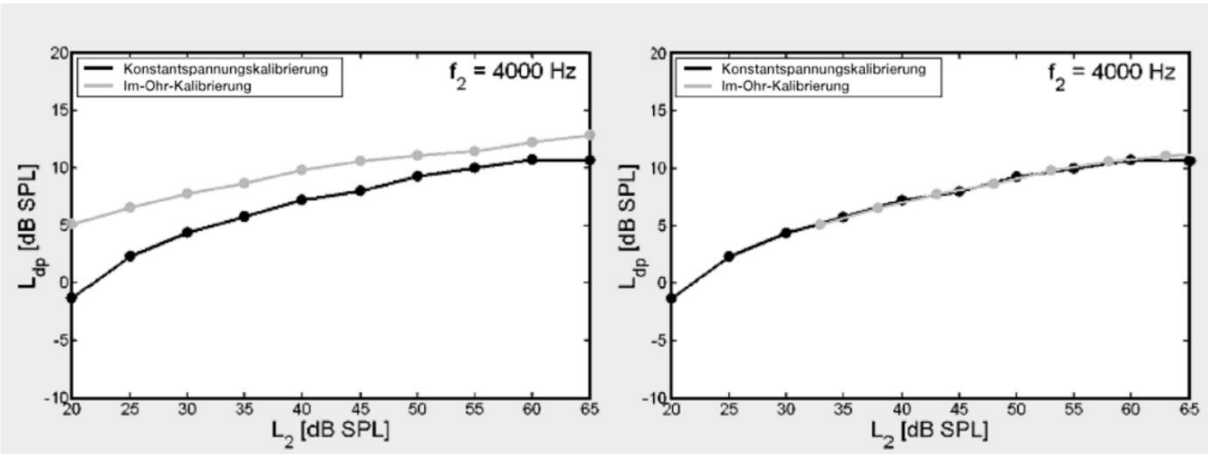

Figure 2: Measurement of DPOAE growth functions at 4 kHz with constant-voltage calibration (black) and in-the-ear calibration (grey) at a subject with an estimated ear canal length of 22 mm (→Minimum of the standing wave is located around 4000 Hz) – left: original DPOAE growth functions; right: DPOAE growth functions with the function measured within-the-ear-calibration shifted 13 dB SPL along the L2axis.

Evidence for a bipolar change in distortion product otoacoustic emissions during contralateral acoustic stimulation in humans

Müller, J., Janssen, Th. (HNO, Techn. University Munich, 2005) et. al.

The aim of this study was to investigate the activity of the medial olivocochlear (MOC) efferents during contralateral (CAS) and ipsilateral acoustic stimulation (IAS) by recording distortion product otoacoustic emission (DPOAE) suppression and DPOAE adaptation in humans. The main question was: do large bipolar changes in DPOAE level (transition from enhancement to suppression) also occur in humans when changing the primary tone level within a small range as described by Maison and Liberman for guinea pigs [J. Neurosci. 20, 4701–4707 (2000)]? In the present study, large bipolar changes in DPOAE level (14 dB on average across subjects) were found during CAS predominantly at frequencies where dips in the DPOAE fine structure occurred. Thus, effects of the second DPOAE source might be responsible for the observed bipolar effect. In contrast, comparable effects were not found during IAS as was reported in guinea pigs. Reproducibility of CAS DPOAEs was better than that for IAS DPOAEs. Thus, contralateral DPOAE suppression is suggested to be superior to ipsilateral DPOAE adaptation with regard to measuring the MOC reflex strength and for evaluating the vulnerability of the cochlea to acoustic overexposure in a clinical context.

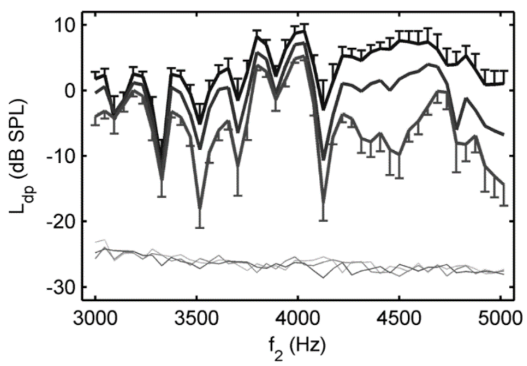

Figure 1: DPOAE fine structure reproducibility for one subject. Data were averaged across ten measurements conducted on different days. The three top lines show from top to bottom mean L_{dp} plotted across frequency for L_2=40, 30, and 20 dB SPL. The standard deviation is given for data measured at L_2=40 dB SPL and L_2=20 dB SPL. The three bottom lines represent the particular mean noise floor levels.

Reference

Maison, S. F., and Liberman, M. C. (2000). "Predicting Vulnerability to Acoustic Injury with a Noninvasive Assay of Olivocochlear Reflex Strength," J. Neurosci. 20, 4701–4707.

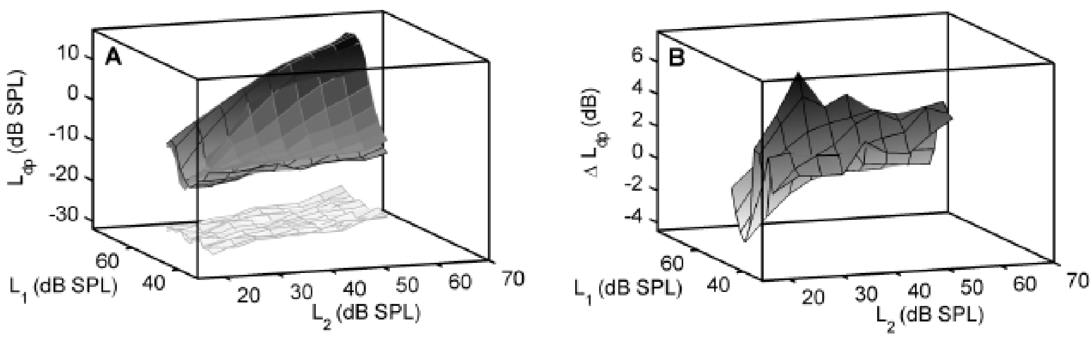

Figure 2: Contralateral acoustic stimulation (CAS) effect on DPOAEs and its reproducibility at f_2=4125 Hz for one subject. Data were averaged across ten measurements conducted on different days. Panel A shows mean L_{dp} plotted above L_2 and L_1 for the condition without (black lines) and with (gray lines) CAS. The light gray area at the bottom represents the noise floor level. Panel B shows the DPOAE level difference ΔL_{dp} between measurements with and without CAS. Negative values mean suppressive, positive values enhancing behavior due to CAS.

High-resolution distortion-product otoacoustic emissions. Method and clinical applications

Janssen, T. (Rechts der Isar Hospital, Techn. University Munich, 2014);

Lodwig, A.; Müller, J. and Oswald, H. (PATH Medical GmbH, 2014)

Abstract

Unlike pure tone thresholds that assess both peripheral and central sound processing, distortion-product otoacoustic emissions (DPOAEs) selectively mirror the functioning of the cochlear amplifier. High resolution DPOAEs are missing in the toolbox of routine audiometry due to the fact that high resolution DPOAE measurements are more time-consuming when compared to normal clinical DP grams with rough frequency resolution.

Measurements of high resolution DPOAEs allow an early assessment of beginning sensory cell damage due to sound overexposure or administration of ototoxic drugs. When using a rough grid, sensory cell damage would be overlooked as in the early state damage only appears at some distinct cochlear sites. A review is given on the method and application of high resolution DPOAEs.

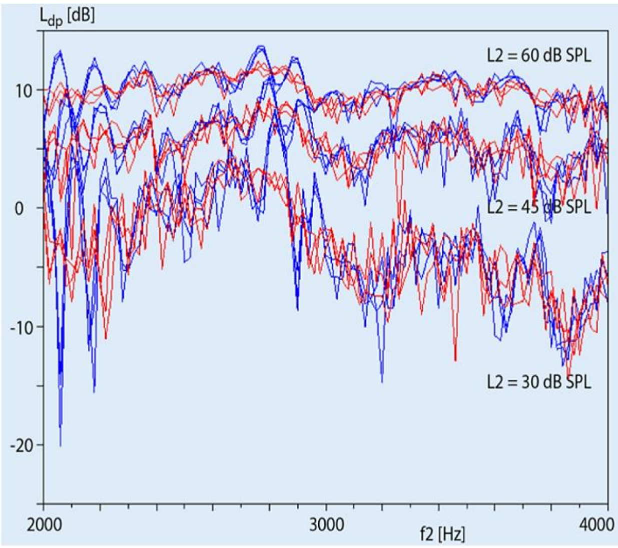

Figure 1: High resolution DPOAE- Grams with (red) and without suppression (blue) of the second source in the frequency range between 2 and 4 kHz at three different primary sound levels

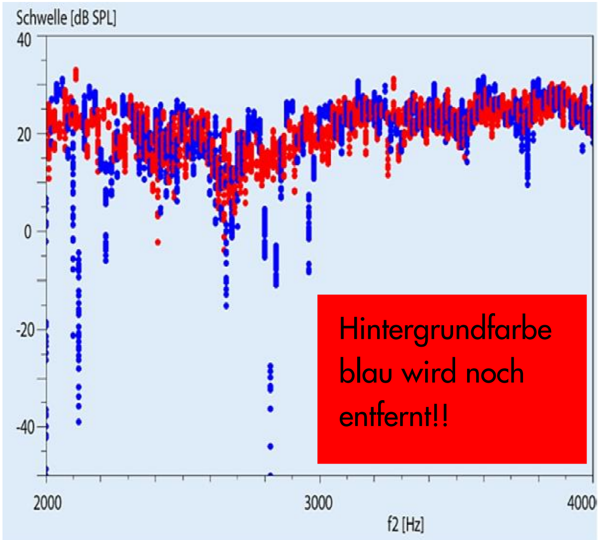

Figure 2: Estimated threshold with suppression (red) and without (blue)

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Distortion product otoacoustic emissions upon ear canal pressurization

Zebian, M. (PTB Braunschweig), Schirkonyer, V. (HNO, Techn. University Munich) et al.

Abstract

Background

The purpose of this study was to quantify the change in distortion product otoacoustic emission (DPOAE) level upon ear canal pressurization. DPOAEs were measured on 12 normal-hearing human subjects for ear canal static pressures between −200 and +200 daPa in (50 ± 5) daPa steps. A clear dependence of DPOAE levels on the pressure was observed, with levels being highest at the maximum compliance of the middle ear, and decreasing on average by 2.3 dB per 50 daPa for lower and higher pressures. Ear canal pressurization can serve as a tool for improving the detectability of DPOAEs in the case of middle-ear dysfunction.

Some middle-ear disorders caused, for instance, by Eustachian tube dysfunction result in a shift of the admittance peak in the tympanogram. How to assess the cochlear function (using DPOAEs) in spite of this shift? As long as the tympanic membrane is not perforated or damaged, one may think of applying counter-pressure to the EC (static pressure in the external meatus) and temporarily compensating for the admittance shift.

Discussion

Clinical advantages of EC pressurization

Although the focus of our study was on the "metrological" aspect, i.e., quantifying the DPOAE slopes over EC static pressure for young normal-hearing test subjects—with higher accuracy than what has been reported in the literature so far—our data may be useful for comparison when assessing DPOAE slopes with EC pressurization on patients with middle-ear disorders.

For subjects with normal hearing (as can be deduced from the pure-tone audiogram) but with a shift in the compliance peak (as can be observed in the tympanogram), DPOAEs may be measured, provided that the EC pressure is adjusted so as to yield the maximum compliance of the system comprising the eardrum and the middle ear. Hence, in the case of a healthy cochlear function, the deliberate pressurization of the EC may be beneficial for patients with middle-ear dysfunction that causes negative (Sun and Shaver, 2009) or positive (Ostergard and Carter, 1981) middle-ear pressure.

Recall that although an EC static pressure is assumed to exert similar effects on the tympanic membrane and middle-ear ossicles as does the opposite middle-ear pressure, the difference between the two effects has yet to be clarified. For example, a negative EC static pressure pulls the tympanic membrane and all parts of the middle ear toward the EC. Although the analogous positive pressure within the middle-ear cavity will still push the tympanic membrane into the EC, it may not push on the stapes in exactly the same way. Hence, the effect of an actual negative middle-ear pressure on DPOAE level may be slightly different than that of a (simulated) negative middle-ear pressure that is obtained by applying positive EC static pressure (cf. Sun and Shaver, 2009).

The curves in Figs. 1[1] and 2 remind us of those obtained with traditional tympanometry. However, unlike the tympanogram (e.g., 226 Hz, 85 dB SPL), which shows "only" the compliance of the eardrum and middle-ear system at one single frequency, combining EC pressurization with DPOAE measurements leads to a frequency-specific assessment which involves both middle-ear transmission characteristics and cochlear function.

Conclusion and outlook

DPOAEs were measured for both positive and negative ear canal pressures with a small step size and a tolerance of only ±5 daPa. These measures allowed for a reliable estimation of the rate of change of DPOAE levels per pressure increment for a young normal-hearing population. On average, DPOAE levels were highest at the static pressure that yielded the maximum middle-ear compliance, decreasing with both positive and negative EC pressures by about (2.3 dB)/(50 daPa).

Due to the increasing interest in high-frequency DPOAEs to detect cochlear disorders at an early stage, future studies should assess the DPOAE level dependency on EC static pressures at higher frequencies. For those frequencies, however, an eardrum-based calibration procedure has to be applied, since the usual in-the-ear calibration strategy is reliable only below about 4 kHz (Whitehead *et al.*, 1995).

It remains to be seen whether similar slopes will occur in the pressure-dependent DPOAE levels in patients with abnormal middle-ear pressure around their individual tympanometric admittance peak pressure. Furthermore, the impact of EC static pressure on the DPOAE alone can be studied by applying one or both stimuli through bone conduction (BC). Upon BC stimulation, both the ear canal and the middle ear are bypassed, and only the DPOAE is affected by an altered EC pressure (Zebian, 2012).

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[1]Note: Figure in the original article.

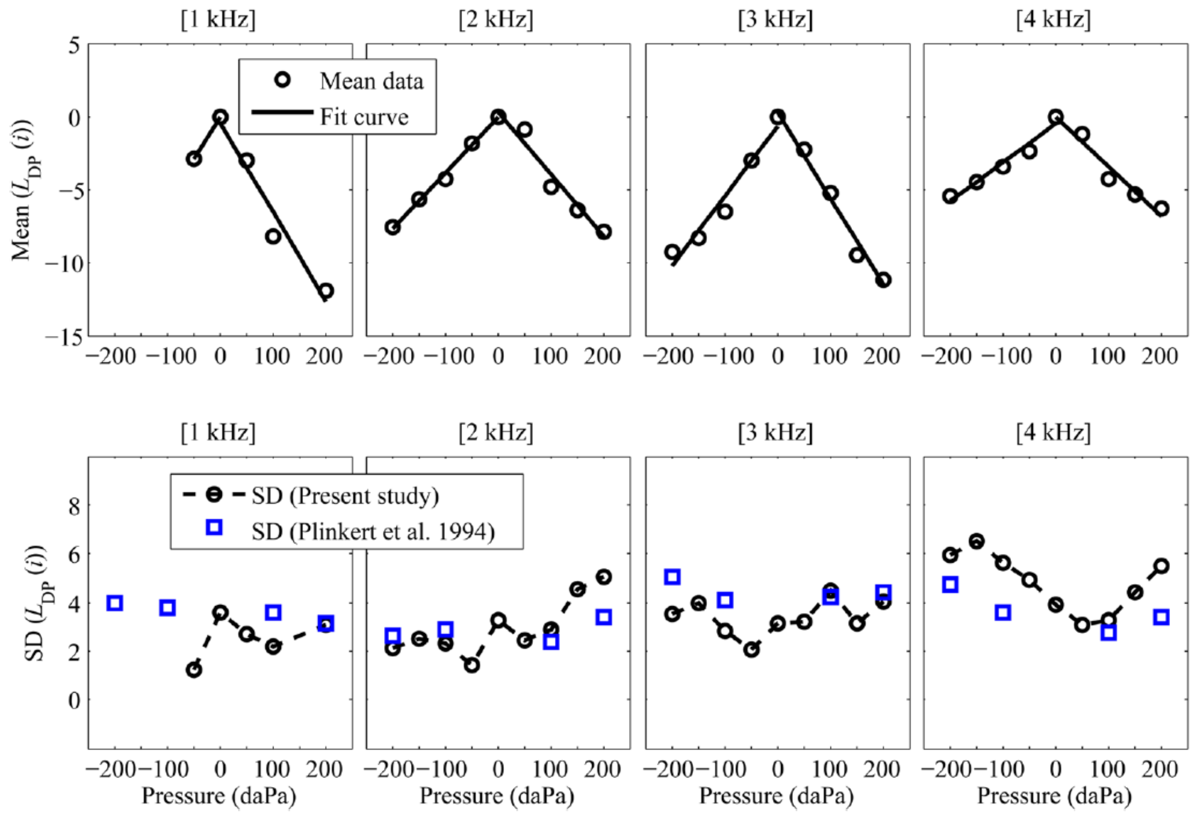

Figure 2: (Top) Mean DPOAE levels over all 12 subjects (circles) (from individual measurements normalized beforehand to 0 dB at 0 daPa), along with the linear regression (straight lines) performed on each half of the data separated by 0 daPa. (Bottom) SDs of the DPOAE levels (circles), along with data from Plinkert et al. (1994) at 6100 and 6200 daPa for comparison (squares), shown for stimulus frequencies f2¼1,2,3,4 kHz.

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