Educational Module
Oto-Acoustic Emission

PATH medical
Germany
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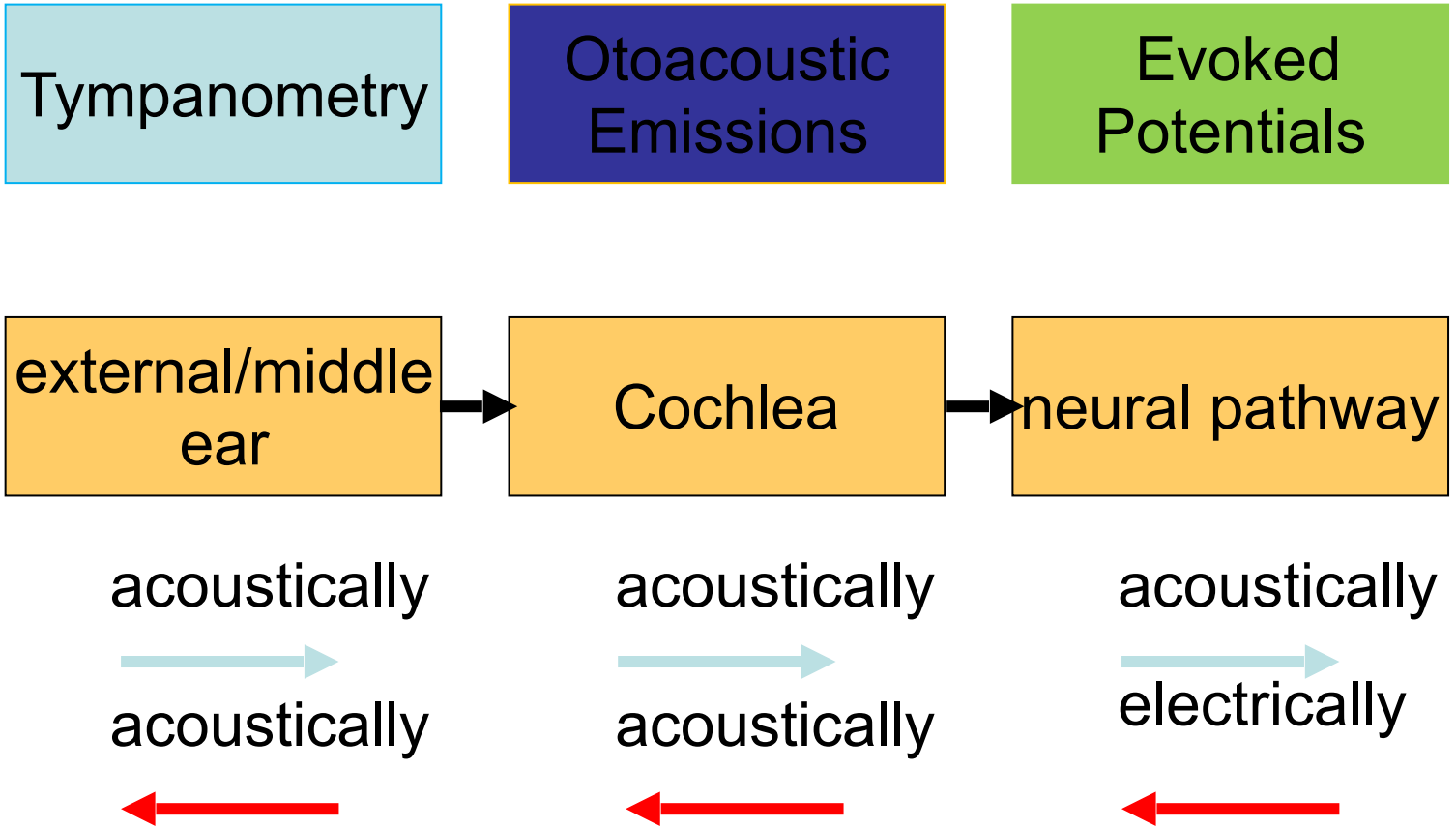
Our educational modules

are made for providing information on how the hearing organ works and which test procedures are used to test the functionality of the sound processing elements along the auditory pathway.

With that knowledge the user of our devices should be prepared to use our test modules efficiently.

Physiological tests



Physiological tests

Physiological test procedures reflect the mechanical and neural function of the auditory system. Therefore, physiological tests are used for reliably detecting the site of impairment along the auditory pathway. Tympanometry (Tymp), oto-acoustic emission (OAE) and auditory evoked potential (AEP) are able to differentiate between middle-ear, cochlear, and neural disorders. In case of Tymp and OAE, both, stimulus and response are acoustic signals. In contrast, in case of AEP there is an acoustical input-signal and an electrical output-signal.

In view of an adequate therapy of a hearing impairment, it is important to known which stage of the auditory pathway is concerned. Tymp, OAE, and AEP allow for selectively assessing middl-ear, sensory (cochlear) and neural disorders. Behavioural testing is less reliable. This is true, especially, in infants and other non-cooperative patients, where psycho-acoustical tests cannot reliably be performed.

We have seven educational modules

1 Sound - Physiology/Pathophysiology of Hearing

2 Tympanometry

3 Oto-Acoustic Emission (OAE)

4 Auditory Evoked Potentials (AEP)

5 Hearing Screening (newborn, pre-school/school children, elderly)

6 Tracking

7 Occupational medicine

TEOAE-test modules

TEOAE – Transient Evoked Otoacoustic Emissions

for checking basic outer hair cell functionality

TEOAE-Quick with **fixed** stop criterion
in different frequency bands

TEOAE Diagnostic with **user-defined** stop criterion
in different frequency bands

DPOAE-test modules

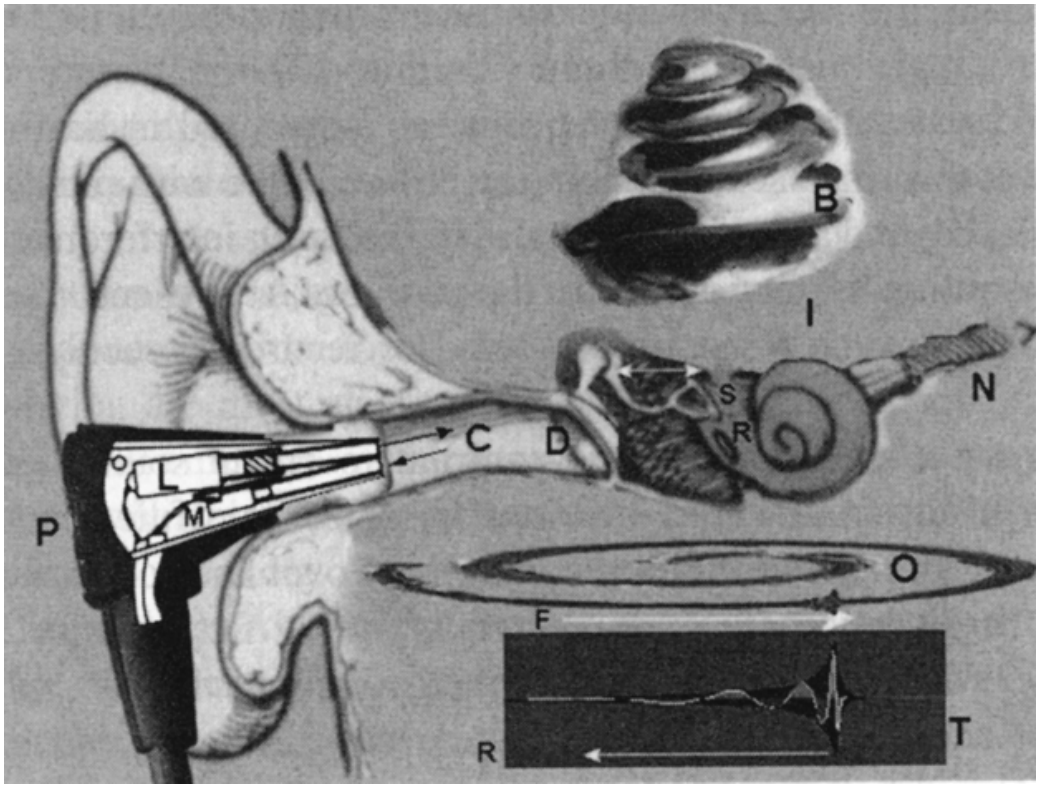
DPOAE – Distortion Product Otoacoustic Emissions

for frequency specific checking of outer hair cell functionality

- ***DPOAE-Quick/Diagnostic*** using one/multiple user defined level(s)
- ***DPOAE-Threshold*** for hearing thershold estimation using automatically controlled stimulus levels
- ***DPHIRES – High Resolution DPOAE*** for assessing fine-structure cochlear impairment using user-defined frequency step size
- ***FMDPOAE - Frequency Modulated DPOAE*** for improving hearing threshold estimation

Oto-Acoustic Emission (OAE)

Discovered by David Kemp in 1978

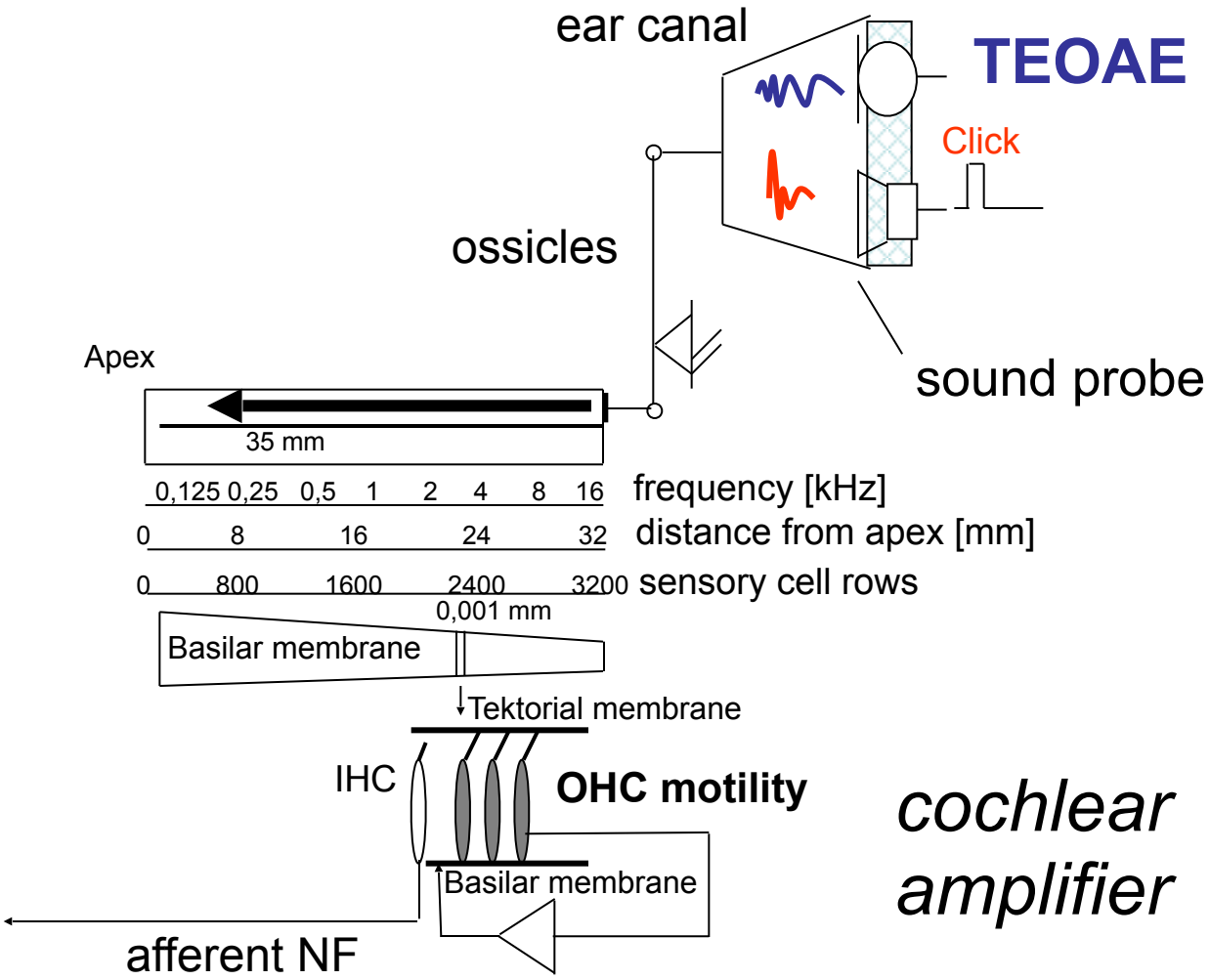


D. T. Kemp: Stimulated acoustic emissions from the human auditory system. J Acoust Soc Am 1978. Figures from „Otoacoustic Emissions in Perspective." In: Otoacoustic Emissions (Eds.: M.S. Robinette, T. J. Glattke) Thieme 1997.

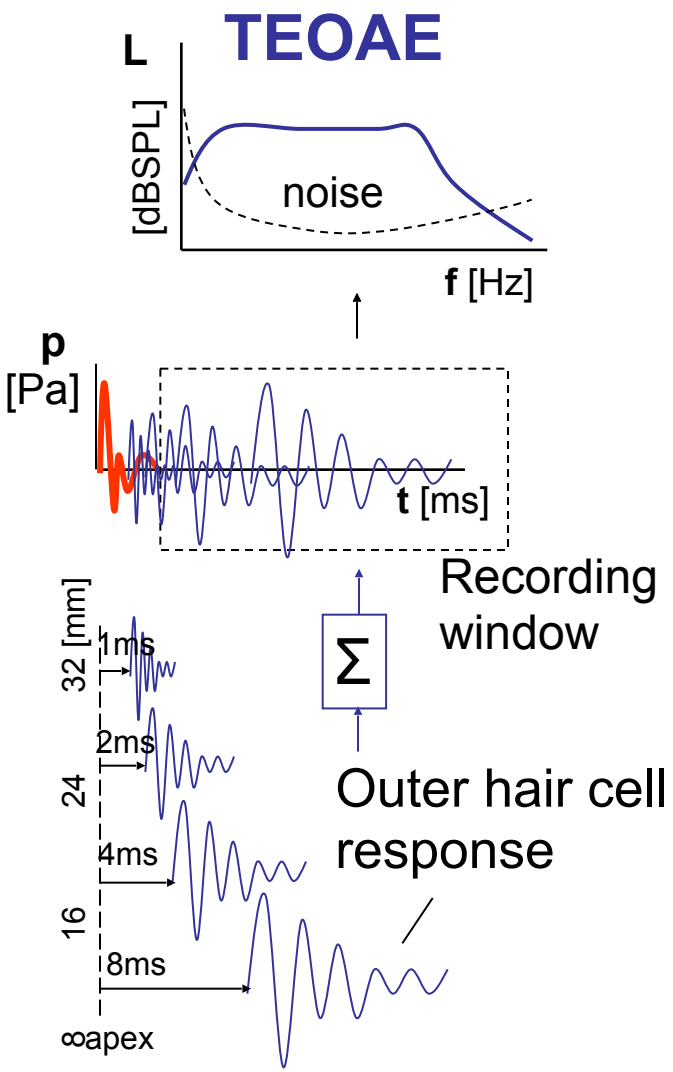
Oto-Acoustic Emission (OAE)

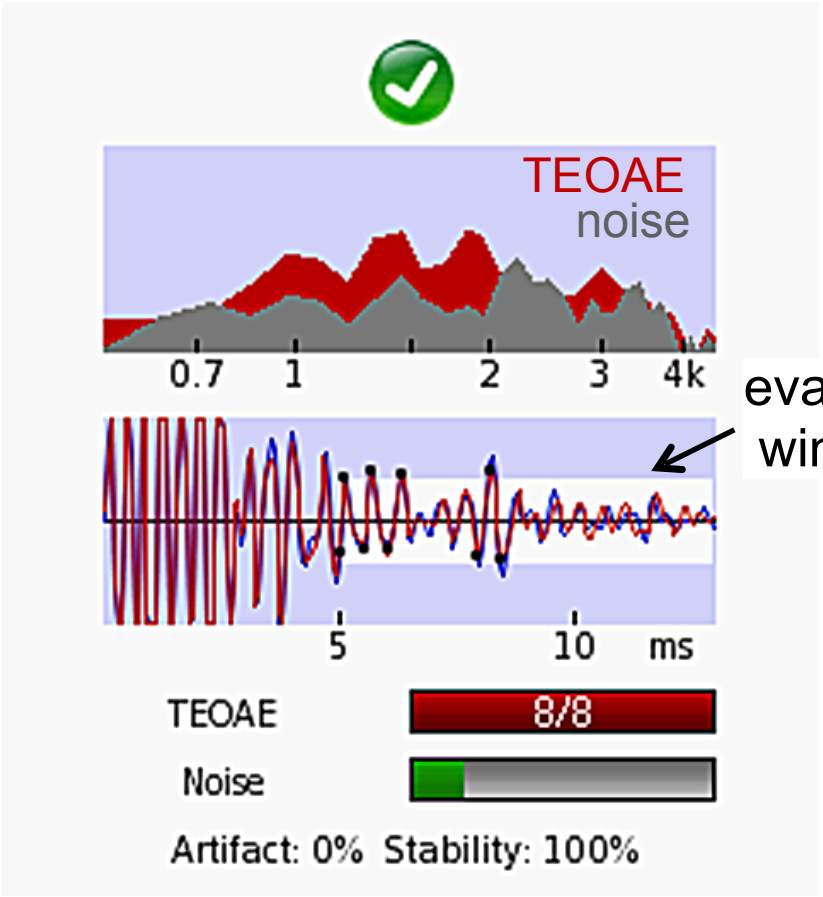
The discovery of oto-acoustic emissions (OAEs) by David Kemp in 1978 has produced a fast, powerful, and versatile tool for diagnosing cochlear integrity. OAE measurements are today a standard part of the audiometric test battery. OAEs are elicited and measured by means of electro-acoustic transducers (loudspeaker and microphone) within an ear probe placed in the outer ear canal. There are spontaneous (SOAEs) and evoked OAEs (EOAEs). EOAEs are the by-product of the non-linear sound amplification process in the cochlea. OAEs are low-level sound emissions generated by the outer hair cells (OHCs) within the cochlea. OAE levels depend on the number of functioning outer hair cells given a normal middle-ear function. OAE levels depend on the ear canal volume. Because of the smaller ear canal volume, OAE amplitude in newborns and infants is higher compared to that in adults. Thus, OAEs are easier to measure and thus provide a suited tool for newborn-hearing screening and follow-up diagnostics.

Transient Evoked Oto-Acoustic Emission (TEOAE)



Transient Evoked Oto-Acoustic Emission (TEOAE)





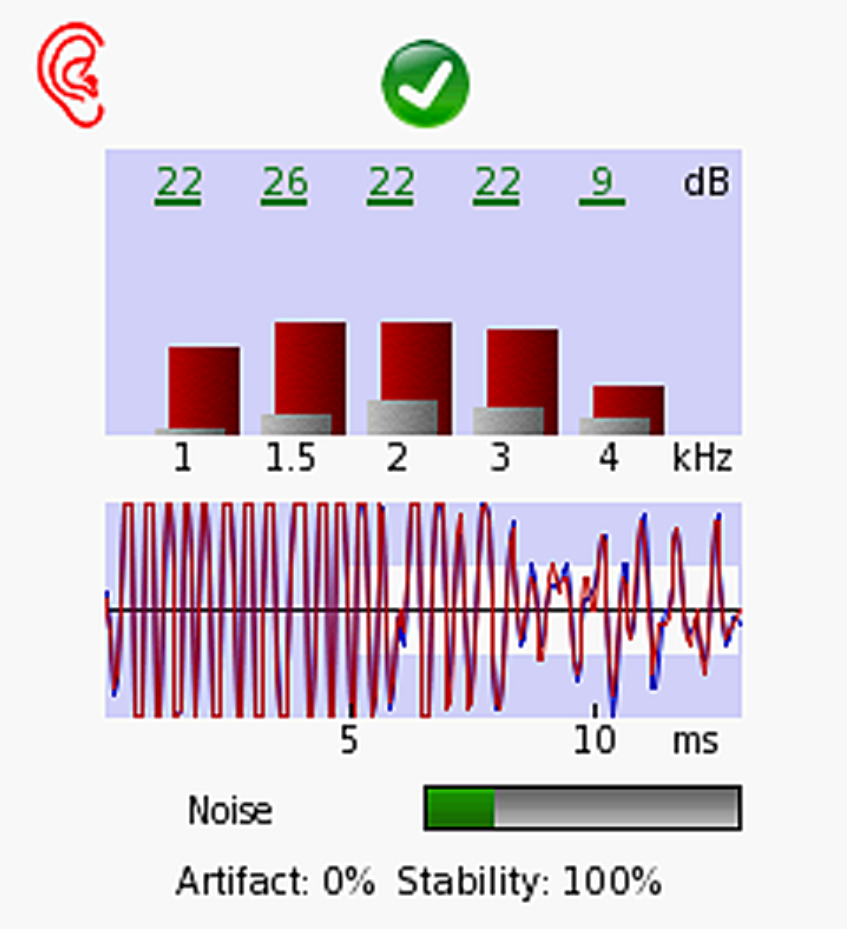
Transient Evoked Oto-Acoustic Emission (TEOAE)

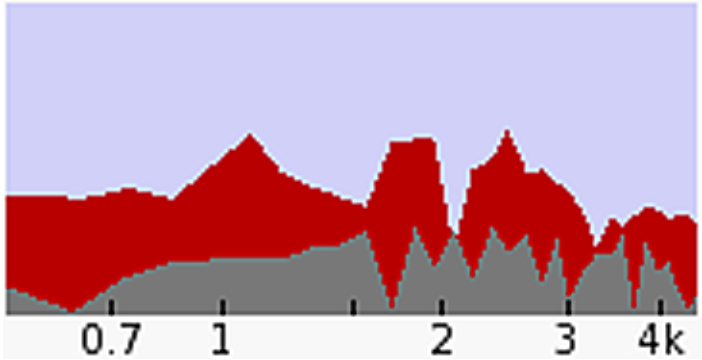
Transient oto-acoustic emissions are elicited by transient acoustic stimuli (clicks ore tone-bursts). TEOAEs represent the sum of acoustic impulse- responses of OHCs along the cochlea. At click-stimulation, almost all OHCs along the cochlear partition are set into movement. When using tone-bursts of different carrier-frequencies a specific part of OHCs along the cochlea is stimulated.

Due to cochlear frequency dispersion, TEOAE components can be directly traced to a specific place. As the basilar membrane at basal sites moves faster than at more apical sites, high-frequency TEOAE components stem from basal cochlear sites, whereas low-frequency TEOAE components come from more apical ones. As a consequence, basal responses appear at the beginning and apical responses at the end of the TEOAE time function. TEOAEs thus provide a rough frequency-specific estimation of cochlear hearing loss. TEOAE‘s sound pressure level is very low varying from about 10 to -30 dBSPL. Thus, measurement and averaging of several hundred signal-epochs are necessary for extracting TEOAE response from noise.

Transient Evoked Oto-Acoustic Emission (TEOAE)

28 years old adult, normal hearing





SNR

22	26	22	22	9	dB
1	1.5	2	3	4	kHz

SNR criteria:

>9	>9	>9	>9	>9	dB

Overall criterion: 5 / 5

Stimulus
Optimized
Level [dB peSPL]
85
Averages
533

Transient Evoked Oto-Acoustic Emission (TEOAE)

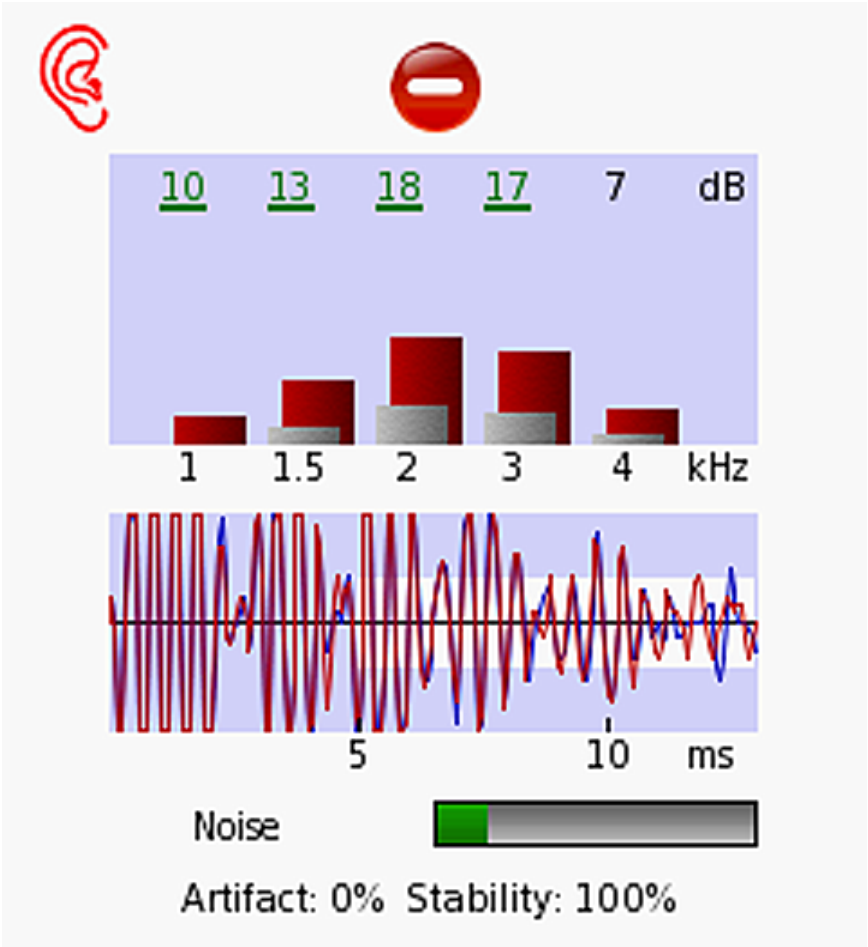
A normally hearing adults exhibits TEOAEs having high levels and a broad signal spectrum. Signal-to-Noise-Ratio (SNR) is high (more than 20 dB with the exception at 4 kHz (9 dB) in the case example). SNR criterion for accepting a response as valid was set to 9 dB.

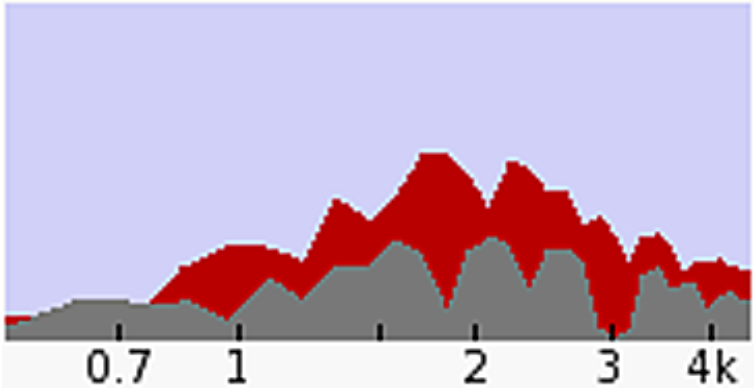
In contrast, in a newborn at birth with a temorary sound conduction deficit due to amniotic fluid in the tympanic cavity (see case example), TEOAE components have lower levels SNRs (10, 13, 18, 17, 7 dB). However, SNR criterion is fullfilled at all test frequencies with exception at the highest test frequency (4 kHz). The reason for this is a high frequency hearing loss due to a reduced sound conduction because of the amniotic fluid.

In contrast, in a six days old newborn no TEOAEs could be measured. SNRs are below the selected criterion (< 9 dB). There was a normal tympanogram (not shown). In this case, a dysfunction of outer hair cells is most likely. TEOAEs already disappear at mild hearing losses and are therefore commonly used in hearing screening programs.

Transient Evoked Oto-Acoustic Emission (TEOAE)

2 hours old newborn, amniotic fluid in tympanic cavity





SNR

10	13	18	17	7	dB
1	1.5	2	3	4	kHz

SNR criteria:

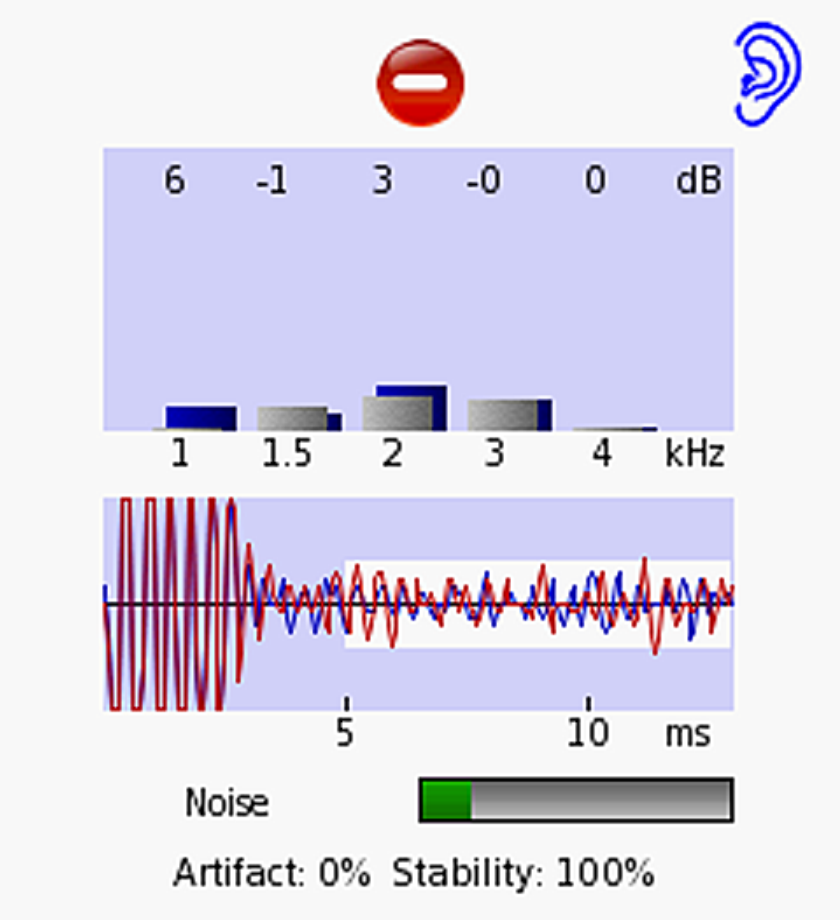
>9	>9	>9	>9	>9	dB

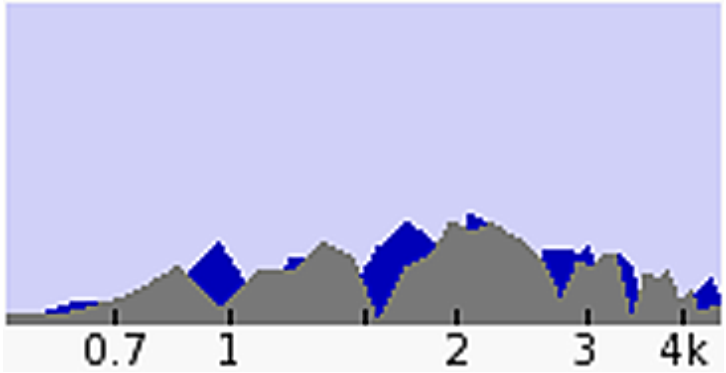
Overall criterion: 5 / 5

Stimulus
Optimized
Level [dB peSPL]
85
Averages
638

Transient Evoked Oto-Acoustic Emission (TEOAE)

6 days old newborn: no TEOAE → OHC dysfunction





SNR

6	-1	3	-0	0	dB
1	1.5	2	3	4	kHz

SNR criteria:

>9	>9	>9	>9	>9	dB

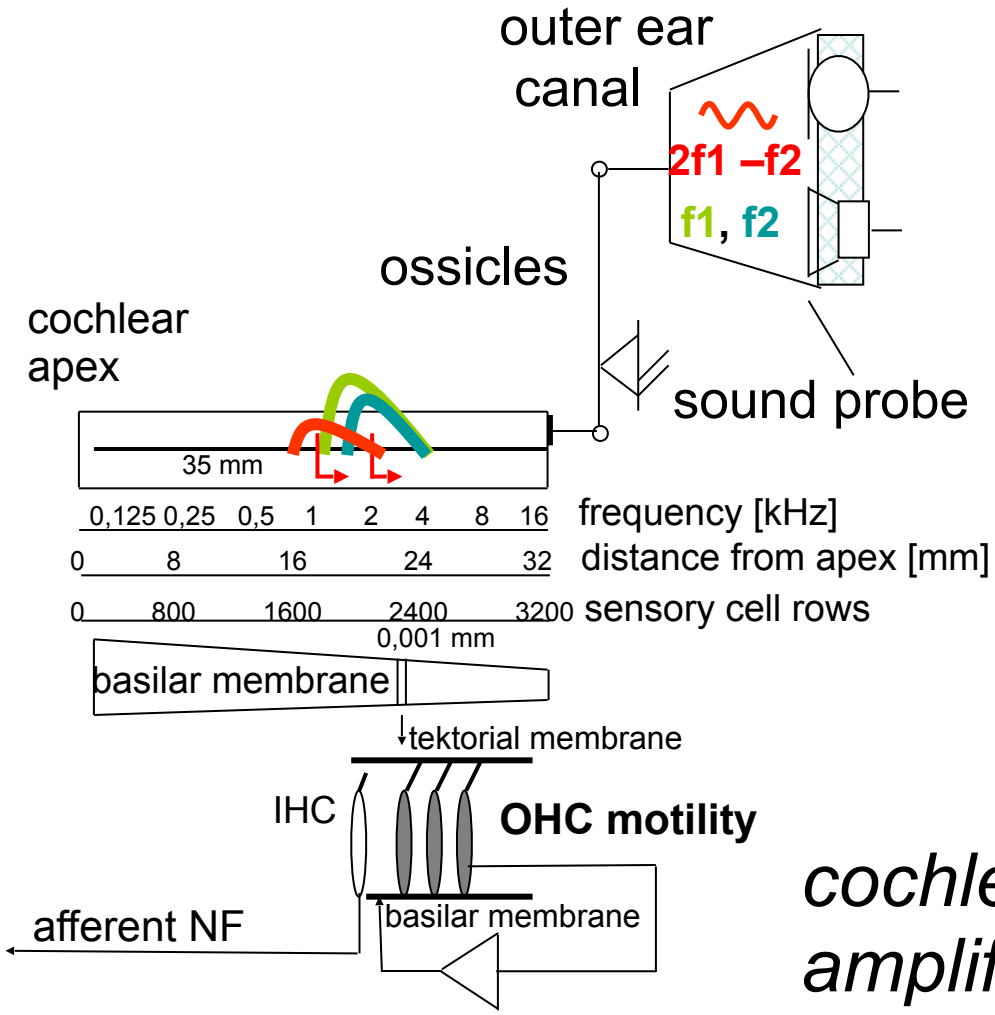
Overall criterion: 5 / 5

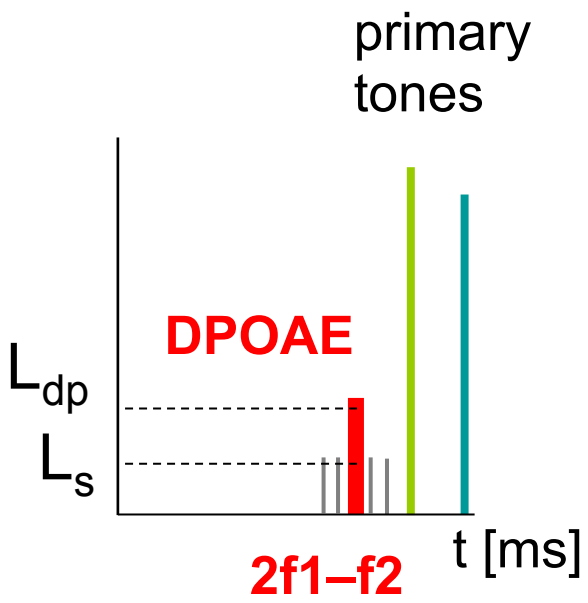
Stimulus
Optimized
Level [dB peSPL]
85
Averages
604

Distortion Product Oto-Acoustic Emission (DPOAE)

DPOAEs are cubic distortions of outer hair cells (OHC) when stimulated simultaneously by two tones f_1 (lower frequency) and f_2 (higher frequency). DPOAEs arise directly from the frequency-selective compressive nonlinearity of OHCs. The two primary tones interact in the cochlea within the region of overlap of the traveling waves of the two primary tones close to the characteristic place of f_2. Thus, DPOAEs can be applied as a probe for frequency-specific assessment of cochlear dysfunction at the f_2 place. In humans, both quadratic (f_2-f_1) and cubic distortion products ($2f_1$-f_2) can be detected. The cubic distortion component $2f_1$-f_2 yields the highest amplitude and is therefore primarily used for diagnostics. DPOAE amplitudes typically range from about 20 dB SPL down to about -30 dB SPL. DPOAEs are measurable at a cochlear hearing loss of up to 40 to 50 dB HL. DPOAEs provide quantitative and frequency-specific information about the range and operational characteristics of the cochlear amplifier, i.e., sensitivity, compression, and frequency selectivity of the hearing organ.

Distortion Product Oto-Acoustic Emission (DPOAE)





cochlear amplifier

Distortion Product Oto-Acoustic Emission (DPOAE)

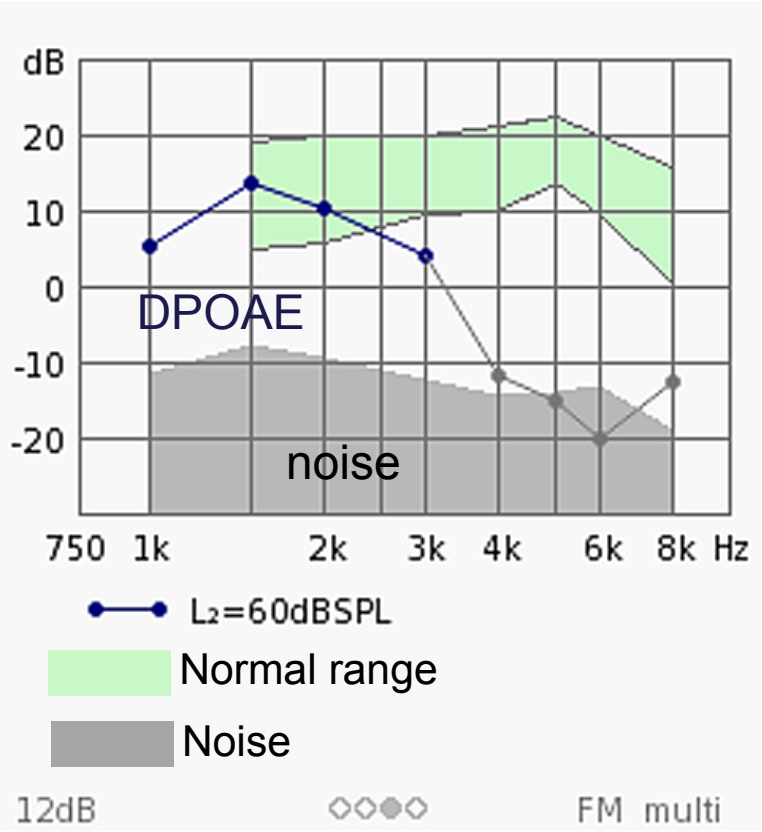
The number of OHCs contributing to DPOAE generation depends on the size of the overlapping region, which is determined by the primary tone levels L_1 and L_2, and the frequency ratio f_2/f_1. A frequency ratio of about 1.2 has been found to be optimal.

A primary tone level setting, which accounts for the different compression of the primary tone traveling waves at the f_2 place, is the scissor paradigm (see below) DPOAE-grams plot the DPOAE level L_{dp} as a function of f_2 (the main DPOAE generation site) for a selected combination of primary-tone levels L_1 and L_2.

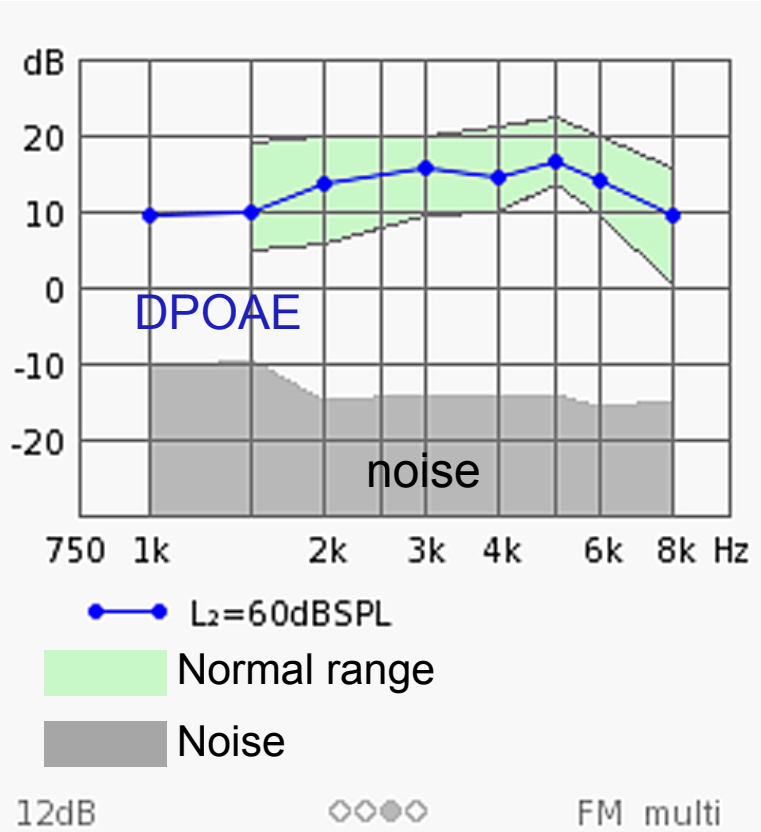
DPOAE-grams reflect the sensitivity of the cochlear amplifier (CA) best when recorded at close-to-threshold stimulus levels. In normal hearing (normal CA), DPOAE-grams are close to each other at high and more separated at low stimulus levels reflecting cochlear non-linear sound processing. In cochlear hearing loss ears (impaired CA), DPOAE-grams are more separated even at high stimulus levels, revealing loss of CA compression.

Distortion Product Oto-acoustic Emission (DPOAE), case examples

DP-gram → OHC-dysfunction



DP-gram → normal OHC-function



Multiple Distortion Product Oto-Acoustic Emission (Multichannel DPOAE)

DPOAE-tests are normally performed by stimulating one ear with one tone pair only. Why not apply multiple tone pair stimulation and binaural stimulation? Both will reduce test time. However, when using multiple and binaural stimulation two facts have to be taken into account. First, when using multiple stimulation, the distance between the primary tone pairs have to be huge enough to avoid overlapping of the travelling waves on the basilar membrane and with that reduction of DPOAE level. Second, stimulus protocol must ensure that there is no crosstalk at the higher stimulus levels. In a study it was evaluated under what conditions mDPOAE measurements have to be done without mutual influence of primary tone pairs in the ipsilateral and the contralateral ear. DPOAE was collected using single- and multi-frequency presentations of the primaries for both monaural and binaural conditions. The mean DPOAE levels collected with mDPOAE and binaural presentation conditions were highly reproducible when compared to those obtained with the single-frequency r

[21]Smyrzinski and Janssen, 20xx)

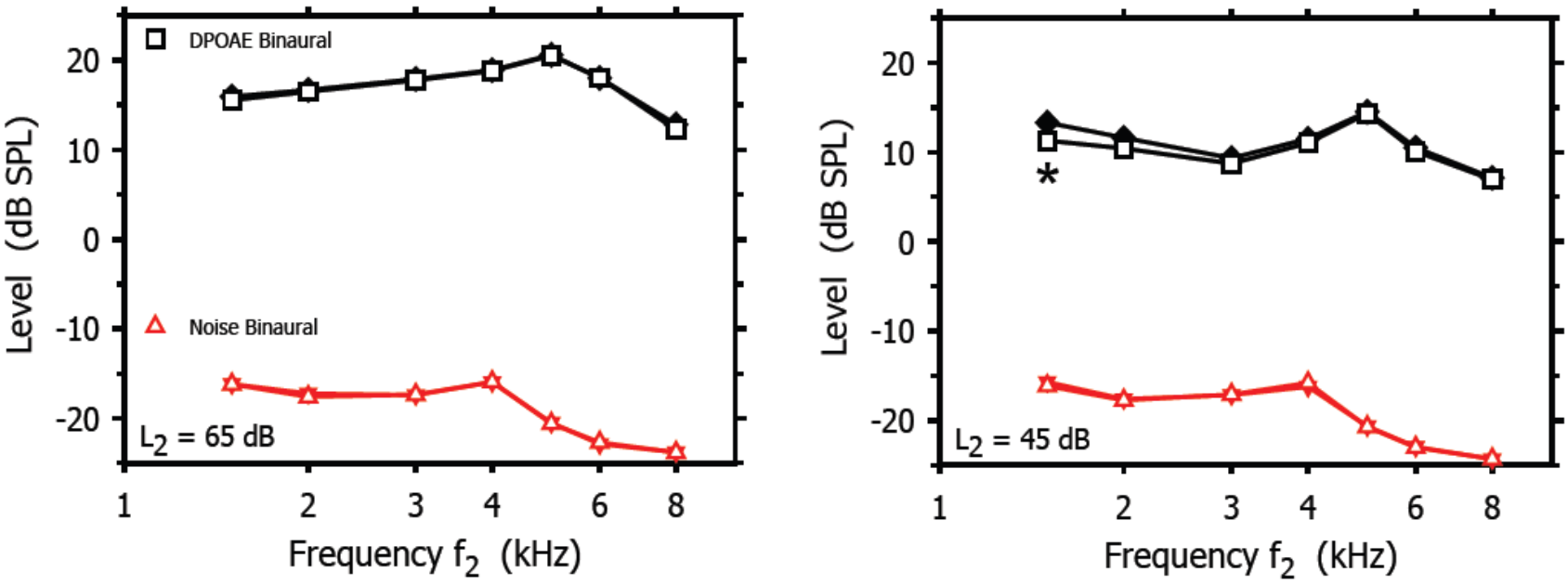
Multiple Distortion Product Oto Acoustic Emission (Multichannel DPOAE)

In detail, the binaural presentation of single-pair stimuli had subtle effects on DPOAE levels. The difference of 2 dB between mean DPOAE levels collected with binaural versus monaural presentations for f_2 = 1.5 kHz and L_2 = 45 dB SPL was the only one that reached statistical significance. All other data measured with the two paradigms were very consistent. Thus, the effects of contralateral inhibition created by binaural stimulations are negligible.

The effect of applying one additional pair of tones with an octave spacing on DPOAE levels was quite small, with the largest decrease of 1.3 dB for f_2 = 4 kHz and L_2 = 65 dB SPL. Slightly lower DPOAE levels obtained with the mDPOAE method than with single-pair stimulation may result from small mutual suppression of cochlear nonlinearities.

In general, the mean DPOAE levels collected with mDPOAE and binaural presentation conditions were highly reproducible when compared to those obtained with the single-frequency monaural paradigm.

Multiple Distortion Product Oto-Acoustic Emission (Multichannel DPOAE)

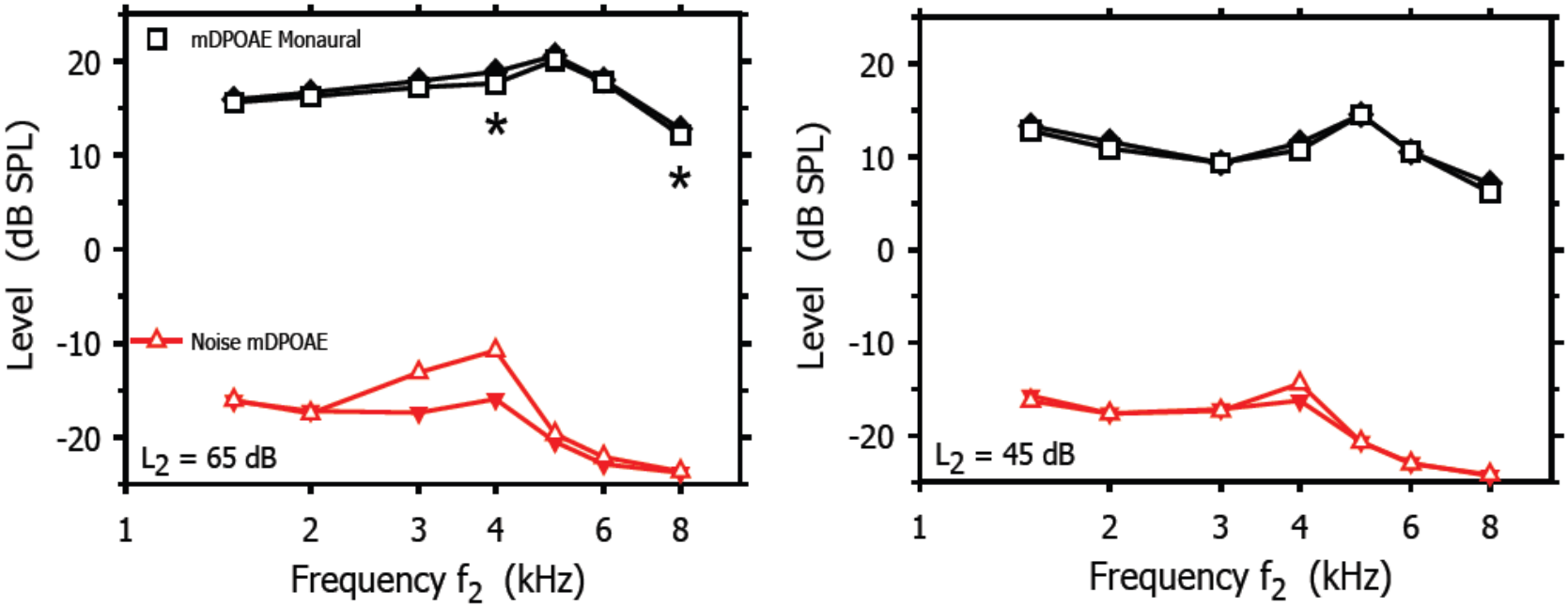


Monaural vs binaural presentation: Single tone-pairs

For L_2 = 65 dB SPL, the mean DPOAE and noise levels were almost identical for the two testing conditions.

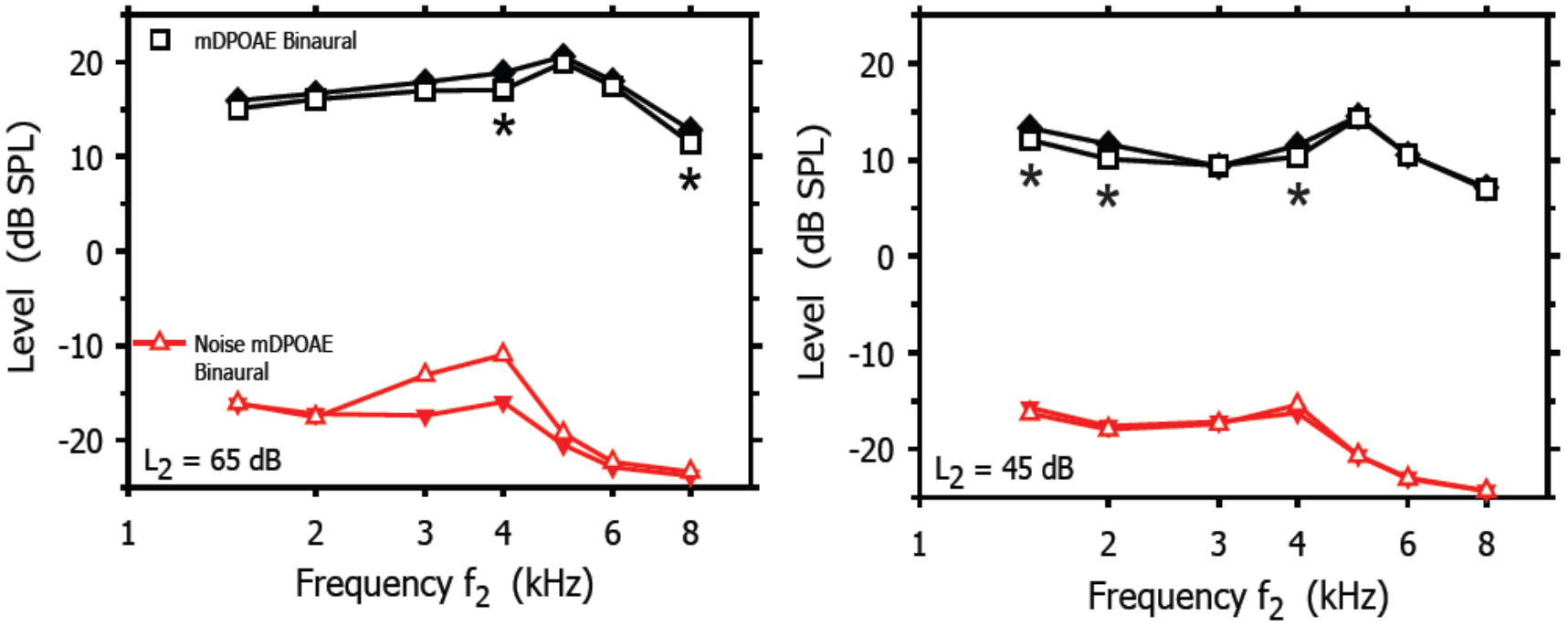
For L_2 = 45 dB SPL, the mean DPOAE levels were lower, mostly at f_2 = 1.5 and 2 kHz, for binaural stimulation than those for monaural stimulation.

Multiple Distortion Product Oto-Acoustic Emission (Multichannel DPOAE)



Monaural presentation**: Single tone-pairs vs mDPOAE**
For L_2 = 65 dB SPL, the mean DPOAEs were lower, mostly at f_2 = 4 and 8 kHz, for the mDPOAE condition than those for the single-pair presentation. The mDPOAE testing resulted in elevated noise levels at 4 kHz for both L_2 values and at 3 kHz for L_2 = 65 dB SPL.

Multiple Distortion Product Oto-Acoustic Emission (Multichannel DPOAE)



Monaural single tone-pairs vs binaural mDPOAE

There was a small decrease of DPOAE levels measured with L_2 = 45 dB SPL, especially at 1.5, 2, and 4 kHz.

For L_2 = 65 dB SPL, an increase of noise levels at 3 and 4 kHz and slightly reduced DPOAEs were observed.

Frequency Modulated Distortion Product Oto-Acoustic Emission (FM-DPOAE™)

When the ear is stimulated by two tones simultaneously, there are **two DPOAE sources**, one at the f2 place and the other at the 2f1 –f2 place. Since DPOAE should serve as a probe for assessing hearing function at solely one place within the cochlea (at f2) the DPOAE source at 2f1-f2 has to be eliminated.

There are two techniques to overcame this problem.
First one is to use a third tone to suppress the second source at the 2f1-f2 place. However, for doing this, there is need for a third loudspeaker within the sound-probe.
A second technique is to use frequency-modulated primary tones. To do this, primary tone frequencies are varied over time, following

$f_1(t) = f_{1norm} + d_1(t)$ and $f_2(t) = f_{2norm} + d_2(t)$ resulting in $f_{dp}(t) = 2*f_1(t) + f_2(t)$.

Frequency Modulated Distortion Product Oto-Acoustic Emission (FM-DPOAE™)

Primary tone frequencies are shifted between ±100Hz with a modulation rate of about 1.5 Hz. Because of the associated phase shift the impact of the second source is reduced. As a consequence, DPOAE detection and hence hearing threshold estimation is significantly improved.

FM-DPOAE™ was developed by **PATH medical** in 2012 as a means of suppressing the impact of the second DPOAE source and with that to improve reliability of DPOAE detection and hence hearing threshold estimation.
Moreover, due to frequency modulation the number of stimulated OHCs is increased resulting in a higher DPOAE level. Thus, FM-DPOAE does not need any additional stimuli and does not extend test time. Therefore, FM-DPOAE has the potential to improve both screening and diagnostic DPOAE testing performance.

High resolution Distortion Product Oto-Acoustic Emission (DPOAE)

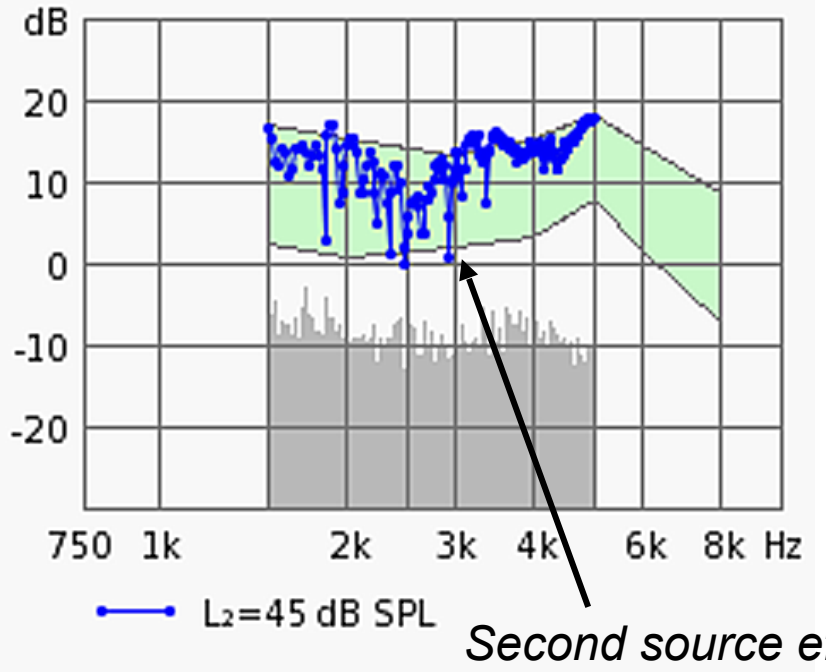
The effect of second DPOAE source elimination by applying FM-DPOAE technique can be shown best, when comparing high-resolution DPOAE measurements with and without elimination of the second source.

The influence of the second DPOAE source may be observed when plotting the DPOAE level across frequency with narrow frequency spacing, i.e. ≤ 100 Hz (**DPOAE fine-structure**). Due to either destructive or constructive superposition of the second source across frequency, a pattern of dips and peaks in the DPOAE fine-structure can be observed in subjects with normal or near-normal hearing.

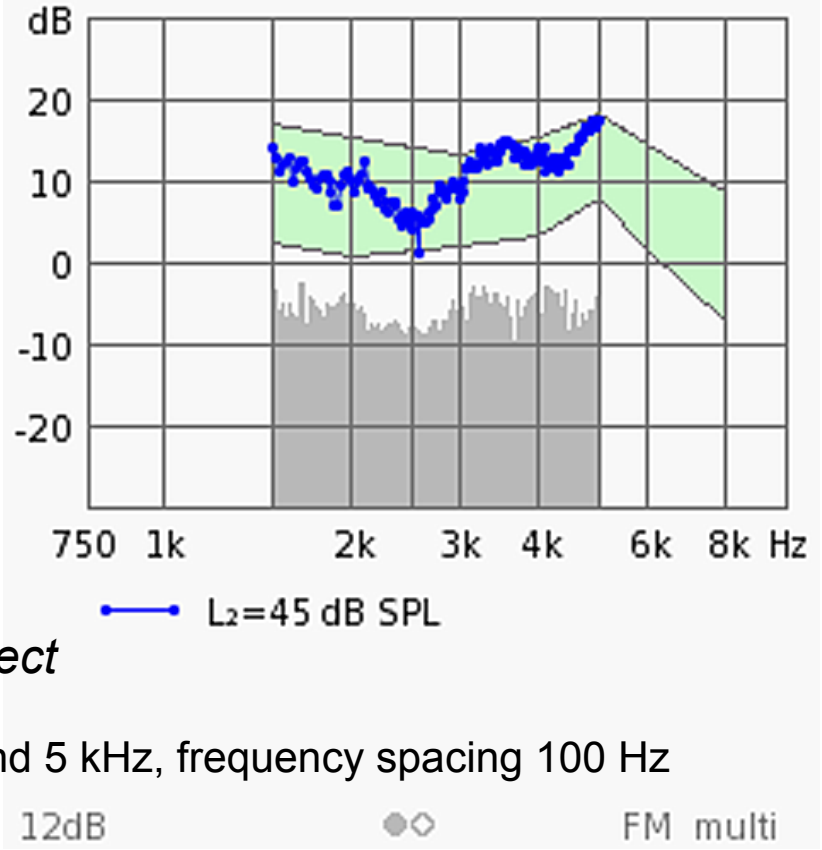
DPOAE fine-structure gives information about the integrity of OHCs and with that about the fine-structure of behavioural pure-tone thresholds. However, due to the superposition of the second source, there is no reliable correlation between the two measures. When using FM-DPOAE technique DPOAE fine-structure is able to reveal OHC impairment in the very early stage, e.g. beginning hearing loss due to noise over-exposure or ototoxic drug administration.

High resolution Distortion Product Oto-Acoustic Emission (DPOAE)

Conventional DPOAE



FM-DPOAE



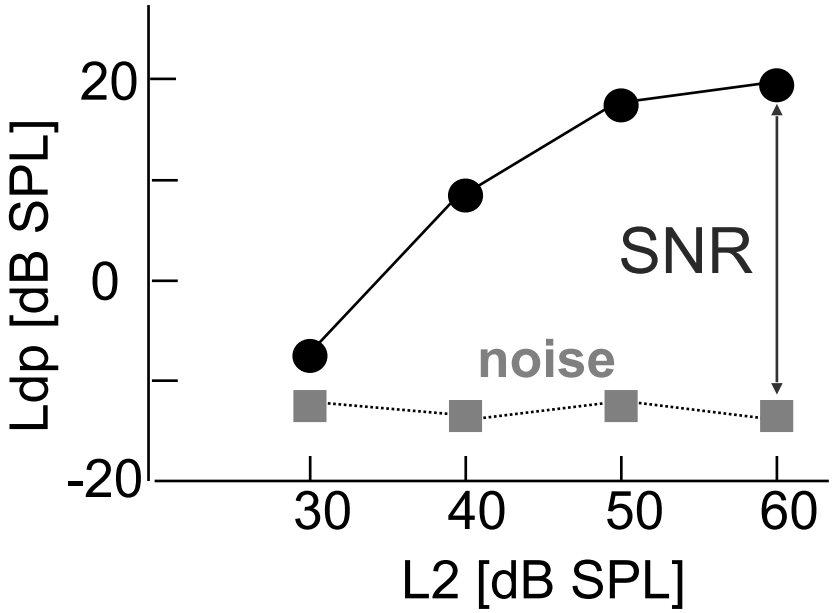
176 measurement points between 1.5 kHz and 5 kHz, frequency spacing 100 Hz

Distortion Product Oto-Acoustic Emission (DPOAE), DPOAE I/O-function

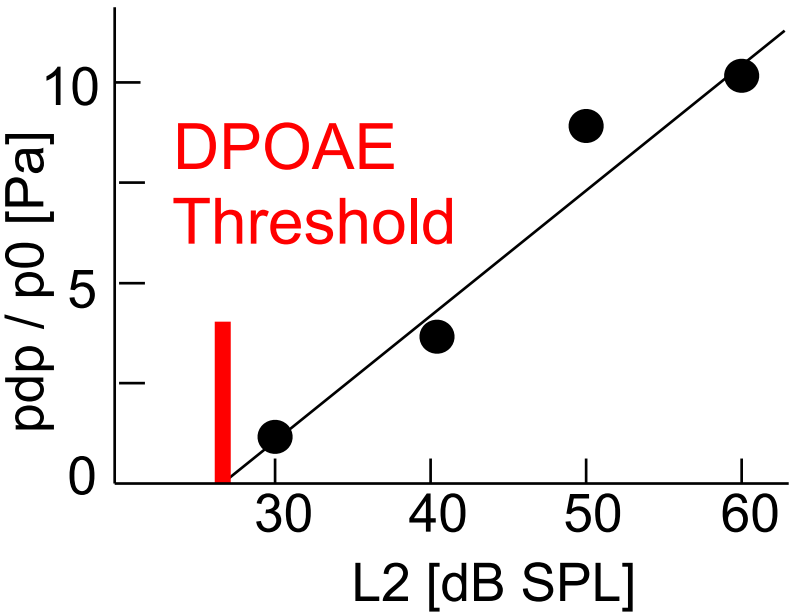
Extrapolated DPOAE I/O functions allow for assessing loss of cochlear sensitivity and compression. The number of OHCs contributing to DPOAE generation depends on the size of the overlapping region, which is determined by the primary tone levels L_1 and L_2, and the frequency ratio f_2/f_1. A frequency ratio of about 1.2 has been found to be optimal for yielding highest amplitudes. A primary tone level setting, which accounts for the different compression of the primary tone traveling waves at the f_2 place, is the scissor paradigm. Due to the steep slope of the traveling wave towards the cochlear apex, the maximum interaction site is close to the f_2 place in the cochlea. To preserve optimum overlap of the primary tone traveling waves at a constant frequency ratio, the primary tone level difference has to be increased with decreasing stimulus level. This results in a decrease of L_1 being lower than the decrease of L_2 (scissor paradigm: L=0.4 L2 + 39 dB SPL).

Distortion Product Oto-acoustic Emission (DPOAE) Threshold

sound pressure level L



sound pressure p



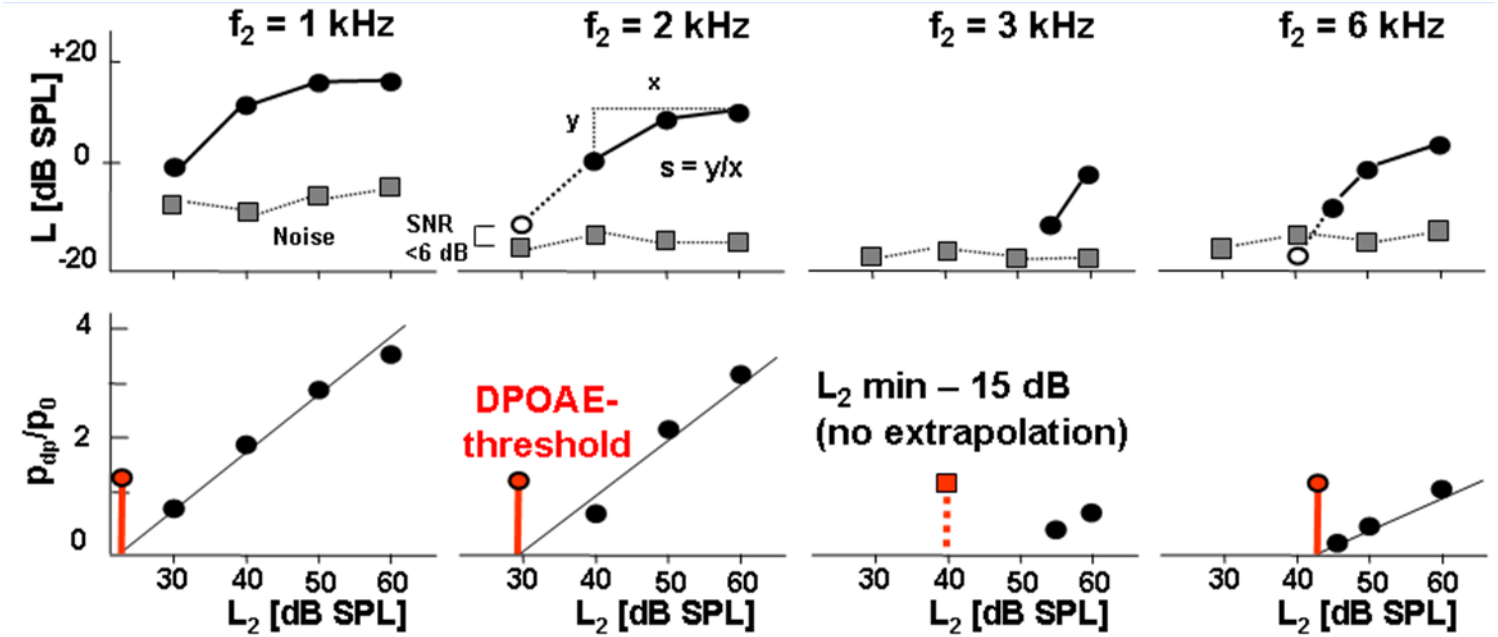
Hearing threshold estimation by means of extrapolated DPOAE pressure I/O-function: intersection between L2-axis and linear regression line

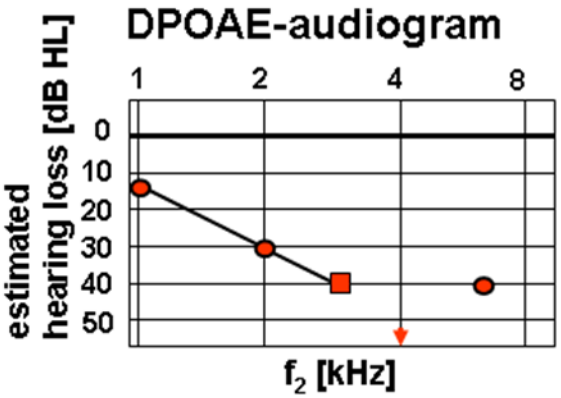
Distortion Product Oto-acoustic Emission (DPOAE) Threshold

DPOAE level I/O-functions plot the DPOAE level L_{dp} as a function of primary-tone level L_2 for a selected f_2 and thus reflect cochlear amplification at the f_2 place. In normal hearing, in response to low-level stimuli, DPOAE level I/O-functions exhibit steep slopes, while at high stimulus levels slopes decrease, thus mirroring the strong amplification at low and decreasing amplification (saturation) at moderate sound levels. However, this is only true when a specific stimulus level setting is used which accounts for the different compression of the primary-tones at the f_2 place (scissor paradigm).

DPOAE pressure I/O-functions plot the DPOAE pressure p_{dp} (instead of the DPOAE level L_{dp}) as a function of the primary-tone level L_2. Due to the logarithmic dependency of the DPOAE level on the primary tone level there is a linear dependency between DPOAE pressure p_{dp} and primary tone level L_2. Thus, DPOAE data can easily be fitted by linear regression analysis. The intersection point of the linear regression line with the L_2-axis at p_{dp} = 0 Pa can then serve as an estimate of DPOAE threshold.

Distortion Product Oto-Acoustic Emission (DPOAE)





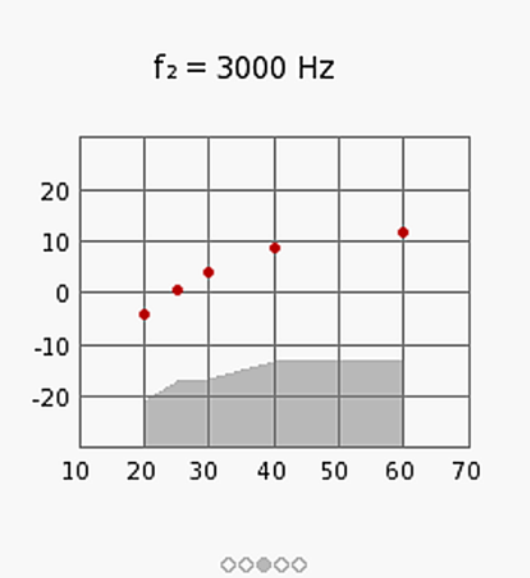
Hearing Threshold Estimation using extrapolated DPOAE I/O-functions

Distortion Product Oto-Acoustic Emission (DPOAE)

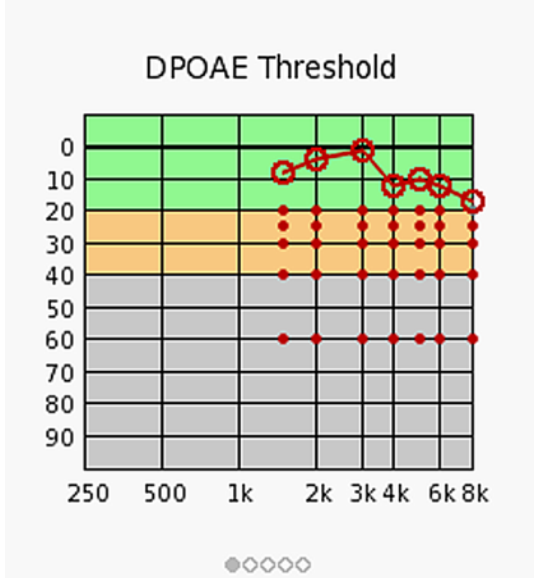
When converting DPOAE level from dB SPL to dB HL (hearing level), estimated DPOAE thresholds can be plotted in an audiogram form (DPOAE audiogram). DPOAE audiograms can be applied in babies due to Eustachian tube dysfunction and/or amniotic fluid in the tympanic cavity or to confirm a persisting cochlear hearing loss in follow-up diagnostics. In case of mild and moderate hearing loss DPOAE audiograms are an alternative method to behavioural audiometry or auditory brainstem responses (ABR, ASSR). Especially in infants where the conditioned free-field audiogram does not reliably reflect hearing threshold. DPOAE audiograms may assess cochlear hearing loss more precisely than behavioural tests. Moreover, unilateral hearing loss can be detected. DPOAE audiograms are able to quantitatively assess the hearing loss at distinct frequencies in a couple of minutes. Predicting hearing loss at five frequencies by tone burst ABR or ASSR may take half an hour and more. Thus, DPOAE audiograms can serve as a suited tool for bridging the gap between screening and behavioural testing in paediatric audiology.

Distortion Product Oto-Acoustic Emission (DPOAE)

DPOAE- Threshold Estimation → normal hearing



f_2	thres	L_2 min
1500	8	20
2000	4	20
3000	1	20
4000	12	20
5000	10	20
6000	12	20
8000	17	25



Full I/O-function-based estimation for right ear

Full I/O-function-based estimation for left ear

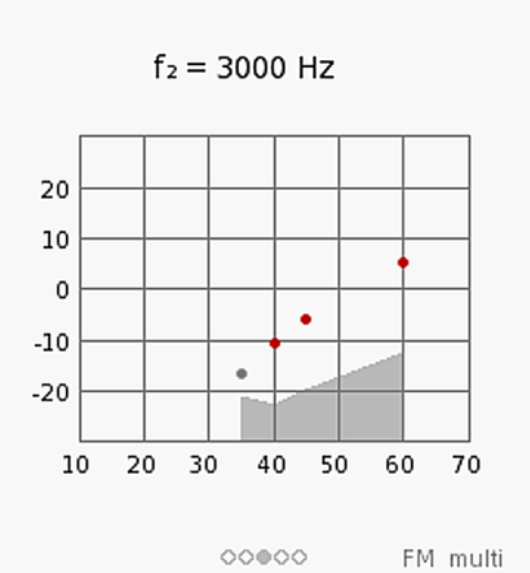
Gray symbols if some levels were skipped

Hearing threshold estimation based on lowest detected DPOAE (right ear in red)

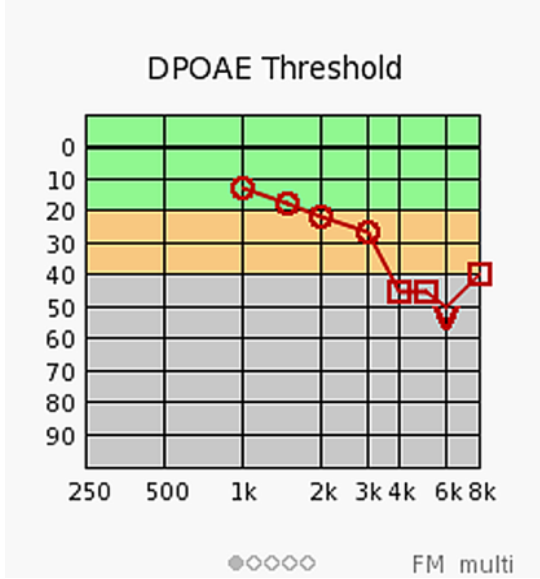
No DPOAE could be recorded for this frequency. Hearing threshold is probably above 50 dB (right ear in red)

Distortion Product Oto-Acoustic Emission (DPOAE)

DPOAE- Threshold estimation → cochlear hearing loss



f_2	thres	L_2 min
1000	13	30
1500	18	30
2000	22	35
3000	27	40
4000	45	60
5000	45	60
6000	50	
8000	40	55



Full I/O-function-based estimation for right ear

Full I/O-function-based estimation for left ear

Gray symbols if some levels were skipped

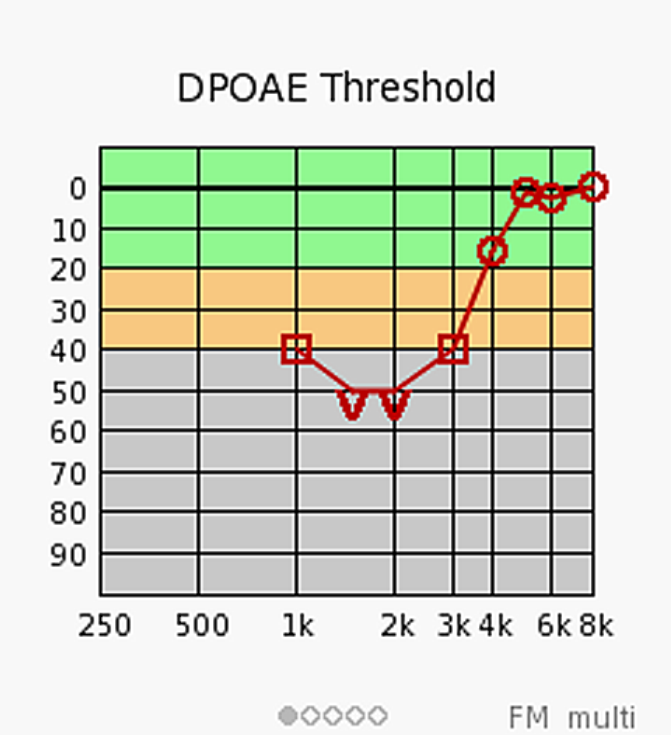
Hearing threshold estimation based on lowest detected DPOAE (right ear in red)

No DPOAE could be recorded for this frequency. Hearing threshold is probably above 50 dB (right ear in red)

Distortion Product Oto-Acoustic Emission (DPOAE)

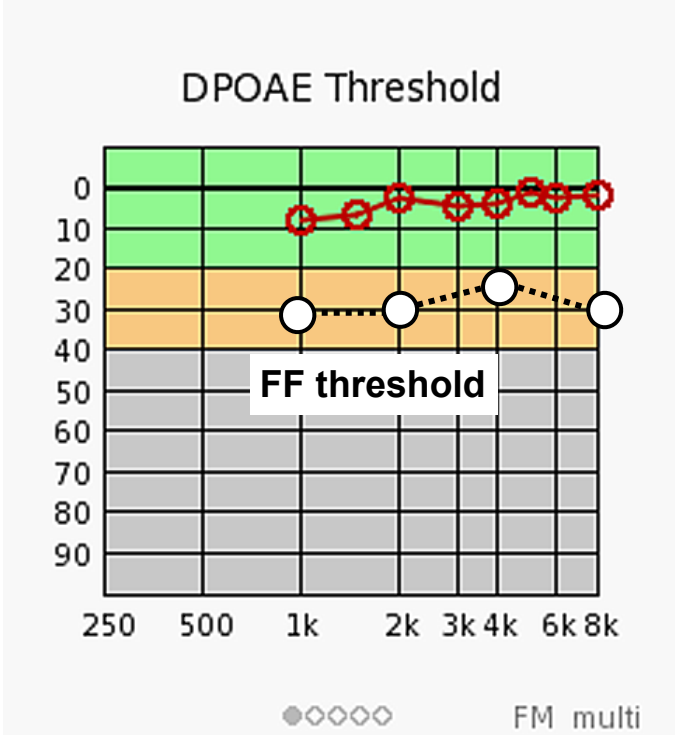
DPOAE- Threshold estimation

6 months old infant



hereditary hearing loss

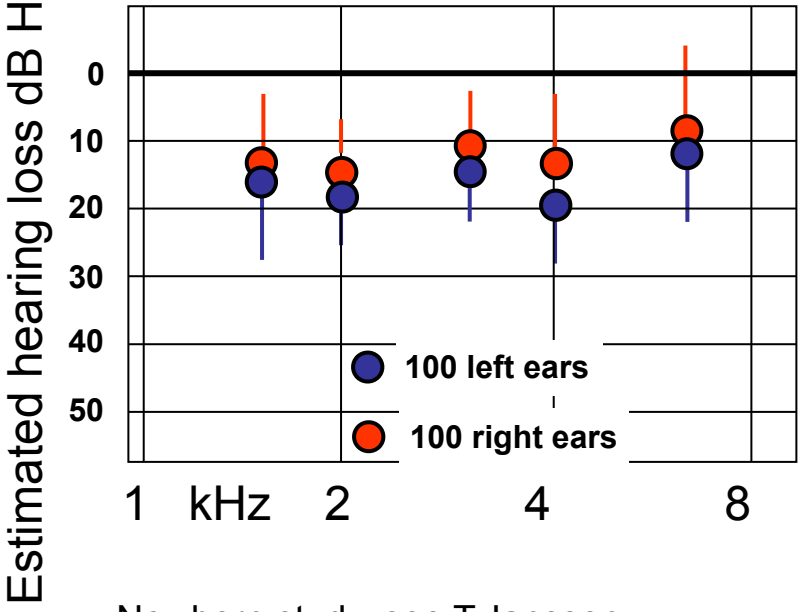
3 months old infant



discrepancy between behavioral and physiological theshold

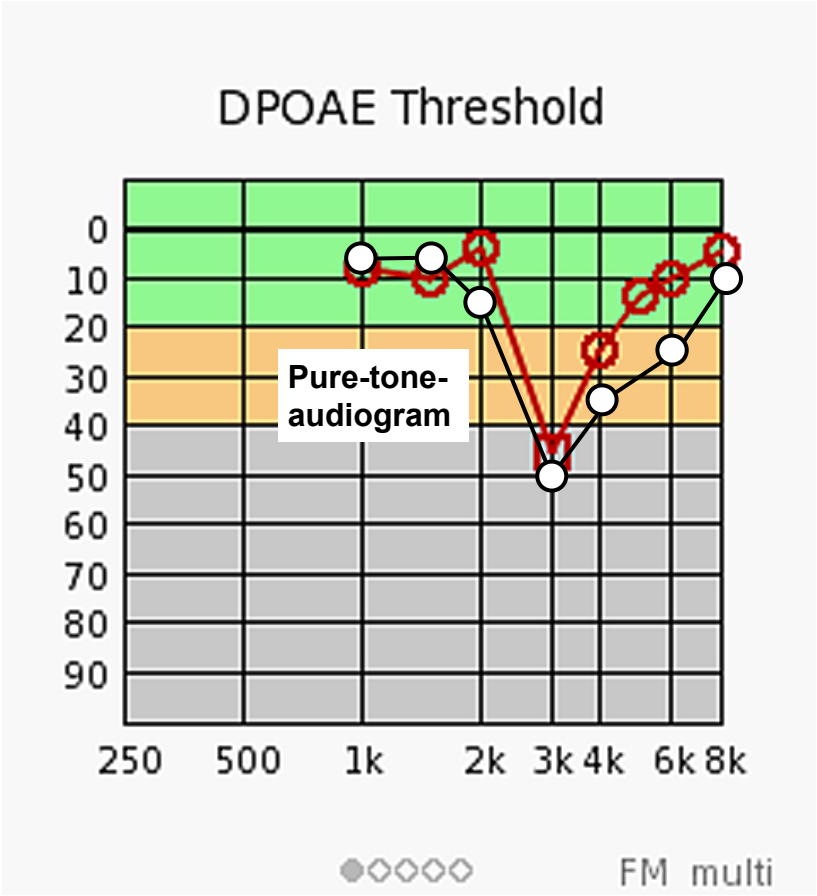
Distortion Product Oto-Acoustic Emission (DPOAE)

100 newborns
< 2,5 days old



Newborn study, see T.Janssen
„Otoakustische Emissionen“ in:
Lehnhardt/Laszig „Praxis der Audiometrie“
Thieme 2009 (ISBN 078-3-13-369009-6)

6 years old child



Oto-Acoustic Emission
Clinical application

- **Newborn hearing screening and Follow-up**
- **Pediatric audiology**

- **Clinical Diagnostics**

à Confirmation of cochlear hearing loss (topological diagnostic, report noise induced hearing loss)

- **Simulation und Aggravation**

à Difference between pure-tone threshold and OAE

- **Follow up: Sudden Hearing Loss and Ototoxic Medication**

Oto-Acoustic Emission
Clinical application

OHCs are reported to be impaired by sound overexposure, ototoxic drugs (e.g. therapeutic antibiotics), infections (e.g. meningitis, mumps, materno-fetal infection), and anoxia (e.g. birth trauma), or to be partly missing in genetic hearing loss. OHC impairment results in a loss of sensitivity and frequency selectivity of the hearing organ. OAEs, as a by-product of cochlear non-linear sound amplification, then appear with reduced amplitude or disappear. Since OAEs are a by-product of the non-linear sound amplification process of OHCs in the cochlea they can only serve as a measure for evaluating OHC integrity. Lesions of inner hair cells or retro-cochlear defects (e.g. neural defects, auditory processing disorders) are not detectable by means of OAE. In sound-conductive hearing-loss, both the stimulus and the response amplitude are reduced. OAEs are not present even at a mild hearing-loss. At a cochlear hearing loss exceeding 20-30 dB HL (TEOAE) or 40-50 dB HL (DPOAE) no OAEs are measurable. In these cases, tympanometry, ABR, and ASSR should be performed to determine type and degree of the hearing loss.

Oto-Acoustic Emission
Clinical application

If there is a suspicion of a hearing disorder, OAEs should be used first. It is fast and helps to confirm normal middle-ear and cochlear function. This is the case if OAEs are present over a wide frequency range. If OAEs are absent, the presence of a middle-ear or cochlear (OHC) pathology is likely. OAEs then should be followed by tympanometry. If the tympanogram is normal and OAEs are absent, then a cochlear disorder is likely. If the tympanogram is abnormal, a sound-conductive hearing-loss is likely. If there is an indication for a hearing disorder and both the tympanogram and OAEs are normal, ABR/ASSR may reveal if there is a cochlear (inner hair cell) or neural pathology. For example, in auditory neuropathy, where synchronization of neural activity is malfunctioning (either due to inner hair cell synaptic or neural dysfunction), normal OAEs and abnormal ABRs occur.

Oto-Acoustic Emission
Clincal application

Typical clinical applications of OAEs are: hearing screening, follow-up diagnostics after newborn hearing screening, confirmation of cochlear hearing loss (together with tympanometry and ABR), quantitative evaluation of hearing loss and recruitment for providing hearing aid fitting parameters, early detection and monitoring of OHC impairment after noise over-exposure or ototoxic drug administration, topological diagnostics, as well as identifying subjects simulating a hearing loss.