OPEN ACCESS GUIDE TO AUDIOLOGY AND HEARING AIDS FOR OTOLARYNGOLOGISTS

OTOACOUSTIC EMISSIONS (OAEs)

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Otoacoustic emissions (OAEs) are low intensity sounds produced by the cochlea as the outer hair cells (OHCs) contract and expand. OAEs are typically elicited by sound stimuli but may also be spontaneously emitted.

What are OAEs?

The presence of cochlear emissions were first shown in the late 1970s (Kemp, 1978) when technical advances made it possible to record these weak signals.

The transmission of sound through the ear is a mechanical process from the movement of the tympanic membrane, through the middle ear ossicles and the oval window causing a travelling wave in the cochlear fluid (perilymph) and along the basilar membrane. The outer hair cells (OHC) on the basilar membrane are part of this mechanical process as they contract and expand, a process named *sensory transmission*, necessary for the further transmission through the inner hair cells (IHC) named *sensory transduction* (Kemp, 2003). This active process elicits both an afferent signal to the auditory nerve and an efferent signal travelling back through the middle ear to the outer ear canal where it can be detected. Each part of the basilar mem-brane has a maximal sensitivity for a speci-fic frequency with the highest frequencies closest to the oval window. This means that higher frequency responses will have the shortest transmission time back to the outer ear canal.

Types of OAEs

There are 4 types of OAEs *(Table 1).*

Type	Stimulus	Prevalence
Spontaneous (SOAE)	None	< 70%
Transient evoked (TOAE/TEOAE)	Click or tone burst	>99%
Distortion product (DPOAE)	Two pure tones	>99%
Sustained frequency (SFOAE)	Continuous tone	??

Table 1: Type of OAEs and prevalence in normal hearing persons

Spontaneous OAEs (SOAE) have been recorded both in humans and in animals. In humans, they are seen in persons with very good hearing; they have no connection with tinnitus symptoms. ***Transient evoked OAEs (TEOAE)*** and ***Distortion product OAEs (DPOAE)*** have been established as objective measures of cochlear function. ***Sustained frequency OAEs (SFOAE)*** have not yet been applied for clinical use.

What is the difference between TEAOE and DPOAE?

The TEOAE and DPOAE response amplitudes reflect the magnitude of active cochlear amplification mechanisms, although by slightly different processes.

TEOAE uses a click stimulus (brief acoustic stimulus with a wide frequency spectrum) that will elicit a response from a large part of the basilar membrane with a latency span of several msec. Clicks or tone bursts mainly generate a response from 1000 to 4000 Hz. This response can be separated into frequency bands for fur-ther analysis of cochlear function *(Figure 1)*. The TEOAE response is a sensitive ob-jective measure of hearing loss, and OAE changes may precede changes of beha-vioral thresholds. The TEOAE response is fast and is the most widely used in hearing screening devices.

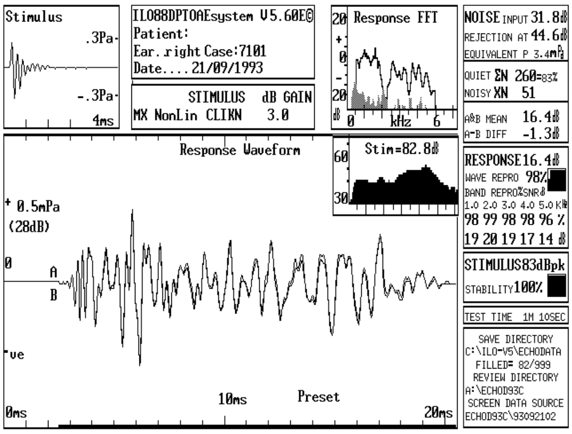


Figure 1: TEOAE from an infant with a pass result. The response waveforms as a function of time show perfect correlation with a reproducibility of 98%. Signal to noise ratio (SNR) is 14-20dB. Frequency analysis (Response FFR) also shows high amplitudes over the whole spectrum with low noise levels

When hearing thresholds are ≥20dB, then TEOEAs are expected to be present in 99% (Robinette, 2003). An absent respon-se indicates a hearing loss of ≥30dB. Re-sponse amplitude in different frequency bands may indicate a hearing loss in *e.g.* high frequencies, but it may not be regar-ded as an audiogram.

DPOAE uses two pure tones of different frequency (f1+f2) that will generate responses that are not present in the input signal. These responses are called distor-tion products and the most prominent is the cubic difference distortion product 2f1-f2 *(Figure 2)*.

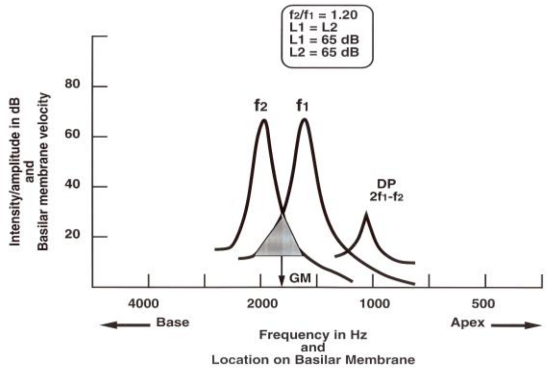


Figure 2: DPOAE uses two pure tones of different frequency (f1+f2) that will generate responses that are not present in the input signal. These responses are called distortion products and the most prominent is the cubic difference distortion product 2f1-f2

This distortion product indicates that OHCs in the region of f1 and f2 have normal function. DPOAE response ampli-tudes decrease with mild to moderate hear-ing impairment and are mostly absent if hearing thresholds are >60dB, when higher primary tones are used. DPOAE is more frequency specific than TOAE and is most reliable for testing high frequencies up to 8000Hz. Thus, high frequency loss due to ototoxity or noise trauma may be assessed with DPOAE. A DP-gram, with several DPOEAs from the whole frequency spec-trum resembles, but may not be interpre-ted, as an audiogram

Clinical applications of OAEs

The primary use of TEOAE and DPOAE is to determine ***cochlear status***, specifically hair cell function. Since the majority of hearing impairments include OHC dama-ge, this information can be used to identify hearing impairment without behavioral responses. The click-evoked response am-plitude is of the same magnitude in infants as in young adults. The usefulness of TEOAE for ***infant hearing screening*** was identified as a possibility to overcome the specific problems associated with testing infants (Elberling et al, 1985, Bray et al, 1987). TEOAE is today widely implemented in ***neonatal hearing screening*** and can also be useful in ***older individuals who are difficult to test*** due to developmental disabilities or ***functional hearing loss***. OAEs can be obtained from patients who are ***sleeping or comatose*** because no behavioral response is required.

Spectral analysis of the TEOAE response can reveal cochlear damage in the high frequencies due to ***noise trauma or ototoxic drugs***. Furthermore, temporary threshold shifts (TTS) on pure tone audiometry have shown a decrease in TEOAE amplitudes and may serve as a sensitive tool for ***early identification of noise trauma*** (Kvaerner et al, 1995, Slliwinska-Kowalska et al, 1999). Furthermore, in so-called ***"hidden hearing loss"*** with normal pure tone audiometry (PTA) despite loss of OHCs, a correlation between OAEs and speech perception has been shown (Hoben et al, 2017). However, ***monitoring the cochlear damage from cisplatin and other ototoxic medication*** with DPOAEs has shown high-er sensitivity than pure tone audiometry (Cevette et al, 2000, Al-Noury, 2011).

OAEs have also proved useful to ***differentiate between sensory and neural components in sensorineural hearing impairment (SNHL)***. In ***auditory neuropathy spectrum disorder (ANSD)*** normal, often high amplitude, TEOAEs occur concurrent with absent or abnormal ABR responses as the typical diagnostic criterium. TEOAEs indicate normal OHC function and the cause of hearing loss is thus located to the inner hair cells (IHCs), ribbon synapses or auditory nerve. In ANSD, PTA may show normal or elevated thresholds, in contrast to reduced speech perception, especially in noise (Berlin et al, 2003, Hood, 2015).

TEOAEs test procedure

The ***test probe*** contains a loudspeaker for sound stimulation and a microphone to record the emissions *(Figure 3).*

A ***good probe fit*** in the ear canal is of utmost importance for recording the low-level emissions. A ***plastic tip*** of different dimensions is attached to the probe for best fit in the ear canal.

Noise must be kept low. The subject tested may produce noise by snoring, coughing or crying and also from muscular movements. Noise may also come from the environment.

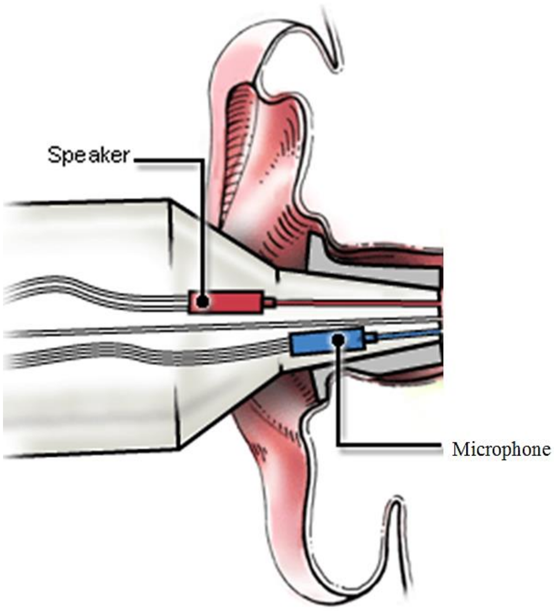


Figure 3: The test probe contains a loudspeaker for sound stimulation and a microphone to record the emissions

Stimulus and noise levels in the ear canal are registered by the test device and used for the calculation of ***signal to noise ratio*** (SNR).

A ***click stimulus*** is presented at 80-85 dB SPL with a stimulation rate of 50-80 Hz. The response latency lies within 20msec post stimulus time. The number of sweeps needed for a response is mainly around 60 and after 260 sweeps the test will ultimately stop.

Alternating responses are stored separately in two memory banks and correlating data are considered as a “response”. Non-correlating data is considered as “noise”. Reproducibility of > 70% is recommended. Response amplitudes may be up to 20dB and should be 3-6dB above the noise level, that is a SNR of 3dB or more *(Figures 1, 4)*.

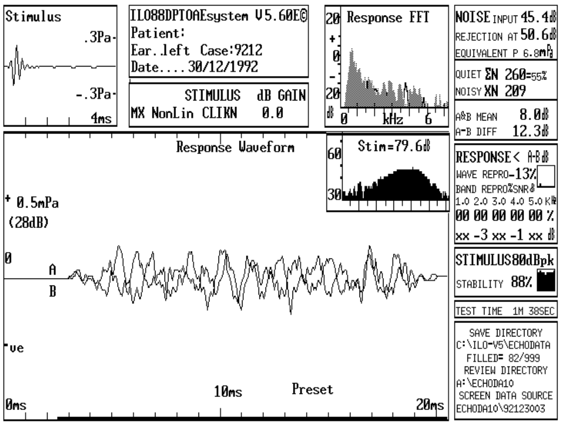


Figure 4: TEOAE from an infant with a no-pass result. The response waveforms as a function of time do not show reprodu-cibility (-13%) and the SNR is 0dB. Frequency analysis (Response FFR) only shows noise. This result indicates a hear-ing impairment, but may also be the result of middle ear problems or noisy recording conditions

Test devices

A small handheld device often works well for screening, but may be like a black box with a “pass” or “refer” response in the display window *(Figure 5)*.

With other devices, more information about the response features and recording conditions are displayed, and several recor-dings from different subjects may be stored.

Figure 5: Handheld device for TEOAE screening

A device connected to a laptop gives further possibilities to display the data and also adjust pass/refer criteria according to collected normative data. The possibility to store test results may also be of great value for diagnosis of later acquired hearing impairment where OAEs may be partly or totally absent. Further information about test devices is not the subject of this chapter, but can be obtained from manu-facturers.

Newborn hearing screening

TEOAEs are quick and easy to obtain in the newborn child during natural sleep and is the most prevalent test method for newborn hearing screening (NHS) (Sloot et al, 2015) *(Figure 6)*.

Figure 6: The test probe is often well accepted by the infant. A good probe fit is essential for a “pass” result

OAE is present if

- Normal cochlear function <30dB HL
- Open ear canal
- Normal middle ear function

OAE is absent if

- Obstructed outer ear canal due to cerumen, debris or malformation
- Middle ear fluid
- Middle ear malformation
- Cochlear hearing impairment
- Noise level too high
- Bad probe fit or seal (indicated by test device)

However, during the ***first days of life the emissions may be absent due to debris in the outer ear canal, or middle ear fluid*** and therefore waiting at least to the second day reduces the number of false negatives. Studies of 30,000 neonates showed a 86% bilateral TEOAE pass on postnatal day 2, and 94% bilateral TEOAE pass on postnatal day 5 (Berninger et al. , 2011), *(Figure 7)*.

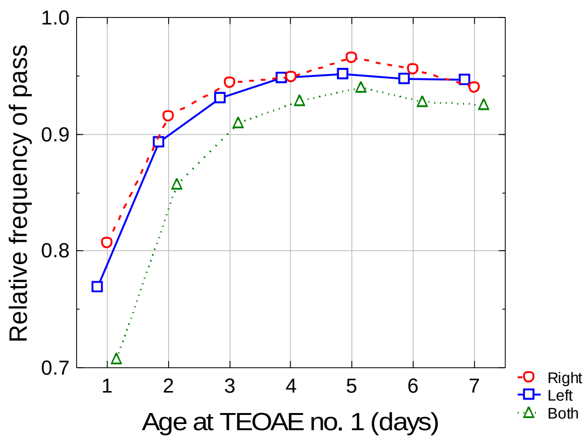


Figure 7: Relative frequency of pass in left, right and both ears vs age of infant at TEOAE test occasion no. 1 (n = 31 092). Day 0 corresponded to time of delivery (Berninger & Westling, 2011)

The ***experience and skill*** of the test person is also of importance for the pass rate (personal experience). An acceptable S/N is more difficult to obtain in the low frequencies where background noise is higher. Increased number of sweeps does not solve this problem *(Figure 8)*.

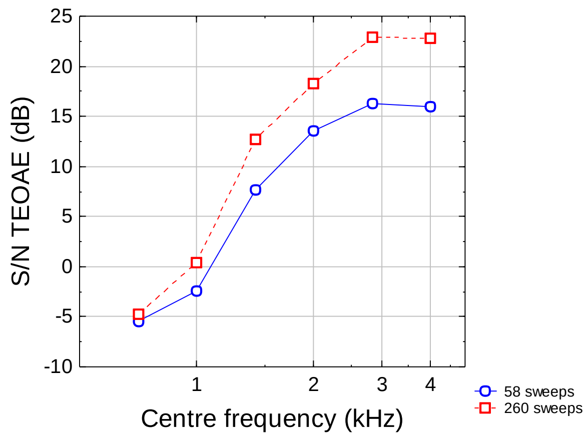


Figure 8: An acceptable S/N is more difficult to obtain in the low frequencies where background noise is higher. Increased number of sweeps does not solve this problem (Berninger, 2007)

Another interesting finding is that ***OAE amplitudes are higher in the right ear than the left ear, and higher in girls than in boys*** *(Figure 9)*.

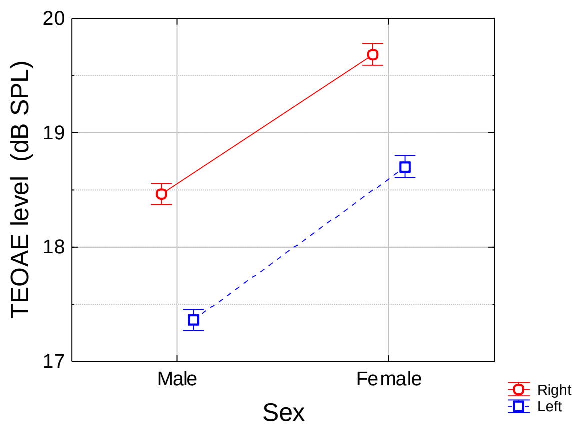


Figure 9: OAE amplitudes are higher in the right ear than the left ear, and higher in girls than in boys (Berninger, 2007)

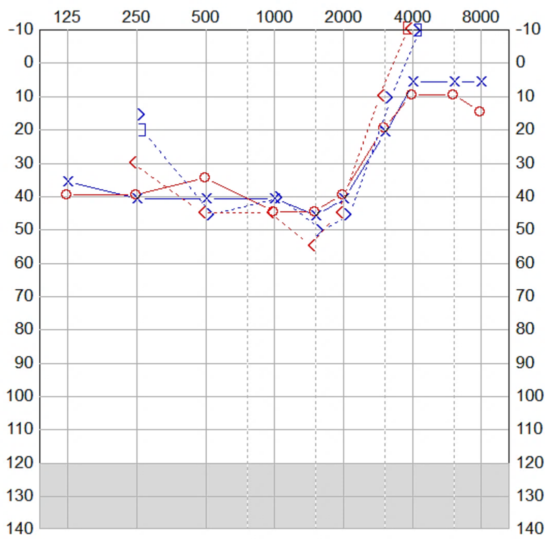
This asymmetry correlated with higher proportions of hearing loss in the left ear and in males (Berninger, 2007). Similar findings have been described in an Australian study of 568 infants (Kei et al, 1997).

Sininger (Sininger et al, 2004), studying 1593 infants, found larger TEOAEs in the right ear but larger DPOAEs in the left ear. At this age, afferent connections from the brainstem to the auditory cortex are not mature, suggesting a connection between early cochlear function and the later development of hemispheric specialisation in sound processing (Sininger et al, 2004).

A "pass" response indicates normal cochlea function, but a mild hearing loss may be missed, especially a low- and mid-frequency hearing loss as seen in a 4-year old child *(Figure 10)*.

Furthermore, the function of inner hair cells, auditory nerve or higher auditory pathways is not assessed. For children at risk for auditory neuropathy spectrum disorder who may pass the screening with normal OAEs, the screening protocol should also include ABR (Hall et al, 2004).

Children with developmental or behavioral disorders, when reliable behavioral thresholds are difficult or impossible to obtain, may also be assessed with TEOAE to exclude any serious hearing impairment. Ventilation tubes do not seem to interfere with OAE testing.



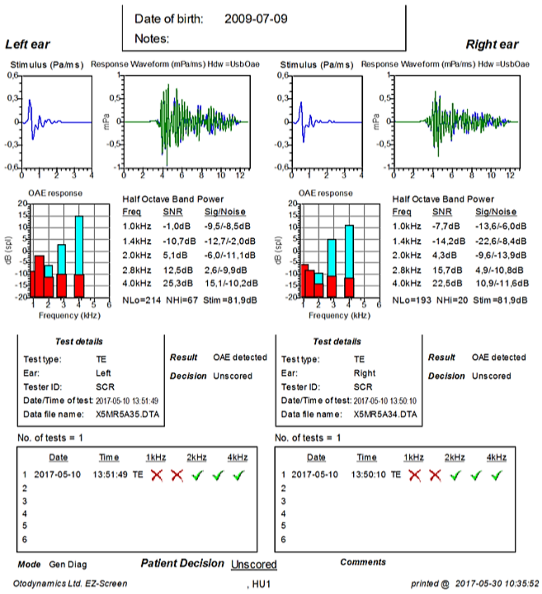


Figure 10: A pass response missing a mild hearing loss because of a low- and mid-frequency hearing loss in a 4-year old child

Interested to learn more?

There is extensive and growing documentation about OAEs indicating cochlear damage in several conditions; noise trauma, ototoxity, hidden hearing loss, etc. Some of them are found in the references listed below. There are also a number of websites with relevant and reliable information *e.g.* Medscape: http://emedicine.medscape.com/article/835943-overview#a3

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