BIAP Recommendation 12-8
Audiometric procedures in the first year of life

Part: 12-8.1.3: Otoacoustic Emissions

General foreword

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Introduction

In most of the cases of babies with the hearing loss Otoacoustic emissions (OAE) are already part of the NHS testing in a fully automated form. For diagnostic assessment OAE are essential as a cross-check of the other hearing test results and as targeted testing of the functioning of the outer hair cells (OHC). OHC provide a mechanical amplification that also allow the inner hair cells to be activated by soft sounds below 60dB$_{HL}$. The motility of the OHC leads to OAE. The presence of OAE for soft sounds is therefore accepted as proof of the functioning of the outer hair cells. OAE cannot confirm the functioning of the inner hair cells, but as the outer hair cells comprise one of the more vulnerable parts of the inner ear, in most cases any damage to any part of the inner ear will also affect the OHC and therefore can be detected by the absence of OAE. Nevertheless, there are cases of functioning OHC and non-functioning inner hair cells or nonfunctioning synapses between the inner hair cells and the cochlear nerve (as in cases of auditory neuropathy spectrum disorders).

A. Otoacoustic emissions–overview

There are two types of OAE that are of primary clinical interest: TEOAE (transient evoked otoacoustic emissions) and DPOAE (distortion product otoacoustic emissions).

a) TEOAE

TEOAE are evoked by a transient stimulus such as a broadband click that stimulates the OHC at the frequency region from 1000 to 4000 Hz. It is often the first choice of test at Universal Newborn Hearing Screening (UNHS).

1) In the diagnostic phase of testing it is important to have all tests done on the same day, so that they are done under the “same ear conditions”, and TEOAE should be repeated even if the baby failed at the initial TEOAE screening.
2) Check the specification of which bands of frequencies the current equipment is testing because TEOAE equipment often evaluates frequencies below 3600 Hz and a clear TEOAE could miss a 4000 Hz hearing loss.
3) The diagnostic TEOAE protocol with a broader time window (20 ms instead 12 ms) allows testing for lower frequencies, but will lead to a longer examination time and can be affected by low frequency noise.
4) A clear TEOAE response is indicative of normal middle ear function because the reverse OAE energy has to be transmitted from the cochlea through the middle ear to the outer ear, where it is recorded.
5) A clear TEOAE response with an abnormal or lacking Auditory Brainstem Response (ABR) is indicative of auditory neuropathy spectrum disorder (ANSD); in order to identify the ANSD both OAE and ABR must be assessed. ANSD is more frequent in babies, who belong to the high-risk group for a hearing loss (see high risk register of the Joint Committee of Infant Hearing).
6) A lack of TEOAE can be indicative of a conductive hearing loss of any degree or of a sensory hearing loss of more than 30dB$_{HL}$. Therefore, further investigations are needed and have to be analyzed by a battery of hearing tests.
7) TEOAE can be used to monitor the effect of ototoxic drugs, as a decline in otoacoustic emissions may indicate damage to the OHC before a hearing loss can be detected in a tone audiogram.
8) Clinical TEAOE studies in normal and hearing-impaired populations show a cut-off at 30dB$_{HL}$, meaning that a person having TEOAE should hear better than 30dB.

b) DPOAE

DPOAE are evoked by two continuous pure tones simultaneously, and the cochlea (OHC) will respond with a distortion which leads to a 3rd tone, different from the primary tones. DPOAE have the advantage that they allow frequency-specific testing, with an emphasis on higher frequencies (most sensitive region from 2000 to 6000 Hz) than with the TEOAE.

1) For diagnostic purposes it is mandatory to use moderate intensities such as 65/55 or 65/50dB$_{SPL}$ because the use of higher intensity tones (70/70) can lead to a DPOAE presence even in ears of up to 50dB hearing loss, and these DPOAE could be falsely interpreted as normal cochlear function.
2) For deciding whether the DPOAE signal (amplitude) is in the normal range, the use of a clinical template can be very helpful. However, care must be taken to ensure that the template is appropriate for the clinical population and the equipment used. Thus, younger children (babies) need a different application of criteria than do older children or adults, because normal-hearing babies have larger DPOAE. Therefore, depending on the equipment the amplitude for a baby may have to be more than 0dB$_{SPL}$ and for older children more than -5dB$_{SPL}$ to reach the normal range.
To minimize errors the DPOAE signal (amplitude) must have a more than 6dB signal-to-noise ratio. To rule out a significant hearing loss, it is also required that the DPOAE meet the criteria at more than one frequency.

3) Patients tested for TEOAE, this person should have DPOAE at the same frequencies.
4) DPOAE are less affected by internal or external noise than TEOAE.
5) By using the input/output (I/O) function of the DPOAE one can estimate the hearing threshold of hearing losses up to 50dB$_{HL}$ and the analysis of the I/O growth slope can provide information on OHC integrity.

B. Measuring Otoacoustic emissions

General remarks:

Probe fitting: Before every OAE measurement, probe fitting is mandatory. Values depend on the type of equipment that is being used (consult the manual of the device).

An optimal probe fit should show:

- Stimulus spectrum: the overall frequency spectrum has to be broad and flat, without any notches; for the amplitude, the level in dB$_{SPL}$ has to be as high as possible (consult the manual of the device on how high the amplitude can/should be).
- Stimulus waveform (in time): the temporal acoustical waveform has to be less than 2 msec, without ringing.
- Stimulus stability: minimum 70%.

Default settings: For every type of device there is a default setting (consult the manual of the device). These settings should be critically reviewed. Below can be found guidelines for each type of OAE.

For diagnostic OAE measurements an ear inspection before any OAE measurement is necessary to determine the size and the direction of the ear canal (for choosing the right size of the ear tip and for correctly inserting the ear tip), to rule out any blockage of the ear canal and to determine as far as possible the state of the eardrum as well as the state of grommets and of the middle ear.

a) TEOAE

Settings:

- Stimulus type: broadband click.
- Linearity: non-linear.
- Number of stimuli: 1000 (or less if stop criteria are reached).
- Intensity level: in from 79 to 85 dB$_{SPL.}$
- Number of frequency bands: 5 (if possible).
- Time window: open at 3 msec (to avoid stimulus artefact interference), closed at 20 msec (to include as much low frequency information as possible) or 15 msec (to minimize low frequency noise).

Analysis:

- To guarantee the reliability of the response, the total reproducibility needs to be at least 70%.
- For diagnostic purposes, TEOAE have to be analyzed at different frequency bands, which can result in a response or lack of a response at each frequency band separately. TEOAE are considered present if the signal-to-noise ratio (SNR), analyzed in every band is a minimum of 6 dB.

Interpretation:

- when present:
  TEOAE are an indication for normal functioning of the outer hair cells (OHC) at the tested frequency. The presence of TEOAE can be found in the following situations:
  - No clinically relevant middle ear problem.
  - Hearing threshold better than 30dB$_{HL}$, except:
    - In auditory neuropathy spectrum disorders (ANSD).
    - In pure neural hearing loss.
- when absent:
  - Sensory hearing loss >30dB$_{HL}$.
  - Conductive hearing loss.
  - Possible in case of middle ear ventilation tubes (grommets).
  - Possible in ANSD*.
  - Possible in neural hearing loss (if indirect damage to cochlea through a decrease of blood circulation to the cochlea because of a tumor in the canal of the cochlear nerve).

*If TEOAE are absent, ANSD needs to be confirmed by the presence of the cochlear microphonic (CM) by using auditory brainstem response (ABR) or electrocochleography.

Remark: If TEOAE are not present in at least three of five frequency bands, it is recommended to have a more frequency-specific analysis with DPOAE.

b) DPOAE

Settings:

- Stimulus type: two pure tones, presented simultaneously.
- Intensity levels: 65 and 55 dB$_{SPL}$.
- Frequency: f2/f1= 1.22.
- Test frequencies: minimum five octave frequencies from 1500 to 6000Hz.

- Number of stimuli: 500 / test frequency.
- Normative data: it is necessary to use normative data for the targeted age group (neonates and infants) and for the specific settings used (see above).

Analysis:

The analysis of DPOAE should be done at each test frequency separately.

- Normal DPOAE: the presence of DPOAE, with SNR minimum 6dB and DPOAE amplitude within the age-appropriate normal range (e.g. more than -5dB$_{SPL}$ for older children and adults, see also above).
- Abnormal DPOAE: the presence of DPOAE at a decreased amplitude, with SNR minimum 6dB, but a DPOAE amplitude below the normal range (e.g. between -10dB$_{SPL}$ to -5dB$_{SPL}$).
- Absence of DPOAE: SNR less than 6dB, or DPOAE amplitude less than -10dB$_{SPL}$.

Interpretation: The following interpretation is for low intensity levels.

- when normal or present: the presence of DPOAE is an indication of normal functioning of outer hair cells (OHC) at the tested frequency.

  The presence of DPOAE can be found in the following situations:

  - No clinically relevant middle ear problem.
  - Hearing threshold better than 40 dB$_{HL}$ (or 50dB$_{HL}$ when using higher input levels!), except:
    - In auditory neuropathy spectrum disorders (ANSD).
    - In pure neural hearing loss.
- when abnormal: inconclusive
- when absent:
  - Sensory hearing loss of more than 50dB$_{HL}$.
  - Conductive hearing loss.
  - Possible in ANSD*.
  - Possible in neural hearing loss (if indirect damage to cochlea).

*If DPOAE are absent, ANSD needs to be confirmed by the presence of the cochlear microphonic (CM) by using ABR or electrocochleography.

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