# *A Guide to* Otoacoustic Emissions (OAEs) for Physicians

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# Introduction

Hearing loss is not uncommon in children and adults. According to recent estimates, 37.5 million people in the United States report difficulty with hearing. Approximately 6 out of every thousand children have some type of unilateral or bilateral hearing loss. When present from birth, or acquired in the pre-school years, hearing loss of any degree, even mild hearing loss, interferes with speech and language development. Hearing loss among school age children contributes to poor academic performance, including reading disorders. More than 7 million older persons have some degree of hearing impairment, and the number is growing as the proportion of the population over the age of 75 years increases rapidly. In fact, among older adults hearing loss is the third most commonly reported chronic health problem. One of the often-encountered etiologies for hearing loss in adults is exposure to excessive levels of noise or music. With very early detection of noise-related inner ear dysfunction, and appropriate counseling and hearing protection, this type of hearing loss can be prevented.

In addition to, and related to, obvious communication deficits, the consequences of hearing loss in children and adults include psychosocial problems, such as frustration, irritability, anxiety, the tendency to withdraw from social interactions, and even depression. The psychosocial problems, of course, affect relationships between the person with the hearing impairment and family members, friends, and others. Older adults with hearing impairment generally perceive themselves as less healthy.

Otoacoustic emissions (OAEs) permit early detection of inner ear abnormalities associated with a wide variety of diseases and disorders, including non-pathologic etiologies like noise exposure and aging. With early detection, the serious consequences of hearing loss can sometimes be prevented. And, fortunately, with proper identification and diagnosis of hearing impairment, medical and non-medical (e.g., audiologic) treatment options almost always lead to effective management.

# The ear and hearing

The *external ear* (the pinna) collects sound and funnels sound to the inner ear. Anatomy of the ear is illustrated in Figure 1. The external ear also plays a role in localization (determining the source of sound), and lateralization (which side the sound is coming from). Cerumen (wax) in the ear canal, and the S-shape of the ear canal, contributes to protection of the delicate tympanic membrane (ear drum). External ear canal acoustics also enhance some of the frequencies in the region of 2000 to 4000 Hz that are important for speech perception.

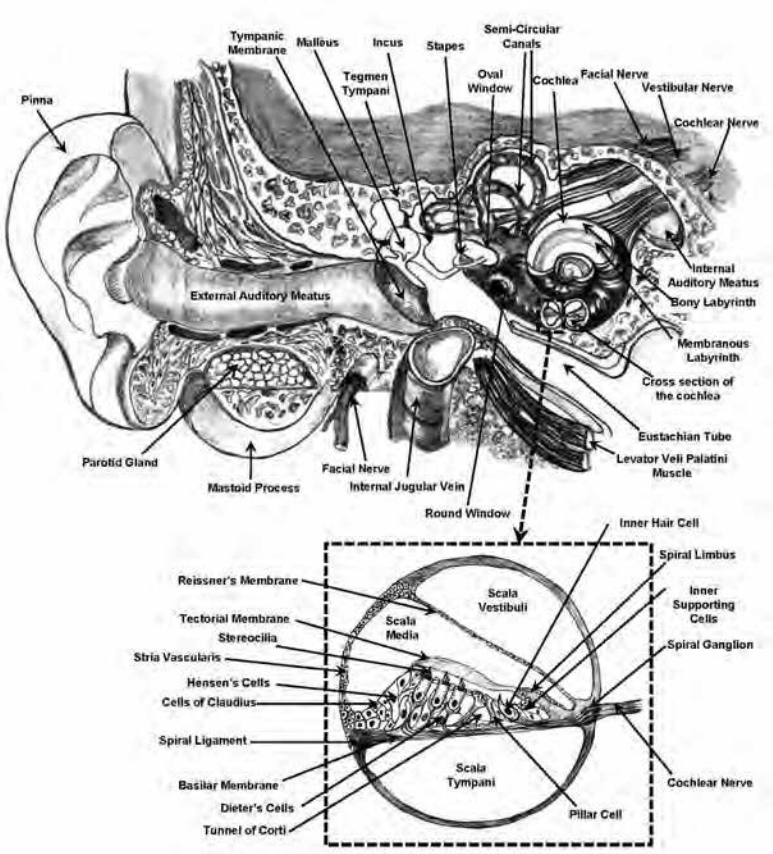



**Figure 1.** Simplified diagram of three portions of the ear (external, middle, and inner ear), the auditory (8th cranial) nerve, and auditory regions of the brain
Illustration appears with permission of artist Anuradha Bantwal.

The *middle ear* consists of the tympanic membrane and the ossicles (malleus, incus, and stapes). Sound waves reaching the tympanic membrane are amplified by the middle ear system, providing an increase in sound intensity of almost 30 dB. Mechanical energy from sound waves is converted to electrical signals by specialized *hair cells* located within the *inner ear* (the cochlea). The term "hair cells" is used because there are extending from the top of each cell hundreds of thin hair-like protein-based cilia. There are about 15,000 hair cells in the human ear. One third of the hair cells, the *inner hair cells* located medially in the cochlea (see Figure 1), communicate (synapse) with auditory (8$^{th}$ cranial nerve) fibers. Activation of the inner hair cells leads to firing of auditory nerve fibers and stimulation of auditory regions of the central nervous system (also shown in Figure 1). The remaining two-thirds of the hair cells located more laterally within the cochlea, referred to as *outer hair cells*, are capable of motility (movement). Upon activation, metabolism within the outer hair cells increases dramatically, and the outer hair cells rapidly elongate (during hyper-polarization) and become shorter (during depolarization). Changes in outer hair cell length generate energy within the cochlea that contributes to hearing sensitivity and the ability to distinguish small differences in the frequencies of sounds. Outer hair cell movement also produces otoacoustic emissions, as reviewed briefly in the next section.

At this point, it's important keep in mind that although the ear is clearly important in hearing, we really hear with our brain. High level auditory processing, including speech perception, occurs within a complex network of central nervous system pathways and centers (nuclei) containing millions of neurons. Clinically, hearing evaluation is not complete unless it includes procedures for evaluating how the brain processes relatively sophisticated sounds, such as speech. Audiologists regularly perform such procedures in hearing assessment. Audiologic tests used to evaluate function of the ear, such as otoacoustic emissions (OAEs), are very important in the diagnosis of hearing loss. However, OAEs alone are not a test of hearing.

# What are otoacoustic emissions (OAEs)?

Otoacoustic emissions (OAEs) are sounds measured in the external ear canal that reflect movement of the outer hair cells in the cochlea. Energy produced by outer hair cell motility serves as an amplifier within the cochlea, contributing to better hearing. Indeed, normal outer hair cells are essential for perfectly normal auditory function. OAEs are produced by the energy from outer hair cell motility that makes its way outward from the cochlea through the middle ear, vibrating the tympanic membrane, and propagating into the external ear canal. Although the amplification produced by outer hair cell movement within the cochlea may be as high as 50 dB, residual energy reaching the ear canal ...otoacoustic emissions ... is normally in the range of 0 to 15 dB.

Two types of OAEs may be measured clinically with FDA-approved devices. *Transient evoked OAEs (TEOAEs)* are elicited with very brief (transient) sounds, such as clicks or tone bursts, presented at an intensity level of 80 dB SPL. TEOAEs reflecting cochlear (outer hair cell) activity are generally recorded over the frequency range of 500 to about 4000 Hz. *Distortion product OAEs (DPOAEs)* are elicited with sets of two pure tone frequencies, abbreviated $f_2$ and $f_1$, that are closely spaced and presented simultaneously at moderate intensity levels, such as (respectively) 55 and 65 dB SPL. DPOAEs can be recorded across a frequency region of 500 to 8,000 Hz and sometimes even higher frequencies. Mechanisms and clinical applications of OAEs are described in recent textbooks (cited at the end of the booklet) and in thousands of peer reviewed journal articles. An Internet search for OAE literature can easily be performed via the National Library of Medicine website (www.nlm.nih.gov, Health Care Professionals).

# How are OAEs recorded?

OAEs are non-invasive and technically simple to record, usually requiring only a few minutes for both ears. Sedation is not indicated for OAE measurement, even in children. No behavioral response is required for participating in the testing, so the procedure is not affected by a patient's motivation, attention, or cognitive status. Briefly, a soft disposable probe tip is gently inserted into the outer portion of the external ear canal (Figure 2). An airtight seal between the probe tip and the ear canal isn't necessary. A miniature speaker within the probe assembly (two speakers for DPOAEs) generates in the ear canal sound stimuli at a moderate intensity level. The stimuli vibrate the tympanic membrane and mechanical energy is transmitted through the middle ear to the cochlea. Tiny waves in the cochlear fluids vibrate a thin membrane, activating outer hair cells located on the membrane. Energy associated with outer hair cell movement, in the frequency region of the stimulus, is propagated back through the middle ear system and, as sound, into the ear canal. A miniature microphone within the probe assembly detects OAE-related sound, as well as any other sound in the ear canal during the recording. By means of sophisticated algorithms in the OAE device, OAE activity is differentiated from other ambient and physiological noise in the ear canal and the presence of OAEs is statistically confirmed. Amplitude values for the OAEs are then compared to normative data for the device.

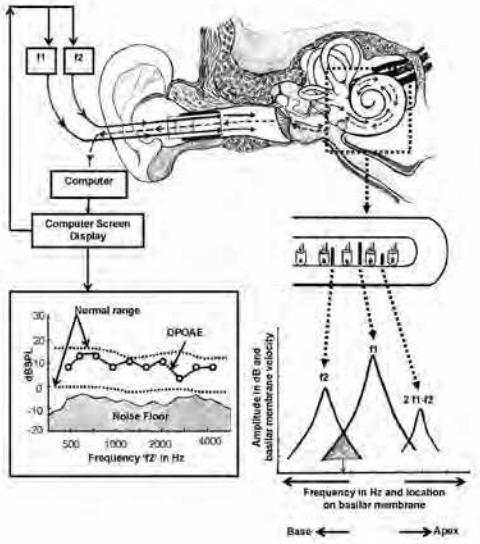



**Figure 2.** Illustration of the measurement of distortion product otoacoustic emissions (DPOAEs) showing a probe assembly that fits into the external ear canal, the delivery of the signals to the ear via the middle ear, the generation of OAEs by outer hair cells in the cochlea and, finally, propagation of OAE energy as sound into the external ear canal
Illustration appears with permission of artist Anuradha Bantwal.

# Analysis and interpretation of OAEs

Modern OAE devices typically include software for automated data analysis in hearing screening, including algorithms for calculation of amplitude values, noise floor levels, and for statistical confirmation the OAEs are present or absent. Visual inspection of OAE data with manual analysis is almost always an option, and particularly important for diagnostic application of OAEs. There are three general steps in the analysis of OAE findings. The first step is to verify adequate measurement conditions. Specifically, noise levels must be sufficiently low (usually less than – 10 dB SPL) to permit confident detection of OAE activity and the stimulus intensity levels in the ear canal should be close to the desired (target) levels. OAE devices invariably perform a quick calibration of stimulus intensity levels prior to data collection. The next step in data analysis is to determine whether reliable (repeatable) OAEs are recorded, that is, whether OAE amplitude exceeds the noise level by 6 dB or more at the test frequency. Finally, when the difference between OAE amplitude and noise floor $\geq$ 6 dB SPL, findings are analyzed with respect to an appropriate normal region for OAE amplitude.

**As an aside, the term "nerve deafness" is often used inappropriately to describe permanent bilateral sensorineural hearing loss. "Nerve deafness" is incorrect on two counts. In almost all cases, the origin of the sensorineural hearing loss is in the cochlea, not the auditory nerve. Auditory nerve dysfunction is very rare in children and adults, and typically unilateral not bilateral. The term "nerve deafness" is incorrect also because in most cases (the audiogram in Figure 3 is a good example) there is some degree of hearing impairment, but not total loss of hearing (deafness).**

Analysis of OAE findings relative to an audiogram (graph of pure tone audiometry) is illustrated in Figure 3. The audiogram shows hearing thresholds in decibels (dB) for pure tone test frequencies of 500 Hz up to 8000 Hz. Hearing threshold is defined as the faintest sound that can be detected about 50% of the time by a patient. Hearing sensitivity for the case shown in Figure 3 is within normal limits for the lowest three frequencies. Hearing thresholds are outside of (worse than) normal limits for higher frequencies, forming a notching pattern with greatest hearing loss at 4000 Hz. The "notching" audiogram pattern is usually consistent with noise induced sensory (cochlear) hearing loss.

Amplitudes for distortion product otoacoustic emissions (DPOAEs) are shown in the lower portion of Figure 3. The symbols (black circles) depict amplitude of the prominent DP in humans (at the frequency $2f_1$-$f_2$) plotted as a function of the $f_2$ stimulus. Also shown in the figure are the noise levels (open squares) detected in the region of each test frequency. Note the correspondence in the decrease of DP amplitudes with poorer hearing thresholds. Abnormal DP amplitudes are recorded when the hearing thresholds exceed 15 dB HL (e.g., at 2000 Hz). There are markedly abnormal DP amplitudes, even the absence of DP activity (no difference between the DP and noise floors), as the sensory hearing loss worsens to about 40 dB HL.

As illustrated by the findings in Figure 3, OAE findings are useful in validating hearing loss, and specifying *sensory* hearing loss, and also in detecting cochlear (outer hair cell) function that is not apparent in the simple audiogram. Clinically, we often view the relationship between OAEs and the audiogram from the opposite perspective. That is, OAEs are used to predict which patients might have a hearing loss. Patients with abnormal OAE findings upon screening are at risk for hearing impairment, and should undergo comprehensive audiological assessment.

**Distortion-Product Otoacoustic Emission Test Report**

**Right Ear:** **REFER**

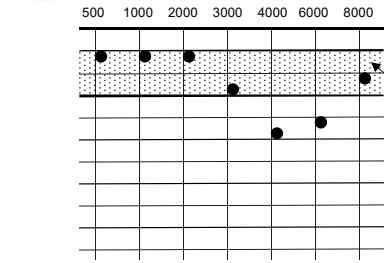
Patient Name: Patient 1

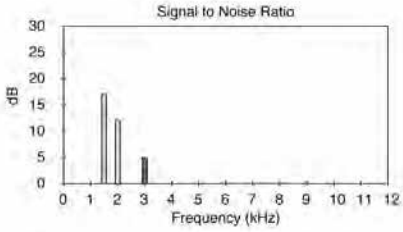
**Protocol:** **DP 1.5 to 6kHz**

Test Number: 19 Test Date: 2009-08-26 09:42:03
Instrument and Probe Serials: 001004 T0840102

Number of frequencies: 6, minimum for a pass 3

| F2 | P1 | P2 | DP | NF | SNR | Result |
|---|---|---|---|---|---|---|
| 1500 | 65 | 55 | 6.0 | -11.0 | 17.0 | P |
| 2000 | 66 | 55 | 0.0 | -12.0 | 12.0 | P |
| 3000 | 66 | 55 | -10.0 | -15.0 | 5.0 | R |
| 4000 | 64 | 55 | -15.0 | -15.0 | 0.0 | R |
| 5000 | 65 | 55 | -15.0 | -15.0 | 0.0 | R |
| 6000 | 65 | 55 | -15.0 | -15.0 | 0.0 | R |



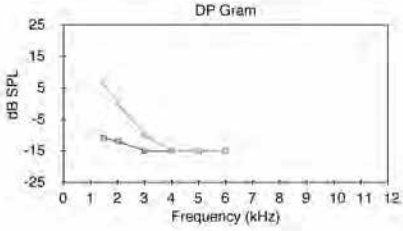




**Figure 3.** Relationship of hearing threshold levels in an audiogram for an adult with noise induced hearing loss in the region of 4000 Hz (top portion) with amplitudes for distortion product OAEs (DPgram). DP amplitudes fall below the normal region as hearing loss exceeds 15 dB HL. DPOAEs are present but abnormal for an $f_2$ stimulus of 2000 and 3000 Hz, and then absent for higher frequencies.

## Why are OAEs clinically valuable?

OAE are widely applied in pediatric and adult patient populations for a variety of reasons. As already noted, OAEs are an index of outer hair cell activity. Because of their dependence on normal cell metabolism, OAEs are exquisitely sensitive to even subtle outer hair cell dysfunction. Almost all insults to the cochlea first affect the outer hair cells. Vascular or hypoxic cochlear deficits will be invariably reflected by reduced OAE amplitude. Therefore, assuming normal middle ear function, OAE abnormalities provide early and compelling evidence of cochlear (outer hair cell) dysfunction. Additional clinical advantages of OAE are:

- Brief test time: Usually less than a minute per ear
- Relatively simple technique: Little training is required
- Objective: Unaffected by attention, cognition, cooperation
- Independent of age: OAEs can even be recorded from newborn infants
- Ear specific: Test results for each ear
- Frequency specific: Information for many individual frequencies

## Clinical applications of OAEs

Given their sensitivity to cochlear dysfunction, and the clinical advantages just cited, it's not surprising that OAEs are useful in auditory assessment of diverse patient populations. One of the most common applications of OAEs is screening persons at risk for hearing impairment. OAE screening outcome is generally described as either "Pass" or "Refer." A pass outcome is reported when OAEs are present (≥ 6 dB above the noise floor) for the majority of test frequencies. Although the presence of OAEs does not always indicate normal hearing sensitivity, a pass outcome rules out serious degrees of hearing loss. A refer OAE screening outcome should be viewed as a clear risk factor for hearing loss that could affect communication. Patients who yield a refer outcome for OAE screening should be referred for diagnostic hearing assessment, and possible audiological or medical management

The literature contains hundreds of peer reviewed scientific papers reporting evidence in support of OAE measurement in children and adults. According to the Joint Committee on Infant Hearing (JCIH), OAEs are a mandatory component of the audiologic test battery. Selected applications of OAE are summarized in Table 1.

**Table 1.** Selected applications of otoacoustic emissions (OAEs) in pediatric and adult patient populations

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**Children:**

- Infant hearing screening
- Screening hearing in pre-school (e.g., Head Start) years
- Screening in school age children
- Monitoring for possible ototoxicity
- Diagnosis of pediatric hearing impairment

**Adults:**

- Screening for cochlear (outer hair cell) hearing loss
- Screening for occupational or recreational noise induced cochlear dysfunction
- Monitoring for possible ototoxicity
- Differentiation of organic versus non-organic hearing loss
- Diagnostic assessment of tinnitus
- Diagnosis of auditory dysfunction adults

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# Limitations of OAEs

No clinical procedure is infallible. Different subject and pathological conditions must be taken into account in the interpretation of results for all screening and diagnostic tests. OAEs are no exception. Some of the factors potentially affecting OAE measurement and analysis in the detection of cochlear dysfunction include:

- Ambient acoustic noise in the test setting
- Physiological noise produced by the patient (e.g., related to breathing or movement)
- Technical factors (e.g., insertion of the probe tip in the ear canal)
- Cerumen, vernix, or debris in the ear canal
- Status of the middle ear system

Finally, OAE findings in isolation cannot be used to diagnose auditory dysfunction or to predict the degree of hearing loss. For diagnostic assessment of auditory function, OAEs must be included within an appropriate test battery. And, again, it is important to keep in mind "OAEs are not a test of hearing."

# OAE billing and reimbursement considerations

**Two Current Procedural Terminology (CPT) codes were established in 1996 for reimbursement of OAE procedures, using either TEOAE or DPOAE technology. CPT code 92587 is appropriate for *screening applications* of OAEs in pediatric or adult populations. As a rule, OAE recording under CPT code 92587 is performed with stimuli presented at a single intensity level (for DPOAEs one set of $f_2$ and $f_1$ frequencies) over a limited frequency region (e.g., 2000 to 5000 Hz), with outcome categorized as either "pass" (e.g., OAEs are present) or "refer" (e.g., OAEs are not detected). With CPT code 92587, OAEs may be recorded by technicians, nurses, or other personnel and in isolation, that is, not as part of an audiological test battery.**

### Please Note!

It is important to distinguish between the screening and the diagnostic codes for otoacoustic emissions, and to utilize the codes accordingly. The diagnostic code (92588) is generally used when otoacoustic emissions are recorded by audiologists or otolaryngologists within a test battery in combination with other audiological procedures, such as tympanometry, comprehensive audiological assessment, conditioned play audiometry, and/or auditory brainstem response.

CPT code 92588 is appropriate when OAEs are applied for *diagnostic purposes*, usually when OAE are measured as one procedure within a battery of diagnostic tests (e.g., with a comprehensive audiological assessment). Using CPT code 92588, OAEs are often recorded several times with stimuli at different intensity levels presented over a wide range of test frequencies (e.g., 500 up to 8000 Hz). OAE results for discrete test frequencies or limited frequency regions may be analyzed separately and then reported according to one of three outcome categories: 1) normal (OAE amplitudes are within a defined normal region), 2) abnormal but present (e.g., OAEs are ≥ 6 dB above the noise floor but below normal limits), or 3) absent (no OAE activity can be distinguished from the noise floor).

### Descriptors for OAE CPT Codes

**92558:** "Evoked otoacoustic emissions, screening (qualitative measurement of distortion product or transient evoked otoacoustic emissions), automated analysis."
**92587:** "Distortion product evoked otoacoustic emissions, limited evaluation (to confirm the presence or absence of hearing disorder, 3–6 frequencies) or transient evoked otoacoustic emissions, with interpretation and report."
**92588:** "Distortion product evoked otoacoustic emissions, comprehensive diagnostic evaluation (quantitative analysis of outer hair cell function by cochlear mapping, minimum of 12 frequencies), with interpretation and report."

## Pulling it all together

OAEs are a quick, non-invasive, sensitive, and objective procedure for detecting in the office, clinic, or hospital hearing loss secondary to middle ear or inner ear (cochlear) auditory dysfunction. In other words, OAEs are a handy and proven technique for identifying persons at risk for hearing impairment. In combination with tympanometry (for middle ear measurement), OAEs also play an important role in ruling out or confirming cochlear (outer hair cell) auditory dysfunction.

Despite the many clinical advantages and applications of OAE measurement, it's important to remember that OAEs are not a test of hearing. OAEs may be absent in persons with normal hearing sensitivity who have residual minor middle ear disorders. Conversely, OAEs may be present, even with amplitudes entirely within normal limits, in children or adults with rarely encountered inner hair cell dysfunction or retrocochlear auditory pathology. However, OAEs are a valuable clinical tool when recorded carefully, and when findings are analyzed cautiously in the context of the patient history, physical examination, and other audiological or medical findings.

# Selected References

Dhar S & Hall JW III. (2010). *Otoacoustic Emissions: Principles, Procedures, and Protocols.* San Diego: Plural Publishing

Hall JW III. (2000). *Handbook of Otoacoustic Emissions.* San Diego: Singular Publishing Company

Year 2007 Position Statement: Principles and Guidelines for Early Hearing Detection and Intervention Programs. Joint Committee on Infant Hearing *Pediatrics*, 120, pp. 898-921

Robinette MS & Glattke TJ (eds). *Otoacoustic Emissions: Clinical Applications* (3rd edition). New York: Thieme Publishers

**NOTE:** Anyone with Internet access can quickly perform a literature review on the topic of otoacoustic emissions at the National Library of Medicine website (www.nlm.nih.gov, Health Care Professionals). A search will produce abstracts of thousands of articles containing the word "otoacoustic emissions." A more refined search can be performed with combinations of terms, such as "otoacoustic emissions" and "dementia." Articles of interest can then be requested via email of the author designated for correspondence.

# Credits

**James W. Hall III, Ph.D.** contributed to the preparation of this booklet. Dr. Hall earned his Masters degree from Northwestern University and his Ph.D. in Audiology from Baylor College of Medicine. He is the author of over 150 journal articles and book chapters, plus 10 textbooks including the*Handbook of Otoacoustic Emissions* and the recently published*Otoacoustic Emissions: Principles, Procedures, and Protocols* . Dr. Hall is Associate Chair and Clinical Professor in the Department of Communicative Disorders at the University of Florida where he maintains a clinical practice, teaches doctoral level students, and conducts externally funded research.

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# Additional Resources

American Academy of Audiology. www.audiology.org

American Academy of Pediatrics. www.aap.org

American Speech-Language-Hearing Association. www.asha.org

Better Hearing Institute. www.betterhearing.org

Otoacoustic Emissions Portal Zone. www.otoemissions.org

## Notes

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