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NEW PERSPECTIVES IN HEARING ASSESSMENT:

PART 2. APPLICATION OF DISTORTION PRODUCT OTOACOUSTIC EMISSIONS IN THE DIAGNOSIS OF HEARING LOSS - STEP A (ANATOMICAL REVIEW AND CLINICAL ADVANTAGES)

Milaine Dominici Sanfins, Piotr Henryk Skarzynski, and James W Hall III

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This is the second in a series of newsletters that focus on the importance of evidence-based hearing assessment in making an accurate audiologic diagnosis. An accurate diagnosis of hearing dysfunction is the first step in developing an effective plan for managing hearing loss. The series, titled "**New Perspectives in Hearing Assessment,**" includes newsletters that review the main testing procedures for diagnostic evaluation of hearing function in children and adults.

A recurring theme in the series is the application of the crosscheck principle. We highlight the unique characteristics and practical advantages of each auditory procedure, as well as the pattern of test results that guide us to a clear and reliable audiologic diagnosis.

INTRODUCTION

Since David Kemp described “stimulated acoustic emissions from within the human auditory system” in 1978 (Kemp, 1978), otoacoustic emissions (OAEs) have evolved into a valuable clinical technique for hearing screening and diagnosis of auditory dysfunction.

OAEs offer a relatively simple, quick, and inexpensive approach for early detection of hearing loss in varied populations, including:

- **newborn infants,**
- **preschool and school children,**
- **adults at risk for noise- and/or music-induced hearing impairment**

(Dhar & Hall, 2018; Hall & Kleindienst Robler, 2024; Joint Committee on Infant Hearing, 2019).

OAEs also play an important and rather unique role in the test battery for diagnosis of hearing loss and related hearing disorders in patients across the lifespan (Hall, 2021)., e.g.:

- **tinnitus,**
- **disorders of decreased sound tolerance,**
- **auditory processing disorders**

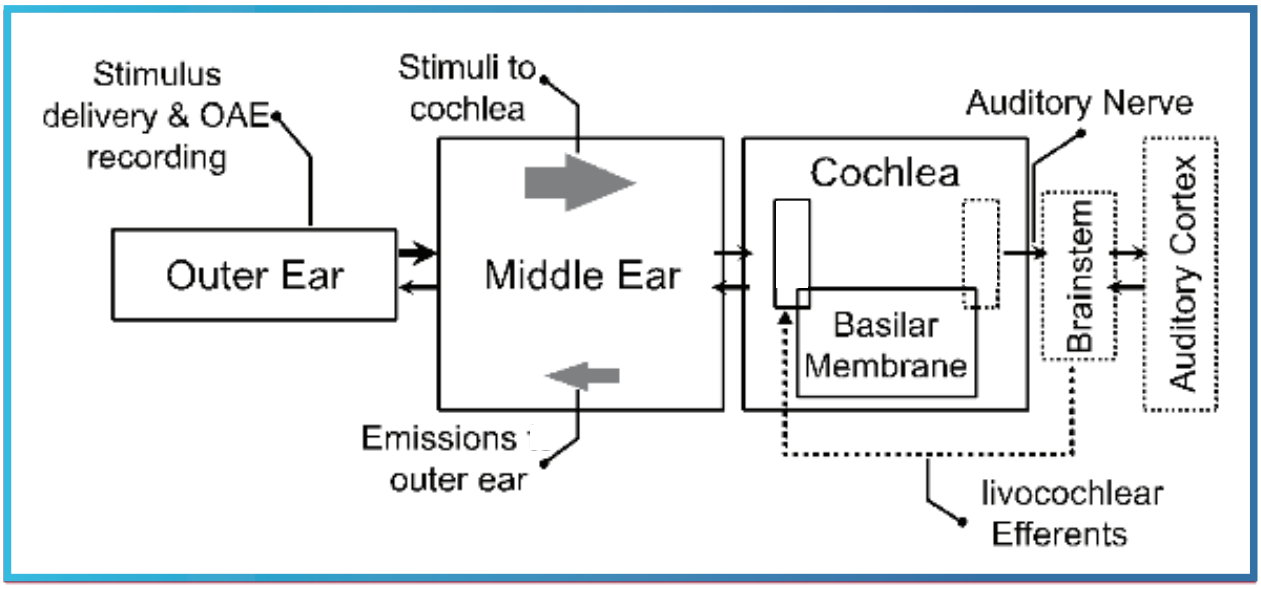
Evidence-based clinical practice guidelines provide detailed recommendations for OAE measurement, analysis, and clinical application (British Society of Audiology, 2023).

Interested readers will have no problem finding resources and reference on OAEs, including detailed discussions of relevant auditory anatomy and physiology, mechanisms, distinctions between transient evoked OAEs (TEOAEs) vs. distortion product OAEs (DPOAEs), and research-based reviews of clinical applications of OAEs in a wide range of auditory disorders and otologic diseases (e.g., Dhar & Hall, 2018; Hall & Swanepoel, 2010). In addition. the scientific literature contains over 6500 peer reviewed publications on OAEs (e.g., *https://pubmed.ncbi.nlm.nih.gov/?term=otoacoustic+emissions.*

This brief paper presents practical information on clinical measurement and analysis of DPOAEs in the diagnosis of auditory dysfunction. The discussion focuses on DPOAEs, not TEOAEs. Also, we don't address the well-documented application of OAEs in hearing screening nor the varied contributions of information from OAE measure in basic investigations of cochlear physiology and pathophysiology. Our overall goal is to encourage audiologists to take full advantage of DPOAEs as a clinical tool, and to provide some practical tips for the most effective clinical application of DPOAEs in pediatric and adult patient populations.

BRIEF REVIEW OF ANATOMIC STRUCTURES INVOLVED IN DPOAE MEASUREMENT

A good understanding of the anatomic and physiologic underpinnings of OAE generation and measurement is essential for recording, analyzing, and interpreting findings in the clinical setting. As illustrated schematically in Figure 1, four general regions of auditory system anatomy are involved in the generation and measurement of OAEs.



Sanfins, Skarzynski and Hall, 2025

Figure 1. Schematic diagram of the four auditory structures or regions involved in the measurement of DPOAEs. Source: Dhar S & Hall JW III (2018). Otoacoustic Emissions: Principles, Procedures, and Protocols. San Diego: Plural Publishing

1 **The EXTERNAL EAR CANAL** plays a crucial role in stimulus delivery and OAE recording. variety of pathologic and non-pathologic conditions of the external ear have serious ramifications on OAE measurements.

2 **The MIDDLE EAR** (tympanic membrane and ossicles) is a vital link in OAE measurement. Stimuli used to elicit OAEs are transmitted to the cochlea via the middle ear. In addition, OAEs generated in the cochlea travel outward through the middle ear on the way to the external ear canal.

3 The source of OAE activity is found within the **COCHLEA.** Specifically, OAEs reflect outer hair cell activity and functional integrity of all components of outer hair cells is essential for generation of OAEs. Other structures in and related to the cochlea also play a crucial role in the generation of normal OAEs, including the blood vessels serving the organ of Corti, the stria vascularis, and the reticular formation.

4 Finally, activation of the **EFFERENT AUDITORY SYSTEM**, particularly the olivocochlear bundle, may also influence OAE recordings.

Readers are referred to Chapter 2 of Dhar & Hall (2018) for a more detailed review of the anatomy and physiology underlying OAE measurement.

DISTINCTIONS IN APPLICATION OF DPOAES FOR DETECTION VERSUS DIAGNOSIS OF HEARING LOSS

Clinical reports describing the diagnostic value of DPOAEs in frequency-specific assessment of hearing loss date back to the mid-1990s (e.g., Gorga et al, 1993; Hall, 2000; Hornsby, Kelly & Hall, 1996; Lonsbury-Martin, Martin, McCoy & Whitehead, 1994).

During this exciting era in the evolution of OAEs, most manufacturers of audiology instrumentation introduced the first generation of clinical DPOAE devices. Research since then has clearly demonstrated the diagnostic sensitivity and specificity of DPOAEs for a diverse collection of etiologies affecting outer hair cell function, such as:

- **perinatal diseases,**
- **exposure to damaging levels of noise or music or ototoxic drugs,**
- **otologic diseases (e.g., Meniere's disease, autoimmune disease),**
- **age-related hearing loss secondary to comorbid conditions like diabetes and cardiovascular disease**

(for reviews see Dhar & Hall, 2018; Hall, 2021).

Longstanding basic and clinical research findings confirm that DPOAEs are a highly sensitive and frequency specific measure of outer hair cell function, with diagnostic qualities unmatched by any other clinical procedure.

As a diagnostic measure, **DPOAEs provide vital information on the status of outer hair cells.** Abnormalities in outer hair cell function may also occur secondary to pathophysiology affecting other cochlear structures, particularly the stria vascularis.

OAEs do not shed any light on inner hair cell function. This limitation has minimal impact on the clinical usefulness of OAEs because outer hair cell dysfunction or damage is an invariable feature of many otologic disorders or diseases associated with a wide assortment of cochlear abnormalities. As a result, the diagnostic value of DPOAEs extends to essentially all etiologies of sensory hearing loss.

There is compelling longstanding research evidence in support of the value of DPOAEs in diagnosis of auditory function. Nonetheless, audiologists often **record and analyze DPOAEs in diagnostic assessments** with the same simple dichotomous “pass” vs. “fail” or “present” versus “absent” approach that is used in hearing screening.

Table 1. delineates distinctions between the application of DPOAEs in hearing screening versus diagnostic assessment. We'll offer at this point several hypothetical clinical scenarios to clarify the obvious limitations resulting from reliance on a simple DPOAE screening protocol when the clinical goal is comprehensive diagnostic assessment.

Table 1. Distinctions in measurement and analysis of distortion product otoacoustic emissions (DPOAEs) in detection of hearing loss (hearing screening) versus the diagnosis of hearing loss (comprehensive audiologic assessment). Refer also to Figures 1.

	HEARING SCREENING	DIAGNOSIS OF HEARING LOSS
DPOAE Measurement		
Stimulus Frequency Range	Test stimuli within a limited frequency range, e.g., 2000 Hz to 5000 Hz	Test stimuli for a wide frequency range, e.g. 500 Hz to > 8000 Hz
Number of Stimulus Frequencies	•Stimuli for a limited number of frequencies, e.g., two or three or frequencies •Few frequencies per octave, e.g., 1 or 2	•Relatively large number of stimulus frequencies, e.g., > 20 frequencies •Numerous frequencies per octave, e.g., > 4
Replication of Recordings	DPOAEs are not replicated (plotted as a single DPgram)	DPOAEs are replicated and plotted as two superimposed DPgrams
Stimulus Intensity	Stimuli are presented at a single fixed intensity level (e.g., L1 = 65 dB SPL; L2 = 55 dB SPL)	Stimuli may be presented at multiple higher and lower intensity levels
DPOAE Analysis		

Description of DPOAEs	RSimple binary summary of findings, e.g., "Pass" versus "Refer"; "Pass" versus "Fail"; or "Present" versus "Absent"	Comprehensive frequency-specific description of DPOAE findings with reference to an appropriate normal region for DP amplitude, such as +/- 2 standard deviations of DP amplitudes for subjects with normal hearing sensitivity (< 15 dB HL)
Criteria	•Criteria for "Pass" versus "Refer" (or fail) is a DP to Noise Floor (DP – NF) difference of > 6 dB SPL •Analysis is not made with reference to appropriate normative data for DP amplitude	•Reference to an appropriate normal region •Minimally, three categories for DP outcome: 1) Normal, 2) Present but abnormal, 3) Absent
Calculation	Simple calculation of the DP to noise floor difference, rather than the absolute DP amplitude	Description of absolute DPOAE amplitude in dB SPL relative to test frequencies
Frequency Specificity	Analysis is not frequency-specific but, rather, general (e.g., "DPOAEs were present")	Highly frequency-specific analysis to describe fine structure of cochlear function

Let's say an audiology colleague refers an adult patient to you for a hearing aid consultation and fitting. The patient arrives in your clinic without an audiogram. When you call the referring audiologist for details about the patient's hearing, the audiologist simply states: "When I performed pure tone audiometry, the patient responded to sounds in each ear". Or imagine that an audiology colleague conducted an ABR assessment on a child and then refers the patient to you for hearing aid consultation and fitting. This time when you call the referring audiologist for details about the patient's hearing, the audiologist simply states: "An ABR was present bilaterally." Naturally, you have every reason to expect a more detailed description of the patient's auditory status in each ear, including the degree and configuration of hearing loss. Indeed, accurate ear-specific and frequency-specific estimation auditory thresholds is essential for any type of audiologic management, including amplification.

Reporting DPOAEs in a binary fashion as simply "present" or "absent" is similarly inadequate in diagnostic assessment of a patient's hearing status. At the least, as noted in Table 1, DPOAE findings for multiple stimulus frequencies or frequency regions should be described relative to an appropriate normal region. We'll expand upon that critical point later in this article.

CLINICAL ADVANTAGES OF DPOAES

Table 2 summarize the diverse clinical advantages of DPOAEs in the diagnosis of auditory dysfunction. Later we'll describe how those clinical advantages contribute importantly to clinical applications of DPOAEs in pediatric and adult patient populations. Some of the clinical advantages inherent in DPOAEs are desirable for any audiologic procedure. Examples are patent safety, brief test time, relatively simple test technique, and the potential for automated measurement and analysis. Perhaps most importantly from a clinical perspective, DPOAE measurement is totally objective, and not dependent on a behavioral patient response.

The objective nature of DPOAEs is a significant clinical advantage for valid assessment of auditory function in patients across the age spectrum, from infants to the elderly. Fortunately, the many listener variables that may compromise behavioral audiometry, such as developmental or neurological status, cognitive function (attention and memory), motivation, are not factors in DPOAE measurement and analysis.

TABLE 2. CLINICAL ADVANTAGES OF DISTORTION PRODUCT OTOACOUSTIC EMISSIONS IN DIAGNOSTIC AUDIOLOGY.

Safe and Simple Measurement Technique

- Non-invasive technique
- Probe tips can be disposed of after single use or effectively disinfected
- Non-audiologists (e.g., a technician) can record valid OAE data
- Brief test time (often < 1 minute per ear.)
- OAE measurement doesn't require a sound-treated room
- Diagnostic test protocols can be programmed on OAE devices
- Commercially available equipment permits automated analysis of results

Objective Measure of Auditory Dysfunction

- Not dependent on a behavioral response
- Valid data collection in infants and young children
- Not influenced by patient cognitive status (e.g., attention, memory)
- Not influenced by patient motivation
- Not influenced by patient state of arousal (e.g., awake versus asleep)
- OAE numerical data can be stored for later on-site or remote analysis

Sensitive, Site-Specific, and Frequency-Specific Measure of Cochlear Function

- Highly sensitive measure of outer hair cell function. Note: Most etiologies for hearing loss involve outer hair cell dysfunction.

Frequency-specific information on cochlear function (e.g., > 5 frequencies per octave)

- Distortion product OAEs (DPOAEs) can be recorded for test frequencies > 10,000 Hz. In contrast, transient evoked OAE measurement is constrained by an upper frequency limit of about 5000 Hz.
- DPOAEs may document cochlear dysfunction in patients with normal audiograms.

• OAEs may document normal cochlear function in patients with neural auditory abnormalities

Contribution to the Diagnosis of Auditory Function in Multiple Clinical Etiologies

Detection of cochlear auditory dysfunction in at risk children e.g.:

• Prematurity
• Admission to a neonatal intensive care unit
• Perinatal infection such as cytomegalovirus
• Meningitis
• Hyperbilirubinemia
• Ototoxicity
• Syndrome associated with hearing loss
• Delayed onset hearing loss
• False hearing loss (e.g., some type of trauma)

Detection of cochlear auditory dysfunction in at risk adults, e.g.:

• Noise exposure
• Tinnitus
• Ototoxicity
• Diabetes
• Cardiovascular disease
• Smoking
• False hearing loss (e.g., claim for financial compensation)

Differentiation of sensory versus neural hearing loss, in combination with information from other auditory measures (e.g., acoustic reflexes, auditory brainstem response), e.g.,

• Auditory neuropathy spectrum disorder (ANSD) in children
• Vestibular schwannoma in adults

Sanfins et al, 2025

Among all available clinical auditory tests, DPOAEs uniquely combine high sensitivity to abnormalities in cochlear functioning while also providing unparalleled specificity to outer cell dysfunction. DPOAEs are a highly frequency-specific auditory measure providing information on cochlear function within the 6 or 8 pure tone frequencies plotted on the audiogram. The sensitivity and frequency-specificity of DPOAEs to cochlear dysfunction is a major reason why DPOAEs are an essential and rather unique component of the test battery employed for audiologic assessment of children and adults. Audiologists who routinely incorporate DPOAEs into their diagnostic test battery readily appreciate that some patients with normal audiograms have very abnormal or even absent DPOAEs.

The combination of a normal audiogram with abnormal DPOAEs is often encounter when assessing the hearing of patients with risk factors for cochlear damage like noise or music exposure, ototoxic medications, and certain comorbid conditions associated with hearing loss (e.g., hyperlipidemia, diabetes, cardiovascular dysfunction, kidney disease).

Similarly, abnormal DPOAEs in combination with a normal audiogram are often found in patients with unhealthy lifestyle factors, among them poor diet, inadequate physical exercise, and smoking. Conversely, entirely normal DP amplitudes invariably imply outer hair cell integrity, and usually normal cochlear integrity as well.

We invite you to join us as we continue this exploration of the clinical utility of distortion product otoacoustic emissions. **Stay tuned for the next edition of this article which includes a step-by-step review of DPOAE measurement and analysis.**

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Quiz

1. According to the anatomical review of the text, which of the following structures is the source of Distortion Product Otoacoustic Emissions (DPOAE) activity?

A. The middle ear (tympanic membrane and ossicles).
B. The cochlea. The cochlea.
C. The efferent auditory system.
D. The external auditory canal.

2. According to 'Table 1' of the text, which of the following statements correctly describes the collection of OAEs in the context of an audiological diagnosis, compared to hearing screening?

A. Use of stimuli at a single fixed intensity level.
B. Dichotomous analysis of the results, such as 'Approved' versus 'Failed'.
C. Test stimuli for a wide range of frequencies (e.g., 500 Hz to > 8000 Hz).
D. Test stimuli in a limited frequency range (e.g., 2000 Hz to 5000 Hz).

3. According to the text, what is a clinical limitation of Otoacoustic Emissions (OAE)? According to the text, what is a clinical limitation of Otoacoustic Emissions (OAE)?

A. They do not clarify the function of the inner hair cells.
B. The measurement of OAEs requires a sound-treated room.
C. They do not provide information about the function of the outer hair cells.
D. They depend on the patient's motivation to provide a behavioral response.

4. Which of the following options is presented in the text as a significant clinical advantage of OAEs in audiological diagnosis? Which of the following options is presented in the text as a significant clinical advantage of OAEs in audiological diagnosis?

A. The analysis of the results is a manual and time-consuming process.
B. They depend on the patient's cognitive state, such as attention and memory. They depend on the patient's cognitive state, such as attention and memory.
C. They require a long testing time (often more than 5 minutes per ear).
D. They are a completely objective measure, not depending on a behavioral response from the patient.

5. The combination of a normal audiogram with abnormal OAEs is a relevant clinical finding. The combination of a normal audiogram with abnormal OAEs is a relevant clinical finding. According to the text, what is the most likely implication of this combination of results?

A. Integrity of the outer hair cells and normal cochlear integrity.
B. The presence of neural hearing loss, such as in auditory neuropathy spectrum disorder (ANSD).
C. Cochlear dysfunction associated with risk factors such as noise exposure or ototoxic medications.
D. The presence of a false hearing loss (simulation).

Answers:
1- B
2- D
3- A
4- D
5- C