REPORT CARD 2026

NEW PERSPECTIVES IN HEARING ASSESSMENT: PART 2. APPLICATION OF DISTORTION PRODUCT OTOACOUSTIC EMISSIONS IN THE DIAGNOSIS OF HEARING LOSS – STEP B (GUIDELINES AND IMPORTANT COMPONENTS OF DIAGNOSTIC DPOAE MEASUREMENT)

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

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NEW PERSPECTIVES IN HEARING ASSESSMENT: PART 2. APPLICATION OF DISTORTION PRODUCT OTOACOUSTIC EMISSIONS IN THE DIAGNOSIS OF HEARING LOSS – STEP B (GUIDELINES AND IMPORTANT COMPONENTS OF DIAGNOSTIC DPOAE MEASUREMENT)

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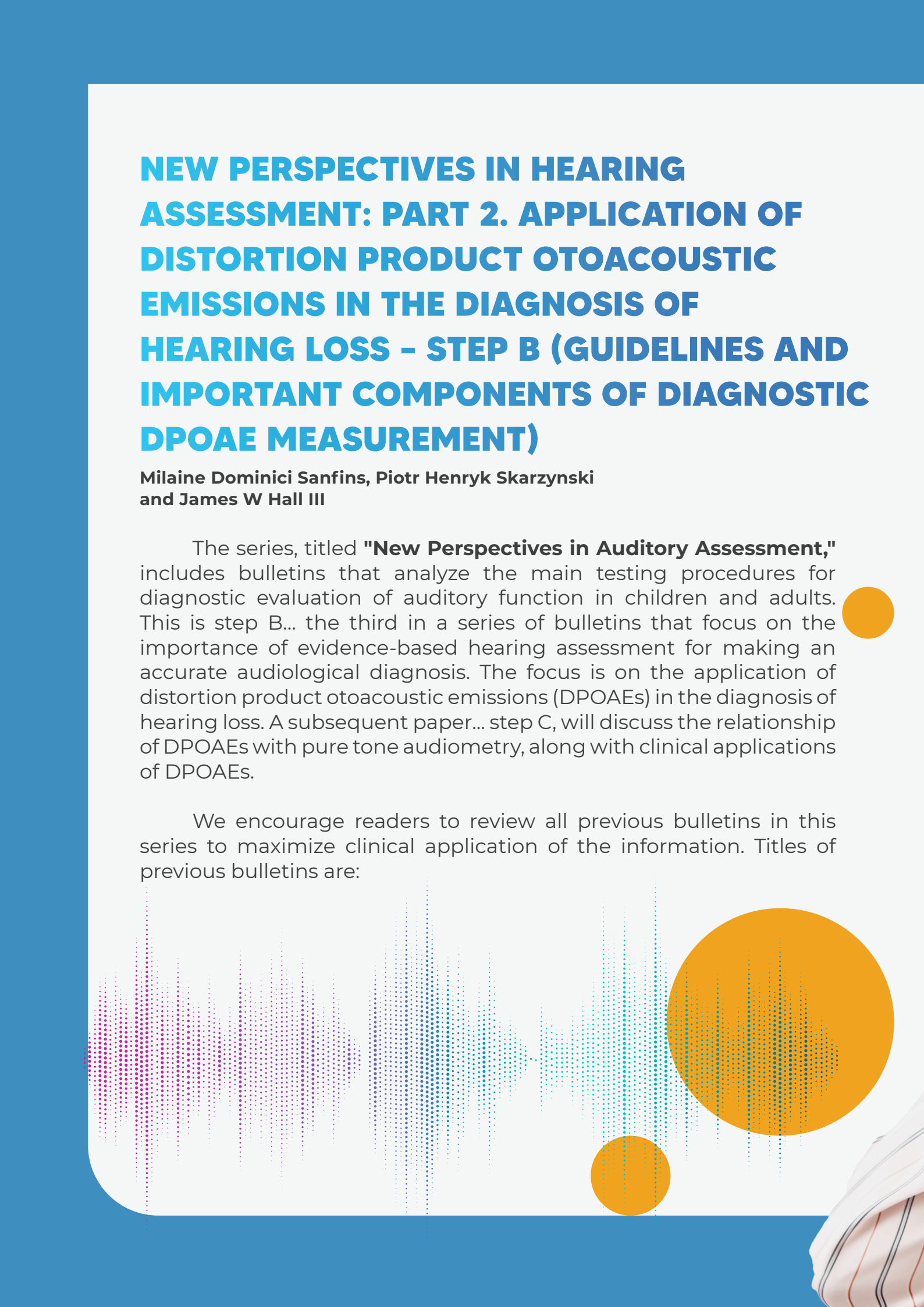
The series, titled **"New Perspectives in Auditory Assessment,"** includes bulletins that analyze the main testing procedures for diagnostic evaluation of auditory function in children and adults. This is step B... the third in a series of bulletins that focus on the importance of evidence-based hearing assessment for making an accurate audiological diagnosis. The focus is on the application of distortion product otoacoustic emissions (DPOAEs) in the diagnosis of hearing loss. A subsequent paper... step C, will discuss the relationship of DPOAEs with pure tone audiometry, along with clinical applications of DPOAEs.

We encourage readers to review all previous bulletins in this series to maximize clinical application of the information. Titles of previous bulletins are:



- **New Perspectives in Auditory Assessment: Part 1. Application of value-added tests in the diagnosis of hearing loss (Sanfins, Skarzynski, and Hall III, 2024);**

- **New Perspectives in Auditory Assessment: Part 2. Application of Distortion Product Otoacoustic Emissions in the diagnosis of hearing loss – Step A (Sanfins, Skarzynski, and Hall III, 2025).**

At the outset of this discussion of guidelines and important components of diagnostic OAE measurement, we'll reintroduce readers to table 1 summarizing differences in the measurement and analysis of OAEs for detection of hearing loss (hearing screening) versus the diagnosis of hearing loss.

Table 1. Distinctions in measurement and analysis of distortion n 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 and 2.

	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.

	Hearing Screening	Diagnosis of Hearing Loss
DPOAE Analysis		
Description of DPOAEs	Simple 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 (see Figure 1)
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

GUIDELINES FOR DIAGNOSTIC OAE MEASUREMENT

Some of the features of diagnostic DPOAE measurement were summarized in the right-hand column of Table 1. At least five factors are critically important in the clinical measurement of OAEs:

01) The status of the external ear
02) The status of the middle ear
03) The coupling (fit) of the probe assembly of the DPOAE device within the external ear
04) Stimulus characteristics and stability
05) Ambient and physiological sources of noise in DPOAE measurement

Each of these factors or a combination of multiple factors may influence measurement of DPOAEs and can contribute to a valid DPOAE recording versus DPOAE recordings that are essentially unusable. In a busy clinic, clinicians may not devote adequate time and attention to preparation for DPOAE measurement. It's tempting to oversimplify DPOAE measurement with the assumption that following manual insertion of the probe the device will automatically complete the rest of the test process. Devotion of less than a minute to several preliminary steps before or during DPOAE measurements is a good investment of clinic time. Readers who are interested in a more detailed review of DPOAE measurement are encouraged to consult Dhar & Hall (2018).

Recent clinical practice guidelines (British Society of Audiology, 2023) are also an excellent source of practical information on important topics such as equipment preparation, test environment, recording conditions, patient or caregiver instructions, probe fitting, and the DPOAE measurement process.

The flowchart in **Figure 1** shows important components of DPOAE measurement. The following is a brief description of a dozen simple steps that should be taken prior to and during the measurement process.

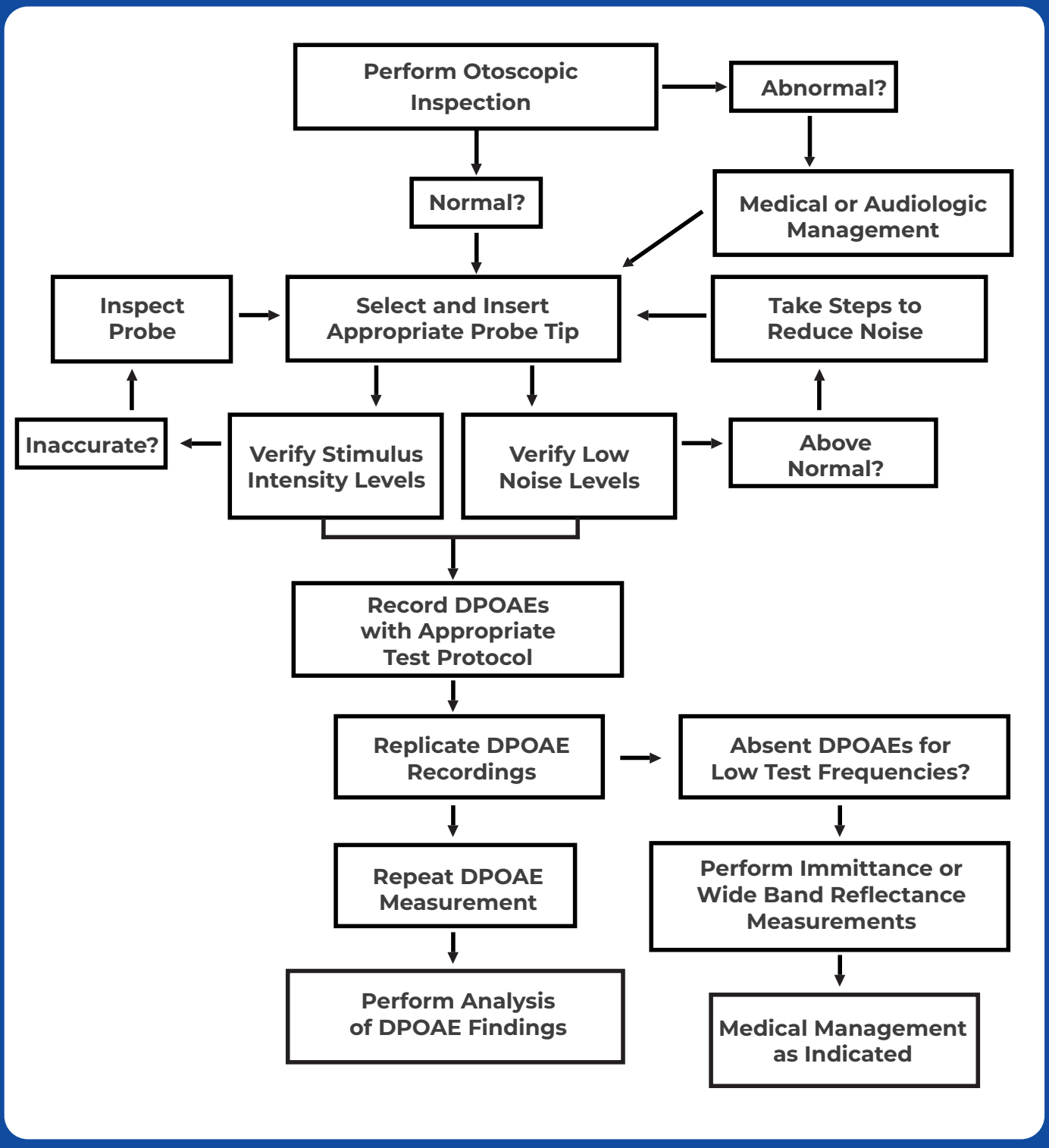
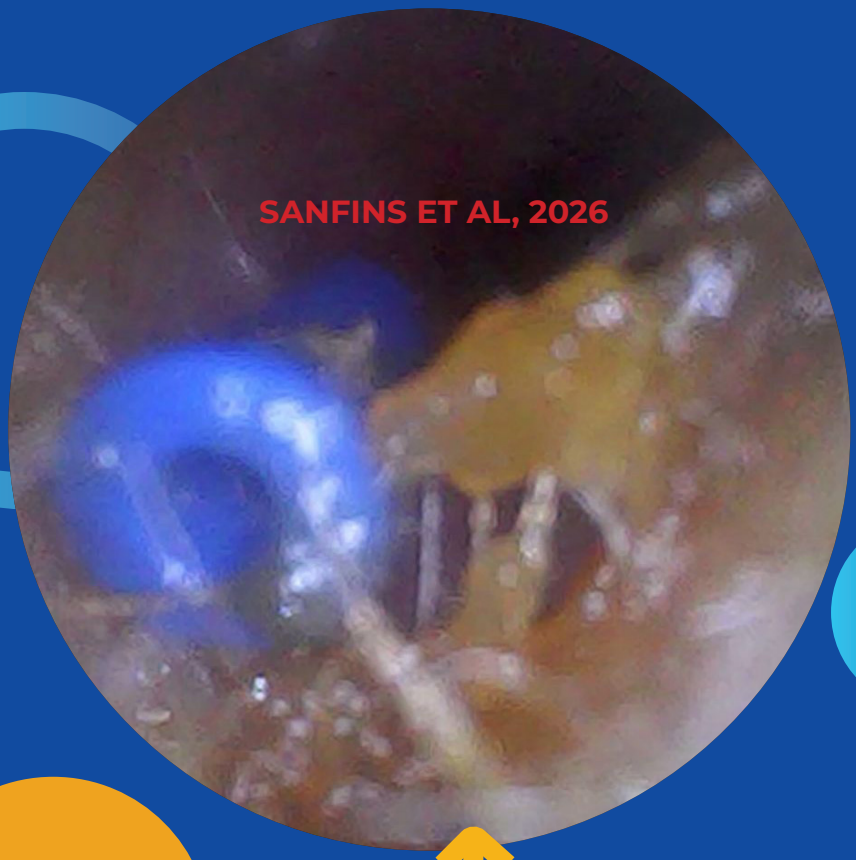


Figure 1: Flowchart of DPOAE Collection

STEP 1: OTOSCOPIC INSPECTION

Otoscopic inspection should routinely be conducted prior to measurement of DPOAEs, assuming it has not already been performed earlier in hearing assessment. For any patient, the main objective of otoscopy prior to recording DPOAEs is to detect the presence of cerumen or other debris that might occlude tiny openings in the OAE probe or that might interfere in other ways. In pediatric hearing assessments, otoscopic inspection may also reveal the presence of unexpected foreign objects in the external canal that would compromise safe insertion of the probe. (see image below from Sanfins et al, 2025).



STEP 2: TYMPANOMETRY

For most diagnostic audiological assessments, tympanometry is best completed before DPOAE measurement with the obvious goal of documenting the status of middle ear function. There is no risk associated with DPOAE measurement in patients with middle ear disease and/or dysfunction, including perforation of the tympanic membrane. However, DPOAEs will probably not yield useful information on cochlear status in patients with middle ear dysfunction.

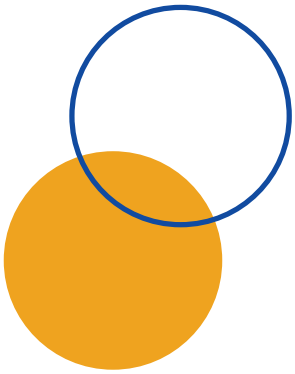
STEP 3: PATIENT OR CAREGIVER INSTRUCTIONS

The patient, or caregiver/parent in the case of young children, should be given a simple explanation of the DPOAE test. For example, the patient or caregiver/parent is told that the test involves the insertion of a small probe with a soft tip into the out end of external ear canal. The patient may hear sounds, but there is no need to pay attention to the sounds or to respond verbally to the sounds. The patient only needs to remain quiet for a minute or two until the test is completed. If tympanometry has already been explained and completed, little additional patient or caregiver instruction is required before DPOAE measurement.

STEP 4: SELECTION OF AN APPROPRIATE DPOAE TEST PROTOCOL

A diagnostically appropriate test protocol should be chosen before DPOAE measurement begins. As noted in Table 1, protocols are distinctly different for screening versus diagnostic applications of DPOAEs. The textbook by Dhar & Hall (2018) includes a detailed discussion of various DPOAE test protocols, along with the parameters and the rationale for each protocol.

Users of DPOAE devices are encouraged to create and set up or configure on the device specific protocols designed to optimize the contribution of DPOAE findings to the diagnosis of patients with different suspected etiologies for hearing loss.



For example, an appropriate DPOAE protocol for a patient at risk for ototoxicity includes multiple frequencies per octave (e.g., 4 or 5) over a high frequency region, such as 2000 Hz to 10,000 Hz. For a patient at risk for sound-induced (noise and/or music) hearing loss, it would be appropriate to record DPOAEs with a protocol focusing on multiple test frequencies within the frequency region of 1000 Hz to 8000 Hz.

Another option is to rely upon a general diagnostic DPOAE protocol with many test frequencies over four or more octaves (e.g., 500 Hz to 8000 Hz) for comprehensive audiologic assessment of most children and adults. Diagnostic DPOAE devices from most manufacturers permit the creation of custom-made protocols for various clinical purposes and applications. Users can easily assign unique names to each protocol, such as “Clinic Name Dx DPOAE 0.5-8kHz.” The tester should access or upload the most appropriate DPOAE protocol before proceeding to the next steps inf the measurement process.

STEP 5: PROBE TIP SELECTION

The probe tip selected for DPOAE measurement should be unused or disinfected. The size should be selected with the goal of obtaining a snug fit in the external ear canal. A hermetic (airtight) coupling between the probe and the external ear canal walls is not required for DPOAE measurement. However, a tight seal is important to limit the amount of ambient noise entering the external ear canal and interfering with confident detection and analysis of DPOAEs. If tympanometry is performed before DPOAE measurement in a patient, the same probe tip can be employed for both ears during both procedures.

STEP 6: PROBE TIP INSERTION

Insertion of the probe tip for a DPOAE device involves the same general technique that is used for insertion of a probe tip for tympanometry, although an air-tight (hermetic) seal is not necessary. Following step 5, the tester grasps the patient's pinna with one hand and gently pulls the pinna outward to straighten the external ear canal. Then, with the other hand the tester inserts the probe as far as possible into the external ear canal. As noted in step 5, a snug and deep probe fit is important to minimize ambient noise interference with DPOAE measurement. The probe should never be held while DPOAEs are recorded.

STEP 7: VERIFICATION OF STIMULUS INTENSITY LEVEL

The next step following probe insertion is verification of stimulus intensity levels. As noted in table 1 of this paper, clinical research in the 1990s confirmed that an intensity level of 65 dB SPL for the lower of two stimulus frequencies (f1) and 55 dB SPL for the higher frequency (f2) offers adequate DPOAE sensitivity to cochlear (outer hair cell) dysfunction. Lower stimulus intensity levels may yield somewhat greater DPOAE sensitivity for detection of sensory deficits, but at the cost of an unacceptably high proportion false-positive test outcomes, i.e., abnormal or absent DPOAEs in persons with apparently normal cochlear function. On the other hand, higher intensity levels lack adequate sensitivity to subtle cochlear dysfunction and are often associated with false-negative test outcomes.

Before DPOAE recording begins, testers must verify that the intensity levels for f1 and f2 stimuli delivered to the external ear canal closely approximate the desired or target intensity levels of L1 = 65 dB SPL and L2 = 55 dB SPL. All DPOAE devices readily provide an indication of the actual stimulus intensity level, and some devices permit ongoing monitoring of stimulus intensity level through DPOAE measurement.

Testers are obligated to trouble shoot possible explanations when the intensity levels of the stimuli do not align with the target stimulus levels. Three common trouble shooting steps include:

1) Checking the probe for debris in the tiny ports (stimuli and the microphone);

2 Reconfirming probe system calibration (daily confirmation of probe system calibration should be done before each clinic day),

3) Carefully reseating the probe in the external ear canal.

STEP 8: MINIMIZATION OF MEASUREMENT NOISE.

As shown in **Figure 1**, one important, yet overlooked, step in successful DPOAE measurement is minimizing noise levels within the external ear canal. Noise levels are invariably shown on the screen of a DP device, often as symbols or a shaded area as seen in **Figure 2.**

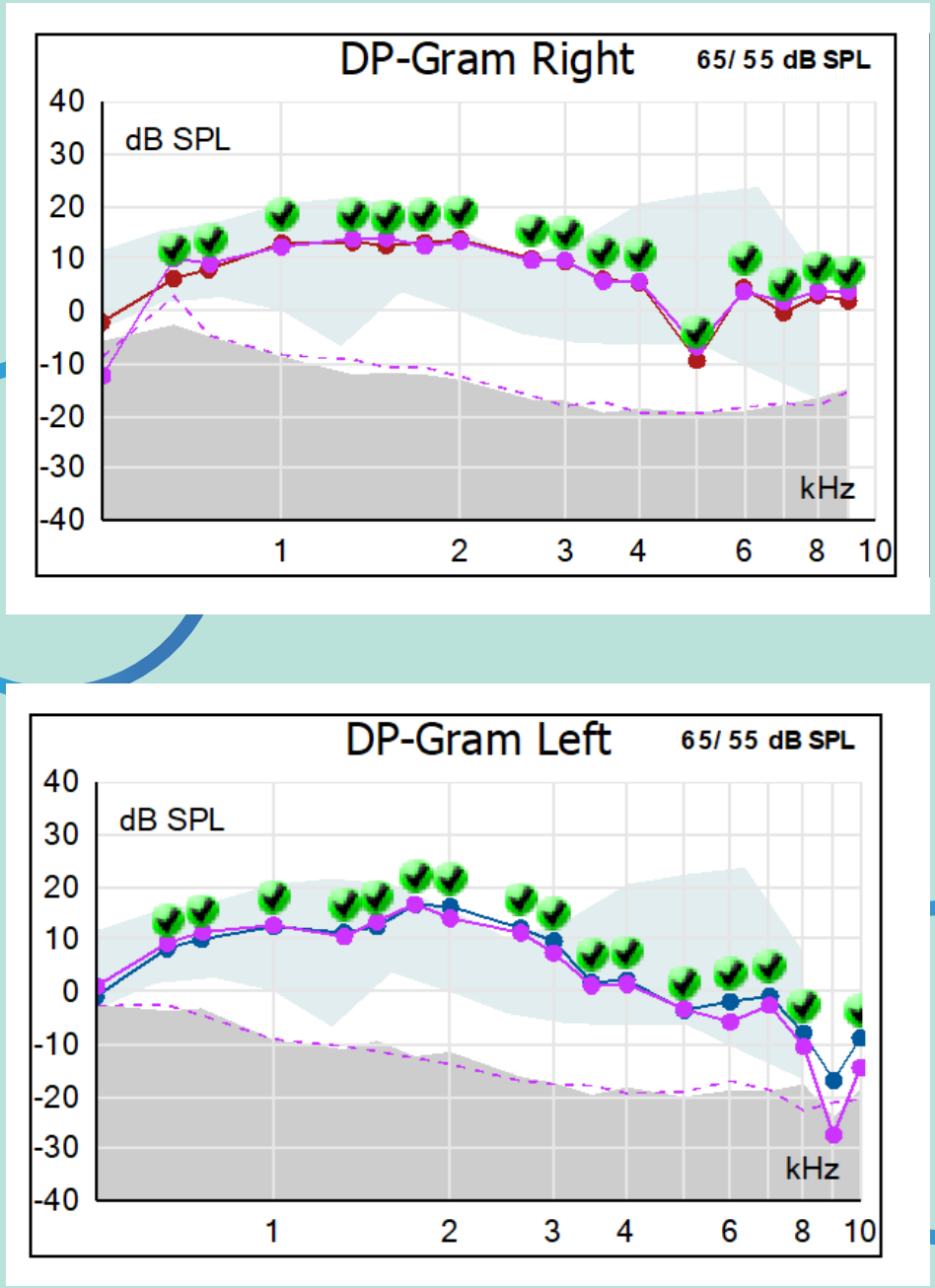


Figure 2 *Diagnostic distortion product otoacoustic emissions (DPOAEs) showing normal region (lightly shaded) and noise floor (dark shading). Check mark symbols indicate reliable DP data. Device: Interacoustics Eclipse.*

There are two general sources of noise. ***Physiologic noise*** is inadvertently generated by the patient. Nothing can be done about physiologic noise related to breathing and blood flow through vessels in the middle ear space. However, movement-related physiologic noise can be reduced by instructing the patient to remain still and to refrain from talking. For infants and young children, physiologic noise is minimal during sleep or quiet rest.

The other source of noise is due to ***ambient sound*** in the test setting. Simple strategies for reducing ambient acoustic noise include:

1) Eliminating obvious sources of noise in the text environment, e.g., close the door to the test room and turn off equipment that is not needed including cell phones

2) Locating the patient away from noise sources

3) Reinserting the probe deeper in the external ear canal.

Optimally, noise levels during DPOAE measurement should be less than - 10 dB SPL for all test frequency regions.

STEP 9: REPLICATION OF DPOAE RECORDINGS

DPOAE measurement may begin as soon as the preceding steps are complete. If it's possible to select the direction of frequency change during DPOAE measurement, the process should begin at the highest test frequency and progress toward the lowest test frequency.

This approach increases the likelihood of reasonably rapid DP data collection at the beginning of testing because noise levels are always minimal within the high frequency region.

Optimally, the DPOAE device should be configured to automatically replicate the measurement as soon as the first DPgram is complete. Alternatively, some devices perform an internal check of data replication throughout the DPOAE measurement process, as indicated by the check marks within each DP symbol in **Figures 2.**

STEP 10: DIGITAL STORAGE AND/OR PRINTING OF DPOAE DATA

Immediate storage of all DPOAE data is highly recommended, and often the default option for clinical devices. DPOAE data displayed on the device can be analyzed as soon as measurement is complete or stored and retrieved for analysis later. It's good clinical practice to supply a printout of DPOAE findings along with a narrative patient report.

STEP 11: PROBE REMOVAL

For the patient's comfort, the probe should be carefully removed from the ear canal as soon as DPOAE measurement is complete and the quality of the data has been confirmed, e.g., visual inspection shows replicable DPOAE data with adequately low noise floor levels. In some clinical settings, institutional policies or standard of care require disposal of probe tips after a single use. In other clinical.

GUIDELINES FOR ANALYSIS OF DIAGNOSTIC OAES

As noted in the right-hand column of **Table 1**, analysis strategies differ considerably when DPOAEs are used to screen for hearing loss versus when DPOAEs are included as part of a test battery for diagnosis of hearing loss. Confident and accurate analysis of DPOAEs is most likely with good measurement technique under optimal test conditions. Good measurement technique includes the use of an appropriate diagnostic test protocol and maintenance of target stimulus intensity levels during replicated DPOAE recordings. Optimal measurement conditions refer to minimal levels of environmental ambient noise and patient physiologic noise.

Graphic displays of DPOAE findings vary somewhat for devices marketed by different manufacturers. The following is a brief explanation of the features common to most devices. A common approach for DPOAE analysis is illustrated with the DPgram displayed in **Figure 2**. The figure shows amplitudes for the DP (the frequency defined by 2f1-f2) plotted in dB SPL as a function of the f2 stimulus, the higher of the two frequencies. Close inspection of the figure shows that there are two separate replications of the DPgram. Stimulus intensity is documented in the top right corner of the graph. DP amplitude is indicated by small circles. Again, with the device used to record the DPOAE data shown in **Figure 2**, a check mark within the circle symbol confirms that established DP criteria have been met.

The lightly shaded area in the figure represents the normative region for DP amplitude for the device. Two common definitions for the normative range on DPOAE devices are +/- 2 standard deviations around mean amplitudes of a group of normal hearing subjects (e.g., pure tone hearing thresholds < 20 dB SPL) or a percentile range for a normal group, such as a range from the 5th to 95th percentile of DP amplitude.

Typical audiometric criteria for people who are enlisted as normal subjects are:

01. Young adults (e.g., age of 18 to 30 years);
02. Pure tone thresholds of < 20 dB HL for audiometric frequencies of 250 Hz to 8000 Hz;
03. Normal tympanometry (Hornsby, Kelly & Hall, 1996; Dhar & Hall, 2018; Canete, El-Haj-Ali & Fereczkowski, 2024).

Analysis of normative data for various DPOAE devices reported in multiple publications reveals that the lower limit for normal DP amplitudes is invariably about 0 dB SPL. **That is, a clinician can assume that a patient's DPOAEs are normal when absolute amplitudes are > 0 dB SPL for most or all stimulus frequencies.**

To reiterate an important clinical point, accurate analysis of diagnostic DPOAE recordings requires reference to an appropriate normative region. By appropriate, we mean a normative region developed with data collected from a comparable age group with the same make/model for the clinical device using the test protocol and under stimulus conditions that are expected when DPOAEs are recorded from a patient.

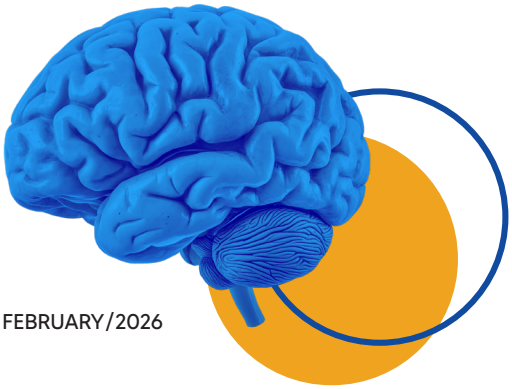
DPOAE amplitudes falling within the normative region provide objective confirmation of normal outer hair cell integrity, whereas absolute DPOAE amplitudes below normal limits, that is < 0 dB SPL, raise concerns about outer hair cell dysfunction. Referring again to **Figure 2**, the dashed line in the graph shown depicts the maximum level of the noise floor in the external ear canal across the frequency range of the DP gram. The darker shaded area represents the extent of measurement noise. As already noted, prior to and during DPOAE measurement clinicians should take simple steps to minimize ambient and physiology noise to less than -10 dB SPL.

One straightforward but useful analysis strategy in a diagnostic audiologic assessment is to describe frequency specific DPOAE findings within three distinct categories:

01. Normal DPOAEs: The difference between DP amplitude and the noise floor (the SNR) is > 6 dB SPL and absolute DP amplitude is > 0 dB SPL.

02. DPOAEs are present but abnormal: The difference between DP amplitude and the noise floor (the SNR) is > 6 dB SPL but absolute DP amplitude is < 0 dB SPL.

03. Absent DPOAEs: The difference between DP amplitude and the noise floor (the SNR) is < 6 dB SPL.



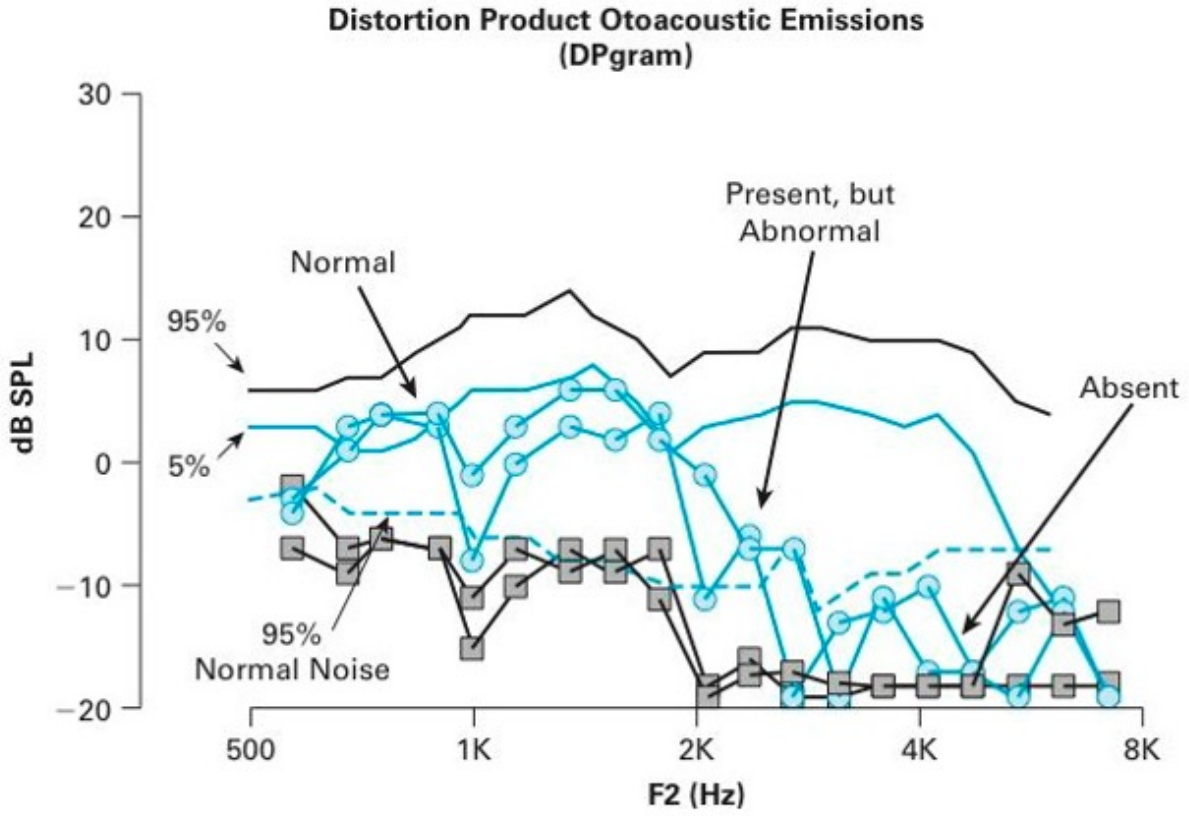


Figure 3 *Analysis of diagnostic distortion product otoacoustic emissions (DPOAEs). Source: Hall JW III (2014). Introduction to Audiology Today. Boston: Pearson Educational.*

Application of this strategy with DPOAE findings for different stimulus frequencies is illustrated in **Figure 4**.

The normal region (5th to 95th percentile for DP amplitudes for a normal hearing sample) is represented by the two solid lines, whereas the upper (95th) perception for noise is shown as a dashed line. DPOAE amplitudes are indicated with circles and noise levels at equivalent frequencies are shown as squares. DPOAEs are generally normal for f2 stimulus frequencies up to 2000 Hz. DPOAEs are present but abnormal for f2 stimulus frequencies from 2000 Hz up to 3500 Hz, and DPOAEs are generally absent or < - 10 dB SPL for higher stimulus frequencies.

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 relation between audiograms and DPOAEs.

Quiz

1. The text highlights five critically important factors for the collection of DPOAEs. Which of the following options is included in this list?

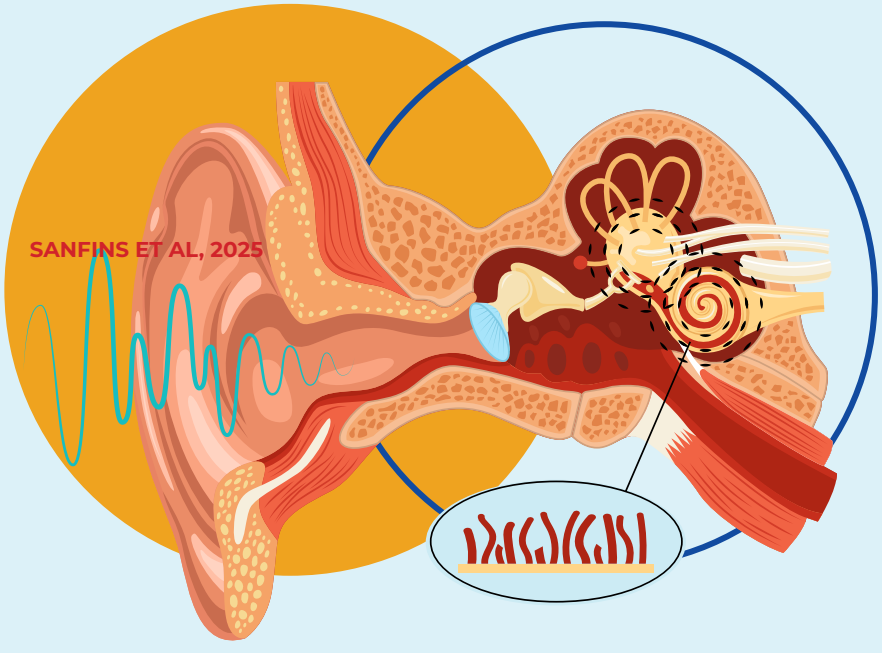
a) The patient's motivation and cooperation.
b) The patient's age and family history of hearing loss.
c) The quality of the probe assembly coupling or fit.
d) The ambient temperature of the clinic.

2. The text describes a series of simple steps for collecting DPOAEs. Which of the following steps is recommended before beginning DPOAE collection in order to document the status of middle-ear function?

a) Replication of DPOAE recordings.
b) Digital storage of data.
c) Tympanometry.
d) Verification of stimulus intensity level.

3. According to the text, which two criteria define a DPOAE recording as "normal" in a diagnostic assessment?

a) The absolute DP amplitude is < 0 dB SPL and the SNR is > 6 dB SPL.
b) The noise level is lower than –10 dB SPL and the DP amplitude is greater than 0 dB SPL.
c) The difference between the DP amplitude and the noise level (SNR) is > 6 dB SPL and the absolute DP amplitude is > 0 dB SPL.
d) The DP amplitude is higher than the noise level, but the absolute DP amplitude is < 0 dB SPL.



4. The text discusses the relationship between audiometry and DPOAEs. When normal DPOAEs are observed in the presence of abnormal tonal thresholds (an abnormal audiogram), what is the first and most likely explanation the clinician should investigate?

a) A dysfunction of the inner hair cells.
b) A middle-ear dysfunction.
c) A technical or non-pathological issue, such as collapsed ear canals.
d) A dysfunction of the outer hair cells.

5. According to the text, in Step 8, minimizing recording noise is an important part of the process. Which of the following strategies is recommended to reduce physiological noise during DPOAE measurement?

a) Turning off unnecessary devices such as mobile phones.
b) Closing the test-room door to block external sounds.
c) Instructing the patient to remain still and not speak.
d) Reconfirming the daily calibration of the probe system.

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Correct Answers to the Quiz

1. Correct answer: c
2. Correct answer: c
3. Correct answer: c
4. Correct answer: c
5. Correct answer: c

Authors

PROF. DR. MILAINE DOMINICI SANFINS

- Professor of the Audiology da Universidade Federal de São Paulo (UNIFESP);
- Research group member, Institute of Physiology and Pathology of Hearing, Kajetany, Poland.
- Professor of the post-graduate program in Clinical Audiology at the Albert Einstein Israelite Institute of research and teaching;
- Postdoc at the World Hearing Center, Warsaw, Poland;
- Sandwich Doctorate by School of Medical Sciences, Universidade Estadual de Campinas (FCM-UNICAMP) and by Università degli Studi di Ferrara/Italy;
- Specialist in Audiology by Federal Council of Speech Therapy and Audiology;
- Speech Therapist and Audiologist, Master by Medical School of University of São Paulo (FMUSP);
- Member of the Teaching and Research Commission of the Brazilian Academy of Audiology (2024-2026);
- Rapporteur of the Research Ethics Committee of the Federal University of São Paulo;
- Reviewer of scientific articles in the area of Neuroaudiology, Neuroscience, Electrophysiology and Audiology;
- Instagram @misanfins / email: msanfins@uol.com.br and msanfins@unifesp.br

PROF. DR. PIOTR HENRYK SKARZYNSKI

- Professor, ENT, Master and Doctorate by Medical University of Warsaw;
- Research, didactic, clinical, and organizational work in World Hearing Center of Institute of Physiology and Pathology of Hearing, Institute of Sensory Organs and Medical University of Warsaw;
- Specialist in ENT, pediatric ENT, audiology and phoniatrics, and public health. Participated in the 3rd Stakeholders Consultation meeting during which the World Hearing Forum of WHO was announced;
- Member of the Roster of Experts on Digital Health of WHO, Vice-President and Institutional Representative of ISfTeH;
- President-elect of International Advisory Board of AAOHNS, member of Congress and Meeting Department of EAONO, Regional Representative of Europe of ISA, VicePresident of HearRing Group, Auditor of EFAS, member of the Facial Nerve Stimulation Steering Committee;
- Board Secretary of the Polish Society of Otorhinolaryngologists, Phoniatrists and Audiologists. Member of Hearing Committee (2018–19);
- Goodwill Ambassador representing Poland at the AAOHNSF 2021 Annual Meeting & OTO Experience, and since 2021 a member of Implantable Hearing Devices Committee and Otology & Neurotology Education Committee of AAOHNS;
- Consultant Committee of International Experts of CPAM-VBMS (by special invitation), honorary member of ORL Danube Society, and honorary member of Société Française d'Oto-Rhino-Laryngologie;
- Member of the Council of National Science Center;
- Expert and member of numerous national organizations.

PROF. DR. JAMES W. HALL III

- He is an internationally recognized audiologist with more than 40 years of clinical, teaching, research, and administrative experience.
- He earned his bachelor's degree in Biology from the American International College, his master's degree in Speech-Language Pathology from Northwestern University, and his doctorate in Audiology from the Baylor College of Medicine under the mentorship of James Jerger.
- Throughout his career, he has held clinical and academic positions in audiology at major medical centers.
- He is a founder of the American Academy of Audiology, where he has held numerous leadership roles within the organization.
- He is the author of more than 200 peer-reviewed publications, invited articles, and book chapters, as well as 12 textbooks.
- He currently holds academic appointments as a Professor at Salus University and the University of Hawai'i, and serves as an Extraordinary Professor at the University of Pretoria, South Africa, in addition to other adjunct and visiting faculty positions in the U.S. and abroad.