Allied Health Media AudiologyOnline

A Clinician's Guide to OAE Measurement and Analysis

Presenter: James W. Hall III, PhD

Moderator: Carolyn Smaka, AuD, Editor in Chief, AudiologyOnline

Allied Health Media AudiologyOnline

- Technical Assistance: 800-753-2160
- CEU Total Access members can earn credit for this course
  - o Must complete outcome measure with passing score (within 7 days for live webinar; within 30 days of registration for recorded/text/podcast formats)
- Questions? Call 800-753-2160 or use Contact link on AudiologyOnline.com

A CLINICIAN'S GUIDE TO OAE MEASUREMENT

James W. Hall III, PhD

Professor
Osborne College of Audiology
Salus University
Elkins Park, Pennsylvania, USA

Extraordinary Professor
Department of Audiology & Speech Pathology
University of Pretoria South Africa

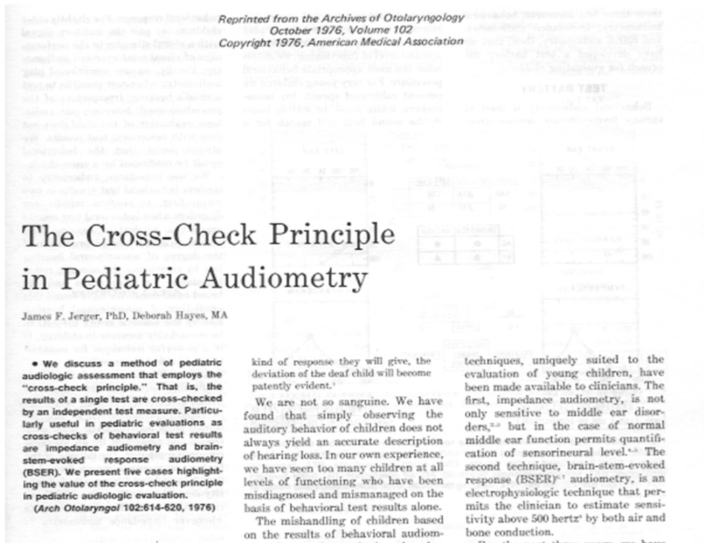
jwhall3phd@gmail.com **www.audiologyworld.net**

A CLINICIAN'S GUIDE TO OAE MEASUREMENT

- ❑ **Introduction**
- ❑ **Update on generation of OAEs**
- ❑ **Protocols for TEOAEs and DPOAEs**
- ❑ **Criteria for OAE analysis**
- ❑ **Factors influencing OAE results**
- ❑ **OAE versus audiogram findings**

The Cross-Check Principle in for Diagnosis of Hearing Loss in Children

(Jerger J & Hayes D. Arch Otolaryngol 102: 1976)



Reprinted from the Archives of Otolaryngology
October 1976, Volume 102

The Cross-Check Principle in Pediatric Audiometry

James F. Jerger, PhD, Deborah Hayes, MA

• We discuss a method of pediatric audiologic assessment that employs the "cross-check principle." That is, the results of a single test are cross-checked by an independent test measure. Particularly useful in pediatric evaluations as cross-checks of behavioral test results are impedance audiometry and brain-stem-evoked response audiometry (BSER). We present five cases highlighting the value of the cross-check principle in pediatric audiologic evaluation.
(*Arch Otolaryngol* 102:614-620, 1976)

kind of response they will give, the deviation of the deaf child will become patently evident.[1]

We are not so sanguine. We have found that simply observing the auditory behavior of children does not always yield an accurate description of hearing loss. In our own experience, we have seen too many children at all levels of functioning who have been misdiagnosed and mismanaged on the basis of behavioral test results alone.

The mishandling of children based on the results of behavioral audiom-

techniques, uniquely suited to the evaluation of young children, have been made available to clinicians. The first, impedance audiometry, is not only sensitive to middle ear disorders,[2,3] but in the case of normal middle ear function permits quantification of sensorineural level.[4,5] The second technique, brain-stem-evoked response (BSER)[6,7] audiometry, is an electrophysiologic technique that permits the clinician to estimate sensitivity above 500 hertz[8] by both air and bone conduction.

The Cross-Check Principle in for Diagnosis of Hearing Loss in Children

(Jerger J & Hayes D. Arch Otolaryngol 102: 1976)

The Cross-Check Principle Pediatric Audiology

(Jerger J & Hayes D. Arch Otolaryngol 102: 1976)

What's missing from the test battery?

"We have found than simply observing the auditory behavior of children does not always yield an accurate description of hearing loss"…

"The basic operation of this principle is that no result be accepted until it is confirmed by an independent measure."

Test Battery:

- **Behavioral audiometry**
- **Immittance (impedance) measurements**
  - ✓ **Tympanometry**
  - ✓ **Acoustic reflexes (contralateral only with SPAR)**
- **Auditory brainstem response (brainstem-evoked response audiometry or BSER)**
  - ✓ **Click stimulus air conduction**
  - ✓ **Click stimulus bone conduction**

The Cross-Check Principle in Audiology Today

40-Years of Clinical Experience

- ❑ **Behavioral Audiometry**
- ❑ **Otoacoustic Emissions (OAEs)**
- ❑ **Aural Immittance Measurements**
  - ● **Tympanometry**
  - ● **Acoustic Reflexes**
- ❑ **Auditory Brainstem Response (ABR)**
  - ● **Air- and Bone Conduction Stimulation**
  - ● **Click, Tone Burst and Chirp Stimulation**
  - ❑ **Auditory Steady State Response (ASSR)**
- ❑ **Electrocochleography (ECochG)**
- ❑ **Cortical Auditory Evoked Responses**

Evidence-Based (“Best”) Practice in Audiology: Clinical Guidelines for Pediatric Assessment

- ❑ 2007 Joint Committee on Infant Hearing (JCIH) Position Statement
- ❑ 2008 2010 American Academy of Audiology Clinical Practice Guidelines: Childhood Hearing Screening
- ❑ 2012 American Academy of Audiology: Audiologic Guidelines for the Assessment of Hearing in Infants and Young Children
- ❑ 2013 American Academy of Audiology Clinical Practice Guidelines: Pediatric Amplification
- ❑ American Academy of Audiology Clinical Practice Guidelines: Otoacoustic Emissions *(in progress)*

2007 Joint Committee on Infant Hearing (JCIH): Protocol for Evaluation for Hearing Loss In Infants from Birth to 6 Months

- ❑ Child and family history
- ❑ Evaluation of risk factors for congenital hearing loss
- ❑ Parental report of infant’s responses to sound
- ❑ Clinical observation of infant’s auditory behavior
- ❑ Audiological assessment
  - Auditory brainstem response (ABR)
  - Otoacoustic emissions (distortion product or transient OAEs)
  - Tympanometry with 1000 Hz probe tone
  - Supplemental procedures, e.g.,
    - ✓Electrocochleography (ECochG)
    - ✓Auditory steady state response (ASSR)
    - ✓Acoustic reflex measurement (for 1000 Hz probe tone)

A CLINICIAN’S GUIDE TO OAE MEASUREMENT: *Assumptions*

- ❑ OAE measurement in children and adults is evidence based
- ❑ Most audiologists under-utilize OAEs clinically
  - Use screening approach for diagnostic measurement … too few frequencies/octave over limited frequency region
  - Use screening approach for diagnostic analysis … OAEs are “Present” versus” Absent”
  - Do not regularly record OAEs in older children and adults
  - Replicated OAE recordings are not routinely made
- ❑ Four steps are important prior to OAE measurement
- ❑ OAE findings provide information not available from the audiogram … discrepancies between OAEs and the audiogram are a good thing!

A CLINICIAN’S GUIDE TO OAE MEASUREMENT

- ❑ Introduction
- ❑ Update on generation of OAEs
- ❑ Protocols for TEOAEs and DPOAEs
- ❑ Criteria for OAE analysis
- ❑ Factors influencing OAE results
- ❑ OAE versus audiogram findings

OAE MEASUREMENT AND ANALYSIS:
Conventional OAE Taxonomy …Stimulus Based

- ❑ Spontaneous OAEs
- ❑ Stimulus evoked OAEs
  - Transient evoked OAEs
  - Distortion product OAEs
  - Stimulus frequency OAEs

OAE MEASUREMENT AND ANALYSIS:
Current OAE Taxonomy … "Mechanism Based"
Shera & Guinan (1999). JASA, 105, 782-798

Evoked otoacoustic emissions arise by two fundamentally different mechanisms: A taxonomy for mammalian OAEs

Christopher A. Shera[a] and John J. Guinan, Jr.
Eaton-Peabody Laboratory of Auditory Physiology, Massachusetts Eye and Ear Infirmary, 243 Charles Street, Boston, Massachusetts 02114 and Department of Otology and Laryngology, Harvard Medical School, Boston, Massachusetts 02115

(Received 2 June 1998; accepted for publication 27 October 1998)

Otoacoustic emissions (OAEs) of all types are widely assumed to arise by a common mechanism: nonlinear electromechanical distortion within the cochlea. In this view, both stimulus-frequency (SFOAEs) and distortion-product emissions (DPOAEs) arise because nonlinearities in the mechanics act as ''sources'' of backward-traveling waves. This unified picture is tested by analyzing measurements of emission phase using a simple phenomenological description of the nonlinear re-emission process. The analysis framework is independent of the detailed form of the emission sources and the nonlinearities that produce them. The analysis demonstrates that the common assumption that SFOAEs originate by nonlinear distortion requires that SFOAE phase be essentially independent of frequency, in striking contradiction with experiment. This contradiction implies that evoked otoacoustic emissions arise by two fundamentally different mechanisms within the cochlea. These two mechanisms (linear reflection versus nonlinear distortion) are described and two broad classes of emissions—reflection-source and distortion-source emissions—are distinguished based on the mechanisms of their generation. The implications of this OAE taxonomy for the measurement, interpretation, and clinical use of otoacoustic emissions as noninvasive probes of cochlear function are discussed.
[S0001-4966(99)02202-X]

OAE MEASUREMENT AND ANALYSIS:
Reflection Source Emissions
Shera & Guinan (1999). JASA, 105, 782-798

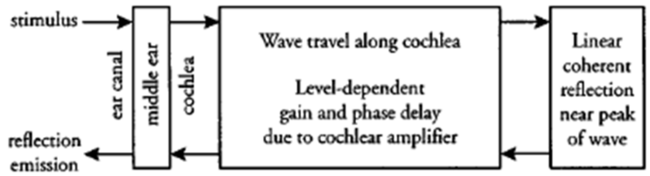
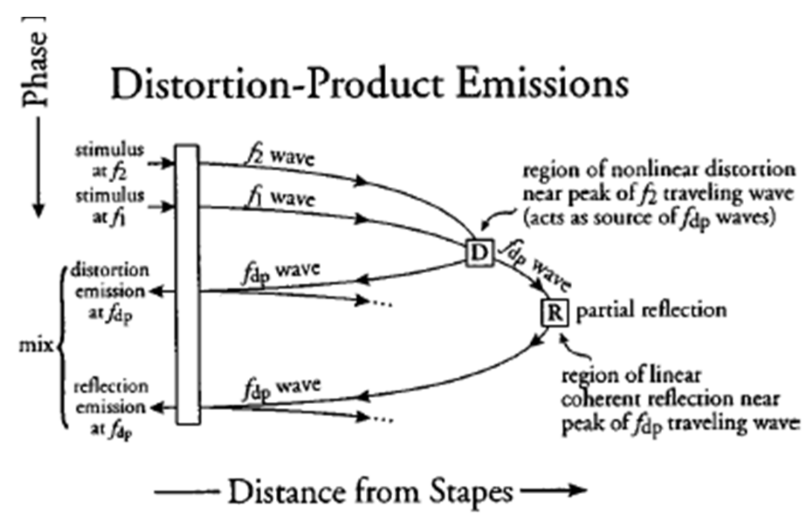
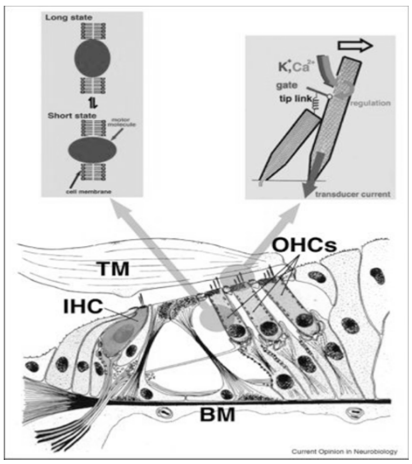


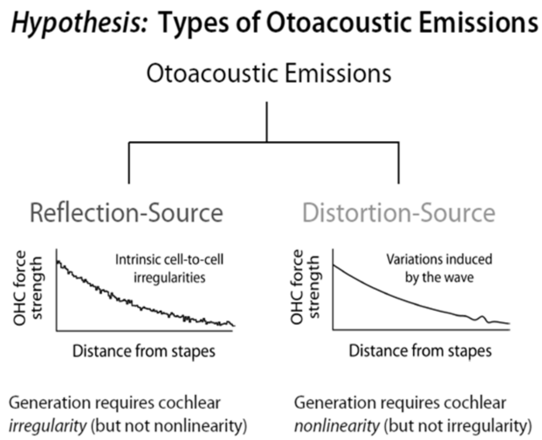
FIG. 11. Simplified conceptual model for the generation of reflection-source emissions. Reflection-source emissions arise from a region of linear coherent reflection near the peak of the traveling-wave envelope. Incident and reflected waves undergo level-dependent gains and phase delays while traveling to, from, and within the scattering reigon. At medium and high stimulus levels, reflection-source emissions therefore exhibit a nonlinear growth with sound level. Note that although they appear separated here for clarity, the regions of coherent reflection and maximal gain overlap within the cochlea. Figure 12 fleshes out this conceptual model (by including phase shifts due to wave propagation) and extends the model to illustrate the mixing of reflection- and distortion-source emissions that occurs during the generation of DPOAEs.

OAE MEASUREMENT AND ANALYSIS:
Distortion Product Emissions
Shera & Guinan (1999). JASA, 105, 782-798

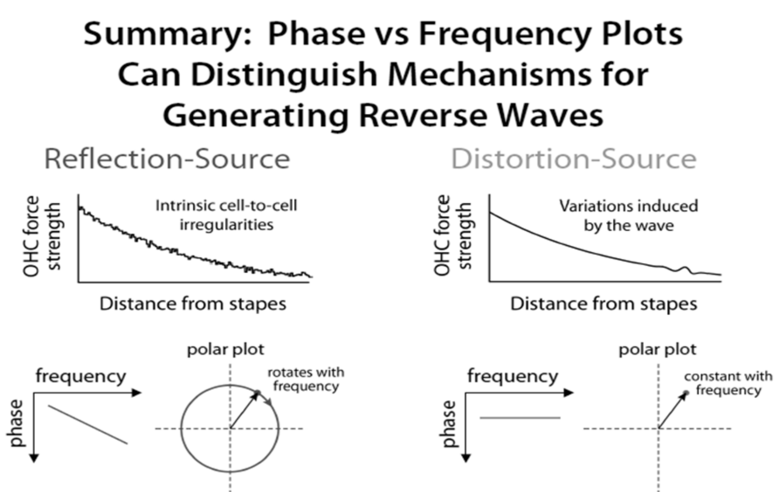


OAE MEASUREMENT AND ANALYSIS:
Current OAE Taxonomy





Phase is a Factor in the Generation of TEOAEs versus DPOAEs

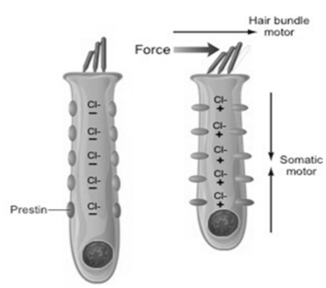


Shera, 2009

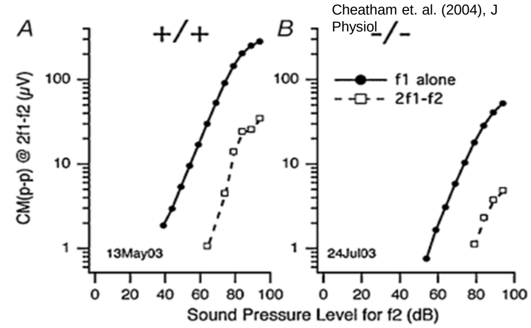
Auditory Anatomy Involved in the Generation of OAEs

- ❑ **Outer hair cell motility**
  - ● **Prestin motor protein**
- ❑ **Stereocilia**
  - ● **Motion**
  - ● **Stiffness**
- ❑ **Tectorial membrane**
- ❑ **Basilar membrane mechanics**
  - ● **Dynamic interaction with outer hair cells**
- ❑ **Stria vascularis**
- ❑ **Middle ear (inward and outward propogation)**
- ❑ **External ear canal**
  - ● **Stimulus presentation**
  - ● **OAE detection**

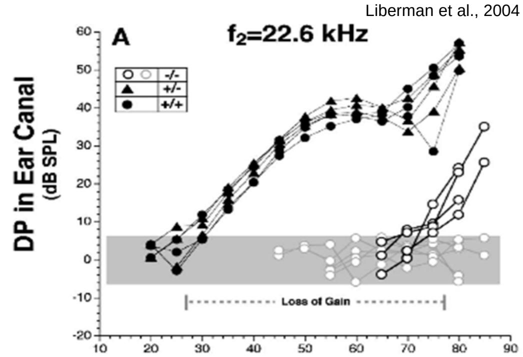
Prestin Knock Out



Cheatham et. al. (2004), J Physiol



Liberman et al., 2004

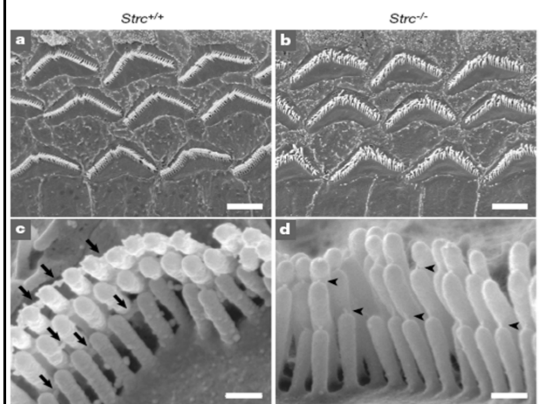


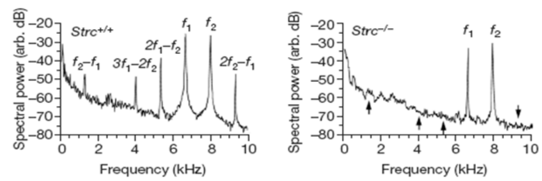
doi:10.1038/nature07380 nature

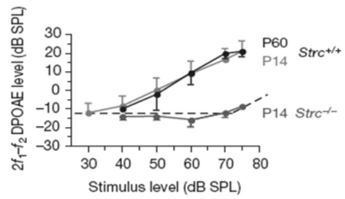
LETTERS

Stereocilin-deficient mice reveal the origin of cochlear waveform distortions

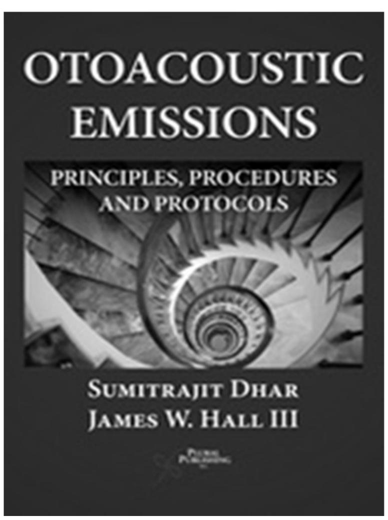
Elisabeth Verpy[1,2,3,4], Dominique Weil[1,2,3,4]*, Michel Leibovici[1,2,3,4]*, Richard J. Goodyear[5], Ghislaine Hamard[6], Carine Houdon[1,2,3,4], Gaelle M. Lefèvre[1,2,3,4], Jean-Pierre Hardelin[1,2,3,4], Guy P. Richardson[5], Paul Avan[7]* & Christine Petit[1,2,3,4]*







An Up-to-Date and Understandable Explanation of the Generation of OAEs and Efferent Inhibition of OAEs



Plural Publishing
(www.pluralpublishing.com)
150 pages, Softcover, 5 x 7.5"
ISBN10: 1-50756-342-0
ISBN13: 978-1-59756-342-0
$45.00

A CLINICIAN’S GUIDE TO OAE MEASUREMENT

- ❑ Introduction
- ❑ Update on generation of OAEs
- ❑ Protocols for TEOAEs and DPOAEs
- ❑ Criteria for OAE analysis
- ❑ Factors influencing OAE results
- ❑ OAE versus audiogram findings

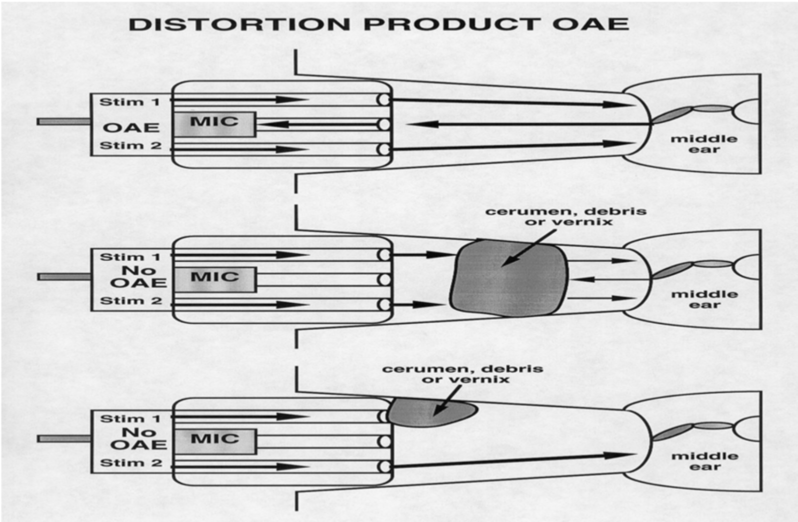
A CLINICIAN’S GUIDE TO OAE MEASUREMENT: *Four Fundamental Steps*

- ❑ Perform otoscopic inspection
- ❑ Determine risk for middle ear dysfunction
  - Patient history
  - Conduct tympanometry and acoustic reflexes as indicated to rule out or confirm middle ear dysfunction
- ❑ Verify stimulus calibration in the patient’s external ear canal
  - Actual stimulus levels are in alignment with target stimulus levels (e.g., L2 = 55 dB; L1 = 65 dB)
- ❑ Confirm low noise levels in the external ear canal
  - Less than 95%ile for normal subjects

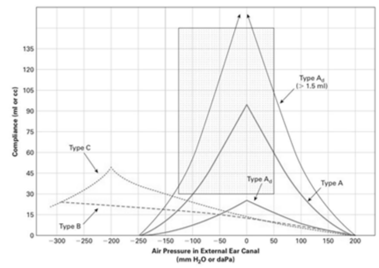
Guidelines for Measurement of Otoacoustic Emissions in Clinical Audiology

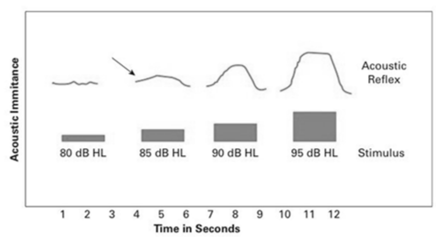
- ❑ Perform otoscopic inspection before OAE recording
- ❑ OAE is recorded in the external ear canal
- ❑ OAE recording may be compromised by ear canal:
  - Cerumen
  - Vernix
  - Debris
  - Foreign objects

Guidelines for Measurement of Otoacoustic Emissions in Clinical Audiology



OAEs: *Four Steps Prior to Measurement …* *Perform Tympanometry and Acoustic Reflexes*





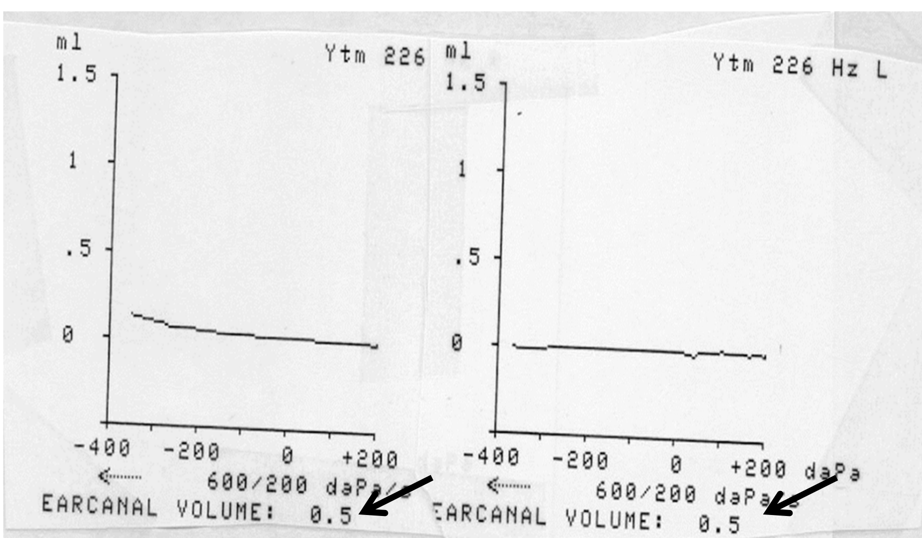
Diagnosis of Hearing Loss: Protocol for Confirmation of Hearing Loss in Infants and Toddlers (0 to 6 months) *Year 2007 JCIH Position Statement*

- ❑ **Child and family history**
- ❑ **Otoacoustic emissions**
- ❑ **ABR during initial evaluation to confirm type, degree & configuration of hearing loss**
- ❑ **Acoustic immittance measures (including acoustic reflexes) *using high frequency (1000 Hz) probe tone***
- ❑ **Supplemental procedures (insufficient evidence to use of procedures as “sole measure of auditory status in newborn and infant populations”)**
  - **Auditory steady state response (ASSR)**
  - **Acoustic middle ear reflexes for infants < 4 months**
  - **Broad band reflectance**
- ❑ **Behavioral response audiometry *(if feasible)***
  - ✓ **Visual reinforcement audiometry *or***
  - ✓ **Conditioned play audiometry**
  - ✓ **Speech detection and recognition**
- ❑ **Parental report of auditory & visual behaviors**
- ❑ **Screening of infant’s communication milestones**

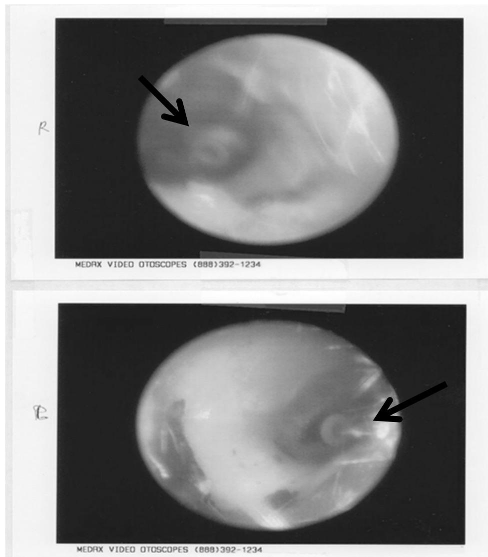
What About Tympanostomy (Ventilation) Tubes?
Can OAEs Be Recorded?

- Daya et al. (1966). Otoacoustic emissions: Assessment of hearing after tympanostomy tube insertion. Clin Otolaryngol 21: 492-494.
- Owens, McCoy, Lonsbury-Martin, Martin. (1993). Otoacoustic emissions in children with normal ears, middle ear dysfunction, and ventilating tubes. Amer J Otol 14: 34-40.
- Tilanus. Stenis, Snik.(1995). Otoacoustic emission measurements in evaluation of the effect of ventilation tube insertion in children. Annals of ORL 104: 297-300.
- Richardson, Elliott, Hill. (1996). The feasibility of recording transiently evoked otoacoustic emissions immediately following grommet insertion. Clin Otolaryngol 21: 445-448.
- Cullington, Kumar, Flood. (1998). Feasibility of otoacoustic emissions as a hearing screen following grommet insertion. Brit J Audio 32: 57-62.

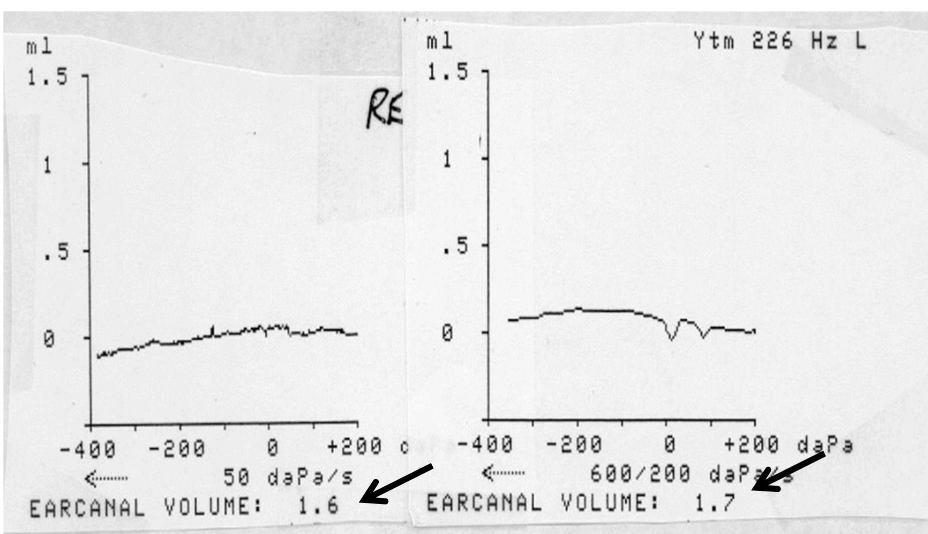
Tympanometry (Type B) in a Child with Otitis Media



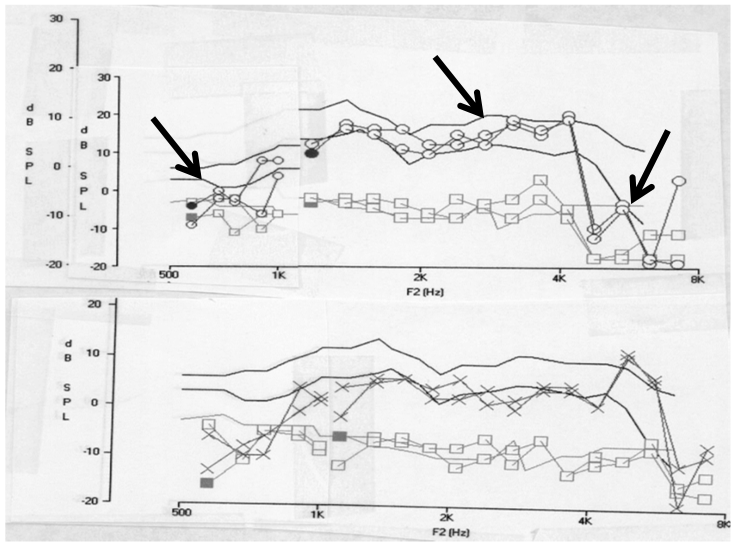
Tympanostomy Tubes for Child with Otitis Media



Tympanometry Following Insertion of Tympanostomy Tubes … Technically Not Possible

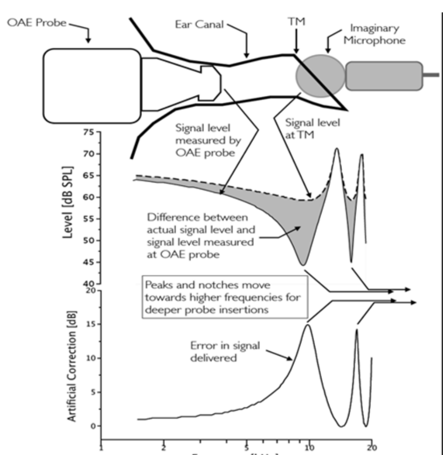


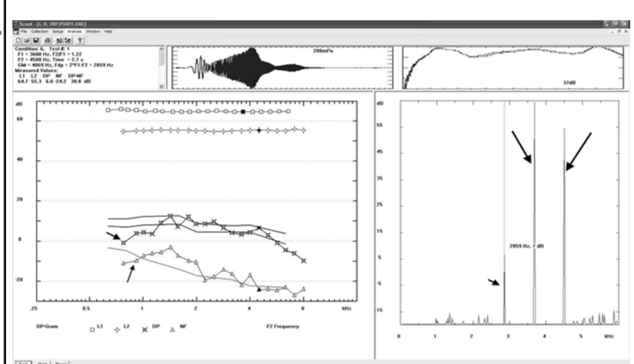
DPOAEs in a Child with Tympanostomy (Ventilation) Tubes



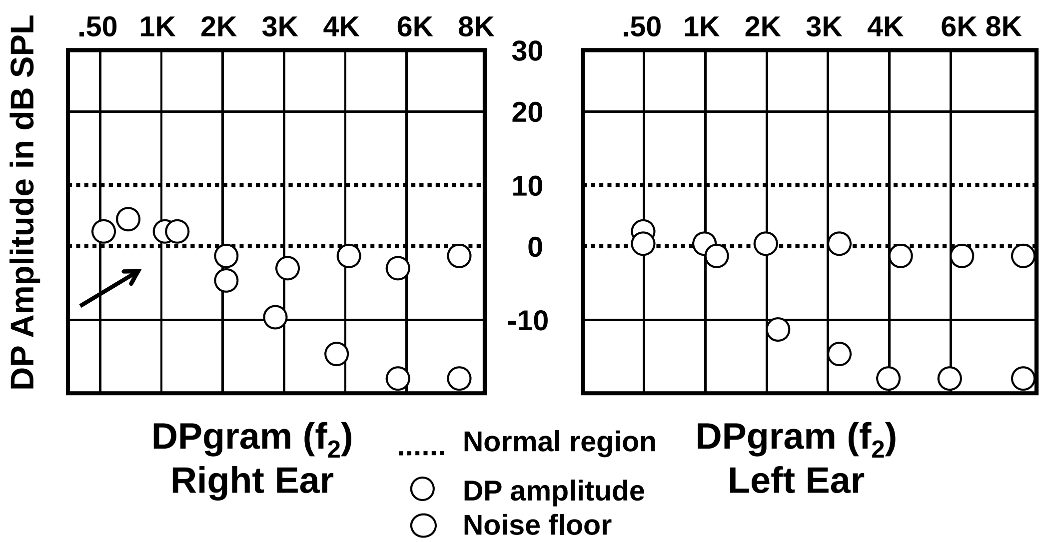
OAE Measurement: Daily Probe Calibration Hard Wall Cavity and *In Ear Calibration wit Patient*

(Dhar & Hall, 2011)

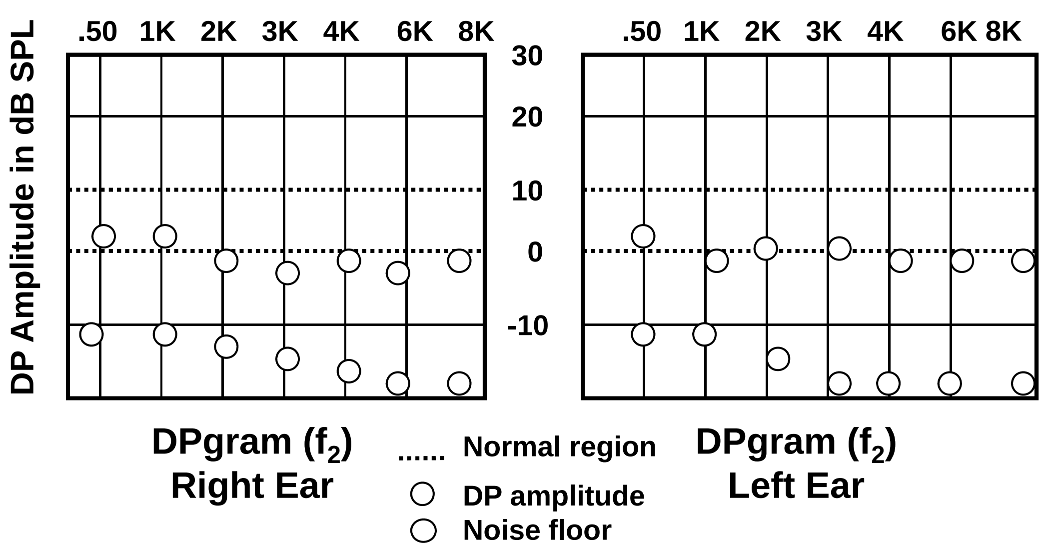




What Is Wrong With This DPOAE Recording?



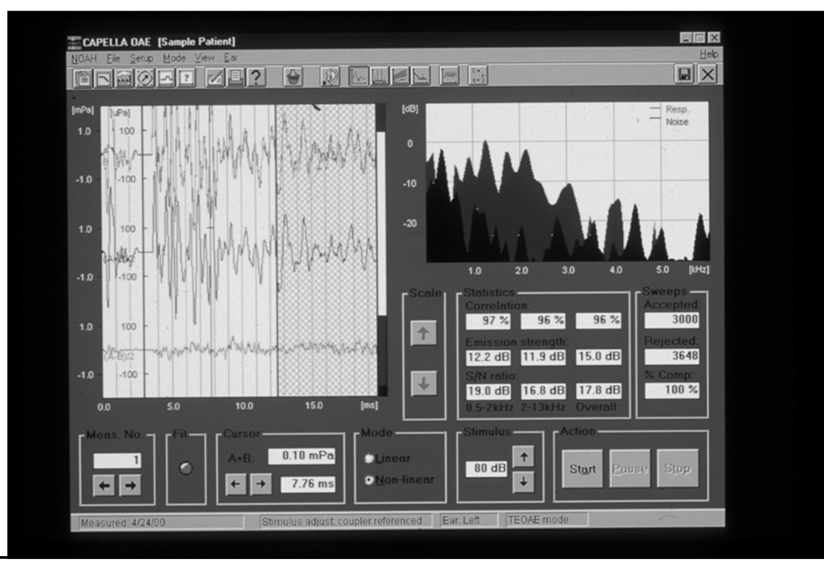
OAEs are Sound Measured in the External Ear Canal:
Goal is Noise Floor of < 10 dB



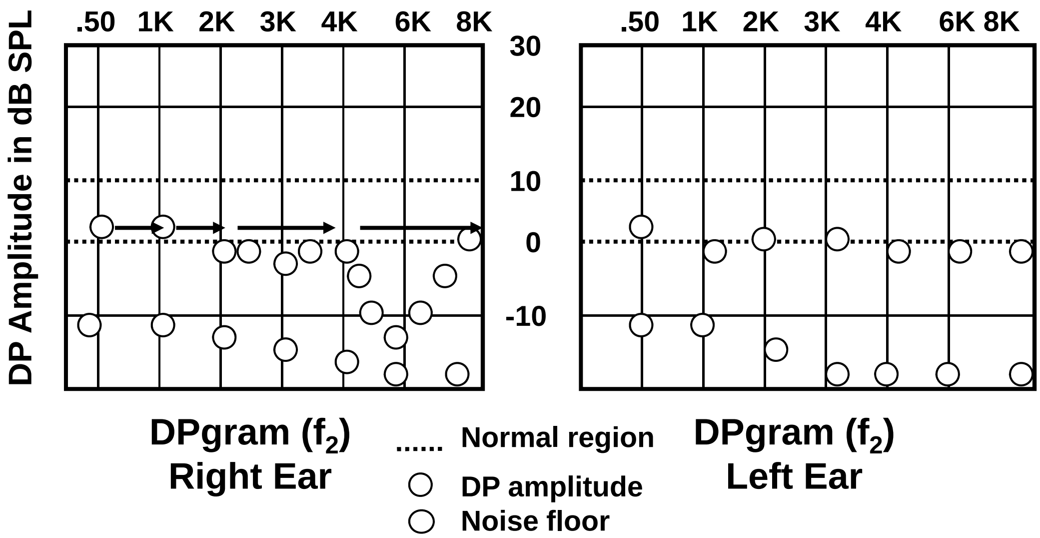
A CLINICIAN’S GUIDE TO OAE MEASUREMENT
Strategies for Lowering Noise Floor

- ❑ **Two sources of noise**
  - **Acoustical**
  - **Physiological**
- ❑ **Techniques for minimizing noise in the EAC**
  - **Reduce ambient noise**
  - **Tight probe fit**
  - **Deep probe insertion**
  - **Locate patient away from OAE equipment**
  - **Modify test protocol**

OAEs are Highly Frequency Specific: TEOAEs with 40 Hz Frequency Resolution



OAEs are Highly Frequency Specific:
Probe Inter-Octave Cochlear Function with 5 to 8 Frequencies/Octave Over a Wide Range of Frequencies



A CLINICIAN'S GUIDE TO OAE MEASUREMENT:
Simple Steps Including Trouble-Shooting

- ❑ **Do all you can to assure patient is quiet and not moving**
- ❑ **Minimize ambient noise in test environment**
- ❑ **Verify clear external ear canal**
- ❑ **Confirm open ports in the OAE probe assembly**
- ❑ **Obtain secure and deep probe fit in the external ear canal**
- ❑ **Verify that target stimulus intensity levels are met**
- ❑ **Verify noise levels are below normal limits**
- ❑ **Rule out middle ear dysfunction for abnormal OAE findings**
- ❑ **Verify that OAE recordings are replicable**
- ❑ **Compare patient OAE findings versus normative data**

Create DPOAE Test Protocols for Specific Clinical Applications

Test Parameters	Diagnostic			Screening	
	General	HF	LF	Newborn	School
L_1/L_2 intensity (dB)	65/55*	65/55*	65/55	65/55	65/55
F_2/F_1 ratio	1.20	1.20	1.20	1.20	1.20
F_2 range (Hz)	0.5-8K	2-10K	0.5-1K	2-5K	2-8K
F_2 / octave	5 - 8	8	5	4	3
Averaging		Less	More	More	
Example of application	Basic test Tinnitus	Ototox. NIHL	MD		

**** Decrease intensity to increase test sensitivity***

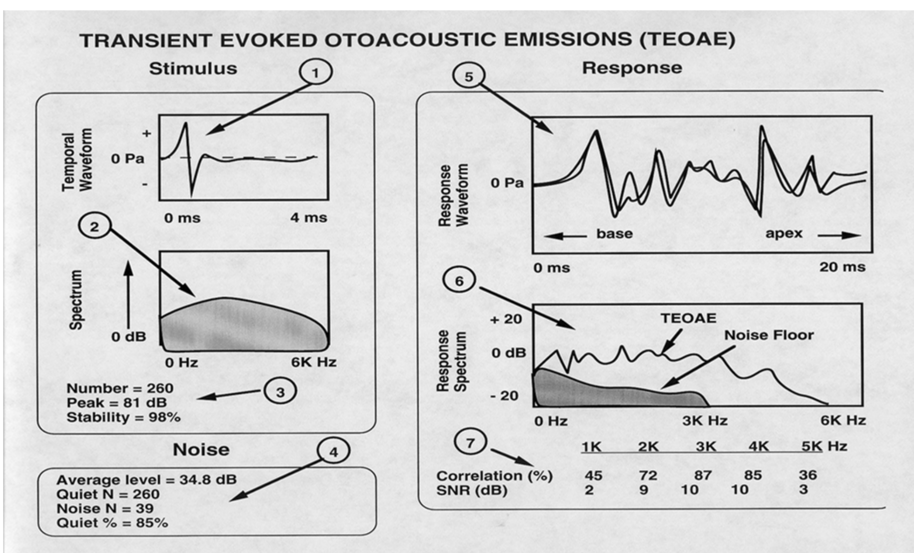
A CLINICIAN'S GUIDE TO OAE MEASUREMENT

- ❑ Introduction
- ❑ Update on generation of OAEs
- ❑ Protocols for TEOAEs and DPOAEs
- ❑ Criteria for OAE analysis
- ❑ Factors influencing OAE results
- ❑ OAE versus audiogram findings

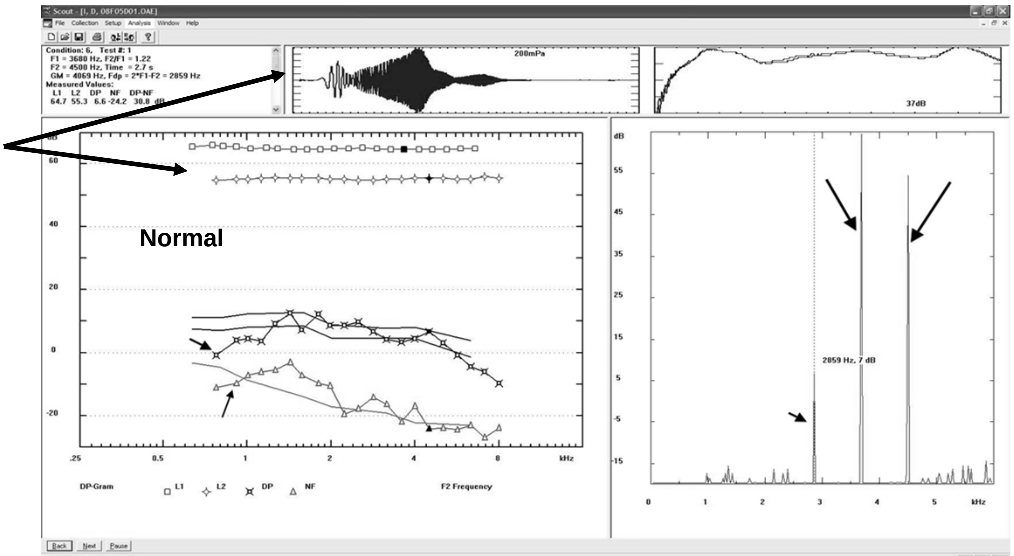
General Steps in Analysis of TEOAE or DPOAE Findings

- ☐ Verify adequately low noise floor (< 90% normal limits)
- ☐ Perform analysis at all test frequencies
- ☐ Verify repeatability of TEOAE or DPOAE amplitude (+/- 2 dB) from at least two runs
- ☐ Is OAE - NF difference > 6 dB?
  - Yes? OAEs are present
  - No? There is no evidence of OAEs
- ☐ Is DP amplitude within normal limits?
  - Yes? OAEs are normal
  - No? OAEs are abnormal (but present)

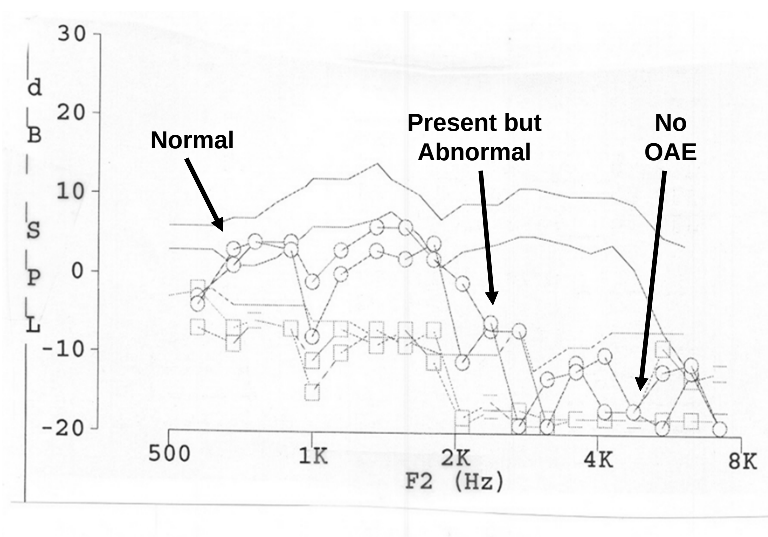
Analysis of Transient Evoked Otoacoustic Emissions (TEOAEs)



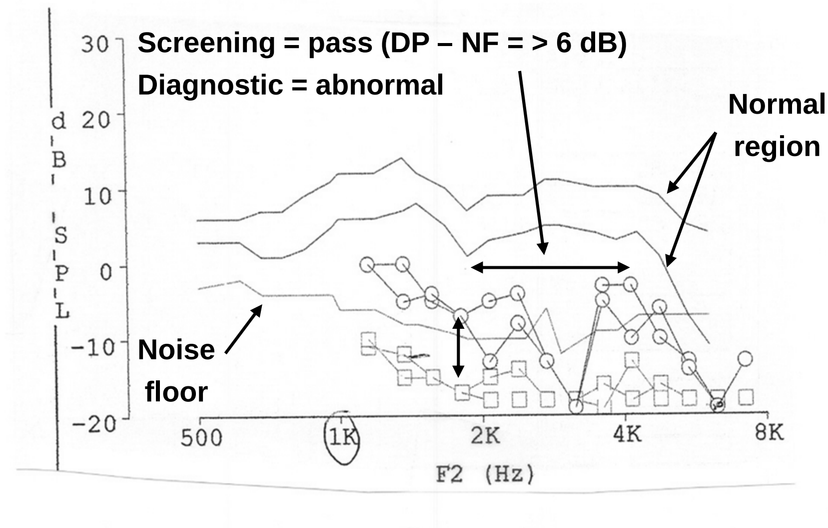
Analysis of Distortion Product Otoacoustic Emissions (DPOAEs)



Analysis of Distortion Product Otoacoustic Emissions (DPOAEs)



Diagnostic Application of OAEs:
Findings for Multiple Frequencies vs. Normal Region



A CLINICIAN'S GUIDE TO OAE MEASUREMENT:
General Steps in Analysis of OAE Findings

- **Three OAE outcomes**
  - **Normal (not simply "present"):**
    - ✓**Repeatable OAES with amplitudes within appropriate normal region**
  - **Present but abnormal**
    - ✓**Repeatable OAEs but amplitudes below normal region**
  - **No OAEs**
    - ✓**Amplitude < 6 dB above noise floor**

A CLINICIAN’S GUIDE TO OAE MEASUREMENT

- ❑ Introduction
- ❑ Update on generation of OAEs
- ❑ Protocols for TEOAEs and DPOAEs
- ❑ Criteris for OAE analysis
- ❑ Factors influencing OAE results
- ❑ OAE versus audiogram findings

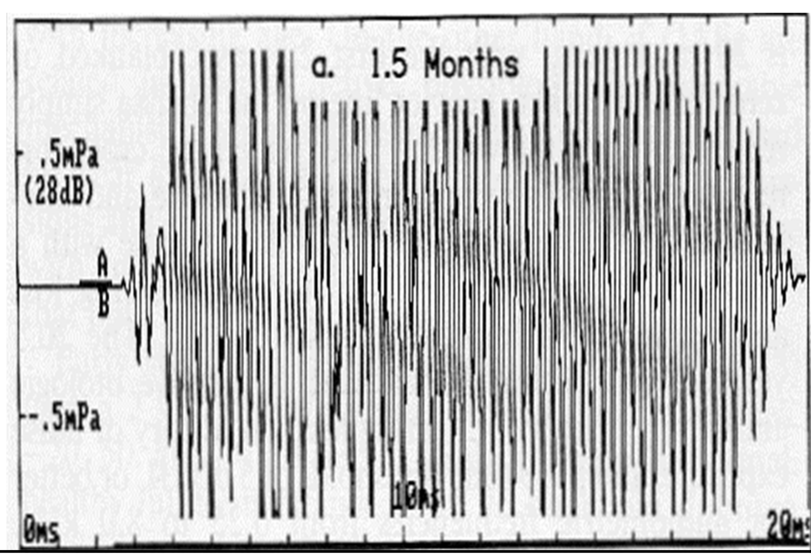
A CLINICIAN’S GUIDE TO OAE MEASUREMENT: *Non-Factors in OAE Interpretation*

- ❑ Diurnal effects (time of day)
- ❑ Body temperature
- ❑ Body position
- ❑ Anesthetic agents (assuming normal middle ear status
- ❑ State of arousal (awake or asleep)
- ❑ Attention to stimulus
- ❑ Listener variables
  - Motivation
  - Cognitive status
  - Language abilities

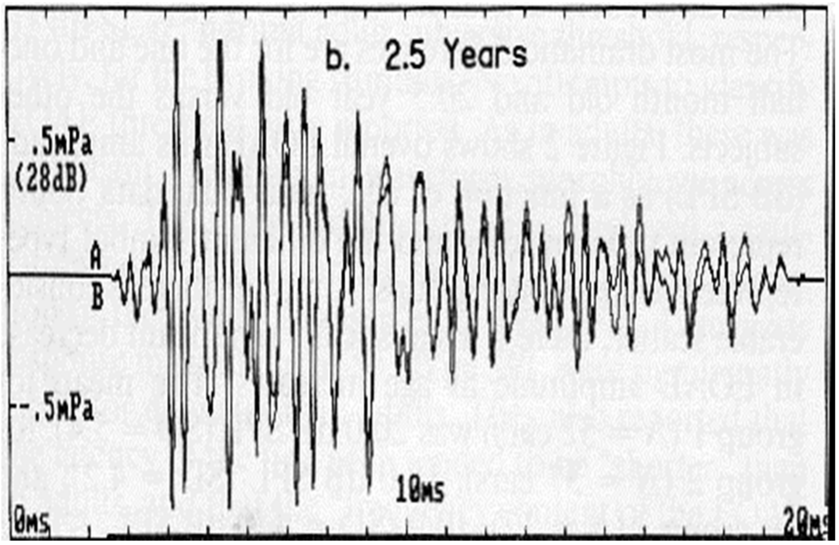
A CLINICIAN'S GUIDE TO OAE MEASUREMENT:
Factors in OAE Interpretation

- ❑ Ear canal status
  - ●Cerumen and vernix
  - ●Debris
- ❑ Noise
  - ●Ambient acoustical noise
  - ●Physiological noise
- ❑ Age
  - ●Young children
  - ●Older Adults
- ❑ Middle ear status
- ❑ Cochlear (outer hair cell) status

OAEs are Largest in Young Children:
Tiny Ear Canal Volume and Immature Efferent System?

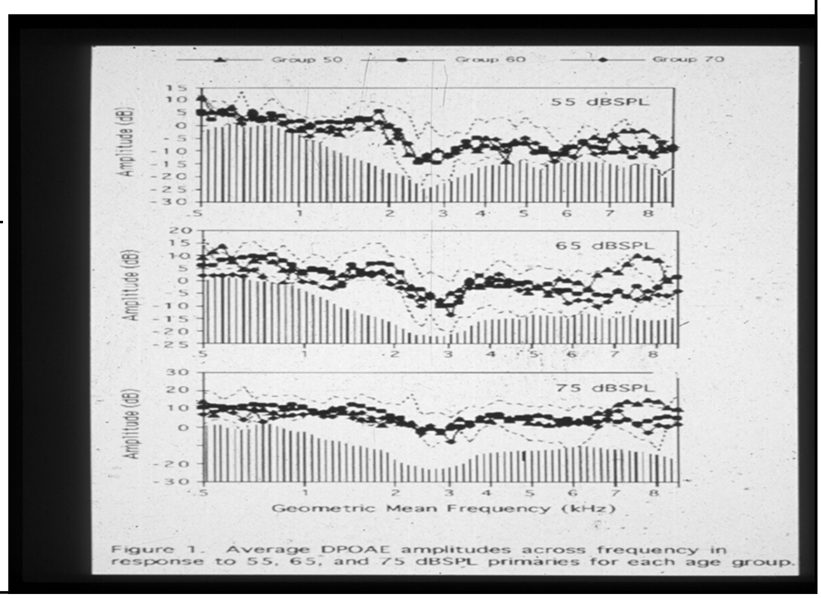


OAE Amplitude Decreases with Age in Children

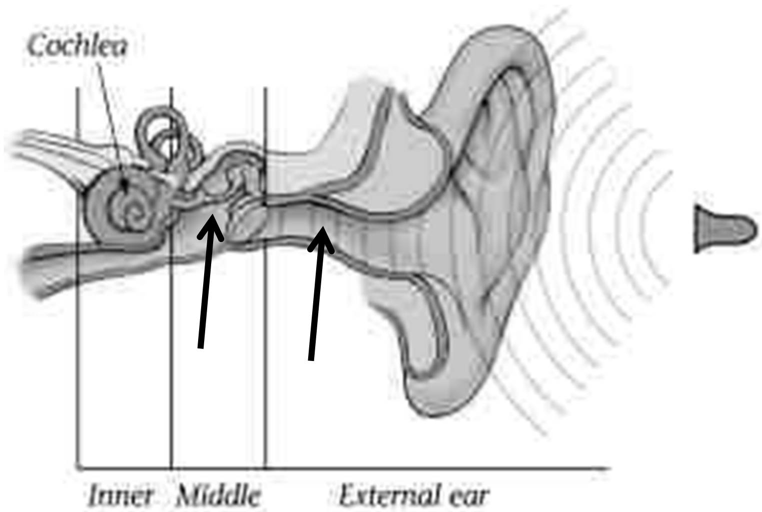


OAE Amplitude is Stable in Aging Adults With Normal Hearing Sensitivity

Strouse, Ochs, Hall, Bess F.H. Evidence against the influence of aging on distortion-product otoacoustic emissions. **JAAA, 7:** 339-345, 1996



Absent or Questionable OAEs?
Find an Explanation



Absent OAEs: Technical Problem or Evidence of A Non-Cochlear Abnormality?

- ❑ **Non-pathologic explanations**
  - **Probe tip placement, size, or condition**
  - **Standing wave interference**
  - **Cerumen or debris**
    - ✓**In ports of probe**
    - ✓**Occluding external ear canal**
  - **Vernix casseous (healthy newborn infants)**
  - **Gender (smaller TEOAEs in men)**
- ❑ **Pathologic explanations**
  - **Stenosis**
  - **External otitis**
  - **Middle ear dysfunction**

Standing Wave Interference:
Possible for DPOAEs Above 5000 Hz

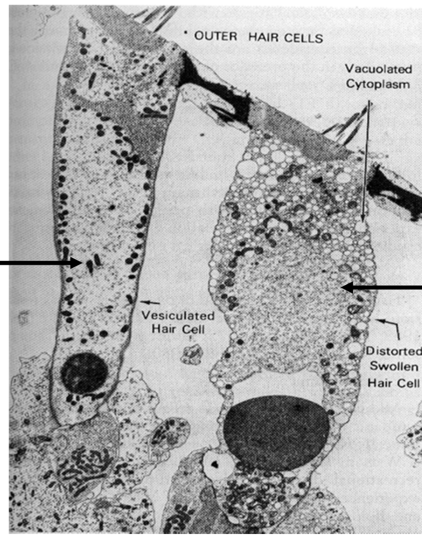
- **Siegel J. 1994. Ear-canal standing waves and high-frequency sound calibration using otoacoustic emission probes. JASA 95: 2589-2597. *[+/- 20 dB error]***
- **Siegel JH. 1995. Cross-talk in otoacoustic emission probes. Ear and Hearing 16: 150-158.**
- **Siegel JH & Hirohata ET. 1994. Sound calibration and distortion product otoacoustic emissions at high frequencies. Hearing Research 80: 146-152.**

A CLINICIAN'S GUIDE TO OAE MEASUREMENT

- **Introduction**
- **Update on generation of OAEs**
- **Protocols for TEOAEs and DPOAEs**
- **Criteria for OAE analysis**
- **Factors influencing OAE results**
- **OAE versus audiogram findings**

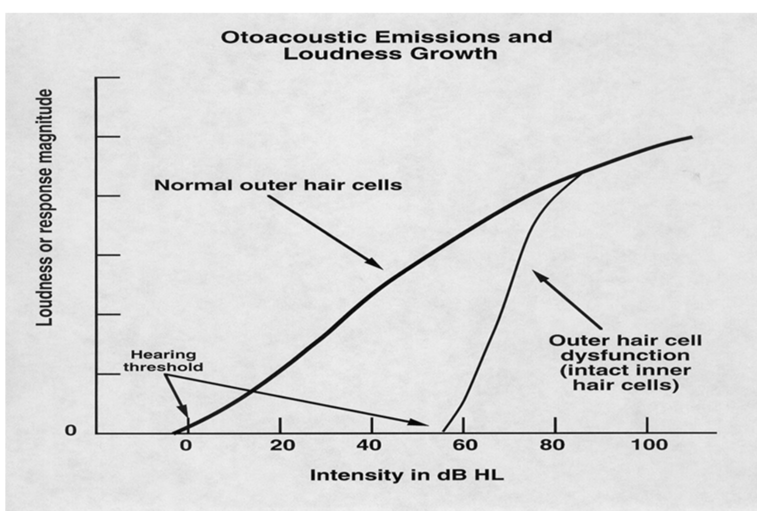
Early Detection of Outer Hair Cell Dysfunction with OAEs:
Rationale Underlying Many Clinical Applications

Normal OHC (OAEs)



Abnormal OHC (OAEs)

OAE MEASUREMENT AND ANALYSIS:
Findings in Outer Hair Cell Dysfunction

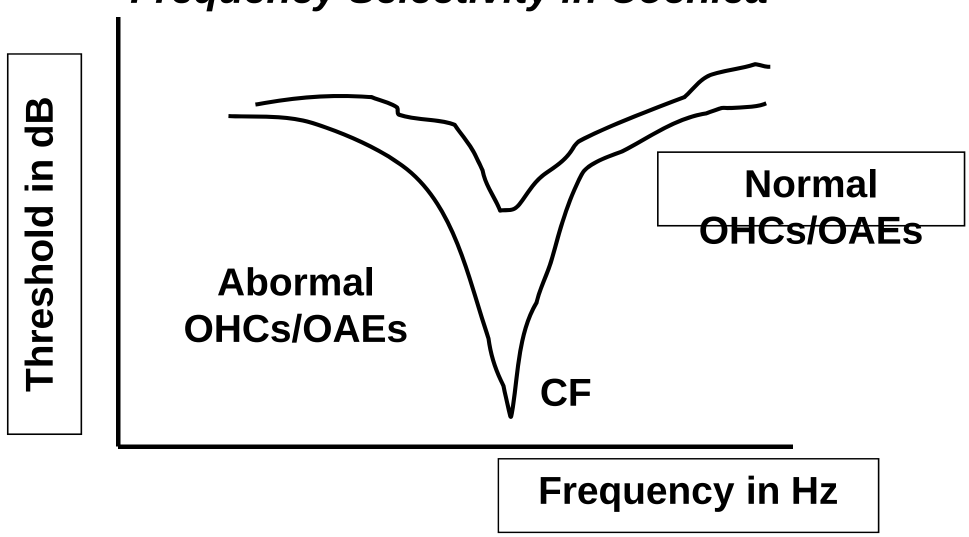


OAEs:
Abnormal OHCs and Loudness Recruitment

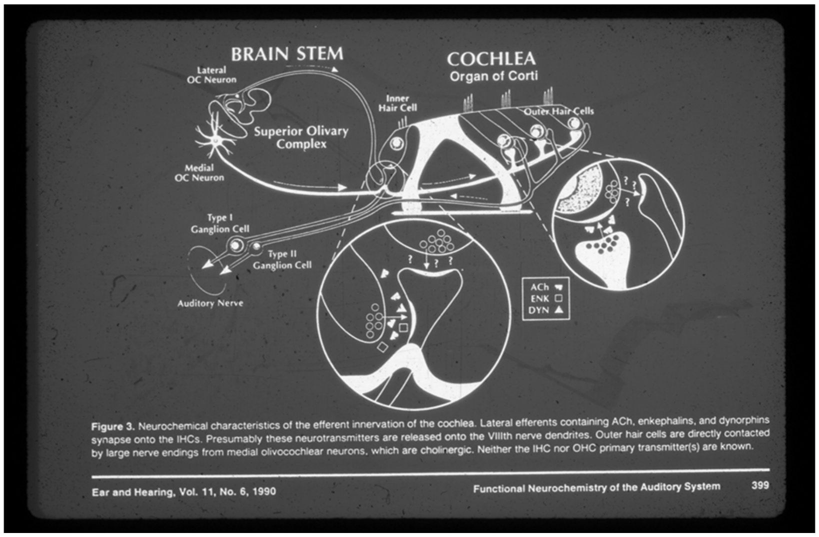
"The phenomenon of loudness recruitment appears to be the psychoacoustic expression of the loss of a large component of outer hair cells and the concurrent preservation of a large component of inner hair cells and type I cochlear neurons."

Schuknecht HF. Pathology of the Ear (2nd ed). 1993, p. 91

OAEs and Auditory Function:
Frequency Selectivity in Cochlea



OAEs and Auditory Function:
Generation of OAEs is "Pre-Neural"
(Very Important for Identification of ANSD)



A CLINICIAN'S GUIDE TO OAE MEASUREMENT:
Relation of OAEs to Audiogram

OAEs	Audiogram	Possible Interpretation
Normal	Normal	Normal cochlear function
Abnormal	Normal	> Outer hair cell dysfunction > Rule out middle ear dysfunction
Normal	Abnormal	> Technical problems > Inner hair cell dysfunction > Neural auditory dysfunction > False hearing loss

Thank You!

Questions?

Grandson Charlie Hall
October 2012
(age 2 weeks)

Grandson William James Finn McNeal
April 2015
(age 24 hours)