Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Essential for Successful EHDI*

James W. Hall III, Ph.D.

Professor
Salus University

Adjunct Professor
Nova Southeastern University

Extraordinary Professor
University of Pretoria South Africa

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

Early Hearing Loss Detection and Intervention (EHDI):

Timely and Accurate Diagnosis of Hearing Loss in Children is an Important Step Toward Early Intervention (Habilitation)

Identification → Diagnosis → Intervention → Outcome

Identification
- Screening
- History
- Parent-Referral
- Professional referral

Diagnosis
- Hearing loss
- SNHL
- CHL
- Unilateral
- ANSD
- APD
- Vestibular disorder

Intervention
- Hearing aids
- Aural Rehab
- Counseling
- Cochlear implant (s)
- Vestibular rehab
- Drugs
- Surgery

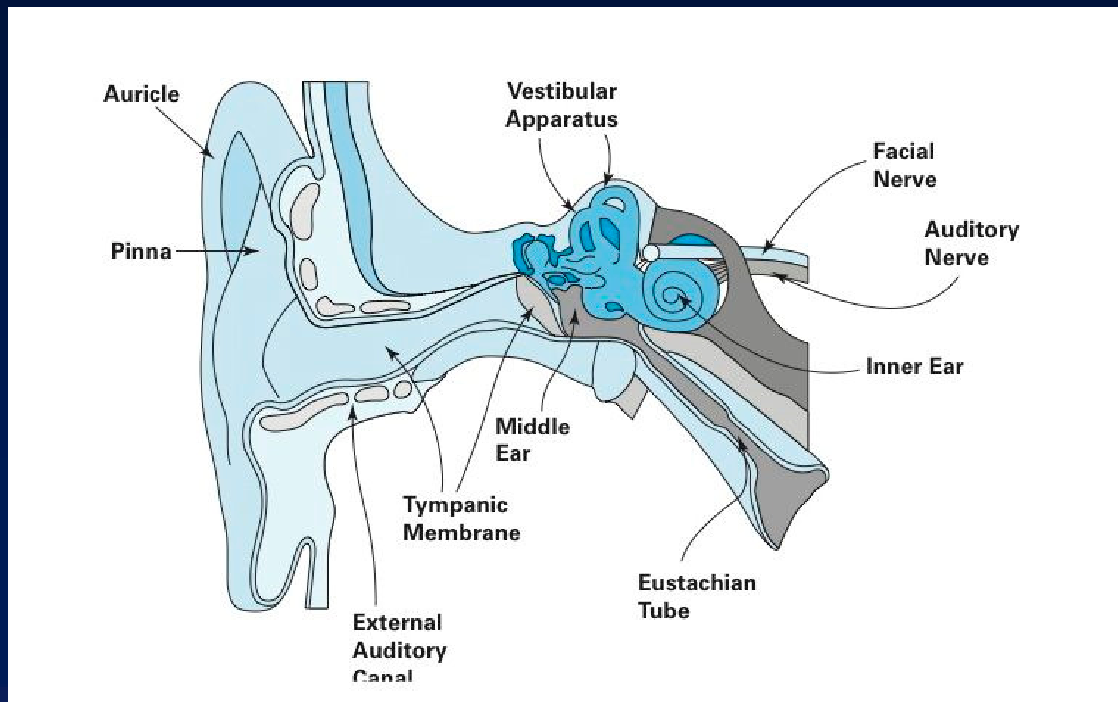
Outcome
- Effective communication
- Efficient communication
- Academic success
- Financial independence
- Quality of life

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Essential for Successful EHDI*

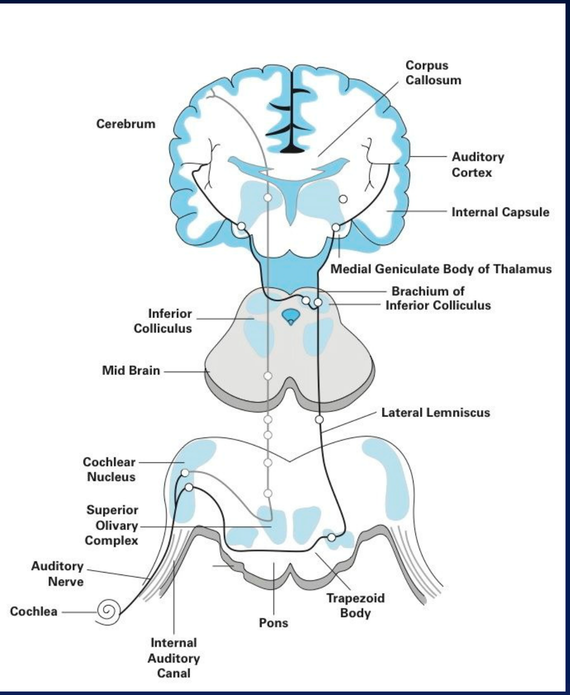
- A brief history of universal newborn hearing screening (UNHS)
- UNHS doesn't always lead to universal diagnosis and intervention of childhood hearing loss
- Rationale for pre-school screening for hearing loss
- Historical perspective on pre-school hearing screening
- Techniques and technology for pre-school hearing screening: What are the options?
- Current clinical guidelines for pre-school hearing screening and diagnosis of hearing loss
- A new strategy for effective and efficient pre-school hearing screening and diagnosis of hearing loss
- Future directions in pre-school hearing screening

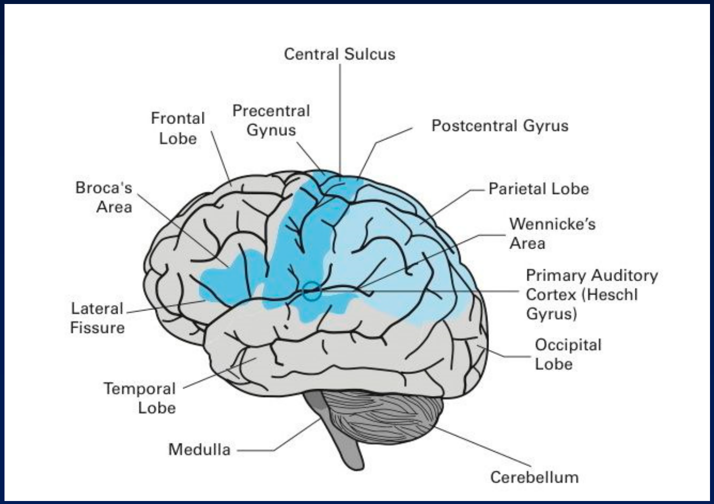
Early Hearing Loss Detection and Intervention (EHDI)

(Hall JW III. Introduction to Audiology Today. Boston: Pearson, 2014)

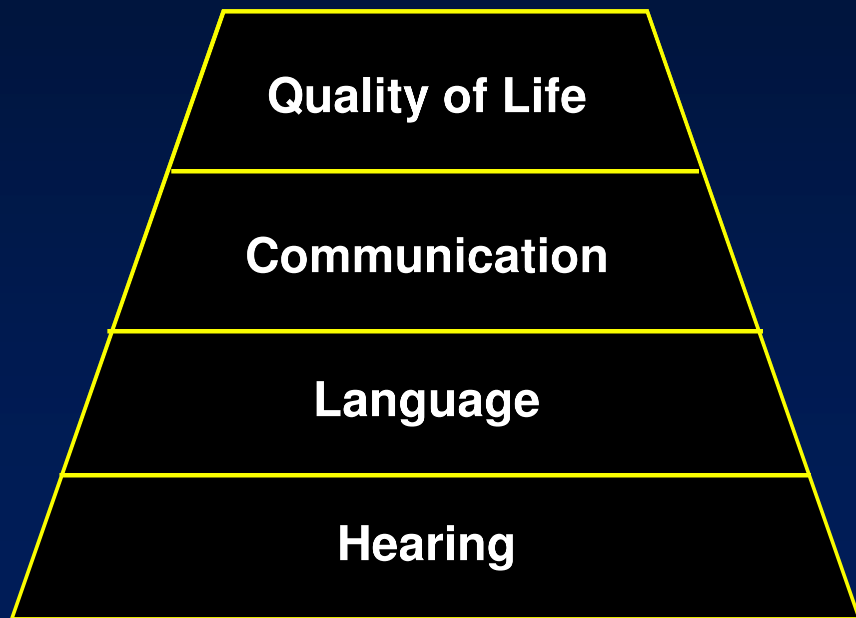


Early Hearing Loss Detection and Intervention (EHDI):
Remember … We Hear with Our Brain
(Hall JW III. Introduction to Audiology Today. Boston: Pearson, 2014)





Hearing: An Important Building Block in the Foundation for Quality of Life



Marion Downs (1914-2014)
"Mother of Newborn Hearing Screening, Pediatric Audiology, and Founder of JCIH"

UNHS HISTORICAL PERSPECTIVE:
Early work by Marion Downs

- **Froding CA. (1960). Acoustic investigation of newborn infants. Acta Otolaryngol 52: 31-41 *(aural-palpebral response)***
- **Downs MP, Sterritt GM. (1964). Identification audiometry for neonates: A preliminary report. J Auditory Res 4: 69-80. *(APR, startle, and behavioral responses to 3000 Hz narrow band stimulus)***
- **Downs MP, Sterritt GM. (1967) A guide to newborn and infant hearing screening programs. Arch Otolaryngol 85: 37-44.**
- **Downs MP, Hemenway WG. (1969). Report on the hearing screening of 17,000 neonates. Int'l Audiology 8: 72-76. *(study led to formation of first Joint Committee on Infant Hearing in 1969)***

Joint Committee on Infant Hearing: Defining Standard of Care for Early Detection and Identification of Hearing Loss

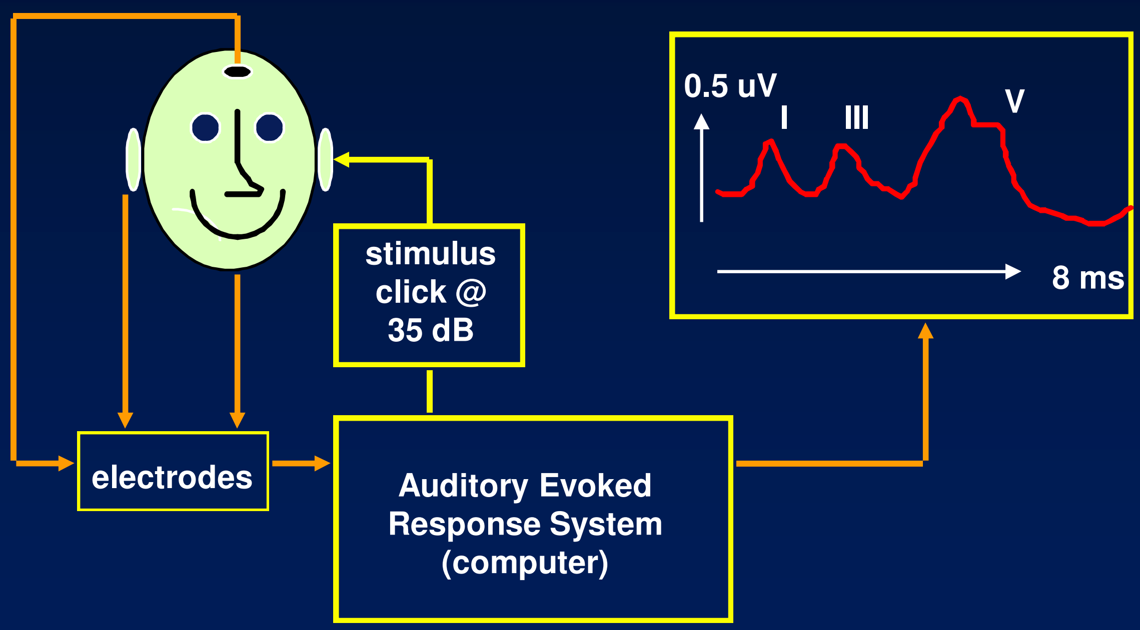
- **Member organizations:**
  - **Alexander Graham Bell Association for the Deaf and Hard of Hearing**
  - **American Academy of Audiology (AAA)**
  - **American Academy of Otolaryngology-Head & Neck Surgery**
  - **American Academy of Pediatrics**
  - **ASHA**
  - **Council on Education of the Deaf**
  - **Directors of Speech and Hearing Programs in State and Welfare Agencies (EHDI state directors)**

Robert Galambos, MD, PhD

Pioneer in ABR and Newborn Hearing Screening

(See tribute in the Hearing Journal, 64, 2011)

Infant Hearing Screening and Diagnosis: Auditory Brainstem Response (ABR)



ABR mature by ~ 18 months

ABR in Newborn Hearing Screening and Diagnosis of Infant Hearing Loss: *Contributions of Robert Galambos*

- **1971: Jewett DL & Williston JS. Auditory evoked far fields averaged from the scalp of humans.** *Brain 4*. **[Note: Don Jewett was a post-doctoral student of Robert Galambos]**
- **1974: Hecox KE & Galambos R. Brain stem auditory evoked responses in human infants and adults.** *Archives of Otolaryngology 99.*
- **1975: Schulman-Galambos C. & Galambos R. Brain stem evoked responses in premature infants.** *JSHR 18*.
- **1979: Schulman-Galambos C. & Galambos R. Brain stem evoked response audiometry in newborn hearing screening.** *Archives of Otolaryngology 105*:

Early Newborn Risk Factors for Hearing Loss: 1982 Joint Committee on Infant Hearing

- Family history of childhood hearing loss
- Congenital infection associated with hearing loss, e.g., cytomegalovirus (CMV), herpes, syphilis, rubella
- Bacterial meningitis
- Craniofacial anomalies (morphologic abnormalities of the ear)
- Low birth weight (< 1500 grams)
- Hyperbilirubinemia (requiring exchange transfusion)
- Aphyxia (APGAR scores of 0 – 3 at five minutes)

Newborn Hearing Screening of At Risk Infants by Audiologists in the 1980s

Universal Newborn Hearing Screening (UNHS): First Clinical Trials with Automated ABR
(Hall, Kileny & Ruth, 1987)

UNHS WITH AUTOMATED AABR: A MULTI-SITE INVESTIGATION
J Perinatology 20 ((8): S128, December 2000.

James W. Hall III, Ph.D.
University of Florida
Gainesville, Florida, U.S.A.

Albert Mehl, M.D.
Boulder Community Hospital
Boulder, Colorado

Vicki Thomson, M.A.
Boulder Community Hospital
Boulder, Colorado

Dan Stewart, M.D.
Kosair Children's Hospital
Louisville, Kentucky

Mark Carroll, M.S.
E.N.T. Associates
Huntsville, Alabama

James Hamlett, M.D.
Baptist Memorial Hospital East
Memphis, Tennessee

NEWBORN HEARING SCREENING WITH AABR (N = 11,711)

SITE	NURSERY	N	SCREENERS	TIME OF SCREEN
Boulder	WBN	1228	volunteers	22 hrs
Louisville	WBN	6061	nurses	28 hrs
Memphis	WBN	1563	technicians	19
Huntsville	WBN	2071	audiologists	24
Nashville	ICN	788	audiologists nurses grad students	- - -

NEWBORN HEARING SCREENING WITH AABR
Age at Initial Screen

			Age at Initial Screen (hours)		
SITE	WBN	ICN	Minimum	Median	Maximum
Boulder	98%	2%	4.5	22	1440 (60 days)
Louisville	>99%	<1%	1.5	28	2304 (96 days)
Memphis	>99%	N=1	2.5	19	120 (5 days)
Huntsville	93%	7%	2	24	3600 (150 days)
Nashville	0%	100%	24	216 (9 days)	2160 (90 days)

Newborn Hearing Screening of At Risk Infants with AABR

(From Hall JW III (2007). *New Handbook of Auditory Evoked Responses*. Boston: Allyn & Bacon)

TABLE 9.4. Published Reports of Automated Auditory Brainstem Response (AABR) in Newborn Hearing Screening (arranged chronologically)

STUDY (YEAR)	N	POPULATION	DEVICE	REFER RATE	COMMENT
Hall, Kileny, & Ruth (1987)	600	HR*	ALGO-1	<10%	Clinical trial of early automated ABR device
Jacobson & Jacobson (1994)	119	HR/WB	ALGO-1	3.8%	TEOAE refer rate was 38.4%
Chen et al. (1996)	260	HR	ALGO-1	15%	Prevalence of SNHL was 3.1%
Oudesluys-Murphy & Harlaar (1997)	277	WB*	ALGO-1	3.5%	Screening in infant's home in Netherlands
Doyle, Sininger, & Starr (1998)	116	WB	ALGO-2	8%	Refer rate of 43% for TEOAE
Mason & Hermann (1998)	10372	WB	ALGO-2	4%	Incidence of bilateral hearing loss of 1.4/1000
Hahn et al. (1999)	388	WB	ALGO-2	9%	Total average screening time was 8.26 minutes
Meyer et al. (1999)	777	HR	ALGO-1 Plus	5%	Bilateral refer rate was 2%
van Strääten et al. (1996)	250	HR	ALGO-1 Plus	2%	No false negatives were discovered
van Strääten (1999)	review article				Summary of AABR technique and rationale
Iley & Addis (2000)	44	WB	ALGO-2	4.5%	Screening time of 5 minutes
Sininger et al. (2000)	4831	HR	custom (Fsp)	<10%	Excellent review of AABR screening technique
	2348	WB	custom (Fsp)	14%	
Stewart et al. (2000)	11711	HR/WB	ALGO-2	<2%	Screening personnel not factor in refer rate
Messner et al. (2001)	5771	WB	ALGO-2	5%	Only volunteers used for screening
van Strääten et al (2001)	90	HR	ALGO-1 E	0%	Pass/refer rate decreased with gestational age
Vohr et al. (2001)	12081	WB	ALGO-2	3.21%	TEOAE refer rate was 6.49%
Meier, Narabayashi, Probst, & Schmuziger (2004)	150	WB	ALGO-3	2%	TEOAE and DPOAE refer rate was 3%
Murray et al. (2004)	194	WB	ALGO 3	5.7%	Average screening time was 70.8 seconds

* HR = high risk; WB = well babies with no risk factors; ALGO device by Natus, Inc.

Rationale for UNHS:
Prevalence of Infant Hearing Loss in the U.S.A.

Category	Births Annually	Prevalence	Total Hearing Loss
Healthy	3,600,000	3/1000	10,800
At-risk	400,000	30/1000	12,000
Total	4,000,000	5.7/1000	22,800

Northern & Hayes, 1994

Universal Newborn Hearing Screening: Rationale … Average Ages in Months for intervention
(Final Slide Part 1)

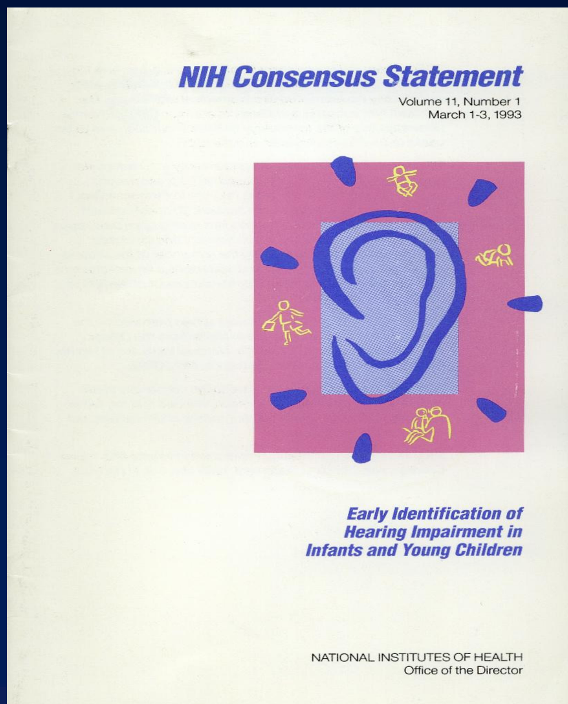
Hearing Loss	Suspicion	Dx	HA fitting	Intervention
No Risk Factor				
Mild/moderate	15	22	28	28
Severe/profound	8	13	16	16
Known Risk Factor				
Mild/moderate	8	12	22	28
Severe/profound	7	12	15	16

Harrison & Roush, 1996

UNHS Rationale: Economic Factors

- Estimated cost associated with deafness from birth to adulthood is approximately $900,000 (education, medical/audiologic expenses, special living expenses)
- Annual earnings for manually communicating deafened persons are 30% less than for general population
- As adults, persons with congenital deafness earn 5% less than those with onset of deafness after 3 years.
- Rate of unemployment for high school graduates who are deaf is twice as great as for normal hearers.
- Profound deafness produces an estimated annual loss of income of $2.5 billion in the United States

Universal Newborn Hearing Screening: Turning Point in the United States of America



- Evidence in support of benefits of early identification on speech and language development (for pediatricians)
- Recognition of economic consequences of hearing loss (by policy makers)
- Emergence of technology for automated auditory brainstem response (ABR) and otocoustic emissions (OAEs)
- Evidence of low failure rates (< 4%) and automated ABR and OAE techniques
- Relatively low cost of identifying infants with hearing loss versus expense of intervention with later identification

UNHS Rationale: Effects of infant hearing loss

NIH Consensus Statement "Early Identification of Hearing Impairment in Infants and Young Children" (March 1-3, 1993)

"There is general agreement that hearing impairment should be recognized as early in life as possible, so the remediation process can take full advantage of the developing sensory systems and so that the child can enjoy normal social development."

Recommendation: Universal Newborn Hearing Screening

UNHS: Criticism and Concern

"Universal hearing screening for infant hearing impairment: Not simple, not risk-free, not necessarily beneficial, and not presently justified"

Fred Bess and Jack Paradise

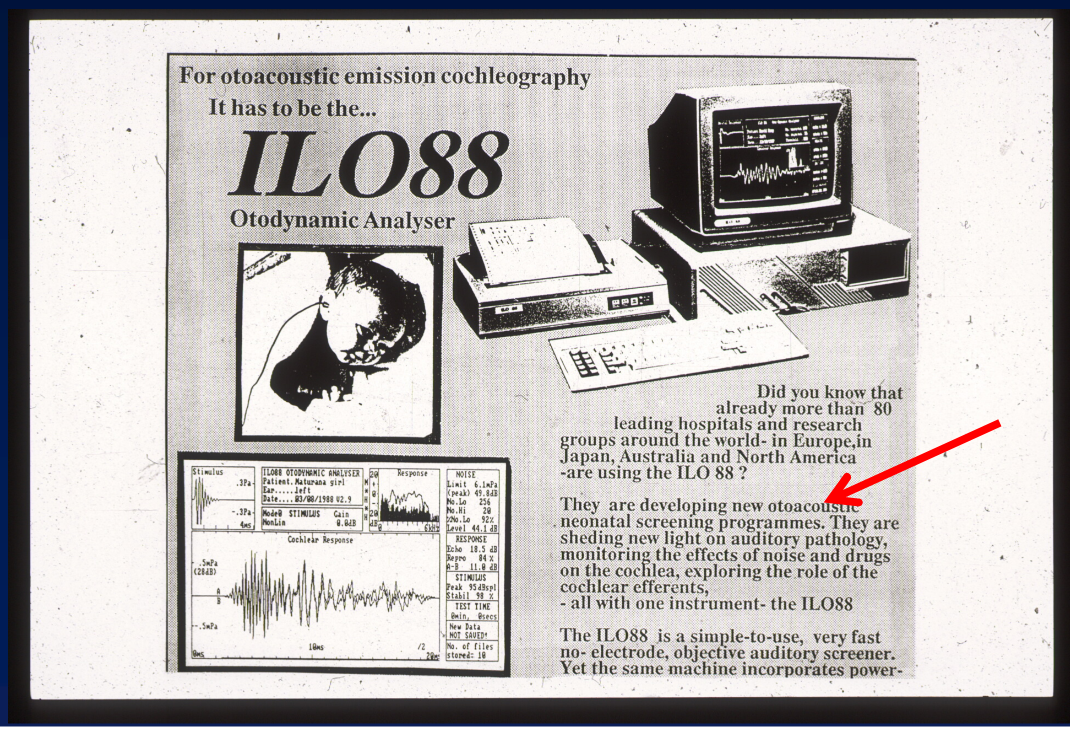
Pediatrics, February, 1994

Universal Newborn Hearing Screening: Endorsed in the *1994 JCIH Position Statement*

- "Hearing loss of 30dB HL and greater in the frequency region important for speech recognition will interfere with the normal development of speech and language.
- "Techniques used to assess hearing of infants must be capable of detecting hearing loss of this degree in infants by age three months and younger.
- Of the various approaches to newborn hearing assessment currently available, two physiologic measures...auditory brainstem response (ABR) and otoacoustic emissions (OAE)...show good promise for achieving this goal"

Joint Committee on Infant Hearing 1994 Position Statement

Newborn Hearing Screening with Otoacoustic Emissions (OAEs)



NEWBORN HEARING SCREENING: OTOACOUSTIC EMISSIONS

- Vohr et al. The Rhode Island Hearing Assessment Program: Experience with statewide hearing screening (1993-1996). Journal of Pediatrics 133: 353-357, 1998
  - 53,121 babies underwent screening (NICU =5130)
  - Average initial failure rate = 10%
  - Failure rate for rescreens at 2 to 6 weeks = 14.7%
  - Over failure (refer) rate = 1.2%
  - 111 infants identified with permanent hearing loss
  - Average age of intervention (amplification) = 5.7 months

Early Hearing Loss Detection and Intervention (EHDI):
OAE Technology for Infant Hearing Screening

Christie Yoshinaga-Itano, PhD

Yoshinago-Itano et al (Univ. of Colorado). Pediatrics 102 (5): 1161-1171, 1998.

Language of Early and Later Identified Children with Hearing Loss

- Yoshinago-Itano et al (Univ. of Colorado). Pediatrics 102 (5): 1161-1171, 1998.
  - N = 72 children with HL identified by 6 months and N = 78 children identified later
  - all children received intervention services with 2 months of identification
  - Conclusion: "Significantly better language development was associated with early ID of hearing loss and early intervention . . . the language advantage was found across all . . . degrees of hearing loss."

American Academy of Pediatrics (AAP) Committee on Newborn and Infant Hearing Loss: Detection and Intervention

- **Pediatrics 103 (2): 527-529, 1999 (February)**
- **Screening**
- **Tracking & Followup**
- **Evaluation**
- **Abstract:** *"This statement endorses the implementation of universal newborn hearing screening. In addition, the statement reviews the primary objectives, important components, and recommended screening parameters that characterize an effective universal newborn hearing screening program."*

NIH Funded Multi-Center Study on "Identification of Neonatal Hearing Implairment"

- Investigators
  - Susan Norton
  - Judith Widen
  - Yvonne Sinninger
  - Barbara Vohr
  - Michael Gorga
  - Richard Folsom
  - Barbara Cone-Wesson
  - Kristin Fletcher
- "Identification of Neonatal Hearing Impairment: Summary and Recommendations. *Ear and Hearing, 21*, 529-535, 2000
  - The purpose of this study was to determine the performance characteristics of three measures of peripheral auditory system status, transient evoked otoacoustic emissions (TEOAEs), distortion product otoacoustic emissions (DPOAEs), and auditory brain stem responses (ABR), applied in the neonatal period in predicting hearing status at 8 to 12 months corrected age.

UNHS:
National Legislation in the United States

- EHDI grants were first authorized in the Newborn Infant Hearing Screening and Intervention Act of 1999
  - Provided federal funds to develop infant hearing screening and intervention programs
  - Congress reauthorized the grants through the Children's Health Act of 2000 (PL 106-310)
  - Included provisions for
    - ✓Early hearing screening and evaluation of all newborns
    - ✓Coordinated intervention
    - ✓Rehabilitation services
    - ✓Research

NHS 2000

NEWBORN HEARING SYSTEMS

INTERNATIONAL CONFERENCE ON NEWBORN HEARING SCREENING DIAGNOSIS AND INTERVENTION

MILAN, ITALY, OCTOBER 12-14, 2000

EHDI

The 1st EHDI Conference

"Building Bridges in Africa: Early Childhood Development for children with hearing loss"

13 – 14 August 2007 (conference) **Emperor's Palace**

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Essential for Successful EHDI*

- A brief history of UNHS
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- Historical perspective on pre-school hearing screening
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- A *new* strategy for effective and efficient pre-school hearing screening and diagnosis of hearing loss
- Future directions in pre-school hearing screening

Early Hearing Loss Detection and Intervention: *The Ideal 1-3-6 Approach to EHDI*

- < 1 month
  - An infant is identified with hearing loss through hearing screening
- < 3 months
  - Hearing loss is diagnosed following JCIH guidelines
- < 6 months
  - Appropriate intervention is implemented based on diagnostic findings.

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *The Problem of "Loss to Follow Up"*

- Most (90 - 98%) newborn infants undergo hearing screening
- Less than half of the children screened undergo timely diagnostic evaluation
- Intervention can't begin without diagnosis
- Multiple and diverse reasons for infants "lost to follow-up"
  - Newborn infants discharged from nursery before screening
  - Infants transferred to another hospital before screening
  - Infants screened in one state and living in another state
  - Failure to document screening or diagnostic findings
  - Family reasons, e.g.,
    - ✓ Transportation problems
    - ✓ Misunderstanding about need for follow-up
    - ✓ Infant has no primary care physician (medically homeless)

Early Hearing Loss Detection and Intervention (EHDI): *The Problem of "Loss to Follow Up"*

Mason et al (2008). Measures of follow-up in early hearing detection and intervention programs: A need for standardization. *Amer J Audiol, 17*, 60-67

Table 1. Newborn Screenings

			N	Percent
Screening Documented	Completed Screening		**180,000**	**90.0%**
	Screening Not Completed	Missed Cases (e.g., LFU)	**4,375**	**2.2%**
		Incomplete Screen or no Rescreen (e.g., LFU)	**2,188**	**1.1%**
		Documented that Screening Not Possible	**1,875**	**0.9%**
		Documented Refusal of Screening	**1,562**	**0.8%**
Screening Not Documented (LTD)	Screening Did in Fact Occur		**4,750**	**2.4%**
	Screening Did Not in Fact Occur		**5,250**	**2.6%**
		Total	**200,000**	

Early Hearing Loss Detection and Intervention (EHDI):
The Problem of "Loss to Follow Up"

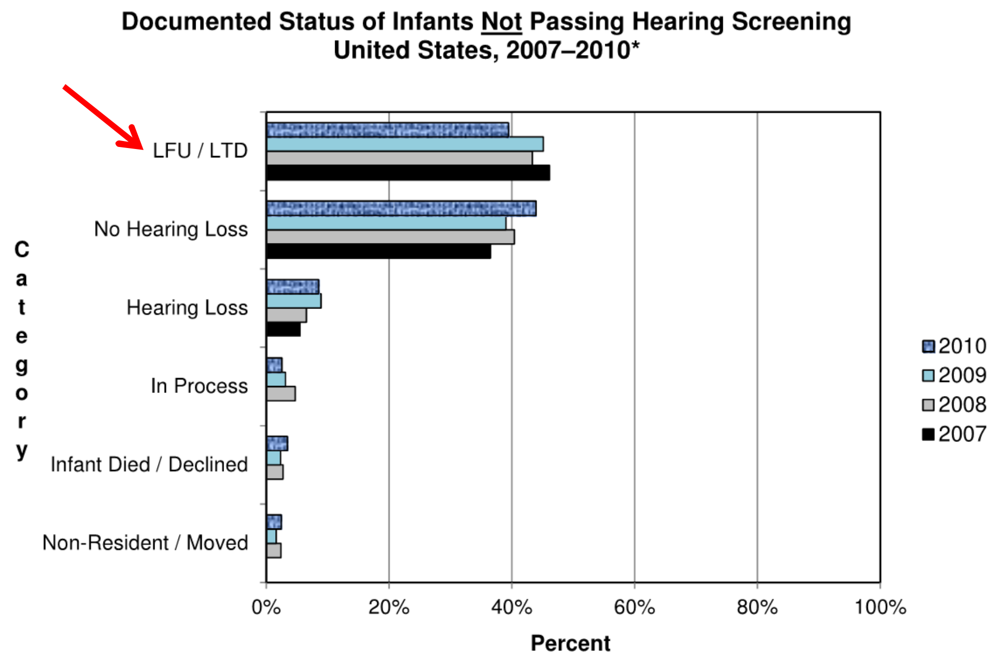
Mason et al (2008). Measures of follow-up in early hearing detection and intervention programs: A need for standardization. *Amer J Audiol, 17*, 60-67

Table 2. Tracking "Not Pass" Screens to Diagnostic Evaluation

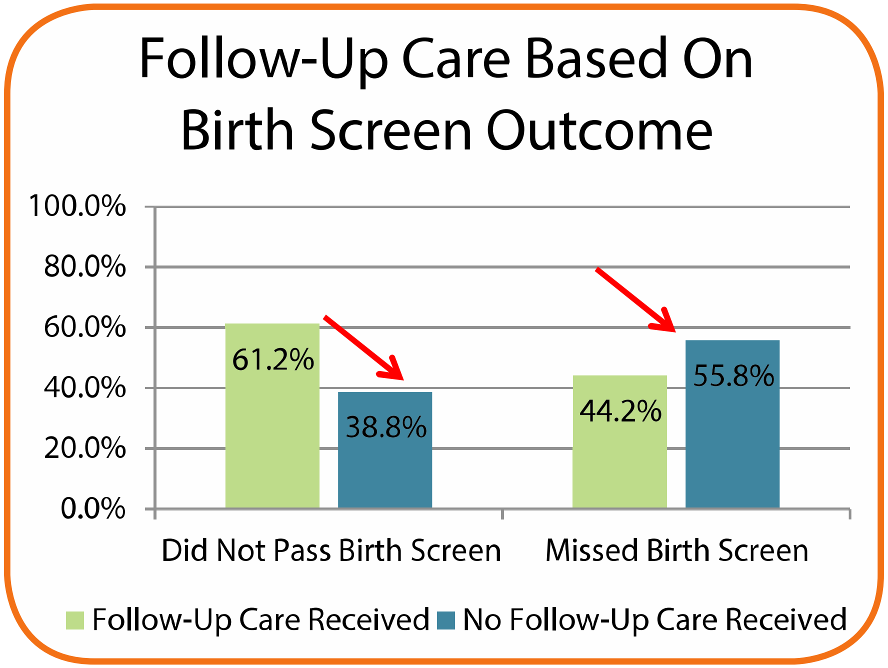
Diagnostic Results for the 3,600 Documented "Not Pass" Screens			Hearing Loss	No Hearing Loss	TOTAL
Diagnostic Evaluation Documented	Diag Evaluation Completed		264	1,500	1,764
	Diagnostic Evaluation Not Completed	Missed Cases (e.g., LFU)	116	410	526
		Incomplete Diagnostic Evaluation (e.g., LFU)	26	90	116
		Documented that Evaluation Not Possible	6	32	38
		Documented Refusal of Evaluation	17	59	76
Diagnostic Evaluation Not Documented (LTD)	Evaluation Did in Fact Occur		71	361	432
	Evaluation Did Not in Fact Occur		138	510	648
		TOTAL	**638**	**2,962**	**3,600**

Early Hearing Loss Detection and Intervention (EHDI):
The Problem of Infants "Lost to Follow Up (LFU)"

CDC EHDI (December 2012)



Early Hearing Loss Detection and Intervention (EHDI):
Follow Up Data: Texas EHDI (2013 Report)



Data Source: TEHDI MIS

Early Hearing Loss Detection and Intervention (EHDI): *California Explanations for "Loss to Follow Up"*

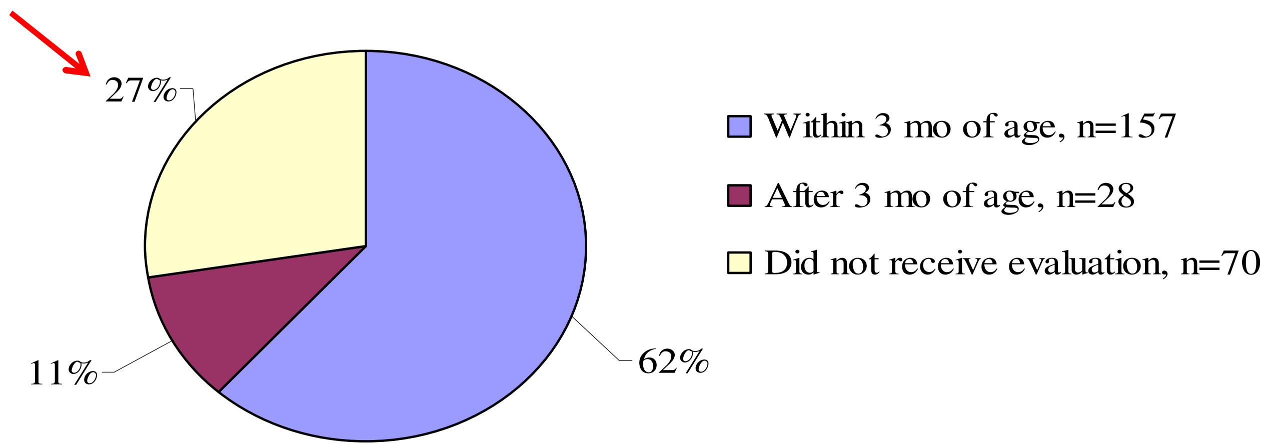
- Not enough qualified pediatric audiologists
- Diagnostic providers are not scheduling appointments but, instead, are waiting for families to call
- Parents are …
  - Not scheduling diagnostic follow up appointments
  - No showing for appointments
- Providers are submitting test results
- CCS Programs are …
  - Delaying diagnostic evaluations
  - Not issuing diagnostic evaluation approval

Early Hearing Loss Detection and Intervention (EHDI):

Follow Up Data: New Hampshire EHDI (2012 Report)

(Note: 97.5% of infants underwent successful screening)

Infants Referred for Diagnostic Evaluation, 2012, N=255



Early Hearing Loss Detection and Intervention (EHDI): *Possible Solutions for the Problem of "Loss to Follow Up"*

- Well-organized systems for data management and tracking
- Education of
  - Hospital personnel
  - Primary care physicians and pediatricians
- Combination OAE/AABR hearing screening approach for lower failure rate and earliy diagnosis of hearing loss
- Diagnostic assessment immediately following screening failures in hospitals with audiology clinical services
- More qualified audiologists widely distribution throughout each state to provide diagnostic evaluations
- Tele-audiology strategies for diagnostic evaluations
- Pre-school hearing screenings

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Early Hearing Loss Detection and Intervention (EHDI):
Pre-School Hearing Screening is a Logical Extension of EHDI

- Rationale for pre-school hearing screening
  - Permits identification of hearing loss in children who were not screened as newborns
  - Up to 50% of children undergoing newborn hearing screening are "lost to follow-up (LFU)"
  - Identifies children with delayed onset or progressive hearing loss
  - Approximately 15% of children with hearing loss passed infant hearing screening
  - Otitis media and other middle ear disorders are common in the pre-school population

Early Hearing Loss Detection and Intervention (EHDI):
Pre-School Hearing Screening is a Logical Extension of EHDI

- Sites or venues for pre-school hearing screening
  - Primary care physician's office
    - ✓Well baby visits
    - ✓Immunizations
    - ✓Concerns about ear infections or hearing
    - ✓Physician visits for non ear-related reasons
  - Head Start Programs
  - Pre-school educational programs
  - Day care facilities

Year 2007 Joint Committee on Infant Hearing (JCIH):
Risk Indicators for Delayed Onset or Progresive Hearing Loss

PEDIATRICS®

OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Year 2007 Position Statement: Principles and Guidelines for Early Hearing Detection and Intervention Programs

Joint Committee on Infant Hearing

Pediatrics 2007;120;898
DOI: 10.1542/peds.2007-2333

Year 2007 JCIH Position Statement: Risk Indicators Associated with Permanent Congenital, Delayed-Onset, or Progressive Hearing Loss in Childhood

- **Delayed onset, late onset, or "acquired" hearing loss:** Normal auditory function (hearing) at birth with the onset of auditory dysfunction (hearing loss) in infancy or early childhood
- **Progressive hearing loss:** Normal auditory function (hearing) at birth with the onset of auditory dysfunction (hearing loss) in infancy or early childhood

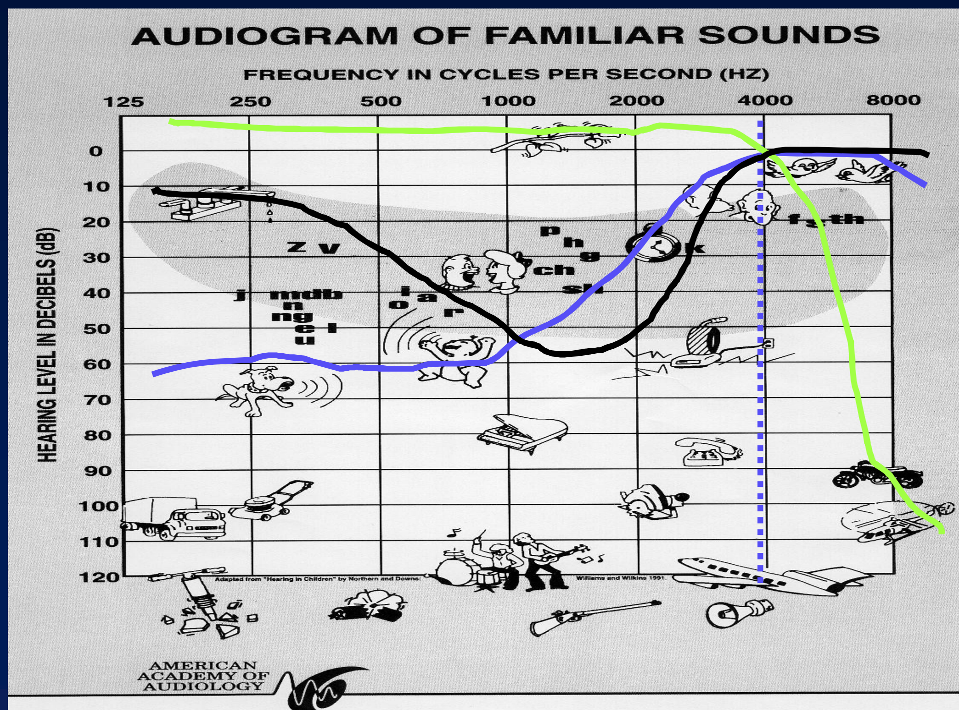
Year 2007 JCIH Position Statement: *Essential EHDI Team Members for Detecting Delayed Onset or Progresive Hearing Loss*

- Birth hospital
- Families
- Primary health care professions (e.g., the medical home)
- Audiologists
- Otolaryngologists
- Speech-language pathologists
- Educators of children who are deaf or hard of hearing
- Other early intervention professionals
- Additional available medical services include, e.g.,
  - Genetics
  - Ophthalmology

Factors Influencing Detection of Progressive versus Delayed Onset Sensorineural Hearing Loss in Hearing Screening

- Hearing screening method and protocol, e.g.,
  - AABR with Click Stimulation
    - ✓ Dependent mostly on hearing sensitivity in 2000 to 4000 Hz region
    - ✓ Not sensitive to low-mild high frequency cochlear auditory dysfunction
  - OAE
    - ✓ Screening protocol includes limited frequency region of 2000 to 5000 Hz
    - ✓ Dependent only on outer hair cell status, not inner hair cell dysfunction

Congenital or Progressive Hearing Loss Masquerading as Delayed/Late Onset Hearing Loss



Factors Influencing Detection of Progressive versus Delayed Onset Sensorineural Hearing Loss in Hearing Screening

- Configurations of hearing loss contributing to "false negative" outcomes
  - High and very high frequency hearing loss > 5000 Hz
  - Mid-to-low frequency hearing loss < 2000 Hz (often genetic)
  - Mid-region "cookie bite" hearing loss (often genetic)
- Hearing loss may initially be unilateral
  - Hearing screening must be completed for both ears
  - Children with unilateral hearing loss at birth are at risk for later bilateral hearing loss
  - Follow up screening or diagnostic assessment of both ears is indicated for children with unilateral screening failures

Year 2007 JCIH Position Statement: Indicators Associated with Permanent Congenital, Delayed-Onset, or Progressive Hearing Loss

- Caregiver concern regarding
  - Hearing
  - Speech and language
  - Developmental delay.
- Family history of permanent childhood hearing loss
- NICU stay of > 5 days or
  - ECMO (Extra-Corporeal Membrane Oxygenation)
  - Assisted ventilation
  - Exposure to ototoxic medicines
  - Hyperbilirubinemia requiring exchange transfusion

Year 2007 JCIH Position Statement: Indicators Associated with Permanent Congenital, Delayed-Onset, or Progressive Hearing Loss

- In utero infections, e.g.,
  - CMV
  - Herpes
  - Rubella
  - Syphillis
  - Toxoplasmosis
- Craniofacial anomalies, including involvement of the
  - Pinna
  - Ear canals
  - Ear tags and pits
  - Temporal bone anomalies

Year 2007 JCIH Position Statement: Indicators Associated with Permanent Congenital, Delayed-Onset, or Progressive Hearing Loss

- Neuro-degenerative disorders, e.g.,
  - Hunter syndrome
  - Sensory motor neuropathies
    - ✓Friedreich ataxia
    - ✓Charcot-Marie-Tooth syndrome
- Culture positive post-natal infections associated with sensorineural hearing loss, e.g., Confirmed bacterial and viral meningitis
- Head trauma requiring hospitalization
- Chemotherapy

Infants with Risk Indicators Associated with Permanent Congenital, Delayed-Onset, or Progressive Hearing Loss

- At least 50% of all congenital hearing loss is hereditary (2007 JCIH)
  - Almost 600 syndromes with hearing loss
  - 125 genes associated with hearing loss
- Approximately 30 to 40% of children with hearing loss have associated disabilities
- Common genetic causes of delayed onset or progressive hearing loss
  - Connexin 26
    - ✓ Accounts for >50% of non-syndromic and some causes of syndromic hearing loss
  - Connexin 30
    - ✓ Severe to profound hearing loss usually occurs with no other medical problems

Year 2007 JCIH Position Statement: Indicators Associated with Permanent Congenital, Delayed-Onset, or Progressive Hearing Loss

- Physical findings associated with a syndrome, e.g., white forelock
- Syndromes associated with hearing loss, e.g.,
  - Neurofibromatosis
  - Osteopetrosis
  - Usher syndrome
  - Waardenburg
  - Alport
  - Pendred
  - Jervell
  - Lange-Nielson

Infants with Risk Indicators Associated with Permanent Congenital, Delayed-Onset, or Progressive Hearing Loss

- Cytomegalovirus (CMV)
  - ✓Progressive, sometimes into school age
  - ✓Hearing loss may fluctuate
  - ✓Hearing loss may be unilateral or bilateral
  - ✓Accounts for 21 to 25% of congenital hearing loss
- Pendrid syndrome
  - ✓Recessive syndromic hearing loss
  - ✓May develop later in infancy or early childhood
  - ✓Usually progressive
  - ✓Accounts for up to 8% of all congenital hearing loss

Infants with Risk Indicators Associated with Permanent Congenital, Delayed-Onset, or Progressive Hearing Loss

- Fortnum, Summerfield, Marshall, Davis & Bamford. (2001). ***BMJ, 323***, 536-554
  - Prevalence within 17,160 children increased from 1% at age 3 years to 2% at age 9 to 16 years
  - Up to 50% of children with hearing loss at age 9 passed newborn hearing screening.
- Grote (2000). Neonatal screening for heairng impairment. ***Lancet, 355***, 513-514
  - UNHS programs do not detect 10 to 20% of permanent hearing loss that begins later
- White (October 2010). ASHA Virtual Audiology Conference
  - Prevalence of 3/1000 for permanent hearing loss in infants increases to 9-10/1000 in school age children

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis*: Review of the Rationale for Pre-School Screening for Hearing Loss*

- Not all newborn infants undergo hearing screening
- A sizeable proportion of infants who are screened as neonates and who fail the screening do not undergo diagnostic hearing assessment before 3 months
- A proportion of children who pass hearing screening as neonates are at risk for delayed onset or progressive hearing loss
- Almost all children will have middle ear disease during the pre-school years (before age 5 years)
- Hearing is important for communication (and reading) throughout pre-school years
- Preschool hearing screening is recommended by the American Academy of Pediatrics, JCIH, the American Academy of Audiology, and ASHA

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Essential for Successful EHDI*

- UNHS doesn't always lead to universal diagnosis and intervention of childhood hearing loss
- Rationale for pre-school screening for hearing loss
- Historical perspective on pre-school hearing screening
- Techniques and technology for pre-school hearing screening: What are the options?
- Current clinical guidelines for pre-school hearing screening and diagnosis of hearing loss
- A *new* strategy for effective and efficient pre-school hearing screening and diagnosis of hearing loss
- Future directions in pre-school hearing screening

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Historical Perspective (1)*

- 1982 US Department of Health and Human Services, PHS
  - Protocols for Screening and Assessment of Preschool Children: Speech, Language, and Hearing”
  - Protocol for 2 to 3 year old children
    - ✓Risk register
    - ✓Three parental questions about auditory responses
    - ✓Pure tone play audiometry
    - ✓Middle ear screening
    - ✓Screening for speech and language development
  - Protocol for 3 to 6 year old children
    - ✓Risk register
    - ✓Follow 1975 ASHA guidelines for identification audiometry

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Historical Perspective (1)*

- 1984 American Academy of Pediatrics Policy Statement
  - "Middle Ear Disease and Language Development"
- 1985 ASHA Guidelines for identification audiometry
  - For children age 3 years and older
  - Pure tone hearing screening under earphones at 20 dB HL for 1000 Hz, 2000 Hz, and 4000 Hz
  - Maximum ambient noise levels stated (e.g., < 49.5 dB SPL at 1000 Hz)
  - Audiologist must conduct screening

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Historical Perspective*

- 1989 US Preventive Services Task Force
  - "Screening for Hearing Impairment"
- 1989 American Public Health Association
  - "Children's Preschool Vision and Hearing Screening and Follow-Up"
- 1990 ASHA Guidelines for Screening of Hearing Impairment and Middle-Ear Disorders
- 1997 ASHA Guidelines for Audiologic Screening

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Historical Perspective*

- ASHA Guidelines for Audiologic Screening (1997) [64 pages]
  - Separate guidelines for:
    - ✓Newborns and infants age birth through 6 months
    - ✓Infants and toddlers age 7 months through 2 years
    - ✓Preschool children age 3 to 5 years
    - ✓School-age children age 5 through 18 years
  - Personnel
    - ✓"Screening infants and children for hearing disorder and hearing impairment requires considerable professional expertise"
    - ✓Screening process should be designed, implemented, and supervised by an audiologist with CCCs

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Historical Perspective*

- ASHA Guidelines for Audiologic Screening (1997): Hearing screening of 7-month old through 2-year old children
  - "The panel concluded that for this age group, the development of screening guidelines to be used only by audiologists was appropriate and necessary."
  - Clinical indications. Screen infants …
    - ✓ "…as needed, requested, or mandated."
    - ✓ "…who have previously received and passed hearing screening"
    - ✓ "if they have indicators…" (JCIH, 1994)

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Historical Perspective*

- ASHA Guidelines for Audiologic Screening (1997): Hearing screening of *7-month old through 2-year old children*
  - For children who can be conditioned for play audiometry
    - ✓Use earphones
    - ✓Screen at 20 dB HL for 1000, 2000, and 4000 Hz
  - For children who can be conditioned for VRA
    - ✓Use earphones
    - ✓Screen at 30 dB HL for 1000, 2000, and 4000 Hz
  - Alternatives
    - ✓Screening in calibrated sound field for those children who do not accept earphones
    - ✓OAEs or ABR may be employed for screening
  - Not permitted: BOA, noncalibrated signals, speech stimuli

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Historical Perspective*

- **ASHA Guidelines for Audiologic Screening (1997): Hearing screening of *children 3 to 5 years***
  - **For children who can be conditioned for play audiometry**
    - ✓ **"Administer a minimum of two conditioning trials at a presumed suprathreshold level to assure that the child understands the task."**
    - ✓ **Use earphones**
    - ✓ **Screen at 20 dB HL for 1000, 2000, and 4000 Hz**
    - ✓ **"At least two presentations of each test stimulus may be required to assure reliability."**
    - ✓ **REFER: If the child does not respond to at least 2 out of 3 times at the criterion decibel level at any frequency in either ear or if the child cannot be conditioned to the task."**

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis:
Historical Perspective

ASHA Guidelines for Audiologic Screening (1997):
Hearing screening of *children 3 to 5 years*

Table 3.2.1. ANSI S3.1-1991 maximum permissible ambient noise levels (MPANLs) for threshold testing to 0 dB HL at 1000, 2000, 4000 Hz and derivation of permissible noise levels for hearing screening at 25 dB HL.

	Frequency in Hz		
Condition	**1000**	**2000**	**4000**
1. MPANL ears not covered	14.0	8.5	9.0
2. Attenuation-supra-aural earphone	12.5	19.5	12.5
3. MPANL ears covered (Line 1 + Line 2)	26.5	28.0	34.5
4. Screening level	25	25	25
5. MPANL for screening (Line 3 + Line 4)	51.5	53.0	59.5
6. Attenuation-insert earphonea	33.5	33.0	40.5
7. MPANL ears plugged (Line 1 + Line 6)	47.5	41.5	49.5
8. Screening level	25	25	25
9. MPANL ears plugged (Line 7 + Line 8)	72.5	66.5	74.5

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Essential for Successful EHDI*

- A brief history of universal newborn hearing screening (UNHS)
- UNHS doesn't always lead to universal diagnosis and intervention of childhood hearing loss
- Rationale for pre-school screening for hearing loss
- Historical perspective on pre-school hearing screening
- Techniques and technology for pre-school hearing screening: What are the options?
- Current clinical guidelines for pre-school hearing screening and diagnosis of hearing loss
- A *new* strategy for effective and efficient pre-school hearing screening and diagnosis of hearing loss
- Future directions in pre-school hearing screening

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis:

Pre-School Hearing Screening Options

- General and non evidence-based strategies = NOT AN OPTION
- Pure tone hearing screening
- Otoacoustic emissions
  - Automated technology
  - Special pass/fail criteria
- Aural admittance measures
  - Tympanometry
  - Tympanometry plus acoustic reflexes
- Combinations of selected techniques depending on:
  - Skills of screening personnel (availability of audiologist)
  - Age of the child
  - Middle ear status

Behavioral Pre-School Hearing Screening: *General Strategies (Not Evidence Based … Worst Practice?)*

- Eiserman W, Shisler L, Foust T, Burhmann J, Winston R & White K (2008). *Updating hearing screening practices in early childhood. Volume 21,* Wolters Kluwer Health/Lippincott Williams & Wilkins, pp. 186-193
- Physician's office "check" for hearing loss includes one or more of the following
  - Parent questionnaire
  - Otoscopy
  - Tympanometry
  - Behavioral observations of response to
    - ✓Hand clapping
    - ✓Bell-ringing
    - ✓Noise makers

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis:

Pre-School Hearing Screening Options

- General strategies
- Pure tone hearing screening
- Otoacoustic emissions
  - Automated technology
  - Special pass/fail criteria
- Aural admittance measures
  - Tympanometry
  - Tympanometry plus acoustic reflexes
- Combinations of selected techniques depending on:
  - Skills of screening personnel (availability of audiologist)
  - Age of the child
  - Middle ear status

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Historical Perspective*

“Historically, the most widely preferred hearing screening procedure and one that has been considered the gold standard is pure tone audiometric sweep test that was first described in 1938 by Newhart” (Krueger W & Ferguson L. A comparison of screening methods in school-aged children. *Otolaryngology-Head & Neck Surgery, 127*, 722-725, 2002).

Source: **2011 American Academy of Audiology Childhood Hearing Screening Clinical Guidelines**

Behavioral Pre-School Hearing Screening
Questions to Ask About Research Studies

- Qualifications of persons performing hearing screening, e.g.,
  - Audiologist
  - Graduate student in audiology or speech pathology
  - Other health professional
  - Trained non-health professional
- Ambient noise levels in the test environment
- Screening protocol including
  - Earphone type (supra-aural versus insert)
  - Test frequencies
  - Response criteria
- How many children could not be tested (CNT)?
- What were the PASS and FAIL (did not pass) rates?

Behavioral Pre-School Hearing Screening
Research Findings

- Krishnamurti, Hawks & Gerling (1999). Performance of preschool children on two hearing screening protocols. *Contemporary Issues in Communication Science and Disorders, 26,* 63-68 [Kent State University]
  - Methods
    - ✓100 preschool children age 36 to 60 months
    - ✓Testing unsuccessful for additional 3 children
    - ✓Screening performed by first author
    - ✓Settings were daycare centers … "moderate to high socioeconomic status"
    - ✓Hand raising response
    - ✓Protocol and ambient noise consistent with ASHA guidelines (1985, 1990) but NOT with ASHA 1997 requiring conditioned play

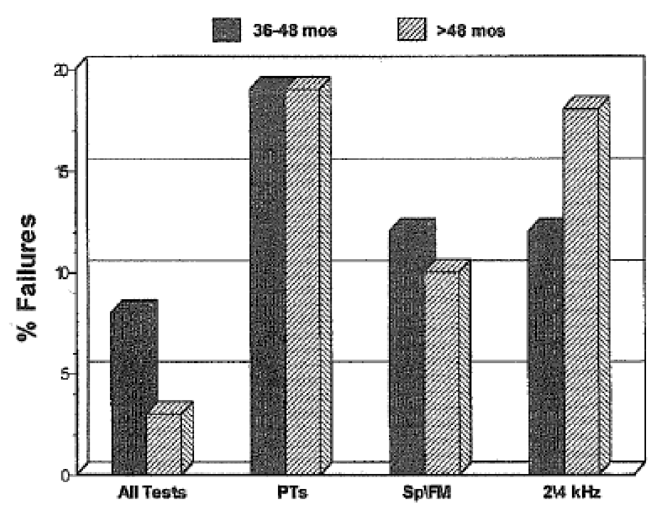
Krishnamurti, Hawks & Gerling (1999). Performance of preschool children on two hearing screening protocols. *Contemporary Issues in Communication Science and Disorders, 26,* 63-68

Table 1. Description of pure-tone and spondee\FM screening protocols.

Protocol/ equipment	*Stimulus type*	*Presentation level (dB HL)*	*Number of presentations*	*Response task*	*Pass/fail criteria*
Pure tone/ Beltone 9D	500 Hz 1000 Hz 2000 Hz 4000 Hz	25 20 20 20	1 per ear 1 per ear 1 per ear 1 per ear	raise hand	failure to respond at any frequency; either ear
Spondee\FM/ GSA 102	Spondees 12 total; 6 per ear	15	each word once per ear	point to appropriate picture	< 4 correct responses; either ear
	FM tones 2000 Hz 4000 Hz	20 20	3 per ear 3 per ear	point to bird picture	< 2 correct responses; either ear

Pure Tone Hearing Screening Failure Rate
(Krishnamurti, Hawks & Gerling, 1999)

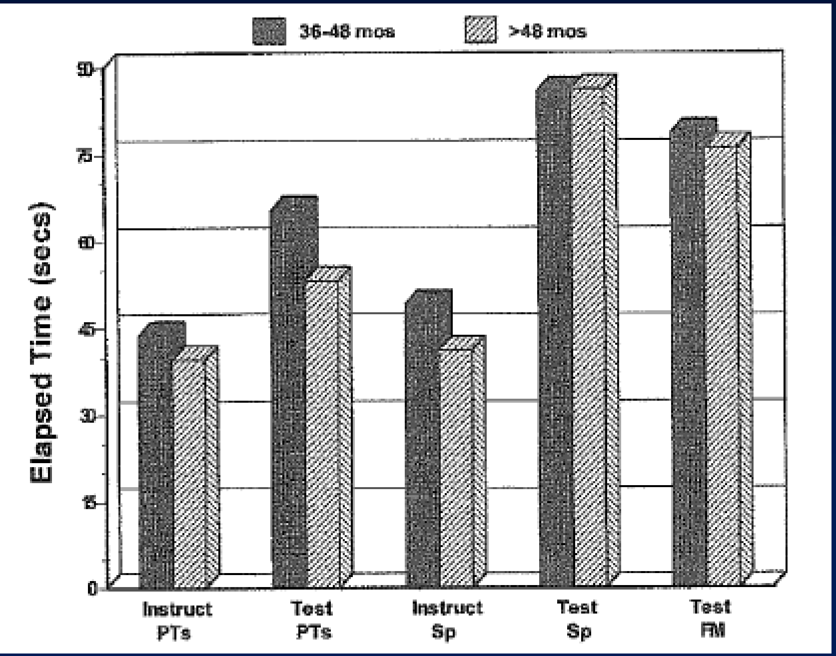
Figure 3. Percentage of screening failures by younger (36 to 48 months) and older (> 48 months) subjects for all tests (pure tone, spondee, and FM tone), pure tone (PTs), spondee and FM tone (Sp\FM), and 2 or 4 kHz pure tones.



Initial pure tone screening failure rate = 24%

Pure Tone Hearing Screening Test Time

(Krishnamurti, Hawks & Gerling, 1999)



Note: Not conditioned play audiometry

Behavioral Pre-School Hearing Screening in Physicians' Office Setting

- Halloran, Wall, Evans, Hardin & Woolley (2005). Hearing screening at well-child visits. *Arch Pediatr Adolesc Med, 159,* 949-955
  - N = 1061 children age 3 to 19 years
  - "Convenience sample" with medical insurance coverage
  - Eight pediatric practices in Alabama
    - ✓5 nonacademic (private) practices
    - ✓3 academically affiliated practices
  - Screening in examination room (trained research assistant)
  - 95% conventional screening and 5% play audiometry
  - PT screening at 20 dB HL for 1000, 2000, and 4000 Hz
  - Screening audiometers with supra-aural earphones

Behavioral Pre-School Hearing Screening Screening in Physicians' Office Setting

Halloran et al (2005)

- Completion of hearing screening
  - Gender
    - ✓Boys: 93%
    - ✓Girls: 94%
  - Race
    - ✓African American: 90%
    - ✓White: 96%
  - Age
    - ✓3 years: 55% (45% unable to complete screening)
    - ✓4 years: 93%
    - ✓5 years: 97%
    - ✓$\geq$ 6 years: 100%

Behavioral Pre-School Hearing Screening Screening in Physicians' Office Setting

Halloran et al (2005)

- Pass outcome of hearing screening
  - Gender (90% for boys and girls)
  - Race
    - ✓African American: 88%
    - ✓White: 91%
  - Age
    - ✓3 years: 95%
    - ✓4 years: 86%
    - ✓5 years: 91%
    - ✓$\geq$ 6 years: 90%
  - Development
    - ✓Delayed: 67% (N=21 or 2% of total population)
    - ✓Normal: 90%

Behavioral Pre-School Hearing Screening Screening in Physicians' Office Setting

Halloran et al (2005)

- **Summary**
  - 67 children (7%) were unable to complete the screening
  - Of the remaining 948 children
    - ✓ 90% passed the screening
    - ✓ 10% failed the screening
    - ✓ A total of 162 children (15%) were CNT or failed screening
  - No further evaluation (pediatricians didn't refer the children)
    - ✓ 59% of the children failing the screening
    - ✓ 73% of the children with CNT results

Behavioral Pre-School Hearing Screening Screening in Physicians' Office Setting

Halloran et al (2005)

- Authors' Conclusions
  - Conventional risk factors did not predict FAIL outcome
  - "Given the high failure rate of 10% detected here using 20 dB HL and the lack of appropriate follow-up, this study supports the recommendations from the AAP [2007] to use a higher screening threshold when conducting hearing screening in the primary care setting." (p. 933)
  - "The findings from this study are worrisome because physicians took no further action in more than 50% of children who failed the hearing screening and more than 70% of the children who could not be tested." (p. 934)

Behavioral Pre-School Hearing Screening Screening in Physicians' Office Setting

Halloran et al (2005)

- Authors' possible explanations for low follow-up rates
  - Pediatricians may have chosen to retest at a later date (e.g., 1 year later) or as part of their typical follow-up plan
  - Financial constraints did NOT play a role as any expenses would have been covered.
  - Physicians in private practice have long standing relationships with families …feel comfortable with continued monitoring for signs and symptoms of hearing loss.
  - Physicians may perceive patients to be a lower risk due to higher socioeconomic status and general health.
  - "Lastly, little is known of the accuracy of conventional audiometry in the primary care setting; Therefore, pediatricians may distrust their screening results and rely primarily on the history and physical examination.

Behavioral Pre-School Hearing Screening Screening in Physicians' Office Setting

Halloran et al (2005)

- "A national survey of general pediatricians found that guidelines were more likely to be followed if they were:
  - Simple
  - Feasible
  - And demonstrated improved outcomes

Flores G, Leo M, Bauchner H & Kastner B (2000). Pediatrician's attitudes, beliefs, and practices regarding clinical practice guidelines: a national survey. *Pediatrics, 105*, 496-501

Cunningham M & Cox EO (2003). Committee on Practice and Ambulatory Medicine and the Section on Otolaryngology and Bronchoesophagology. Hearing assessment in infants and children: recommendations beyond neonatal screening. *Pediatrics, 111,* 436-440

Harlor AD & Bower C. (2009) Hearing assessment in infants and children: Recommendations beyond neonatal screening. Pediatrics, 124, 1252-1263

Behavioral Pre-School Hearing Screening Screening in Physicians' Office Setting … Follow Up Study

- Halloran, Hardin & Wall (2009). Validity of pure-tone hearing screening at well-child visits. *Arch Pediatr Adolesc Med, 163,* 158-163
  - Of the total of 1061 children undergoing hearing screening, a group of 130 children received complete audiological evaluation
  - "With audiologic evaluation used as the gold standard"
    - ✓Sensitivity of a screening tests that were not passed was 50%
    - ✓Specificity was 78%
    - ✓None of the 28 children who could not be tested had hearing loss

Behavioral Pre-School Hearing Screening Screening in Physicians' Office Setting

Halloran et al (2009)

Table 2. Presence of Hearing Loss vs Pure-Tone Audiometry Screening Results

Screening Results	Hearing Loss, No. of Children: Present	Hearing Loss, No. of Children: Absent	Total, No.
Did not pass	2	21	23
Passed	2	74	76
Total	**4**	**95**	**99**

Behavioral Pre-School Hearing Screening Screening in Physicians' Office Setting
Halloran et al (2009)

Table 3. Presence of Hearing Loss vs Ability to Complete Pure-Tone Audiometry Screening

Screening Results	Hearing Loss, No. of Children: Present	Hearing Loss, No. of Children: Absent	Total, No.
Did not complete	0	10	10
Completed	4	95	99
Total	**4**	**105**	**109**

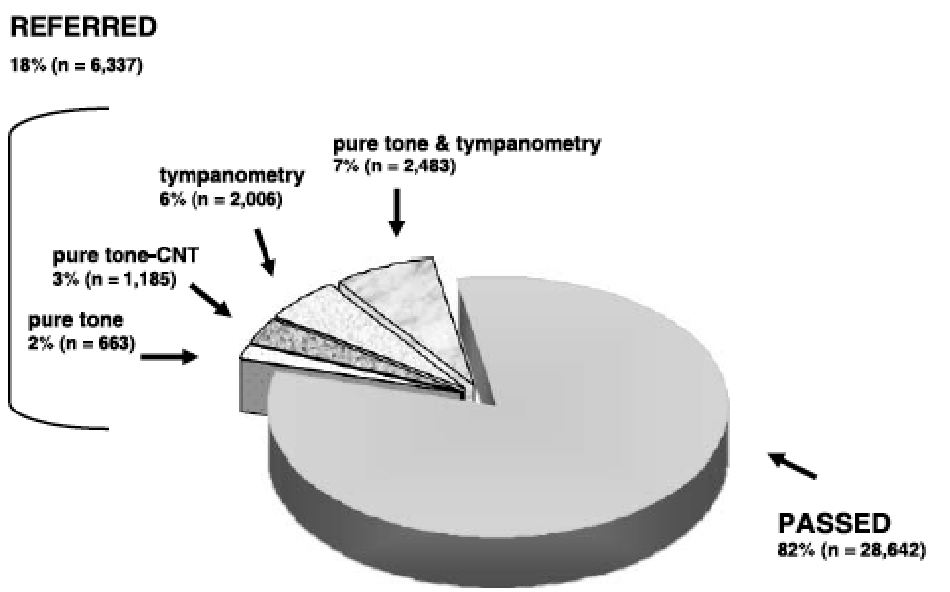
Behavioral Pre-School Hearing Screening in Public Pre-School, Day Care or Head Start Settings

- Serpanos YC & Jarmel F (2007). Quantitative and qualitative follow-up outcomes from a preschool auditory screening program: Perspectives over a decade. *American Journal of Audiology 16,* 4-12
  - 34,979 preschool children age 3 to 5 years
  - Settings were public pre-school, day care, or head start centers
  - Pure tone screening at 20 dB for 1000, 2000, 3000 & 4000 Hz
  - Audiology or SLP graduate students from 6 different academic programs in NYC and Long Island area performed screening
  - Hand raising response with CPA if CNT
  - "Difficult to test" children were screened by supervisor
  - Immediate rescreen of failures by supervising audiologist
  - Tympanometry after pure tone screening by supervisor

Evidence-Based Problems with Behavioral Pre-School Hearing Screening

Serpanos & Jarmel, 2007

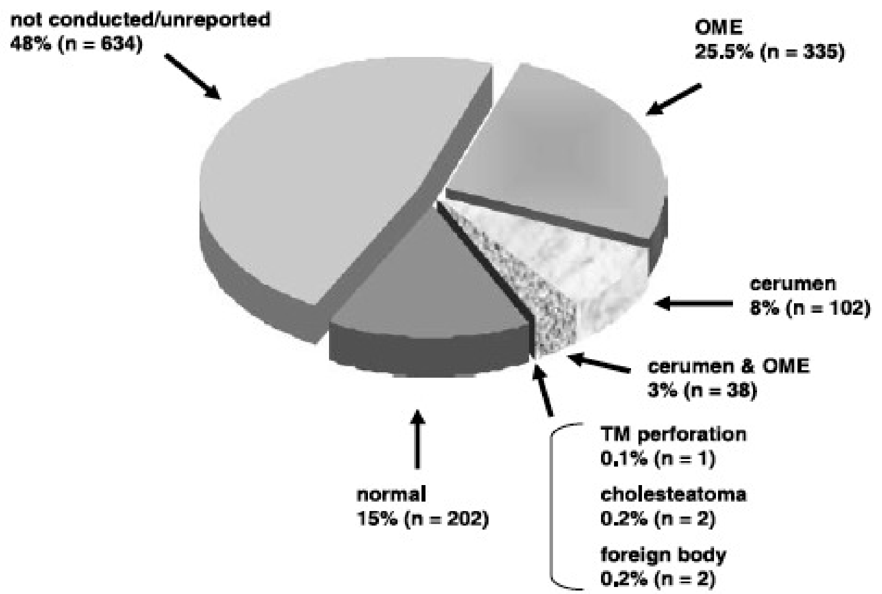
Figure 1. Pass/refer pure-tone and tympanometry screening outcomes. Total number of children screened = 34,979. CNT = could not test.



Evidence-Based Problems with Behavioral Pre-School Hearing Screening

Serpanos & Jarmel, 2007

Figure 3. Medical ear evaluation outcomes. Data represent follow-up outcomes of 1,316 children; OME = otitis media with effusion; TM = tympanic membrane.



Evidence-Based Problems with Behavioral Pre-School Hearing Screening

Serpanos & Jarmel, 2007

Table 3. Reasons why follow-up was not pursued.

Responses	*n*
By physicians	
Child was too young to be tested	11
(Test when child is older	3)
(Test when child is 4 years old	2)
Child being treated for middle ear disorder at time of screening	3
No problem with hearing	2
By parents	
Child being treated for middle ear disorder at time of screening	5
Parent did not suspect a hearing problem	5
Parent felt child too young to be tested	3
Physician said child was too young to be tested (test when child is 4 years old)	1
Physician said there was no problem with hearing (test when child is older)	1
Child did not understand directions due to language barrier	1

Note. Reasons were derived from 32 unsolicited comments written by parents (n = 16) or physicians (n = 16) who did not follow up (n = 99) with audiologic screening recommendations.

Evidence-Based Problems with Behavioral Pre-School Hearing Screening:
Allen et al (2004)

- **Allen RL, Stuart A, Everett D & Elangovan S (2004). *American Journal of Audiology, 13*. 29-38**
  - **N = 1462 3 and 4 year old children in Head Start programs**
  - **Followed ASHA 1997 Guidelines for pure tone screening, tympanometry, plus otoscopy**
  - **54% passed initial screening with all three procedures**
  - **Pass rate for each procedure**
    - ✓ **90% for otoscopy**
    - ✓ **71% for tympanometry**
    - ✓ **71% for pure tones**
  - **Rescreen pass rate was 76%**
  - **Only about 71% received recommended evaluation**
  - **Hearing status of 18% of the children never determined**

Problems with Behavioral Pre-School Hearing Screening

(Adapted from: *FitzZaland and Zink (1984). A comparative study of hearing screening procedures. Ear & Hearing, 5, 205-210)*

- According to ASHA and AAA guidelines, audiologists must conduct or supervise hearing screenings
- Preschool hearing screenings may be conducted in settings lacking audiologists e.g., Head Start centers, physician offices
- Ambient sound levels > 50 dB SPL (1000 Hz) ASHA criterion
- Environmental distractions in test setting
- Screening time per child may be 4 to 5 minutes or longer
- A proportion of children will not or cannot:
  - Cooperate in the hearing screening process
  - Tolerate earphones
  - Participate in conditioned play audiometry
- Behavioral hearing screening is not “rapid and simple” for children age 3 years and younger (Northern & Downs, 1991)

Evidence-Documented Problems with Behavioral Pre-School Hearing Screening

"Successful completion of pure tone screening can be challenging when screening young children or those with special needs. An analysis of pure tone hearing screening results from well-child visits at the pediatrician's office found that 3-year-olds are 33 times more likely than older children to be recorded as "could not test" for pure tone screening (Halloran et al., 2005). Forty five percent of 3-year-olds did not complete the screening, compared with 7% of the 4-year-olds, and this percentage decreased with increasing. **These challenges suggest the need for considering an alternative to pure tone screening for young children.** "

2011 AAA Childhood Hearing Screening Guidelines, page 28

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis:

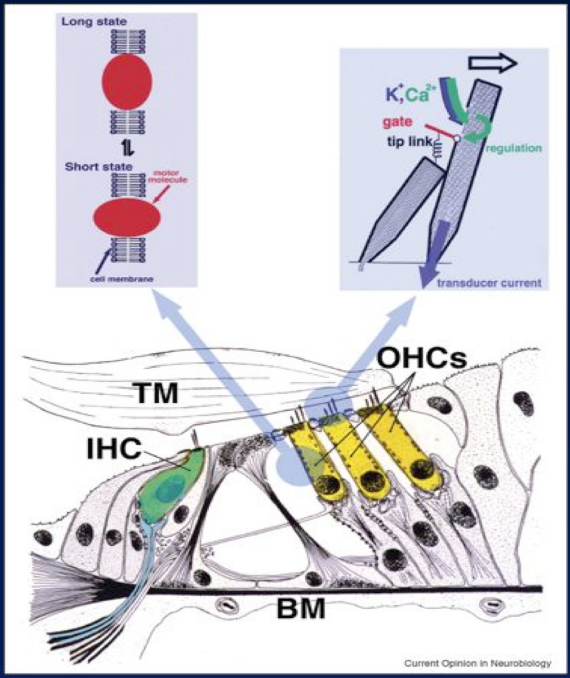
Pre-School Hearing Screening Options

- Parent survey (used by physicians)
- Pure tone hearing screening
- Otoacoustic emissions
  - Automated technology
  - Special pass/fail criteria for pre-school hearing screening
- Aural admittance measures
  - Tympanometry
  - Tympanometry plus acoustic reflexes
- Combinations of selected techniques depending on:
  - Skills of screening personnel (availability of audiologist)
  - Age of the child
  - Middle ear status

Hearing Screening in the Pre-School Population With Distortion Product OAEs

Recording OAEs:
Relevant Anatomy and Physiology

- 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 propagation in and out
- External ear canal
  - Stimulus presentation
  - OAE detection



Evidence-Based Clinical Applications of OAEs in Pediatric Populations

- Pediatric Applications
  - Infant hearing screening
  - Diagnosis of auditory dysfunction in infants and young children
    - ✓ Identification of auditory neuropathy spectrum disorder
  - Monitoring ototoxicity
  - Pre-school/school screenings
  - Identification of false and exaggerated hearing loss

Effective and Efficient Pre-School Hearing Loss with OAEs:
Concerns Expressed in 2011 AAA Childhood Hearing Loss Guidelines

- Question sensitivity to hearing loss
  - "TEOAEs may be recorded from some ears with hearing loss in the mild range (20 to 30 dB HL)"
  - "DPOAEs may be seen in some ears with hearing sensitivity in the moderate range (20 to 50 dB HL)"
- Not possible to complete OAE screening for test frequencies < 1000 Hz due to ambient noise
- OAEs will miss children with ANSD
- OAE future research needs
  - Establish equipment and test parameters
  - Appropriate pass/fail criteria
  - Validate OAE outcomes with "gold standard" for diagnosis
  - Cost data are needed

Effective and Efficient Pre-School Hearing Loss with OAEs:

Response to Concerns Expressed in 2011 AAA Childhood Hearing Loss Guidelines (1)

- Concern about OAE sensitivity to hearing loss
  - Research data and clinical experience confirms that OAEs are more sensitive to middle ear and cochlear (outer hair cell) dysfunction than pure tone measures
  - OAE sensitivity to hearing loss can be manipulated by
    - ✓Stimulus intensity levels
    - ✓Analysis criteria
- "Not possible to complete OAE screening for test frequencies < 1000 Hz due to ambient noise
  - Same is true for pure tone hearing screening
  - Prevalence of isolated low frequency hearing loss is rare
  - Low frequency conductive hearing loss will be detected by OAEs and/or tympanometry and acoustic reflex measurement

Effective and Efficient Pre-School Hearing Loss with OAEs:

Response to Concerns Expressed in 2011 AAA Childhood Hearing Loss Guidelines (2)

- ❑ OAEs will miss children with ANSD
  - ● Some children with de-synchronous type ANSD will be missed by pure tone screening (normal pure tone hearing thresholds)
  - ● Adding acoustic reflex measure to objective hearing screening will detect children with ANSD
- ❑ OAE future research needs … ALL GOOD SUGGESTIONS
  - ✓ Establish equipment and test parameters
  - ✓ Appropriate pass/fail criteria
  - ✓ Validate OAE outcomes with "gold standard" for diagnosis
  - ● Cost data are needed

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Otoacoustic Emissions*

- Ho et al (2002). Otoacoustic emissions and tympanometry screening among 0-5 year olds. Laryngoscope, 112, 513-519
- Eisermann et al (2007). Using otoacoustic emissions to screen for hearing loss in early childhood care settings*. Int J Pedi ORL, 72,* 475-482
- Hunter et al (2007). Hearing screening and middle ear measures in American Indian infants and toddlers. *Int J P ORL, 71,* 1429-1438
- Bhatia et al (2013). Early identification of young children with hearing loss in Federally qualified health centers. *J Developmental Behavioral Pediatrics, 34,* 15-21
- Kreisman BM, Bevliacqua E, Day K, Kreisman NV & Hall JW III (2013). Preschool hearing screenings: Comparison of distortion product otoacoustic emission and pure-tone protocols. Journal of Educational Audiology, 19, 48-57

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *OAE Research Findings*

- Kreisman BM, Bevilacqua E, Day K, Kreisman NV & Hall JW III (2013). Preschool hearing screenings: Comparison of distortion product otoacoustic emission and pure-tone protocols. *Journal of Educational Audiology, 19*, 48-57
- Methods
  - 198 preschool children age 3 to 6 years (mean 4.5 years)
  - Testing unsuccessful for another 2 children (PTs only)
  - Screening procedures
    - ✓DPOAEs
    - ✓PT screening with conditioned play (block in bucket)
  - Data collected by audiology and SLP grad students in 8 different preschool facilities
  - Protocol consistent with ASHA 1997 guidelines

Hearing Screening Time for DPOAEs versus Pure Tone Technique in Pre-School Children

(Kreisman et al, 2013)

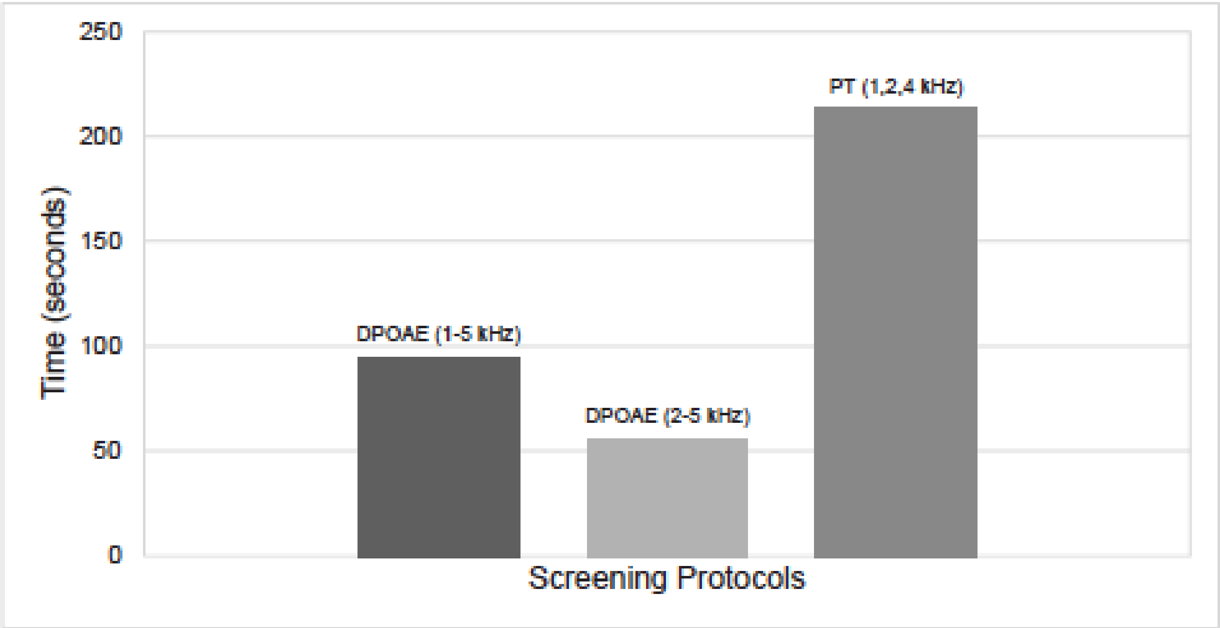


Figure 1. Mean time to complete each screening protocol.

Hearing Screening Pass/Fail Data for DPOAEs versus Pure Tone Technique in Pre-School Children

(Kreisman et al, 2013)

Table 2. Pass/Fail Rates for DPOAE (1-5 kHz), DPOAE (2-5 kHz) and Pure-Tone (1,2,4 kHz) Protocols

Protocol	Pass	Fail	Total
DPOAE (1-5 kHz)	134	64	198
DPOAE (2-5 kHz)	141	57	198
Pure-Tone (1,2,4 kHz)	175	21	196

Note. DPOAE=Distortion Product Otoacoustic Emissions. Two children would not cooperate to be screened using pure tones.

Early Hearing Loss Detection and Intervention (EHDI):
OAE Screening in Healthcare Settings
(Foust, Eiserman & Shisler, 2013, Utah State University)

Early Hearing Loss Detection and Intervention (EHDI):
OAE Screening in Healthcare Settings
(Foust, Eiserman & Shisler, 2013, Utah State University)

- Foust T, Eiserman W, Shisler L & Geroso A (2013). Using otoacoustic emissions to screen young children for hearing loss in primary care settings. *Pediatrics,*
- Subjects
  - N = 864 children undergoing hearing screening
  - Children with families at <150% of US poverty level
  - 63% of Hispanic ethnicity
  - Mostly children age 0-3 years
- Methods
  - DPOAE hearing screening technique
  - Trained Head Start staff screeners (medical assistants)
  - Training conducted by audiologist

Early Hearing Loss Detection and Intervention (EHDI):
Initial Pass/Refer Findings
Foust, Eiserman & Shisler, 2013, Utah State University

- Well child subjects
  - 86% pass
  - 10% refer
  - 4% CNT
- Illness visit subjects
  - 74% pass
  - 13% refer
  - 13% CNT
- Ear/hearing visit subjects
  - 6% pass
  - 85% refer
  - 9% CNT

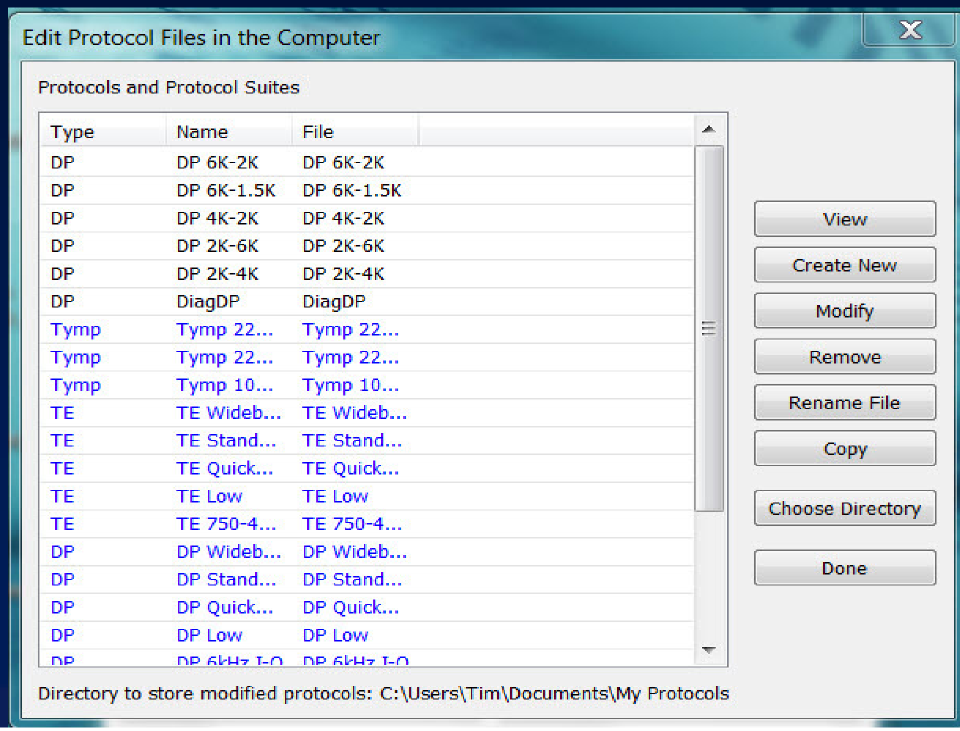
Early Hearing Loss Detection and Intervention (EHDI):
OAE Screening in Healthcare Settings
(Foust et al, 2013)

- Final Results
  - 5% (183%) referred for medical or audiological follow up
  - Among the 183 children
    - ✓80 identified with hearing loss
    - ✓63 were identified with otitis media
    - ✓11 managed for occluded ear tubes or excessive cerumen
- Summary
  - Initial pass rate = 81%
  - Overall pass rate = 96%
  - 0.4% permanent hearing loss (rate of ~4/1000)
  - 3% follow result not known
  - 4% could not test (CNT)

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Advantages of OAEs*

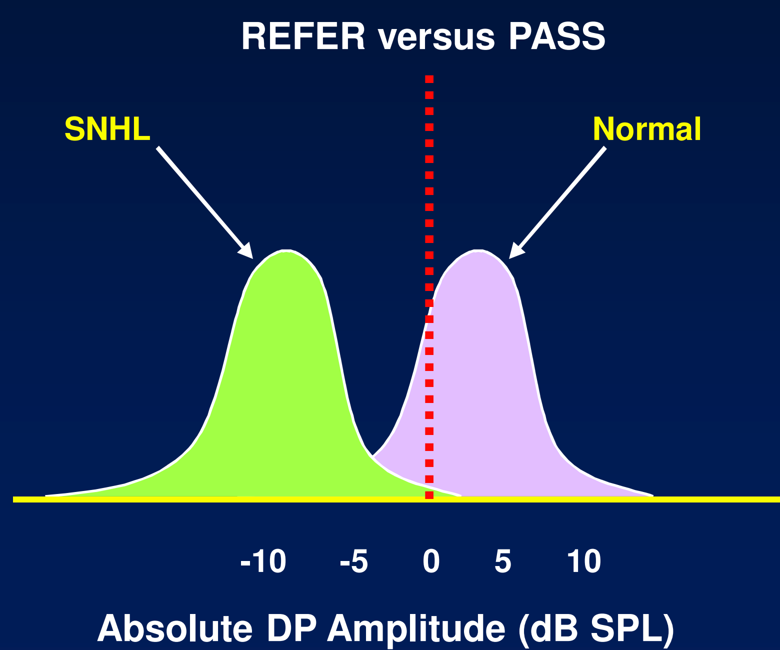
- Objective and not dependent on child's
  - Behavioral response
  - Cognition
  - Language level or native language
- Painless
- Reliable
- Efficient and quick to administer (< 4 minutes)
- Simple to administer with low level of technical skill …Does not require an audiologist
- Does not require an acoustically treated test environment
- Hand-held and portable equipment
- Test outcome is documented electronically or in printout

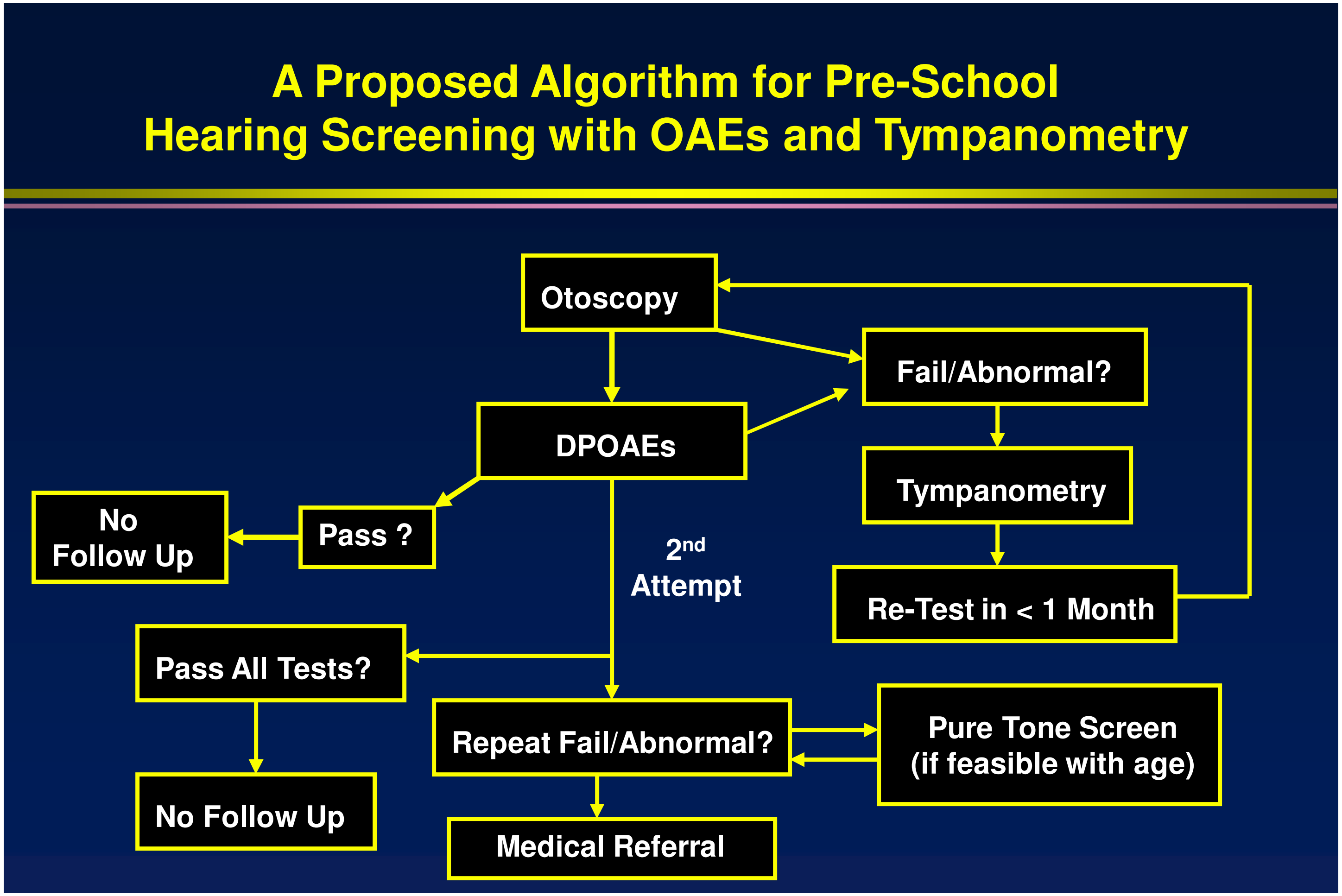
Pre-School Hearing Screening with DPOAEs:
Creating an Evidence-Based Protocol with To Enhance Sensitivity to Hearing Loss and Auditory Dysfunction



OAE Screening in Pre-School and School Age Children: Criterion for PASS versus REFER

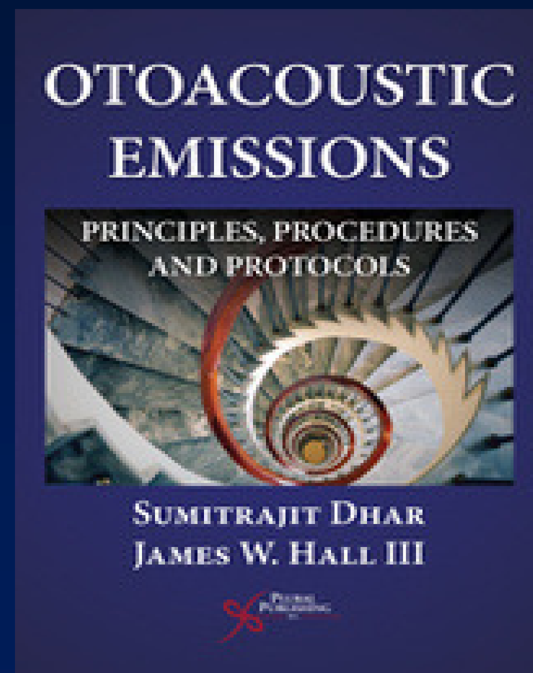
(Data for adults and older children from Gorga, Stover & Neely, 1996)




A Proposed Algorithm for Pre-School
Hearing Screening with OAEs and Tympanometry
Otoscopy
Fail/Abnormal?
DPOAEs
Tympanometry
No
Follow Up
Pass ?
2nd
Attempt
Re-Test in < 1 Month
Pass All Tests?
Repeat Fail/Abnormal?
Pure Tone Screen
(if feasible with age)
No Follow Up
Medical Referral

Otoacoustic Emissions:
Principles, Procedures, and Protocols
Sumitrajit Dhar, Ph.D., James Hall III, Ph.D.

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



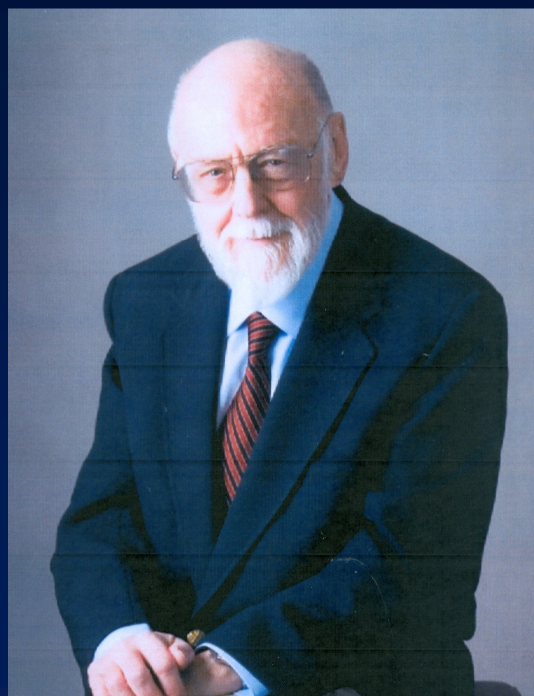
Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis:

Pre-School Hearing Screening Options

- Parent survey (used by physicians)
- Pure tone hearing screening
- Otoacoustic emissions
  - Automated technology
  - Special pass/fail criteria
- Aural admittance measures
  - Tympanometry
  - Tympanometry plus acoustic reflexes
- Combinations of selected techniques depending on:
  - Skills of screening personnel (availability of audiologist)
  - Age of the child
  - Middle ear status

James Jerger

Classic Impedance Studies in Early 1970s at Methodist Hospital And Baylor College of Medicine in Houston Texas, USA



Clinical Experience With Impedance Audiometry

James Jerger, PhD, Houston

Impedance audiometry was performed as part of the routine clinical examination in a consecutive series of more than 400 patients with various types and degrees of hearing impairment. An electroacoustic bridge (Madsen, ZO 70) was used to carry out the measurement of tympanometry, acoustic impedance, and threshold for the acoustic reflex. Results indicate that, while individual components of the total impedance battery lack diagnostic precision, the overall pattern of results yielded by the complete battery can be of great diagnostic value, especially in the evaluation of young children.

THE development of impedance audiometry during the past decade has added new scope and dimension to clinical audiology. Based on the pioneering efforts of Metz,[1] subsequent workers have refined instrumentation, technique, and interpretation to produce an invaluable tool for differential diagnosis.

The development of contemporary instrumentation for impedance audiometry has, in the main, followed two essentially parallel paths. In the United States, Zwislocki and his colleagues[2-6] developed an electromechanical bridge. In Europe, Thomsen, Terkildsen, Møller, and others,[7-10] pioneered the application of the electroacoustic approach, culminating in the present commercially available electroacoustic bridge.

The present paper reports our clinical experience with the latter instrument based on its routine administration to well over 400 successive patients over a one-year period. Our aim was to assess the efficacy of the electroacoustic approach as a routine clinical procedure and to evaluate its diagnostic value in a typical audiologic case load.

In general we found that the testing procedure was easily mastered, even by audiologically unsophisticated personnel, that valid and meaningful results could be obtained for almost every patient, and that, with certain reservations, the data of impedance audiometry constitute extremely valuable diagnostic information.

Subsequent sections present statistical information when patients are grouped according to age and type of hearing loss, and individual case reports illustrating the diagnostic value of impedance audiometry.

Method

Apparatus.—Impedance audiometry was carried out by means of an electroacoustic impedance bridge (Madsen, type ZO-70) and an associated pure-tone audiometer (Beltone, type 10D). Figure 1 shows a schematic diagram of the principal components of the impedance bridge.

A probe tip containing three tubes is sealed in the external meatus, forming a closed cavity bounded by the inner surface of the probe tip, the walls of the external meatus, and the tympanic membrane. One tube is used to deliver, into this closed cavity, a probe tone generated by a 220-hertz oscillator driving a miniature receiver. The second tube is connected to a miniature probe microphone which monitors the sound pressure level of the 220-Hz probe tone in the closed cavity and delivers the transduced voltage through an amplifier to a bridge circuit and balance meter. The balance meter is nulled by an SPL of exactly 95 dB in the closed cavity. A potentiometer on the output of the 220-Hz oscillator permits variation of the SPL over a range corresponding to a compliance variation (equivalent volume) of 0.2 to 5.0 cc. The third tube is connected to an airpump which permits variation in air pressure in the closed cavity over a range of ±400 mm (water). Air pressure is read on an electromanometer.

Accepted for publication June 19, 1970.

From the Department of Otolaryngology, Baylor College of Medicine, and the Audio-Vestibular Laboratory, the Methodist Hospital, Houston.

Reprint requests to 11922 Taylorcrest, Houston 77024.

Year 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)

Year 2007 Joint Committee on Infant Hearing (JCIH): Protocol for Evaluation for Hearing Loss In Infants from *6 to 36 months*

- Child and family history
- Parental report of infant's responses to sound
- Behavioral audiometry (either VRA or CPA)
- Otoacoustic emissions (distortion product or transient OAEs
- Acoustic immittance measures
  - Tympanometry
  - Acoustic reflex measurement
- Auditory brainstem response if
  - Behavioral audiometry responses are not reliable *or*
  - ABR measurement has not been done in the past

Acoustic Reflex Amplitude in Auditory Dysfunction
Dissertation: James W. Hall III, 1979

ACOUSTIC REFLEX AMPLITUDE IN
AUDITORY DYSFUNCTION

A Dissertation Submitted to the Faculty of
The Graduate School
Baylor College of Medicine

In Partial Fulfillment of the
Requirements for the Degree
of

Doctor of Philosophy

by

JAMES W. HALL III

Houston, Texas
August 3, 1979

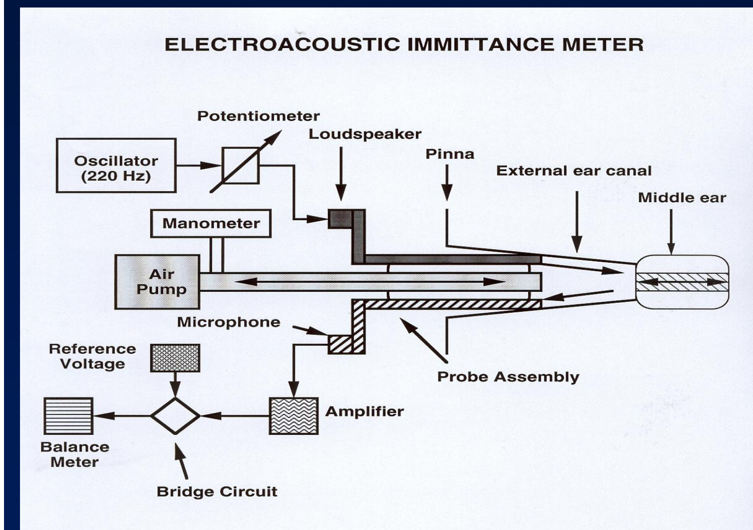
Acoustic Reflex Publications from Dissertation

- Hall JW III. Acoustic reflex amplitude: I. Effect of age and sex. *Audiology (Basel) 21:* 294-309, 1982
- Hall JW III. Acoustic reflex amplitude: II. Effect of age-related auditory dysfunction. *Audiology (Basel) 21:* 386-399, 1982
- Hall JW III. Quantification of the relationship between crossed and uncrossed acoustic reflex amplitude. *Ear and Hearing 3:* 296-300, 1982

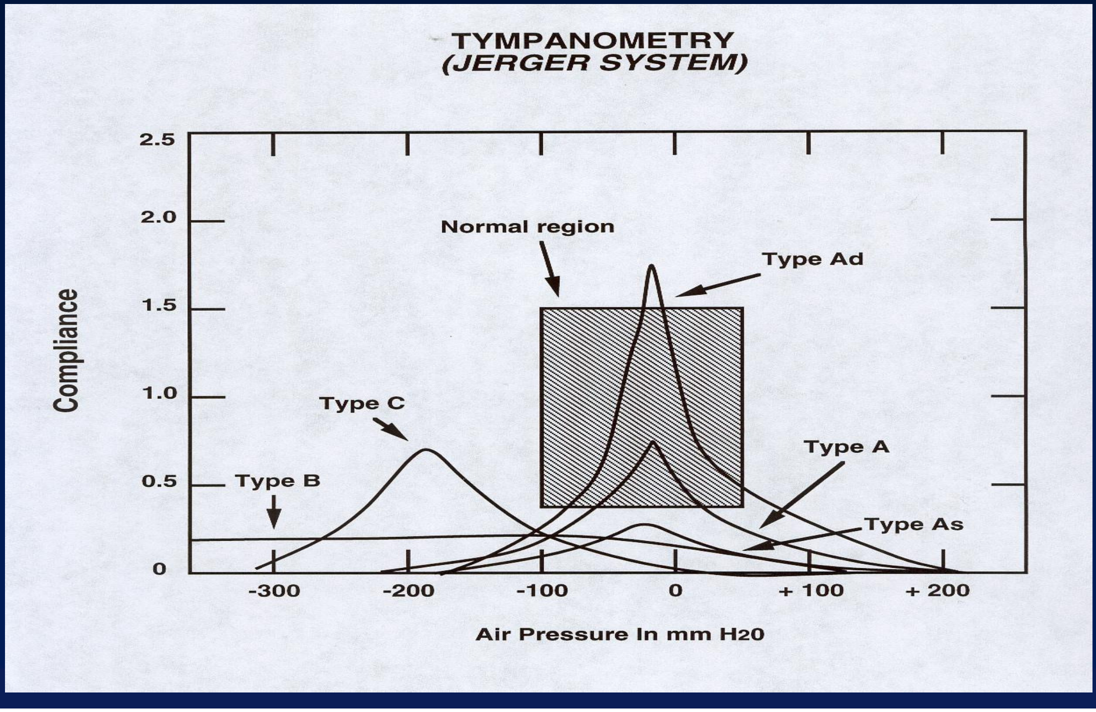
Acoustic Reflex in the Identification of Hearing Loss in Children

- Hall JW III and Bleakney ME. Hearing loss prediction by the acoustic reflex: Comparison of seven methods*. Ear and Hearing 2:* 156-164, 1981
- Hall JW III. Hearing loss prediction in a young population: Comparison of seven methods. *International Journal of Pediatric Otorhinolaryngology 3*: 225-243, 1981
- Hall JW III and Koval C. Accuracy of hearing prediction by the acoustic reflex. *The Laryngoscope 92*: 140-149, 1982
- Hall JW III, Berry GA and Olson K. Identification of serious hearing loss with acoustic reflex data: Clinical experience with some new guidelines. Scandinavian Audiology 11: 251-255, 1982

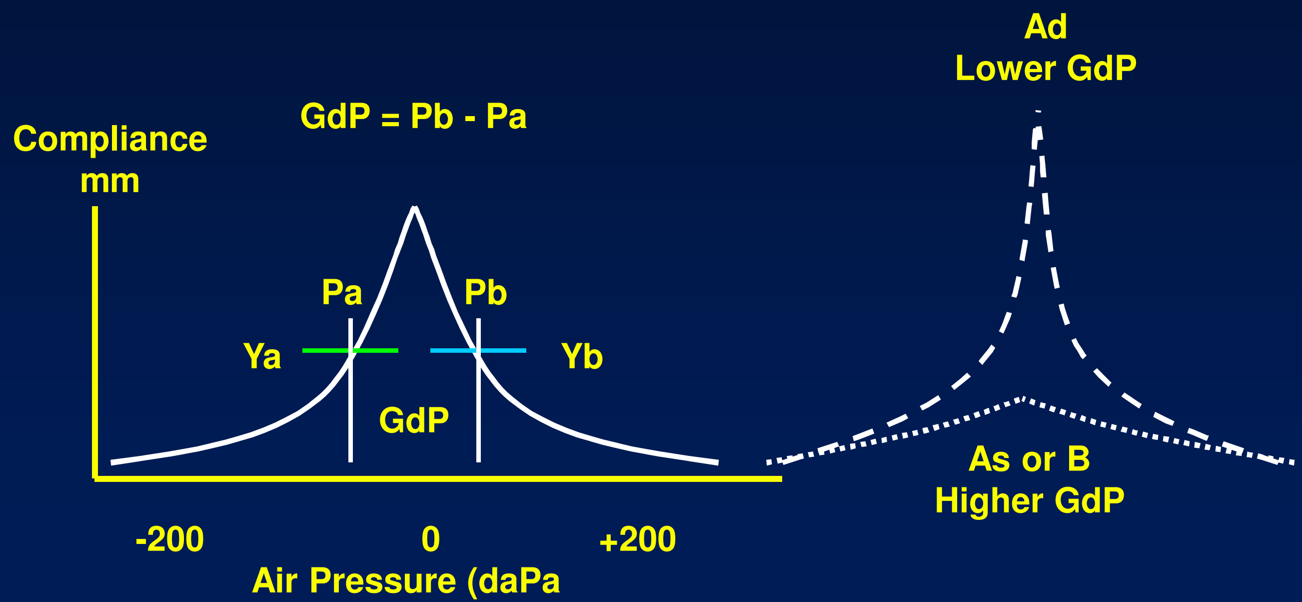
Aural Immittance Instrumentation and Measurement:
In Most Audiology and Pediatrics Clinics



One Component Tympanogram (Admittance or Impedance):
Analysis as Simple as A, B, C

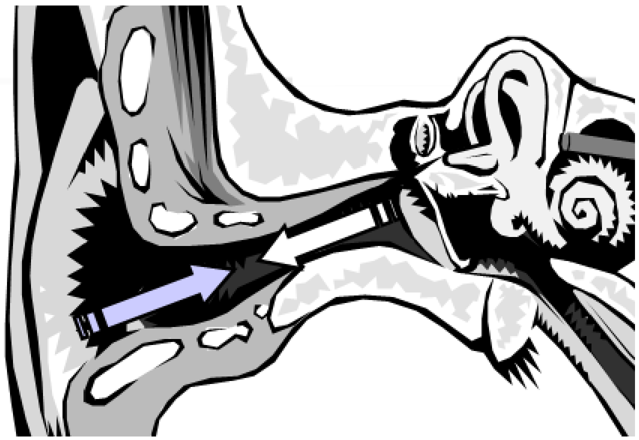


Automated Tympanometry Analysis: *Tympanogram Gradient*



Wideband Reflectance/Absorbance

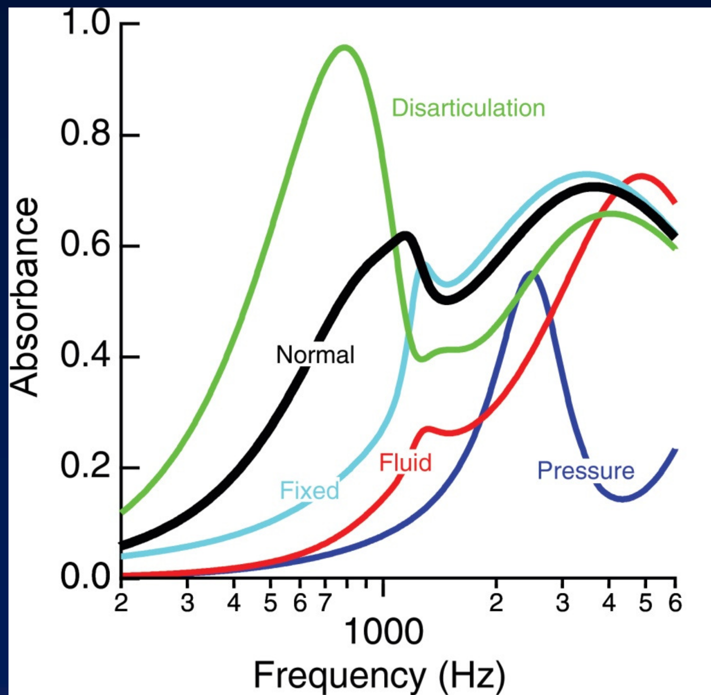
(Courtesy of Bue Kristensen, Interacoustics, 2013)



$$\text{Energy Absorbance} = \frac{\text{Absorbed Power}}{\text{Incident Power}} = 0$$

$$= 1 - \text{Energy Reflectance}$$

Wideband Reflectance/Absorbance
(Voss et al. Ear & Hearing, 2008)
Courtesy of Bue Kristensen, Interacoustics, 2013

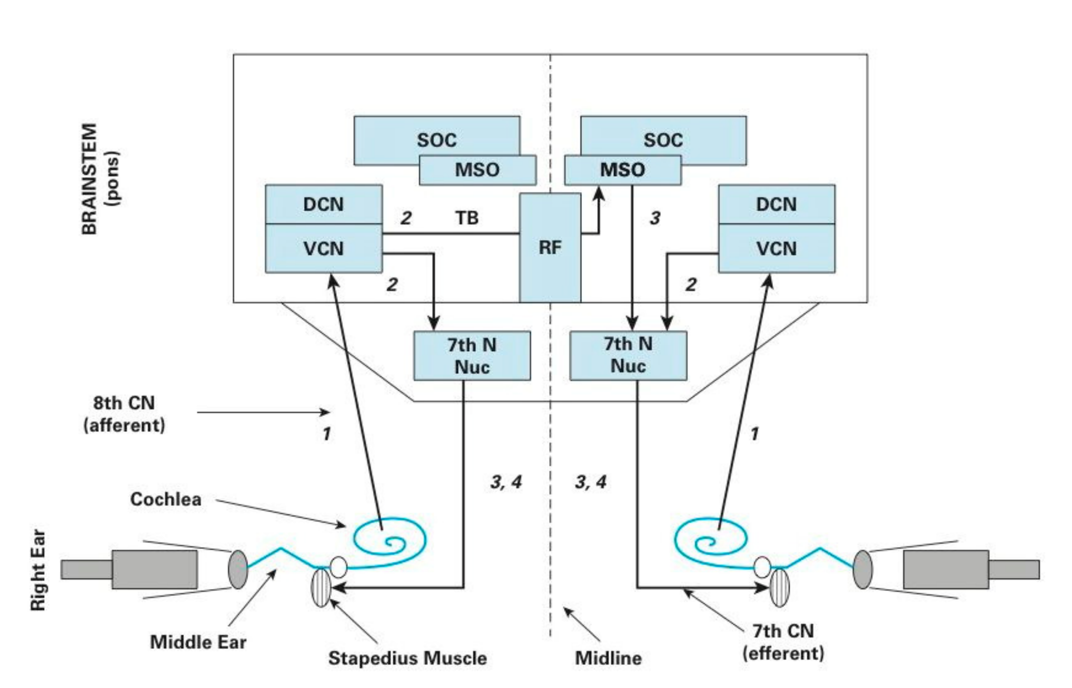


Acoustic Reflex in the Identification of Hearing Loss in Children: *2011 AAA Childhood Hearing Screening Guidelines*

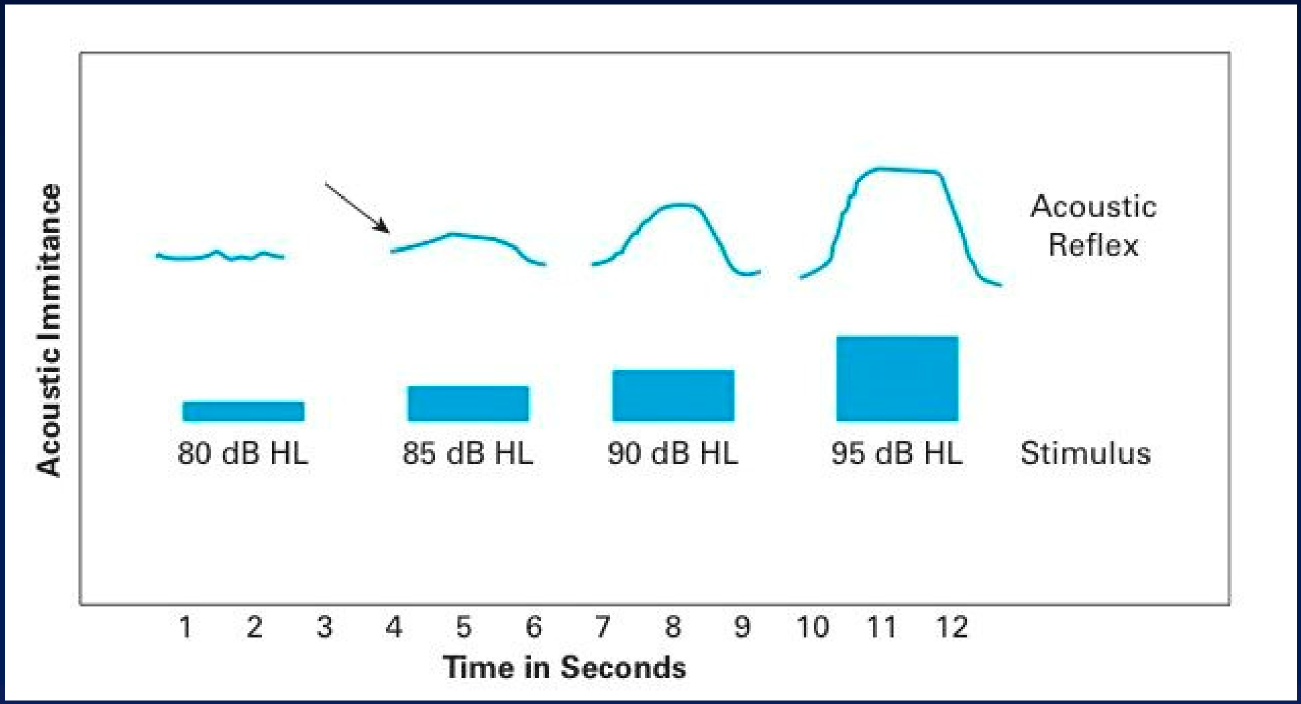
- "Due to the unacceptable false-positive rate, contralateral acoustic reflex can be ruled out as an acceptable screening measure
- Authors cite outdated studies conducted with old instrumentation
  - Brooks D (1974). The role of the acoustic impedance bridge in pediatric screening. *Scand Aud, 3*, 99-104
  - Renvall U & Liden G (1980). Screening procedure for detection of middle ear and cochlear disease. Annals of ORL, (Supplement 68) 89, 214-216
  - FitzZaland R & Zink G (1984). A comparison of hearing screening procedures. *Ear & Hearing,* 5, 205-210

Acoustic Stapedial Reflex Pathways According to Erick Borg

From Hall JW III (2014). Introduction to Audiology Today. Boston: Pearson



Acoustic Reflex Measurements
Acoustic Reflex Threshold



Acoustic Reflex Presence as a Function of Age

(From Kankkunen & Liden (1988). Ipsilateral acoustic reflex thresholds in neonates and in normal-hearing and hearing impaired preschool children. Scand Audiol, 13, 139-144)

Age of Child	Percentage of Children with Reflexes Present (600 Hz Probe Tone)
1 month	100%
2 months	92%
3 months	90%
4 months	87%
5-11 months	85%
1 year	72%
2 years	67%
3 years	47%
4 years	47%

Acoustic Reflexes in Neonates

- Kei J. Acoustic stapedial reflexes in healthy neonates: normative data and test-retest reliability. *JAAA, 23,* 2012
  - 66 full term infants
  - Acoustic reflexes recorded with 1000 Hz probe tone
  - Tone and BBN stimuli
  - All neonates had acoustic reflexes

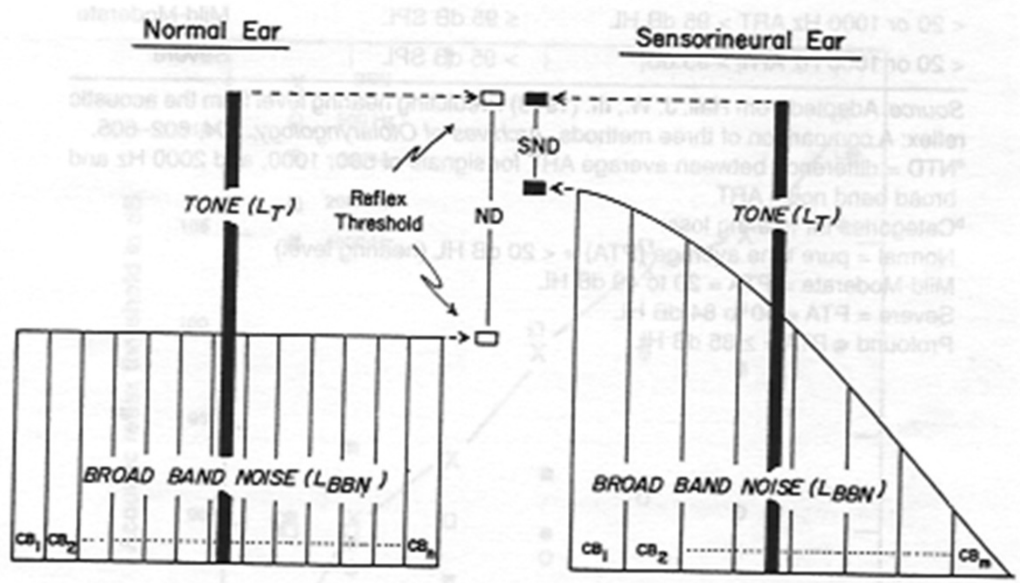
Acoustic Reflexes in Neonates

(Kei J. Acoustic stapedial reflexes in healthy neonates: normative data* and test-retest reliability. *JAAA, 23,* 2012)

Stimulus	Median ART (dB HL)	90% Range
500 Hz	80	70 - 95
2000 Hz	70	60 - 85
4000 Hz	65	50 - 80
BBN	55	50 – 75

** N = 68 ears*

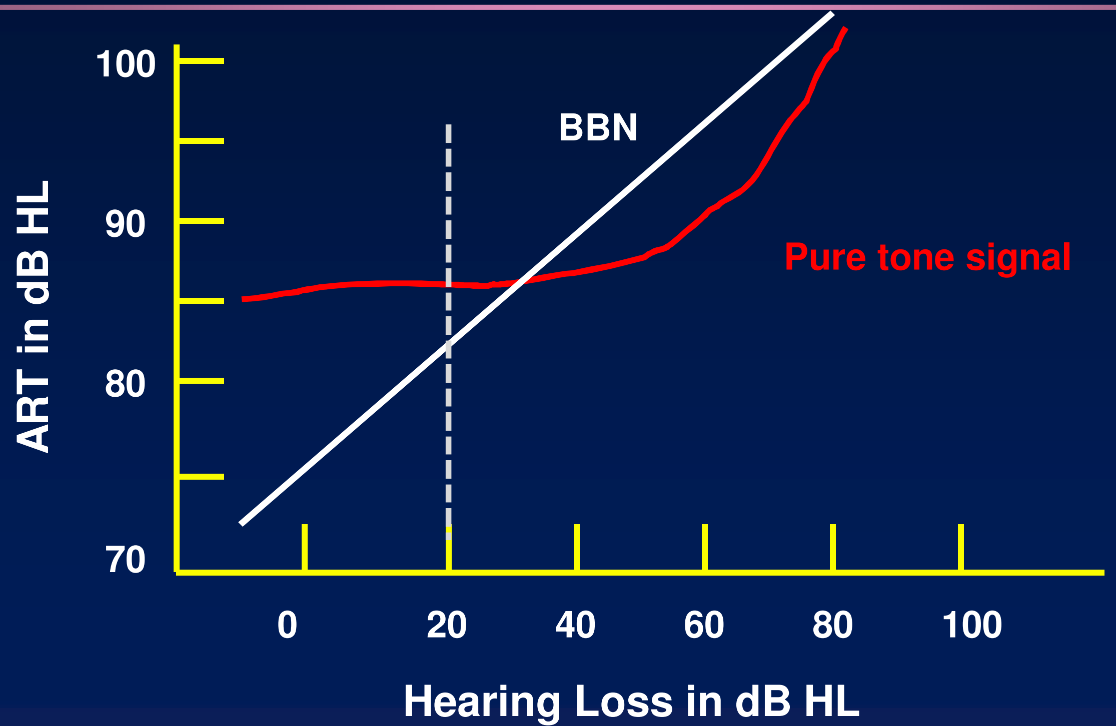
Jerger J, Burney P, Mauldin L & Crump B (1974).
Predicting hearing loss from the acoustic reflex. ***JSHD, 39,*** **11-22**



From the original paper on Sensitivity Prediction by Acoustic Reflex (SPAR) by Jerger et al., 1974.

Simplified SPAR (Sensitivity Prediction by the Acoustic Reflex)

Hall JW III, Berry GA and Olson K. Identification of serious hearing loss with acoustic reflex data: Clinical experience with some new guidelines. Scandinavian Audiology 11: 251-255, 1982



Year 2007 Joint Committee on Infant Hearing (JCIH): *Medical Evaluation for Children with Confirmed Hearing Loss or Middle Ear Dysfunction*

- Purpose of medical evaluation
  - Determine etiology of the hearing loss
  - Identify related physical conditions
  - Provide recommendations for
    - ✓ Medical or surgical treatment
    - ✓ Referral for other services
- Essential components of the evaluation
  - Clinical history
  - Family history of child-onset permanent hearing loss
  - Identification of syndromes associated with hearing loss
  - Physical examination
  - Radiologic and laboratory studies

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis:

Pre-School Hearing Screening Options

- Parent survey (used by physicians)
- Pure tone hearing screening
- Otoacoustic emissions
  - Automated technology
  - Special pass/fail criteria
- Aural admittance measures
  - Tympanometry
  - Tympanometry plus acoustic reflexes
- Combinations of selected techniques depending on:
  - Skills of screening personnel (availability of audiologist)
  - Age of the child
  - Middle ear status

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Essential for Successful EHDI*

- UNHS doesn't always lead to universal diagnosis and intervention of childhood hearing loss
- Rationale for pre-school screening for hearing loss
- Historical perspective on pre-school hearing screening
- Techniques and technology for pre-school hearing screening: What are the options?
- Current clinical guidelines for pre-school hearing screening
- A *new* strategy for effective and efficient pre-school hearing screening and diagnosis of hearing loss
- Future directions in pre-school hearing screening

Current Clinical Guidelines: Best Practices in Audiology are Evidence-Based

"Those who fall in love with practice without science are like a sailor who steers a ship without a rudder or compass, and who can never be certain whither he is going."

Leonardo Da Vinci (1452-1519)

Evidence-Based Efficient and Effective Identification of Infant Hearing Loss: *Standard of Care*

- Consistent with local, regional or national clinical practice
- Follows guidelines or recommendations on clinical practice approved by national multi-disciplinary professional committees or panels
- Follows guidelines or recommendations on clinical practice approved by national professional organizations
- Is consistent with statements of
  - Scope of Practice
  - Code of Ethics
- Is in compliance with Federal guidelines for clinical practice and services, e.g., Joint Committee on Accreditation of Healthcare Organizations (JCAHO)

A Common Evidence Grading System:
Four Categories

- Grade 1
  - 1a: Well-designed meta-analysis of randomized controlled trials
  - 1b: Well-designed randomized controlled trials
- Grade 2
  - 2a: Well-designed controlled studies without randomization
  - 2b: Well-designed quasi-experimental studies
- Grade 3: Well-designed non-experimental studies, i.e.,
  - Correlational studies
  - Case studies
- Grade 4:
  - Expert committee reports, consensus conferences and clinical experience

Another Evidence Grading System: *US Preventative Services Task Force* *(www.fpnotebook.com/prevent/epi)*

- Level I: Randomized control trial
- Level II: Non-randomized control trial
- Level III: Cohort or case-control study
- Level IV: Ecological or descriptive studies
- Level V: Opinions of respected authorities based on
  - Clinical experience
  - Descriptive studies *or*
  - Reports of expert committees

Evidence-Based Efficient and Effective Identification of Pre-School Hearing Loss: *Clinical Guidelines*

- 1997 ASHA Guidelines for Audiologic Screening
- Cunningham M & Cox EO (2003). Committee on Practice and Ambulatory Medicine and the Section on Otolaryngology and Bronchoesophagology. Hearing assessment in infants and children: recommendations beyond neonatal screening. *Pediatrics, 111,* 436-440
- 2007 Joint Committee on Infant Hearing Position Statement: Principles and Guidelines for Early Hearing Detection and Intervention Programs. *Pediatrics, 120*, 2007-2333
- Harlor AD & Bower C. (2009) Hearing assessment in infants and children: Recommendations beyond neonatal screening. *Pediatrics, 124*, 1252-1263
- 2011 AAA Childhood Hearing Screening Clinical Guidelines

2011 American Academy of Audiology Childhood Hearing Screening Clinical Guidelines

- Pure tone (PT) hearing screening
  - *Screening personnel and training not defined in guidelines*
  - Perform biologic equipment calibration
  - Screen populations age 3 (chronologically and developmentally) and older using pure tone screening
  - Perform PT sweep at 1000, 2000, and 4000 Hz at 20 dB HL
  - Present a tone once but not > 4 times if a child fails to response
  - Screen in an acoustically appropriate environment
  - Lack of response at any frequency in either ear is a failure
  - Rescreen immediately
  - Use tympanometry with pure tone screening in preschool
  - Minimum grades to be screening include preschool

2011 American Academy of Audiology Childhood Hearing Screening Clinical Guidelines

- Tympanometry screening
  - Calibrate equipment daily
  - Used as a second stage screening after pure tone or OAE screening failure
  - Referral criteria
    - ✓ Recommended = 250 daPa tympanometric width
    - ✓ If width isn't possible, use 0.2 mmhos static compliance
    - ✓ Final option is negative pressure of > - 200 daPa
  - Target young pediatric populations
  - Results of OAE and tympanometric screening inform next steps"

2011 American Academy of Audiology Childhood Hearing Screening Clinical Guidelines

- Rescreening
  - "Rescreen with tympanometry after a defined period"
    - ✓ After failing immediate pure tone rescreening
    - ✓ In 8 to 10 weeks for children failure pure tone or OAE screening and tympanometry
  - "Do not wait to perform a second stage screening on children who fail pure tone screening only

2011 American Academy of Audiology Childhood Hearing Screening Clinical Guidelines

- OAEs
  - Use only for preschool and school age children for whom PT screening is not developmentally appropriate (< 3 years)
  - Calibrate OAE equipment daily
  - Maintain primary DPOAE levels at 65/55 dB SPL
  - Select DPOAE or TEOAE cut-off values carefully
  - Default settings may not be appropriate
  - Screening OAE programs must involve experienced audiologist
  - Children failing OAE should be screened with tympanometry
- Acoustic reflex testing, reflectometry, and hearing screening using speech materials are not recommended

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Essential for Successful EHDI*

- A brief history of universal newborn hearing screening (UNHS)
- UNHS doesn't always lead to universal diagnosis and intervention of childhood hearing loss
- Rationale for pre-school screening for hearing loss
- Historical perspective on pre-school hearing screening
- Techniques and technology for pre-school hearing screening: What are the options?
- Current clinical guidelines for pre-school hearing screening and diagnosis of hearing loss
- Strategies for effective and efficient pre-school hearing screening and diagnosis of hearing loss

Effective and Efficient Screening for Pre-School Hearing Loss:
Let's Consider a New Feasible and Evidence-Based Approach

Birth to 4 Years

DPOAES
- **2000 – 5000 Hz**
- **PASS = DP ≥ 0 dB SPL**

Immittance measures
- **Tympanometry**
- **ART for BBN**
- **PASS = type A; BBN < 80 dB)**

Otoscopy as indicated

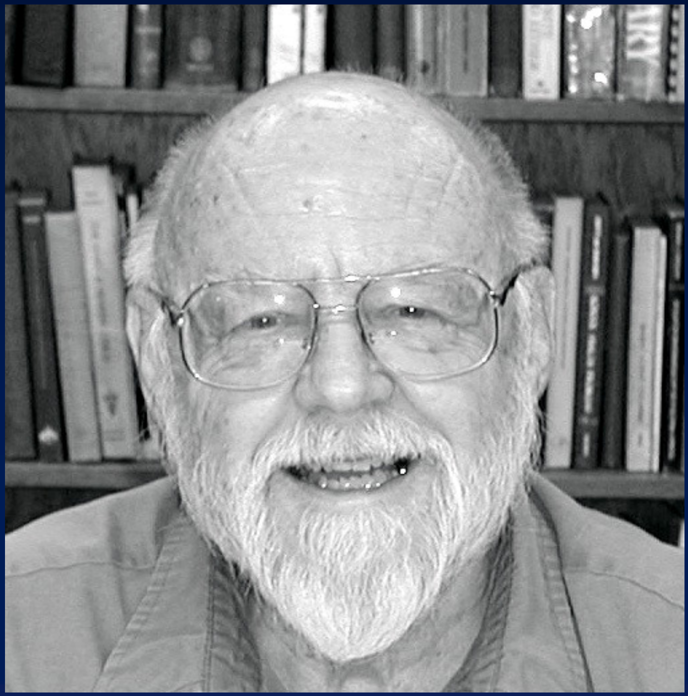
≥ 4 Years

PASS for previous hearing screening? Follow birth to 4 year objective test protocol.

Previous FAIL outcome or no documented hearing screening? Follow 2011 AAA Guidelines (Pure tone screening at 20 dB HL)

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

Year 2007 JCIH Position Statement Protocol for Evaluation for Hearing Loss In Infants and Toddlers 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
- Audiological assessment
  - Auditory brainstem response (ABR)
    - ✓ Click-evoked ABR with rarefaction and condensation single-polarity stimulation (rule out ANSD)
    - ✓ Frequency-specific ABR with air-conduction tone bursts
    - ✓ Bone-conduction stimulation (as indicated)
    - ✓ Auditory steady state response (ASSR) is optional
  - Otoacoustic emissions (distortion product or transient OAEs)
  - Tympanometry with 1000 Hz probe tone
  - "Clinical observation of infant's auditory behavior. *Behavioral observation alone is not adequate for determining whether hearing loss is present in this age group, and is not adequate for the fitting of amplification devices."*

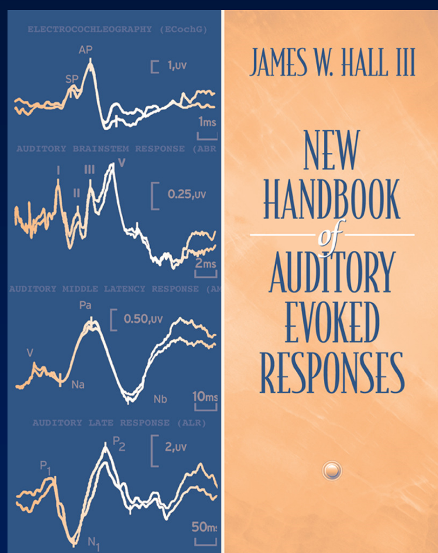
Year 2007 Joint Committee on Infant Hearing (JCIH): Protocol for Diagnostic Evaluation for Hearing Loss in Infants from 6 to 36 Months

- Child and family history
- Parental report of infant's auditory and visual behaviors and communication milestones
- Behavioral audiometry
  - VRA or CPA depending on the child's developmental level
  - Pure tone audiometry across frequencies for each ear
  - Speech detection and recognition measures
- Objective audiological assessment
  - Otoacoustic emissions
  - Tympanometry and acoustic reflex thresholds
  - ABR if
    - ✓ Behavioral results are not reliable *or*
    - ✓ ABR has not been performed in the past

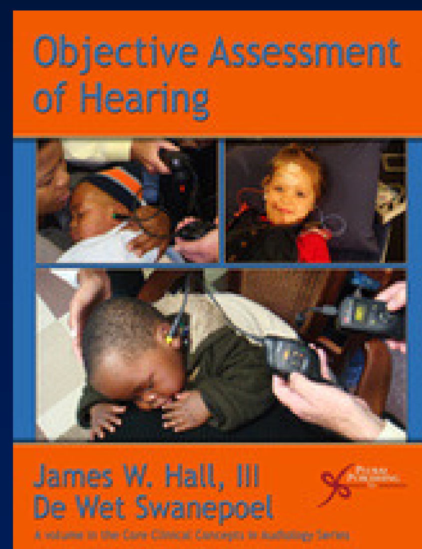
Effective and Efficient Screening and Diagnosis of Pre-School Hearing Loss: *Additional Clinical Guidelines*

- 2004 ASHA Guidelines for audiologic assessment of children birth to 5 years of age
- 2010 American Academy of Audiology Clinical Practice Guidelines: Childhood Hearing Screening
- 2010 Guidelines on Identification, Diagnosis, and Management of Auditory Neuropathy Spectrum Disorder in Infants and Young Children
- 2012 American Academy of Audiology: Audiologic Guidelines for the Assessment of Hearing in Infants and Young Children

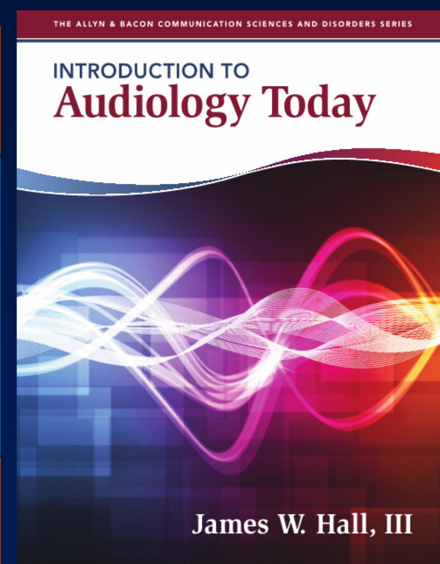
Sources of Detailed Information on Identification and Diagnosis of Infant and Toddler Hearing Loss



Digital Version in 2015



Plural Publishers 2011
www.pluralpublishing.com



Pearson Publishers 2014
www.allynbaconmerrill.com

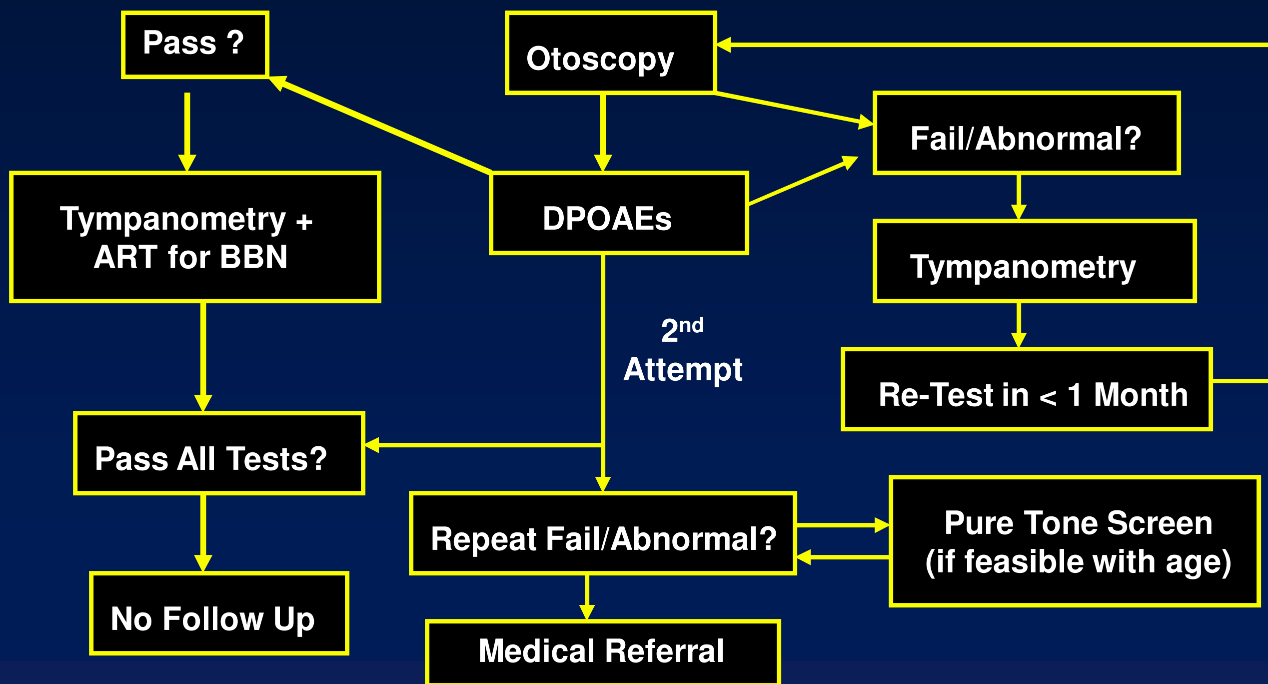
Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis:
Future Directions in Research and Clinical Practice

Early Hearing Loss Detection and Intervention (EHDI):

New Directions in Early Identification of Infant Hearing Loss

(Devices for OAEs, Tympanometry and Acoustic Reflexes)

New Strategy for Pre-School Hearing Screening with OAEs, Tympanometry, and Acoustic Reflexes

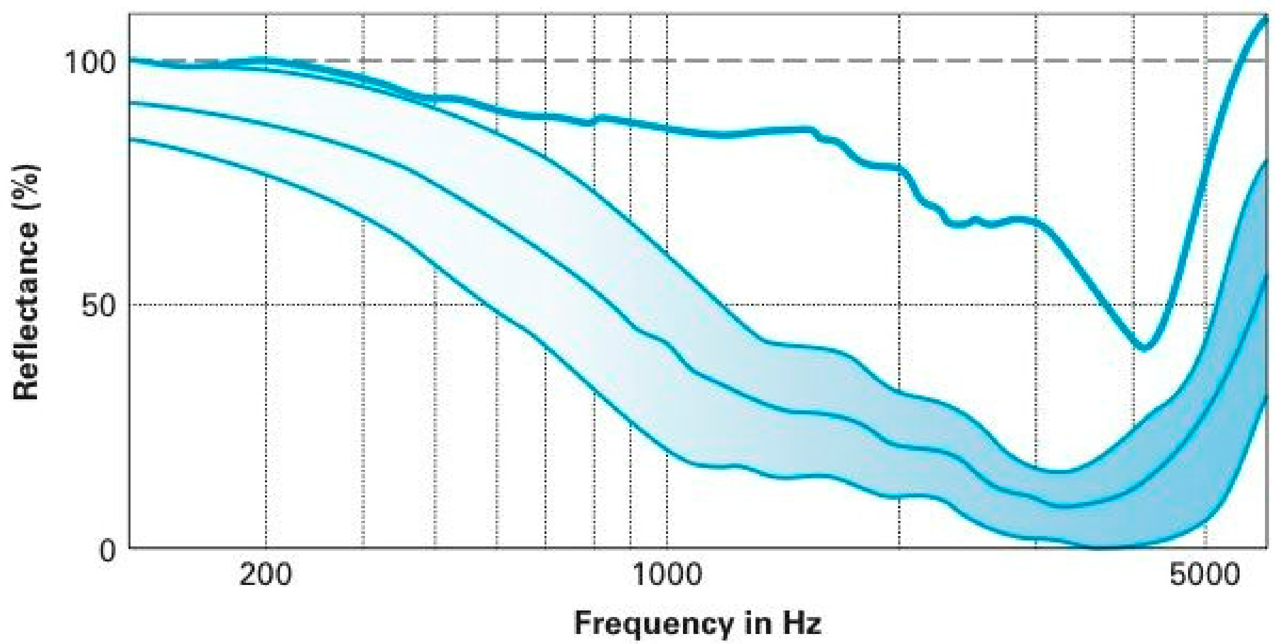


Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Advantages of New Strategy Using OAEs, Tympanometry, and Acoustic Reflexes*

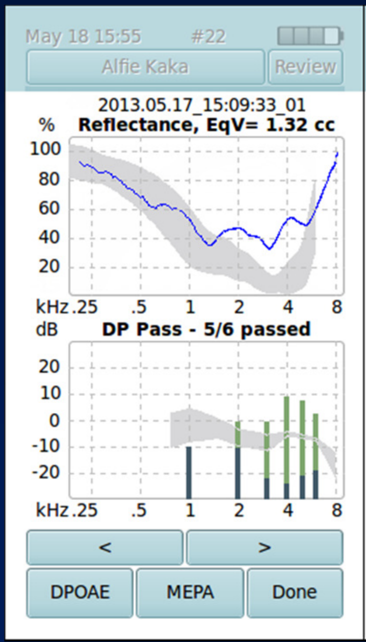
- Objective and not dependent on child's behavioral response, cognition, developmental age, or language level
- Reliable
- Efficient and quick to administer (< 4 minutes)
- Simple to administer with low level of technical skill
- Does not require an audiologist
- Does not require an acoustically treated test environment
- Hand-held and portable equipment
- Test outcome is documented electronically or in printout
- Sensitive measure of
  - Middle ear function
  - Cochlear (outer and inner hair cell) function
  - ANSD

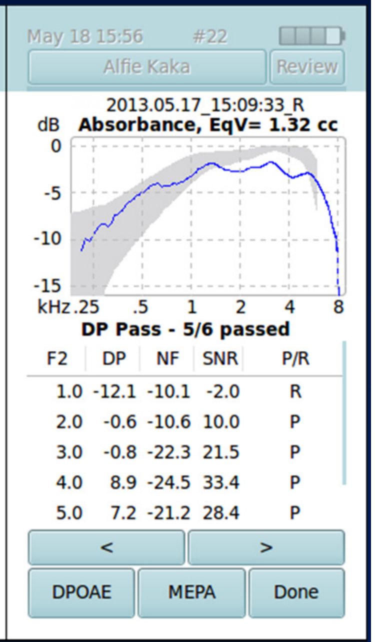
Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis:

Wideband Reflectance or Absorbance (Normal vs. Otitis Media)



Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis:
(OtoStat Device for WBR/A and OAEs)





Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Wideband Reflectance/Absorbance*

- Hunter, L., Feeney, M. P., Lapsley Miller, J. A., Jeng, P. S., & Bohning, S. (2010). Wideband reflectance in newborns: Normative regions and relationship to hearing screening results. *Ear & Hearing,* 2010, 31:599-610
- Hunter, LL, Tubaugh, L, Jackson, A, Propes, S. Wideband middle ear power measurement in infants and children: Reliability and normal characteristics. *Journal of the American Academy of Audiology,* 2008, 19:309-324.
- Hunter, LL, Tubaugh, L, Jackson, A, Propes, S. Wideband middle ear power measurement in infants and children. *Journal of the American Academy of Audiology,* 2008, 19:309-324.

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Wideband Reflectance/Absorbance*

- Hunter, L., Feeney, M. P., Lapsley Miller, J. A., Jeng, P. S., & Bohning, S. (2010). Wideband reflectance in newborns: Normative regions and relationship to hearing screening results. *Ear & Hearing,* 2010
- Kei, J., Sanford, C.A., Prieve, B.A., Hunter, L.L. (Aug, 2013) Wideband acoustic immittance measures: Developmental characteristics (0 -12 months). *Ear and Hearing,* 34(7 Suppl 1), 17s-26s
- Feeney, M.P., Hunter, L.L., Kei, J., Lilly, D.J., Marolis, R.H., et. al. (Aug, 2013) Consensus Statement: Eriksholm Workshop on Wideband Absorbance Measures of the Middle Ear. *Ear and Hearing 34(Suppl 1), 78s-79s*

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Tele-Audiology*

(www.audiologyworld.net)

A Systematic Review of Telehealth Applications in Audiology

De Wet Swanepoel, Ph.D.,[1,2] and James W. Hall, III, Ph.D.[3,1]

[1]Department of Communication Pathology, University of Pretoria, Pretoria, South Africa.
[2]Callier Center for Communication Disorders, School for Behavioral and Brain Sciences, University of Texas at Dallas, Texas.
[3]Department of Communicative Disorders, University of Florida, Gainesville, Florida.

Abstract

Hearing loss is a pervasive global healthcare concern with an estimated 10% of the global population affected to a mild or greater degree. In the absence of appropriate diagnosis and intervention it can become a lifelong disability with serious consequences on the quality of life and societal integration and participation of the affected persons. Unfortunately, there is a major dearth of hearing healthcare services globally, which highlights the possible role of telehealth in penetrating the underserved communities. This study systematically reviews peer-reviewed publications on audiology-related telehealth services and patient/clinician perceptions regarding their use. Several databases were sourced (Medline, SCOPUS, and CHINAL) using different search strategies for optimal coverage. Though the number of studies in this field are limited available reports span audiological services such as screening, diagnosis, and intervention. Several screening applications for populations consisting of infants, children, and adults have demonstrated the feasibility and reliability of telehealth using both synchronous and asynchronous models. The diagnostic procedures reported, including audiometry, video-otoscopy, oto-acoustic emissions, and auditory brainstem response, confirm clinically equivalent results for remote telehealth-enabled tests and conventional face-to-face versions. Intervention studies, including hearing aid verification, counseling, and Internet-based treatment for tinnitus, demonstrate reliability and effectiveness of telehealth applications compared to conventional methods. The limited information on patient perceptions reveal mixed findings and require more specific investigations, especially post facto surveys of patient experiences. Tele-audiology holds significant promise in extending services to the underserved communities but require considerable empirical research to inform future implementation.

Introduction

The field of audiology encompasses prevention, assessment, and rehabilitation of hearing, auditory function, balance, and other related systems.[1,2] With an estimated 642 million people in the world affected to a mild or greater degree, and 278 million to a moderate and greater degree, hearing loss is clearly a significant global healthcare concern[3] with pervasive and far-reaching consequences. If not identified and treated early, children with hearing loss may suffer lifelong disability due to developmental delays in language, literacy, academic achievement, and social well-being.[4,5] Hearing loss in adults tends to isolate and stigmatize them, leading to poor social participation and severely restricting vocational opportunities, as evidenced by significantly higher under- and unemployment.[6] Hearing loss is therefore reported as one of the most significant contributors to the global burden of disease.[7]

Audiological diagnosis and intervention for children and adults with hearing loss offer the possibility of excellent outcomes as opposed to the negative consequences of undetected and undiagnosed hearing loss without intervention services.[8,9] The problem in providing the necessary services, however, is the shortage of audiological professionals and services in the majority of regions in the world.[10,11] Even in developed countries like the United States and Australia, rural and remote communities may not be able to access the necessary hearing healthcare services. Telehealth applications in audiology may offer some solutions to the mismatch in the apparent need for services and the limited capacity to deliver services.[12] Using information and communication technology in healthcare, as implied in telehealth,

DOI: 10.1089/tmj.2009.0111

informa healthcare

Original Article

International Journal of Audiology 2010; 49: 195–202

Telehealth in audiology: The need and potential to reach underserved communities

De Wet Swanepoel[1,2]
Jackie L. Clark[2,3]
Dirk Koekemoer[4]
James W. Hall III[5,1]
Mark Krumm[6]
Deborah V. Ferrari[7]
Bradley McPherson[8]
Bolajoko O. Olusanya[9]
Maurice Mars[10]
Iêda Russo[11]
Jose J. Barajas[12]

[1]Department of Communication Pathology, University of Pretoria, South Africa
[2]Callier Center for Communication Disorders, University of Texas at Dallas, TX, USA
[3]Department of Speech and Hearing Therapy, University of Witwatersrand, South Africa
[4]Research and Development Department, GeoAxon, South Africa
[5]Department of Communicative Disorders, University of Florida, Gainesville, FL, USA
[6]School of Speech Pathology and Audiology, Kent State University, OH, USA
[7]Department of Speech Language Pathology and Audiology, Dentistry

Abstract

Permanent hearing loss is a leading global health care burden, with 1 in 10 people affected to a mild or greater degree. A shortage of trained healthcare professionals and associated infrastructure and resource limitations mean that hearing health services are unavailable to the majority of the world population. Utilizing information and communication technology in hearing health care, or tele-audiology, combined with automation offer unique opportunities for improved clinical care, widespread access to services, and more cost-effective and sustainable hearing health care. Tele-audiology demonstrates significant potential in areas such as education and training of hearing health care professionals, paraprofessionals, parents, and adults with hearing disorders; screening for auditory disorders; diagnosis of hearing loss; and intervention services. Global connectivity is rapidly growing with increasingly widespread distribution into underserved communities where audiological services may be facilitated through telehealth models. Although many questions related to aspects such as quality control, licensure, jurisdictional responsibility, certification and reimbursement still need to be addressed; no alternative strategy can currently offer the same potential reach for impacting the global burden of hearing loss in the near and foreseeable future.

Sumario

La pérdida auditiva permanente es una importante carga para los cuidados de la salud a nivel mundial, con 1 de cada 10 personas afectadas en grado ligero o mayor. La escasez de profesionales entrenados en cuidados de la salud y de infraestructura asociada y la limitación de recursos determina que los servicios de salud auditiva no estén disponibles para la mayoría de la población mundial. La utilización de información y tecnología de la comunicación para los cuidados de la salud auditiva o teleaudiología, combinada con la automatización, ofrece oportunidades únicas para mejorar los cuidados clínicos, ampliar el acceso a los servicios y tener cuidados de salud auditiva costoefectivos y sustentables. La Teleaudiología ha demostrado un potencial significativo en áreas como las de educación y adiestramientio de profesionales de la salud auditiva, profesionales afines, padres y adultos con problemas auditivos; tamiz de problemas auditivos; diagnóstico de pérdidas auditivas y servicios de intervención. La conectividad global está creciendo rápidamente y ha aumentado de manera generalizada su distribución en comunidades con pocos servicios, en donde los servicios audiológicos pueden facilitarse a través de modelos de telesalud. No obstante, existen muchas dudas que deben resolverse y que están relacionadas con aspectos como control de calidad, regulación del ejercicio profesional, responsabilidad jurisdiccional, certificación y reembolso de servicios, pero no existe como alternativa ninguna otra estrategia que pueda ofrecer actualmente el mismo potencial, para impactar el peso global de las pérdidas auditivas en el futuro cercano o previsible.

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Another Audiology Application of Tele-Health*

- Tele-audiology is the audiology application of tele-health
- Two general categories of tele-audiology
  - Asynchronous (store-and-forward)
  - Synchronous (real time or live)
- Tele-consultation regarding challenging patients
- Tele-education
  - Students in audiology training programs anywhere
  - Technicians *(such as preschool hearing screeners)*
  - Audiologists
    - ✓Advanced training
    - ✓Continuing education

Audiology Applications of Tele-Health:
Technologies and Strategies

- Asynchronous (store-and-forward) tele-audiology
  - Any type of test information, e.g.,
    - ✓Audiogram
    - ✓Tympanogram
    - ✓DPOAE test results
    - ✓ABR recordings
    - ✓Video-otoscopy image
  - May include findings from automated testing
  - Transmitted via
    - ✓Email
    - ✓Fax
    - ✓Direct storage (e.g, DropBox)

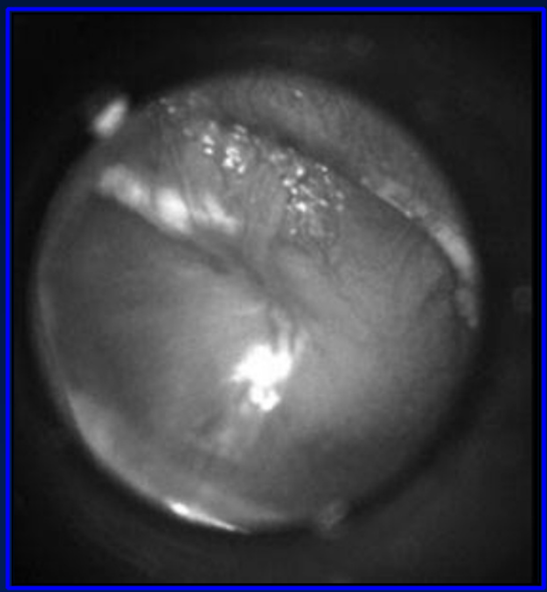
Audiology Applications of Tele-Health: *Technologies and Strategies*

- Synchronous (real time or live) tele-audiology: Model 1
  - High quality interactive video (e.g., dedicated or laptop Web camera)
  - Audiologist views and oversees facilitator provision of services
  - Audiologist intervenes to assure quality of services
  - Audiologist analyzes findings following data collection
- Synchronous tele-audiology: Model 2
  - Audiologist remotely controls test equipment using
    - ✓ Application sharing software
    - ✓ Internet connection
  - Technician test skills and training are not important

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Audiology Applications of Tele-Health*

- Video-otoscopy
- Pure tone audiometry
- Infant and preschool hearing screening
  - Pure tone
  - OAE
  - Tympanometry and acoustic reflex
- ABR estimation of hearing loss
- Diagnostic auditory assessment
- Vestibular assessment
- Rehabilitation, e.g.,
  - Counseling patients and families
  - Hearing aid fitting and programming
  - Cochlear implant programming

Tele-Audiology:
Video Otoscopy in Adults



Video Otoscopy
(Acute Otitis Media)

Biagio L, Swanepoel D, Adeyemo A, Hall JW III & Vinck B (2013). Asynchronous video-otoscopy with a teleheatlh facilitator. *Telemedicine and e-Health, 19,* 1-7

Tele-Audiology:
Video Otoscopy in Children

Biagio et al (2014). Video-otoscopy recordings for diagnosis of childhood ear disease using telehealth at primary care level. *J Telemed Telecare*

Audiology Applications of Tele-Health:
Trans-Atlantic Pure Tone Audiometry (AAA, 2009)

Photo taken at the Featured Session on Tele-Audiology at AudiologyNOW! 2009 shows Hall at a computer performing pure-tone audiometry on a woman in rural South Africa, who can be seen on the screen, along with the test results. At the podium is Dirk Koekemoer, MD, a South African physician and self-described "social entrepreneur."

Tester in Dallas Texas, USA
Patient in rural South Africa

Equipment:
KUDUwave Automated Audiometer

Audiology Applications of Tele-Health:
Automated Audiometry with a Facilitator

KUDUwave Automated Audiometer

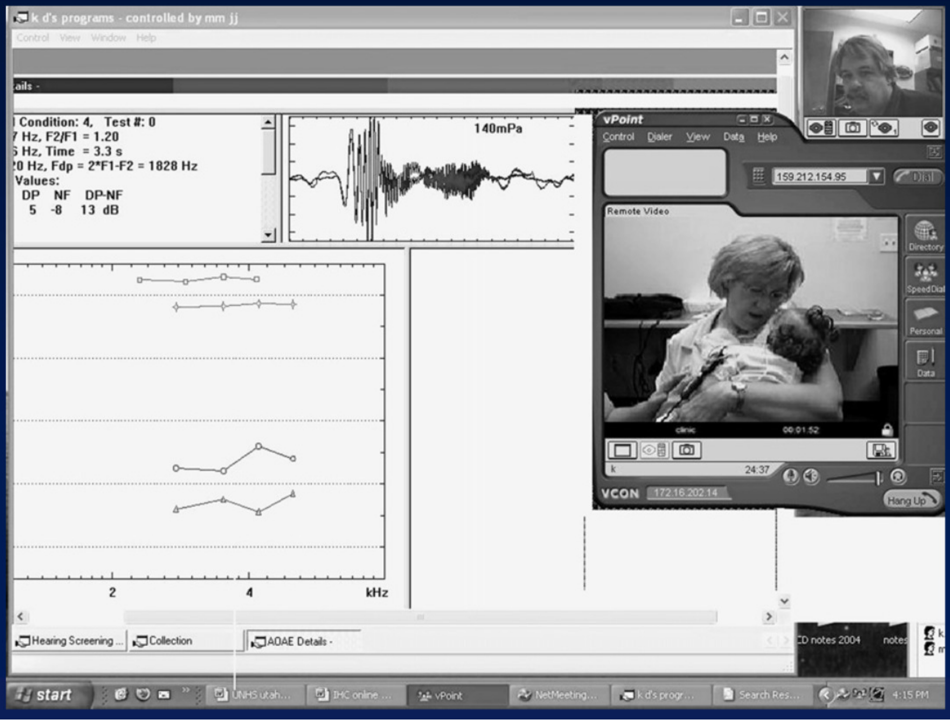
- **Swanepoel D, Maclennan-Smith F & Hall JW III (2013). Diagnostic pure tone audimometry in schools: Mobile testing without a sound-treated environment. *JAAA, 24,* 992-1000**
- **Matthysen C, Swanepoel D, Hall JW III (2014). Automated pure tone audiometry outside a sound-booth using earphone attenuation and integrated ambient noise monitoring.**

Automated Audiometry for Pre-School Hearing Screening

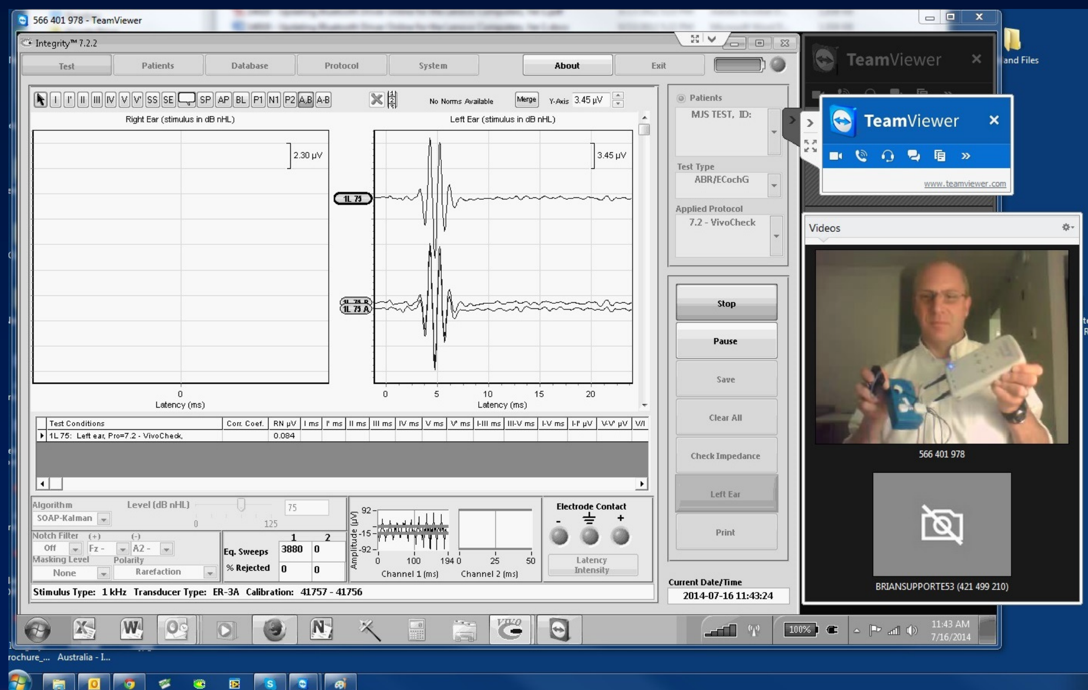
- Kam et al (2014). Automated hearing screening for preschool children. *Journal of Medical Screening, 21*, 71-75 [Shanghai China; Hong Kong]
- Wi et al (2014). A new hearing screening system for preschool children. *Intternational Journal of Pediatric Otorhinolaryngology,* 78, 290-295

Audiology Applications of Tele-Health:
Synchronous Technology for DPOAEs

(Krumm M & Syms MJ. Teleaudiology. Otolaryngol Clinics North America, 44, 2011)



Audiology Applications of Tele-Health:
Instrumentation for Remote ABR Measurement



Audiology Applications of Tele-Health:
Breaking News About Technology

informa healthcare

International Journal of Audiology 2014; Early Online: 1–9

International Journal of Audiology

Original Article

Smartphone hearing screening with integrated quality control and data management

De Wet Swanepoel*,†,‡,#, Hermanus C. Myburgh$, David M. Howe*,$, Faheema Mahomed* & Robert H. Eikelboom*,†,‡

**Department of Speech-Language Pathology and Audiology, University of Pretoria, Pretoria, South Africa, †Ear Sciences Centre, School of Surgery, The University of Western Australia, Nedlands, Australia, ‡Ear Science Institute Australia, Subiaco, Australia, #Callier Center for Communication Disorders, University of Texas at Dallas, USA, and $Department of Electrical, Electronic and Computer Engineering, University of Pretoria, Pretoria, South Africa*

Tele-Audiology:
Smart Phone hearScreen Application

Figure 5. Clinical hearing screening test on school child using smartphone with hearScreen™ application and HD202 headphones. Phone is held upside-down to ensure the microphone faces towards the test subject for environmental noise monitoring.

Table 3. Cross tabulation of screening outcomes for ears using conventional and mobile phone based hearing screening (n = 324 ears).

		Conventional screening		
		Pass	*Refer*	*Total*
Mobile phone screening	Pass	96.3% (312)	0.9% (3)	**97.2% (315)**
	Refer	1.2% (4)	1.5% (5)	**2.7% (9)**
	Total	**97.5% (316)**	**2.4% (8)**	

Effective and Efficient Pre-School Hearing Loss Identification and Diagnosis: *Essential for Successful EHDI*

Austin Hall screens Victoria Hall (1986)

Austin, Alessandra, Charlie & Ana Sofia Hall (2015)