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Combined OAE and AABR Approach for Newborn Hearing Screening

James W. Hall III, Ph.D.

Professor
Salus University
Elkins Park, Pennsylvania, USA

Extraordinary Professor
University of Pretoria South Africa

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Learner Outcomes: As a result of this Continuing Education Activity, participants will be able to …

- Identify 3 advantages of using a combined OAE/AABR hearing screening approach.
- Cite a clinical guideline that recommends combined OAE/AABR hearing screening.
- Describe how OAE and AABR techniques are used in well baby versus NICU infants.
Combined OAE and AABR Approach for Newborn Hearing Screening

- Introduction
- Brief historical overview
- Rationale for combined OAE and AABR strategy
- Review of literature
- Guidelines for clinical implementation of combined OAE and AABR strategy
- Summary, questions, answers

Early Hearing Loss Detection and Intervention (EHDI): Focusing on the Goal, Not the Process

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

UNHS HISTORICAL PERSPECTIVE: Early work by Marion Downs

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

- 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)

Universal Newborn Hearing Screening:
Rationale ... Average Ages in Months for intervention

<table>
<thead>
<tr>
<th>Hearing Loss</th>
<th>Suspicion</th>
<th>Dx</th>
<th>HA fitting</th>
<th>Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Risk Factor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild/moderate</td>
<td>15</td>
<td>22</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Severe/profound</td>
<td>8</td>
<td>13</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Known Risk Factor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild/moderate</td>
<td>8</td>
<td>12</td>
<td>22</td>
<td>28</td>
</tr>
<tr>
<td>Severe/profound</td>
<td>7</td>
<td>12</td>
<td>15</td>
<td>16</td>
</tr>
</tbody>
</table>

Harrison & Roush, 1996
Rationale for UNHS: Prevalence of Infant Hearing Loss in the U.S.A.

<table>
<thead>
<tr>
<th>Category</th>
<th>Births Annually</th>
<th>Prevalence</th>
<th>Total Hearing Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy</td>
<td>3,600,000</td>
<td>3/1000</td>
<td>10,800</td>
</tr>
<tr>
<td>At-risk</td>
<td>400,000</td>
<td>30/1000</td>
<td>12,000</td>
</tr>
<tr>
<td>Total</td>
<td>4,000,000</td>
<td>5.7/1000</td>
<td>22,800</td>
</tr>
</tbody>
</table>

Northern & Hayes, 1994

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

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
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

Christie Yoshinaga-Itano, PhD
Yoshinago-Itano et al (Univ. of Colorado).
Language of Early and Later Identified Children with Hearing Loss

  - 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.”
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
Combined OAE and AABR Approach for Newborn Hearing Screening

- Introduction
- Brief historical overview
- Rationale for combined OAE and AABR strategy
  - Background on AABR
  - Background on OAEs
- Review of literature
- Guidelines for clinical implementation of combined OAE and AABR strategy
- Summary, questions, answers

The First Comprehensive Description of the Auditory Brainstem Response (ABR) in Humans

Jewett D and Williston J.

Auditory evoked far fields averaged from the scalp of humans.


Don Jewett
Jewett & Williston, 1971
Normal Subject Waveform Consistency … the Ideal Clinical Tool

Newborn Hearing Screening: Auditory Brainstem Response (ABR)

Stimulus click @ 35 dB
Electrodes
Auditory Evoked Response System (computer)

0.5 uV
8 ms

I II III IV V VI VII
Robert Galambos, MD, PhD
Director of the Laboratory (Yale University) Where the ABR was “Discovered” and Pioneer of Early Pediatric Applications of ABR


James Jerger, Ph.D.
“Father of Diagnostic Audiology”
*Baylor College of Medicine and Methodist Hospital, Houston TX*

Larry Mauldin Circa 1975
Helped Build Early AER System
Newborn Hearing Screening of At Risk Infants by Audiologists in the 1980s

AABR Test Protocol: Recording Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Selection</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transducer</td>
<td>ER-3A inserts or custom earphones</td>
<td>Numerous infant advantages</td>
</tr>
<tr>
<td>Type</td>
<td>Clicks or chirp clicks</td>
<td>Available on all systems</td>
</tr>
<tr>
<td>Duration</td>
<td>0.1 ms</td>
<td>Synchronous firing of auditory fibers</td>
</tr>
<tr>
<td>Rate of stimulation</td>
<td>&gt; 30/second</td>
<td>Faster rate = shorter test time</td>
</tr>
<tr>
<td>Electrode type</td>
<td>Disposable or custom</td>
<td>Minimize risk of infection</td>
</tr>
<tr>
<td>Electrode sites</td>
<td>Fz-Ai or Fz-Nape</td>
<td>Nape = larger wave V</td>
</tr>
<tr>
<td>Filter settings</td>
<td>30 – 3000 Hz</td>
<td>Low frequency infant ABR spectrum</td>
</tr>
</tbody>
</table>
ABR Transducer Options for Pediatric ABR Recordings:

*Insert Earphone with Adaptor*

UNHS WITH AUTOMATED AABR: A MULTI-SITE INVESTIGATION


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

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

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

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

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

James Hamlett, M.D.
*Baptist Memorial Hospital East*
*Memphis, Tennessee*
### NEWBORN HEARING SCREENING WITH AABR

**Site**

<table>
<thead>
<tr>
<th>Site</th>
<th>Nursery</th>
<th>N</th>
<th>Screeners</th>
<th>Time of Screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boulder</td>
<td>WBN</td>
<td>1228</td>
<td>volunteers</td>
<td>22 hrs</td>
</tr>
<tr>
<td>Louisville</td>
<td>WBN</td>
<td>6061</td>
<td>nurses</td>
<td>28 hrs</td>
</tr>
<tr>
<td>Memphis</td>
<td>WBN</td>
<td>1563</td>
<td>technicians</td>
<td>19</td>
</tr>
<tr>
<td>Huntsville</td>
<td>WBN</td>
<td>2071</td>
<td>audiologists</td>
<td>24</td>
</tr>
<tr>
<td>Nashville</td>
<td>ICN</td>
<td>788</td>
<td>audiologists, nurses, grad students</td>
<td>- - -</td>
</tr>
</tbody>
</table>

### Test Performance and Outcome

<table>
<thead>
<tr>
<th>Site</th>
<th>WBN</th>
<th>ICN</th>
<th>Refer % D/C</th>
<th>Refer Lost F/U</th>
<th>False Pos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boulder</td>
<td>98%</td>
<td>2%</td>
<td>2%</td>
<td>16%</td>
<td>2%</td>
</tr>
<tr>
<td>Louisville</td>
<td>&gt;99%</td>
<td>&lt;1%</td>
<td>1%</td>
<td>45%</td>
<td>.35%</td>
</tr>
<tr>
<td>Memphis</td>
<td>&gt;99%</td>
<td>N=1</td>
<td>3%</td>
<td>13%</td>
<td>2.5%</td>
</tr>
<tr>
<td>Huntsville</td>
<td>93%</td>
<td>7%</td>
<td>1%</td>
<td>21%</td>
<td>.05%</td>
</tr>
<tr>
<td>Nashville</td>
<td>0%</td>
<td>100%</td>
<td>6%</td>
<td>32%</td>
<td>2%</td>
</tr>
<tr>
<td>N = 11,711</td>
<td></td>
<td></td>
<td>2%</td>
<td>28%</td>
<td>0.9%</td>
</tr>
</tbody>
</table>

AAP ≤ 4% < 5% < 2%
Newer AABR Technology: Chirp Stimuli and No “Disposables” (Maico MB-11)


ABR in Infant Hearing Screening: *Chirp Stimuli*


- Stuart & Cobb (2014). Effect of stimulus and number of sweeps on the neonate ABR. *Ear Hear, 35*, 585-588 [chirp]


ABR in Infant Hearing Screening: *Minimizing False-Positive Errors*

  - Published false-positive rates are between 2.5 – 8%
  - Concerns about high false-positive rates include:
    - Emotional trauma for parents
    - Inappropriate disease labeling
    - “Iatrogenesis” from unnecessary testing
    - Increased expense ... time and money
  - N = 3142 well babies screened with AABR
  - 80% of babies who failed initial screening passed rescreen
  - At 2nd screening false-positives decreased from 3.9% to 0.8%
Combined OAE and AABR Approach for Newborn Hearing Screening: OAE Technology

Newborn Hearing Screening with OAEs: Historical Perspective

1978 Kemp discovers OAEs
1983 Kemp introduces ILO 88
1988 Danes Johnsen et al describe TEOAEs in neonates
1988-1992 TEOAE Studies Bonfils Stevens Kok Salomon
1993 RIHAP Study Report (27% fail)
1994 DPOAE devices at AAA
1994 NIH Consensus Conference JCIH report
1996 DPOAE Screening Studies
1996 Auditory Neuropathy
1998 Automated OAE devices
1999 AAP endorses UNHS
Newborn Hearing Screening with Otoacoustic Emissions (OAEs)

For otoacoustic emission cochlography it has to be the...

ILO88 Otodynamic Analyser

Did you know that already more than 40 leading research groups around the world (in Europe, Japan, Australia and North America) are using the ILO 88?

They are developing new otoacoustic emitted screening programmes. They are shining light on auditory pathways, monitoring the effects of noise and drugs, and discovering the role of the cochlea elements.

It is a simple-to-use, very fast, non-invasive, objective auditory screening.

Newborn Hearing Screening with TEOAEs (Otodynamics ILO 88)

Stimulus

Power Analysis Stim Noise

Response Waveform

QuickScreen
Validation of Universal Newborn Hearing Screening with OAEs

  - 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

Newborn Hearing Screening with DPOAEs

(> 500 Peer Reviewed Published Papers)
Newborn Hearing Screening with Combined Otoacoustic Emissions and Auditory Brainstem Responses

James W. Hall III*
Steven D. Smith†
Gerald R. Popelka* ** ††

Abstract
Accurate assessment of neonatal hearing screening performance is impossible without knowledge of the true status of hearing, a prohibitive requirement that necessitates a complete diagnostic evaluation on all babies screened. The purpose of this study was to circumvent this limitation by integrating two types of screening measures obtained near simultaneously on every baby.
Combined Automated OAE and ABR Technique

**AUDIOscreener (GSI)**

- **OAE**
- **AABR**

- N = 300 infants (600 ears)
- All babies underwent OAE and ABR screening
- Newborns that failed first DPOAE or ABR were re-screened prior to discharge
- Newborns discharged with ‘refer’ result returned within 2 to 3 weeks for follow-up diagnostic audiologic evaluation
Combination OAE/ABR Screening:
Differentiation of Peripheral Auditory Dysfunction

<table>
<thead>
<tr>
<th>Type of dysfunction</th>
<th>OAE</th>
<th>ABR</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>External/middle ear</td>
<td>Abnormal</td>
<td>Normal</td>
</tr>
<tr>
<td>Sensory (OHC)</td>
<td>Abnormal</td>
<td>Abnormal</td>
</tr>
<tr>
<td>Neural</td>
<td>Normal</td>
<td>Abnormal</td>
</tr>
</tbody>
</table>

*Minor dysfunction in most cases

Advantages and Disadvantages of AABR versus OAE for Infant Hearing Screening

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>OAE</td>
<td>No electrodes</td>
<td>Affected by vernix</td>
</tr>
<tr>
<td></td>
<td>Inexpensive</td>
<td>Failure rate higher &lt; 24 hours</td>
</tr>
<tr>
<td></td>
<td>No “disposables”</td>
<td>Affected by ambient noise</td>
</tr>
<tr>
<td></td>
<td>Generally quick</td>
<td>Affected by middle ear disorder</td>
</tr>
<tr>
<td></td>
<td>Detects OHC dysfunction</td>
<td>Normal in ANSD</td>
</tr>
<tr>
<td>AABR</td>
<td>Low failure rate &lt; 24 hours</td>
<td>Electrode placement</td>
</tr>
<tr>
<td></td>
<td>Detects ANSD</td>
<td>“Disposables” may add cost</td>
</tr>
<tr>
<td></td>
<td>Higher reimbursement</td>
<td>Test time may be longer</td>
</tr>
</tbody>
</table>
Potential Sites of Auditory System Abnormality

- Blockage
- Dysfunction
- Abnormal development
- Abnormal structure

Combined OAE and AABR Study: Results (N = 600)
(Hall, Smith & Popelka. JAAA, August 2004)

<table>
<thead>
<tr>
<th>Diagnostic Outcome</th>
<th>Screening Outcome</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pass</td>
<td>Refer</td>
</tr>
<tr>
<td>Normal</td>
<td>590</td>
<td>2</td>
</tr>
<tr>
<td>Hearing Impaired</td>
<td>0</td>
<td>8</td>
</tr>
</tbody>
</table>

N 590 10

Sensitivity = 100.0%
Specificity = 99.7%
Refer Rate = 1.7%
Positive Predictive Value = 80.0%
OAE and AABR Screening Techniques: Additional Literature

  
  “If all infants were screened for hearing loss using the 2-stage OAE/A-ABR newborn hearing screening protocol currently used in many hospitals, then approximately 23% of those with PHL at approximately 9 months of age would have passed the A-ABR. This happens in part because much of the A-ABR screening equipment in current use was designed to identify infants with moderate or greater hearing loss.”

  
  Based on the cost-effectiveness and potential health outcomes, the optimal path for scale-up would be to start with targeted OAE and then expand to universal OAE and universal OAE plus AABR.

  
  “OAE and ABR screening of infants at risk for significant hearing loss is a clinically efficient and cost effective approach for early detection of significant hearing loss.”
Combined OAE and AABR Screening Approach: Recent Findings

- Xu & Li (2005). Performance of two hearing screening protocols in the NICU. *B-ENT, 1*, 11-15 [Shanghai China]
  - N = 200 NICU infants
  - Initial DPOAE failure rate = 14.5%
  - Combined DPOAE/AABR failure rate = 4.5%
  - At 3 months, 3% of infants had ABR confirmed hearing loss
  - None of the infants referred by DPOAE who passed AABR had actual hearing loss

Outcomes with OAE and AABR screening in the first 48 h—Implications for newborn hearing screening in developing countries

Michelle van Dyk¹, De Wet Swanepoel²,³,⁴, James W. Hall III²,³

¹ Department of Speech-Language Pathology and Audiology, University of Pretoria, Pretoria, South Africa
² Ear, Nose, and Throat, School of Surgery, The University of Western Australia, Nedlands, WA, Australia
³ Ear, Nose, and Throat, School of Surgery, University of Western Australia, Nedlands, WA, Australia
⁴ Ear, Nose, and Throat, School of Surgery, The University of Western Australia, Nedlands, WA, Australia

CONTINUED
Combined OAE and AABR Screening Approach:
(Van Dyk, Swanepoel & Hall, 2015)
N = 150 babies (300 ears)

TOAEs
(GSI AudioScreener)

AABR
(Maico MB 11)

Combined OAE and AABR Screening Approach:
(Van Dyk, Swanepoel & Hall, 2015)
N = 150 babies (300 ears)

Fig. 3. Initial screening outcomes according to age at screen (TIEAE n = 289 ears; AABR n = 260 ears).
OAE and AABR Screening Techniques:
2007 Joint Committee on Infant Hearing Recommendations

- **Well baby nursery (WBN)**
  - Screening with OAEs or AABR
  - Refer outcome for AABR
    - Schedule for diagnostic follow up assessment < 3 months
  - Refer outcome for OAEs?
    - Immediate follow up screening with AABR
  - Refer outcome for OAEs and AABR?
    - Schedule for diagnostic follow up assessment < 3 months
- **Neonatal intensive care unit (NICU) or intensive care nursery (ICN)**
  - Screening AABR (to detect auditory neuropathy)
  - Pass outcome for AABR?
    - Follow as indicated by risk factors for progressive/delayed onset hearing loss
  - Refer outcome for AABR?
    - Perform OAEs to identify possible auditory neuropathy
    - Schedule for diagnostic follow up assessment < 3 months

Combined OAE and AABR Approach for Newborn Hearing Screening

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- **Review of literature**
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- **Summary, questions, answers**
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- Vestibular rehab
- Drugs
- Surgery

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

Thank You!
*Questions?*

Austin Hall screens Victoria Hall (July 1986)

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