Early identification of hearing loss in infants and young children using objective electrophysiological measures: Best practices and new research

PART 2 (3:00-4:00 pm)

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University of British Columbia
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CASLPM, Winnipeg, MN
April 20-21, 2017
PART 2:
Clinical application of auditory steady-state responses (ASSRs) & cortical auditory evoked potentials (CAEPs): a brief overview of new research

3:00-4:00 pm: a) ASSRs: 80-Hz (brainstem) ASSR
b) CAEPs: unaided/aided; onset response; acoustic change complex
Overview of ASSRs

Clinical goal for ASSR testing?

- Identification of hearing loss
  -- Air-conduction (AC) thresholds within normal limits?
  -- AC thresholds elevated?

- If AC thresholds elevated, estimate bone-conduction (BC) thresholds
  -- type of hearing loss
  -- degree of conductive loss if present

- When hearing loss is identified, frequency- & ear-specific thresholds estimated to plan intervention services
What are ASSRs?

- Evoked potential that is repetitive in nature & is analyzed in terms of its frequency components rather than its waveform.

- For high enough rates, a “sinusoidal” response is elicited with a frequency that matches the presentation or “modulation” rate.

Amplitude maxima in adults (reviewed in Picton et al., 2003)

- 70-110 Hz modulation rate: 1<sup>0</sup> brainstem response (Picton et al., 2003)
- ~40 Hz modulation rate: 1<sup>0</sup> cortical & brainstem (Herdman et al, 2002)

- Most research and clinical applications for infants
  -- 40-Hz smaller in sleep in infants versus adults (Picton et al., 2003)
  -- 80-Hz or “brainstem”– most of research & today’s focus!

- Single- & multiple-ASSRs presented to two ears simultaneously
  -- depends on equipment available (focus on multiple ASSRs)
Why consider ASSRs for the clinic when we have brief-tone auditory brainstem responses (ABRs)?
-- brief-tone ABRs require considerable training & skill to interpret:
  o Visual replicability of wave V? Absence of response? Waveform too noisy to interpret? Amplitude & latency features across test conditions?

Infant ABR-- 2000 Hz
Large pediatric centres: skilled, experience clinicians are available for ABR testing and do an excellent job!

Practical challenges:
(i) New clinicians
(ii) Clinicians with low infant-ABR case loads
(iii) Countries or regions within countries with fewer resources for training
   -- face difficulties conducting/interpreting AC & BC ABRs

Solutions:
(i) Method that requires less training & skill—ASSR?
(ii) Telehealth ABR (emerging but still requires skilled clinician)
Why ASSRs?

(i) frequency-specific stimuli
   - growing # of choices (advantage or disadvantage?)

(ii) response presence/absence is statistically determined
   - objective rather than subjective interpretation of waveforms

(iii) multiple stimuli can be presented to both ears simultaneously
   - efficient use of clinical time (2/3 time of ABR)

[van Maanen & Stapells, 2009]
One example of ASSR analysis
Comparison of response amplitude @ modulation rate to surrounding noise frequencies: F statistic (p < .05) (for review see Picton et al., 2003)

<table>
<thead>
<tr>
<th>Multiple 80-Hz ASSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency</td>
</tr>
<tr>
<td>500 Hz</td>
</tr>
<tr>
<td>1000 Hz</td>
</tr>
<tr>
<td>2000 Hz</td>
</tr>
<tr>
<td>4000 Hz</td>
</tr>
<tr>
<td>Modulation rate</td>
</tr>
<tr>
<td>77.1 Hz</td>
</tr>
<tr>
<td>84.9 Hz</td>
</tr>
<tr>
<td>92.8 Hz</td>
</tr>
<tr>
<td>100.6 Hz</td>
</tr>
</tbody>
</table>

Time domain
“sinusoid”
Average of accepted epochs

Polar plot
- amplitude
- phase
- circle radius

Frequency domain
Fast Fourier Transform

Amplitude: 24 nV
Onset phase: 320°
p value: 0.012
Circle radius: 19 nV
EEG noise: 10 nV
Stimuli & EEG parameters
Many types of “frequency-specific” ASSR stimuli

brief tones

\[ x(t) \]

continuous

- AM
- FM
- AM/FM
- AM²

+ narrow-band chirps
-- not as well researched but more infant data emerging in last few years

1000 Hz

multiple
**EEG recording set up**

- can avoid post-auricular muscle response
**EEG recording set up**

- Can record EEG ipsilateral & contralateral to mastoid stimulated to assist with isolation of the test ear (discussed earlier)
Estimation of infant hearing thresholds
Mean AC & BC ASSR thresholds across 11 infant & 10 adult studies

**INFANT**

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>AC Threshold (dB HL)</th>
<th>BC Threshold (dB HL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>35</td>
<td>16</td>
</tr>
<tr>
<td>1000</td>
<td>32</td>
<td>9</td>
</tr>
<tr>
<td>2000</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>4000</td>
<td>28</td>
<td>16</td>
</tr>
</tbody>
</table>

**ADULT**

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>AC Threshold (dB HL)</th>
<th>BC Threshold (dB HL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>17</td>
<td>26</td>
</tr>
<tr>
<td>1000</td>
<td>13</td>
<td>19</td>
</tr>
<tr>
<td>2000</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>4000</td>
<td>15</td>
<td>13</td>
</tr>
</tbody>
</table>

AC: low > high frequencies
BC: low < high frequencies

- **Maturational air-bone gap**

   - AC: low > high frequencies
   - BC: low < high frequencies
   - AC & BC: similar across frequency -- tendency for BC 500 Hz to be greater than other frequencies

(Lins et al., 1996; Cone-Wesson et al., 2002; John et al., 2004; Rance et al., 2005; Swanepoel & Steyn, 2005; Luts et al., 2006; Rance & Tomlin, 2006; van Maanen & Stapells, 2009; Ribeiro et al., 2010; Casey & Small, 2014; Valeriote & Small, 2015)

(AC ASSR data reviewed in Tlumak et al., 2007)
How well do AC ASSRs predict the audiogram in infants?

AC multiple ASSR versus AC behavioural thresholds/brief-tone ABR

Correlation coefficients:

**Adult**
- .70-.85 for 500 Hz
- .80-.95 for 1000-4000 Hz (for review see Tlumak et al., 2007)

**Infant**
- .97 @ 500-4000 Hz (includes profound loss with “no response”)
- .77-.89 @ 500-4000 Hz (excludes “no responses”)

(Van Maanen & Stapells, 2010)
**Normal ASSR maximum levels & eHL correction for infants**

*Air- and bone-conduction ASSR*

**Preliminary & conservative!**

<table>
<thead>
<tr>
<th>AM</th>
<th>AM/FM</th>
<th>COS³</th>
<th>AM²</th>
<th>(Ages: 0-79 ms)</th>
</tr>
</thead>
<tbody>
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<table>
<thead>
<tr>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>AC</td>
<td>AC</td>
<td>AC</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>10 studies</th>
<th>Normal ASSR Max (dB HL)</th>
<th>Range in literature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40-50</td>
<td>40-52</td>
</tr>
<tr>
<td></td>
<td>40-45</td>
<td>30 to &gt;50</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>30-50</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>28-44</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6 studies**</th>
<th>eHL correction (dB)</th>
<th>Range in literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-20</td>
<td>10-15</td>
<td>0-17</td>
</tr>
<tr>
<td>10-15</td>
<td>10-15</td>
<td>0-6</td>
</tr>
<tr>
<td>5-15</td>
<td>5-15</td>
<td>-3 - 14</td>
</tr>
</tbody>
</table>

(Reviewed in Small & Stapells, Ch. 21, 2017: *Lins et al, 1996; John et al., 2004; Rance et al., 2005; Swanepoel & Steyn, 2005; Luts et al., 2006; Rance & Tomlin, 2006; van Maanen & Stapells, 2009; Ribeiro et al., 2010; Casey & Small, 2014; Valeriote & Small, 2015;**Rance & Briggs, 2002; Hanh et al., 2006; Luts et al, 2006; van Maanen & Stapells, 2010; Rodrigues & Lewis, 2010; Chou et al., 2012)
How well do BC ASSRs predict the audiogram in infants?

BC multiple ASSR versus AC behavioural thresholds/brief-tone ABR

Correlation coefficients:

**Adult (sensorineural & simulated)**
- .71 for 500 Hz
- .84-.94 for 1000-4000 Hz (Ishida, Cuthbert & Stapells, 2011)
- Adult BC-ASSR data is promising

**Infant**
- No correlational data available
  -- need data for a large group of infants with a range of hearing losses
Valeriote & Small (in prep): Infant: normal hearing versus mild conductive loss at 500 Hz

- AC & BC ASSR data fall within ABR normal maximum levels

500 & 2000 Hz

Normal hearing (NH)
AC: trend for elevated ASSR thresholds -- but overlap for NH and mild CHL for ASSR

BC: CHL and NH did not differ significantly as expected

Conductive hearing loss (CHL) (mild)

Valeriote & Small (in prep)
Case 1: Adult with asymmetric conductive loss (stapes fixation bilaterally, poor surgical outcome left)

Small, unpublished
# Normal ASSR maximum levels & eHL correction for infants

**Air- and bone-conduction ASSR**

**Preliminary & conservative!**

<table>
<thead>
<tr>
<th></th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AM/FM</strong></td>
<td>BC</td>
<td>BC</td>
<td>BC</td>
<td>BC</td>
</tr>
<tr>
<td><strong>AM²</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>8 studies (0-24 mos)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal ASSR Max (dB HL)</td>
<td>30</td>
<td>20</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td><strong>Range in literature</strong></td>
<td>30-40</td>
<td>10-30</td>
<td>30-40</td>
<td>10-40</td>
</tr>
<tr>
<td><strong>BC EHP</strong></td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>eHL correction (dB)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Range in literature</strong></td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
</tbody>
</table>

(Small & Stapells, Ch. 21, 2017)
Are multiple ASSRs more or less efficient than single ASSRs?

NH infants @ 60 dB SPL

<table>
<thead>
<tr>
<th>Amplitude</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single &gt; Multiple</td>
<td>Multiple &gt; Single</td>
</tr>
</tbody>
</table>

(Hatton & Stapells, 2011 & 2013)

➢ Note: stimuli with broader spectra or higher presentation levels exhibit > interactions (Ishida & Stapells, 2012; Mo & Stapells, 2008, Wood, 2009)

Recommend:
Low-mid intensities – multiple ASSR
High intensities – consider single ASSR
What about simultaneous AC & BC multiple ASSRs?

- New study from Cuba (Torres-Fortuny et al., 2016)
  -- compared ASSR amplitudes elicited to AC & BC stimuli at same time in both ears to only one mode at a time in NH infants

<table>
<thead>
<tr>
<th>Simultaneous</th>
<th>Only Stimulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC: 2000 Hz AM tones (L: 111.4 Hz; R: 115 Hz)</td>
<td>AC: 2000 Hz AM tones (115 Hz)</td>
</tr>
<tr>
<td>BC: 500 Hz AM tones (L: 104.2 Hz; R: 107.8 Hz)</td>
<td>BC: 500 Hz AM tones (115 Hz)</td>
</tr>
</tbody>
</table>

- No significant reduction in amplitude for simultaneous AC/BC conditions; more data needed but clinical potential ...
AC & BC ASSRs & severe-to-profound loss

Caution: can elicit vestibular responses to high-intensity AC & BC stimuli using ABR & ASSRs

- ABR– negative wave at ~ 3 ms at 95 & 110 dB nHL due to activation of the vestibular system– not auditory in nature but easy to identify in the waveform (Stapells, 2011)

- ASSRs can also be elicited from vestibular sources– cannot be differentiated from auditory responses – no time domain waveform available
  -- spurious responses recorded at 50-60 dB HL for BC ASSRs; 118-120 dB HL for AC ASSRs (Small & Stapells, 2004)
Isolation of test cochlea

(i) consistent ipsi/contra asymmetries in BC ASSR @ near-threshold levels for 500 & 4000 Hz in normal-hearing infants (Small & Stapells, 2008; Small & Love, 2014)

(ii) clinical masking for BC ASSRs

Recommended EMLs (dB SPL) for BC ASSR stimuli presented at 35 dB HL

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant</td>
<td>81</td>
<td>68</td>
<td>59</td>
<td>45</td>
</tr>
<tr>
<td>Adult</td>
<td>66</td>
<td>63</td>
<td>59</td>
<td>55</td>
</tr>
</tbody>
</table>

-more research needed for ASSRs in infants with hearing loss
Clinical implications

AC ASSRs
- Screening for normal hearing @ normal maximum levels 500, 1000, 2000 & 4000 Hz
- Threshold estimation @ 500, 1000, 2000 & 4000 Hz
  - More data to assess accuracy of recommended eHL corrections

BC ASSRs
- Screening for normal hearing @ normal maximum levels 500, 1000, 2000 & 4000 Hz
  -- accuracy of normal levels need to be verified for larger # of infants with hearing loss
- Threshold estimation @ 500, 1000, 2000 & 4000 Hz
  - More data to assess accuracy of recommended eHL corrections
Future research needed

AC ASSRs

** more infants with hearing loss
-- Comparisons to AC brief-tone ABR & behavioural data for all stimuli available in clinical equipment

BC ASSRs

** many more infants with hearing loss
-- Comparisons to AC brief-tone ABR & behavioural data for all stimuli available in clinical equipment

Simultaneous AC & BC ASSRs

** more work on infants with normal hearing and hearing loss

** more work needed on isolation of test ear

** more infants with hearing loss
-- Comparisons to AC brief-tone ABR & behavioural data for all stimuli available in clinical equipment
Questions?
Overview of CAEPs
Cortical auditory evoked potentials

- Infants undergo rapid changes in the first year of life in the normal course of development while they are acquiring speech, language, cognitive and social skills.
INTRODUCTION

• How can we best assess and plan intervention services for infants with hearing loss to help optimize speech, language, cognitive and social skills?

Limited/Altered Auditory Experience

- skull size & structure (& overlying tissues)
- ear structures/function
- oral mechanism
- motor control
- vision structures/function
- cognition
INTRODUCTION

Limited/Altered Auditory Experience

sensory (neural) 
conductive/mixed 
-- unilateral/bilateral

auditory neuropathy spectrum disorder (ANSD)

(i) until hearing loss is identified 
-- less/no peripheral auditory input 
-- varying degrees of temporal processing deficits

(ii) Intervention 
-- enhanced/altered auditory input 
hearing aids, cochlear implants, auditory brainstem implants
In the clinic: Assessment & prediction of functional auditory skills in young infants (< 6-8 months) presents challenges

- ABR and 80-Hz ASSR
- Otoacoustic emissions, immittance measures
- Behavioural tests (more difficult)
- Observation
  - parent & intervention team
Auditory brainstem
-- unaided --

• Brief-tone ABR
  ✓ years of clinical data
  ✓ use to establish initial hearing-aid fitting targets

• 80-Hz auditory steady-state response (80-Hz ASSR)
  -- some time savings relative to the ABR
  -- normal maximum levels (AC & BC) & eHL correction factors (AC)

  ✗ no information for ANSD
Auditory brainstem
-- aided --

Aided brainstem measures
– ABR & ASSR thresholds, FFR, etc.
(e.g., Graham et al., 2000; Stoebel et al., 2007; Shemesh et al., 2012; Sardari et al., 2015)

- more research & clinical data needed
- no information for ANSD?

Real-ear verification measures - predict audibility

Detection

EARLY VALIDATION
OF HEARING DEVICES
Auditory cortex -- unaided --

- Cortical auditory evoked potentials (CAEPs) -- ear-specific responses to many types of stimuli (tones, noise, speech tokens, words)
  (e.g., Sharma & Dorman, 2006; Shucard et al., 1987; Wunderlich et al., 2006; Small & Werker, 2012; Purdy et al., 2013; Sharma et al., 2013)

Onset response to /m/

- EARLY IDENTIFICATION OF HEARING LOSS

- some clinical data available -- primarily AC stimuli

- Can be recorded in infants with ANSD -- less reliant on neural synchrony than brainstem measures

(Small, Sharma, Bradford, Mandikal Vasuki, submitted)
Auditory cortex -- unaided --

Clinicians are less familiar with these measures than brainstem measures

(i) How do CAEP findings (presence/absence & amplitude/latency) correlate with perception (threshold/suprathreshold)?

✓ Presence of response can be interpreted as auditory information reaching the auditory cortex

? Where does stimulus falls within dynamic range for the infant?

-- need to understand influence of stimulus/recording parameters on infant CAEP waveforms

e.g., stimulus type, absolute level, signal-to-noise ratio (SNR), stimulus duration, stimulus presentation rate, sleep state, individual variability
Adult data supports:
-- SNR is more important than absolute level for eliciting unaided CAEPs (e.g., Phillips, 1990; Billings et al., 2012)
-- CAEP presence/absence is dependent on SNR & correlates with perceptual measures

Infant data shows...
-- Studies done by Purdy et al. (2013) & Golding et al. (2006)
  ➢ Input-out functions differ for speech stimuli with low- & high-frequency content e.g., /m/ & /t/ presented at 30-80 dB SPL in normal-hearing infants
  ➢ Audibility influences the response characteristics but only for a limited range of intensities
  × Cannot be certain where stimulus falls within dynamic range of infant
• Very few published studies have investigated SNR effects in infants
  -- Sharma et al. (2014) found no effect of noise for CAEPs elicited to /da/ presented at SNR of 5 dB versus /da/ in quiet for normal-hearing infants (in contrast to adults)

Some recent data -- Small, Sharma, Bradford & Mandikal Vasuki (submitted)
  ➢ normal-hearing infants (4-11 mos) & adults
  ➢ /m/ & /t/ presented at 75 dB SPL
  ➢ Conditions: Quiet & in presence of white noise: SNR 20, 15 & 10 dB
**Grand mean waveforms**

**Adult**

/m/  

/t/

**Infant**

/m/  

/t/

- **Adults**: 98% responses present

- **Infants**: % responses present

<table>
<thead>
<tr>
<th></th>
<th>/m/</th>
<th>/t/</th>
</tr>
</thead>
<tbody>
<tr>
<td>quiet</td>
<td>87-93</td>
<td>100</td>
</tr>
<tr>
<td>SNR20</td>
<td>81</td>
<td>100</td>
</tr>
<tr>
<td>SNR15</td>
<td>52-67</td>
<td>100</td>
</tr>
<tr>
<td>SNR10</td>
<td>26-30</td>
<td>89</td>
</tr>
</tbody>
</table>

(i) stimulus-dependent: /m/ >> /t/

(ii) age-dependent: Infants >> adults

-- except for /t/

*(Small, Sharma, Bradford, Mandikal Vasuki, submitted)*
Cannot generalize SNR effects across speech stimuli & cannot predict infant findings from adult data

How do we interpret the absence of CAEPs to /m/ in noise in infants?

1. Many NH infants cannot perceive /m/ in noise at SNR 15 & 10 (some at SNR 20)
2. Infant CAEPs to some stimuli are more affected by SNR compared to adults so we fail to detect a response when the stimulus is actually perceived
3. Combination of 1. & 2.

More research & clinical data needed

Absence of a CAEP cannot be interpreted with confidence
**Auditory cortex -- aided --**

- **Real-ear verification measures**
  - predict audibility

**Detection**

- **hearing aids**: AC ear-specific information
  
  (e.g., Ching et al., 2012 & Van Dun et al., 2013)

- **bone-conduction devices**: recent BC data
  
  (Rahne & Ehelebe, 2014)

- Presence of **aided response**
  
  -- can be interpreted as auditory information reaching auditory cortex
  
  -- does not indicate whether stimulus is minimally audible or providing adequate amplification

  [e.g., Ching et al., 2012 & Van Dun et al., 2013]
Auditory cortex -- aided --

Cross

Absence of aided CAEP? Inaudible?

- Unexpected absence of aided CAEPs in ~25% of infants when speech stimulus was perceived using behavioural testing (e.g., Ching et al., 2012 & Van Dun et al., 2013)

- Hearing aid processing effects add further complexity to interpretation of the presence & absence of aided responses (e.g., Marynewich et al., 2012; Jenstad et al., 2012; Billings et al., 2007; Easwar et al., 2012)

- More research & clinical data needed
- Refer to research by Easwar, Billings & others

Real-ear verification measures - predict audibility

EARLY VALIDATION OF HEARING DEVICES
Auditory cortex -- unaided --

Acoustic change complex (ACC)
– onset response to a change within a stimulus – many possibilities
  e.g., change in frequency, phase modulation, vowel contrasts (e.g., Martin & Boothroyd, 1999)
**Auditory cortex -- unaided --**

**Acoustic change complex**

(i) discrimination of speech contrasts e.g., vowel contrasts (/u-i/ & /u-a/) (Martinez et al., 2013; Cone, 2015) & consonant contrasts (/daba/ & /daDa/) (Small & Werker, 2012; Chen & Small, 2015)

(ii) measure of different aspects of cortical processing
e.g.1, temporal resolution -- gap detection threshold (WCA poster: Jordan et al., 2016)
e.g.2, pitch perception

** Sharma, Tian, Lau & Small (in prep)**

➢ early days-- more research needed
Auditory cortex -- aided --

Acoustic change complex
- aided versus unaided speech discrimination
e.g., vowel contrasts (/u-i/ & /u-a/) (Martinez et al., 2013)

➢ early days—much more research needed
Thank you for your attention today!