Infants, auditory steady-state responses (ASSRs), and clinical practice

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Phonak 2016, Atlanta, GA
October 2-5, 2016
Disclosure statement
BC Early Hearing Program (consultant): receive honorarium that contributes to my research program; Hamber Chair position: small contribution to research program

Other funding
UBC Faculty of Medicine
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: $1^0$ brainstem response (Picton et al., 2003)
- ~40 Hz modulation rate: $1^0$ 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, experienced 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>Modulation rate</td>
</tr>
</tbody>
</table>

- **Time domain**
  - “sinusoid”
  - Average of accepted epochs

- **Frequency domain**
  - Fast Fourier Transform
  - 84.9 Hz
  - Amplitude: 24 nV
  - Onset phase: 320°
  - p value: 0.012
  - Circle radius: 19 nV
  - EEG noise: 10 nV

- **Polar plot**
  - amplitude
  - phase
  - circle radius

Green checkmark
Stimuli & EEG parameters
Many types of “frequency-specific” ASSR stimuli

brief tones

continuous

+ narrow-band chirps
-- previous presentation
with Dr. Y. Sininger
Bone oscillator coupling method in infants

BC ASSR threshold data (Small et al., 2007)

**Recommend:** Either

**Bone oscillator placement**

- **Hand-held** vs **elastic head band**
- **least likely to wake infant**
- **No significant differences (with training)**

- **No difference T versus M**
- **Significantly poorer F versus T & M**

**Recommend:** “T” position
Occlusion effect (OE): earphones in or out during infant BC testing?

Young infants (< 12 months)
- negligible OE

Older infants (1-2 years)
- emerging occlusion effect

(Small et al., 2007, Small & Hu, 2011)

Recommend:
0-1 year: leave earphones in
1-2 years +: remove earphones (conservative)
**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 (more later in presentation)
Estimation of infant hearing thresholds
Definition of terms currently used for ABR (BCEHP, 2012)

*Normal behavioural threshold:*
- 25 dB HL

*Normal ABR maximum level:*
- ABR presentation level at which the majority of normal-hearing infants have a response present

\[ \text{normal response must be present at normal ABR (dB nHL) max} \]

*eHL correction:*
- Correction factor used to estimate behavioural hearing threshold (dB HL) from the ABR threshold

\[ \text{ABR threshold (dB nHL) - eHL correction (dB) = estimated behavioural threshold (dB HL)} \]
## Normal ABR maximum levels & eHL correction for infants

**Air- and bone-conduction ABR**

<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>AC</strong></td>
<td>BC</td>
<td>AC</td>
<td>BC</td>
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<tr>
<td><strong>BC</strong></td>
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</tbody>
</table>

| **BC EHP**       |        |         |         |         |
| **Normal ABR Max** | 35    | 20      | 35      | na      |
| (dB nHL)         | 30-35  | 20      | 30-35   | na      |

<table>
<thead>
<tr>
<th><strong>Range in literature</strong></th>
<th>30-35</th>
<th>20</th>
<th>30-35</th>
<th>na</th>
</tr>
</thead>
</table>

| **BC EHP** |        |         |         |         |
| **eHL correction (dB)** | 10    | 5       | 10      | na     |
| (dB nHL)   | 10-15  | -5      | 5-10    | na     |

<table>
<thead>
<tr>
<th><strong>Range in literature</strong></th>
<th>10-15</th>
<th>-5</th>
<th>5-10</th>
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(BC-EHP 2012, 2015; Small & Stapells, Ch. 21, 2017)
Mean AC & BC ASSR thresholds across 11 infant & 10 adult studies

INFANT

Mean threshold (dB HL)

500 Hz 1000 Hz 2000 Hz 4000 Hz

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

Maturational air-bone gap

ADULT

Mean threshold (dB HL)

500 Hz 1000 Hz 2000 Hz 4000 Hz

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)

(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>
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<tbody>
<tr>
<td>AC</td>
<td>AC</td>
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### 10 studies

**Normal ASSR Max (dB HL)**

| 40-50 | 40-45 | 40     | 40     |

**Range in literature**

| 40-52 | 30 to >50 | 30-50 | 28-44 |

### 6 studies**

**eHL correction (dB)**

| 10-20 | 10-15 | 10-15 | 5-15  |

**Range in literature**

| -3 to 20 | 0-17 | 0 - 6 | -3 - 14 |

(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; wan 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
Valeriote & Small (in prep):
Infant: normal hearing versus mild conductive loss at 500 Hz

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

Behavioural
Open: Right AC
Filled: Left AC

ASSR
Open: Right AC
Filled: Left AC

Small, unpublished
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<td>BC</td>
</tr>
<tr>
<td>AM²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 studies (0-24 mos)</td>
<td>30</td>
<td>20</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Normal ASSR Max (dB HL)</td>
<td>30-40</td>
<td>10-30</td>
<td>30-40</td>
<td>10-40</td>
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(Small & Stapells, Ch. 21, 2017)
Are multiple ASSRs more or less efficient than single ASSRs?

NH infants @ 60 dB SPL

- **Amplitude**
  - Single > Multiple
- **Efficiency**
  - Multiple > Single

(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 the same time in both ears to only one mode at a time in NH infants

<table>
<thead>
<tr>
<th>AC: 2000 Hz AM tones (L: 111.4 Hz; R: 115 Hz)</th>
<th>simultaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC: 500 Hz AM tones (L: 104.2 Hz; R: 107.8 Hz)</td>
<td></td>
</tr>
<tr>
<td>AC: 2000 Hz AM tones (115 Hz)</td>
<td>only stimulus</td>
</tr>
<tr>
<td>BC: 500 Hz AM tones (115 Hz)</td>
<td>only stimulus</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
BC ABR: Utilize ipsilateral/contralateral asymmetries

- Expected pattern for normal cochleae up to 1-2 years of age -- normal hearing or conductive loss (e.g., aural atresia)
  [e.g., Foxe & Stapells, 1993; Stapells & Ruben, 1989; Stapells & Mosseri, 1991]

BC left mastoid

2000 Hz @ 40 dB nHL

BC right mastoid

Amplitude: contra smaller than ipsi

Contra

Latency: contra later than ipsi
Factors contributing to ipsi/contra asymmetries?

1. Greater IA (10-35 dB) compared to adults due to unfused cranial sutures
   (Yang & Stuart 1987; Small & Stapells, 2008; Hansen & Small, 2012)

2. Infant-adult differences in positioning of neural generators

   ➢ Infant BC ABR/ASSRs show consistent ipsi/contra asymmetries @ near-threshold levels (adult do not)
     BC ABR: 500 & 2000 Hz (e.g., Stapells & Ruben, 1989)
     BC ASSR: 500 & 4000 Hz (less consistent @1000 & 2000 Hz) (Small & Stapells, 2008; Small & Love, 2014)

   ➢ more research needed for ASSRs to determine accuracy in infants with hearing loss

(see for review: Small & Stapells, 2017)
What if ipsi/contra asymmetries in BC ABR or ASSRs are ambiguous?

➤ **MASK!**

Main reason masking not routinely used clinically for infant BC ABRs: -- effective masking levels (EMLs) for BC ABR stimuli in young infants have not been measured directly

➤ We estimated EMLs for BC ASSRs using binaural AC masking

(Hansen & Small, 2012; Small, Smyth & Leon, 2014)
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>

* Significant infant minus adult EML difference (dB)

- Frequency-dependent infant-adult differences in EMLs except at 2000 Hz

(Hansen & Small, 2012; Small, Smyth & Leon, 2014)
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
- Threshold estimation @ 500, 1000, 2000 & 4000 Hz
  - More data to assess accuracy of recommended eHL corrections
  - Accuracy of normal levels need to be verified for larger # of infants with hearing loss
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

** more work needed on isolation of test ear

Simultaneous AC & BC ASSRs

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