School of Audiology and Speech Sciences

Blending real-life learning with sound science.

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

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TOPIC AREAS TO BE ADDRESSED

Overview of ASSRs

Stimuli & EEG parameters

Estimation of infant hearing thresholds

Isolation of test cochlea

Clinical implications

Future research needed

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)

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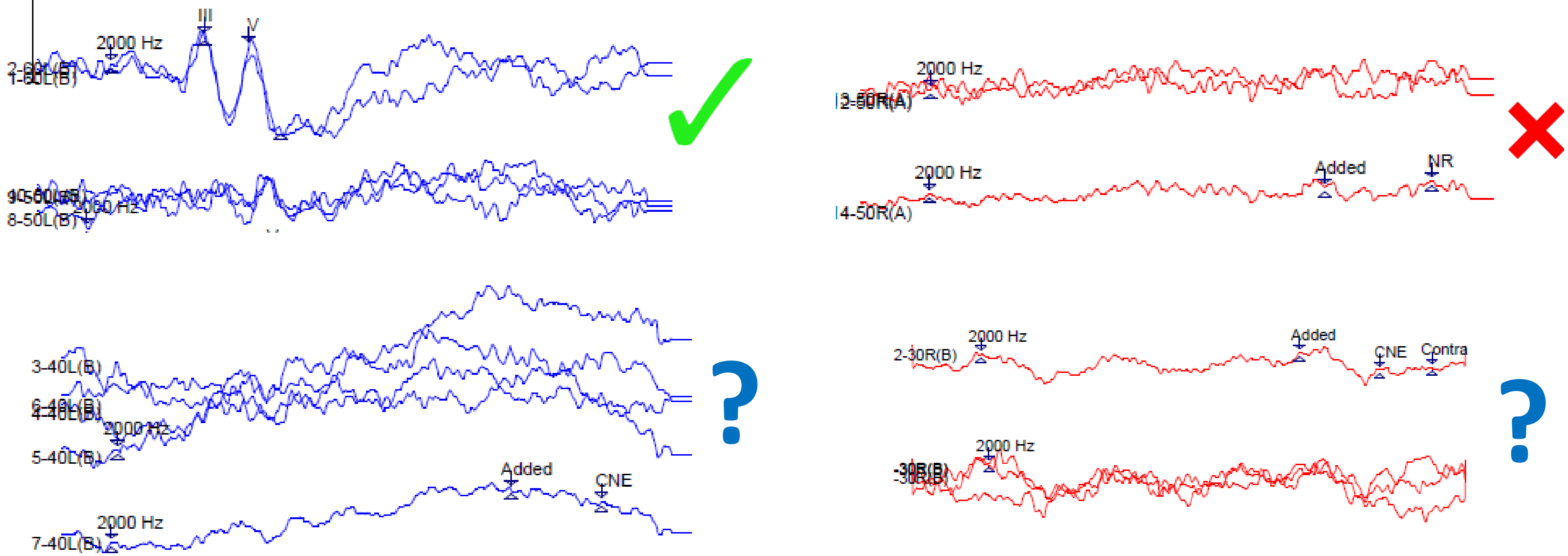
Blending real-life learning with sound science.

- 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

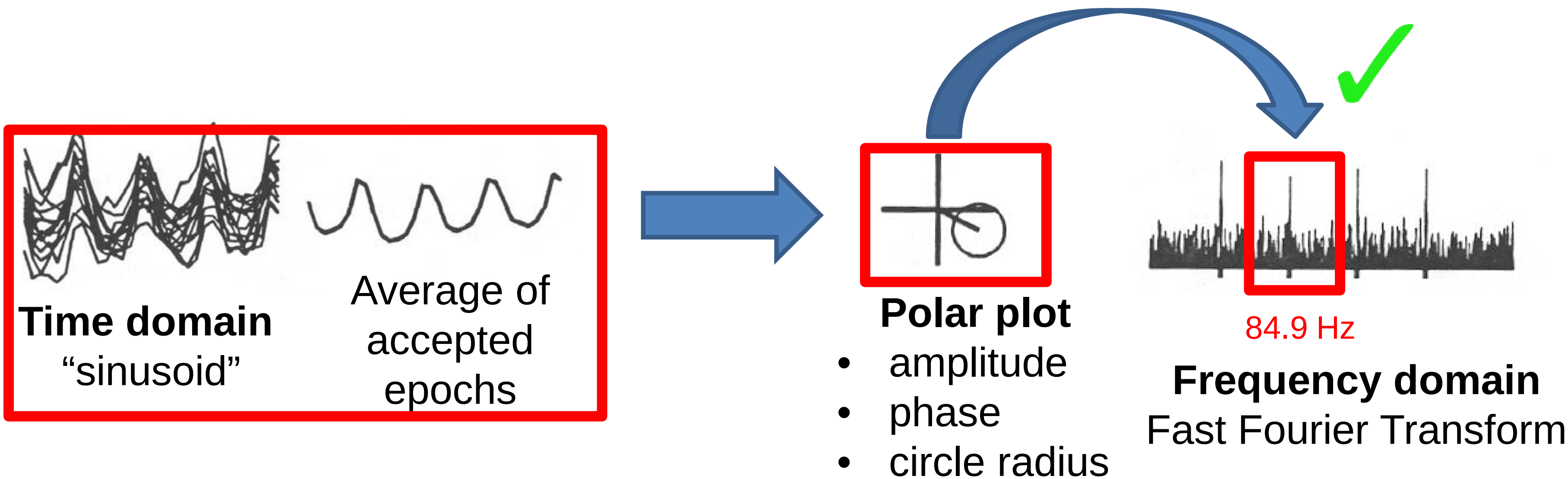
- efficient use of clinical time (2/3 time of ABR)

[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)

Multiple 80-Hz ASSR				
Carrier frequency	500 Hz	1000 Hz	2000 Hz	4000 Hz
Modulation rate	77.1 Hz	84.9 Hz	92.8 Hz	100.6 Hz



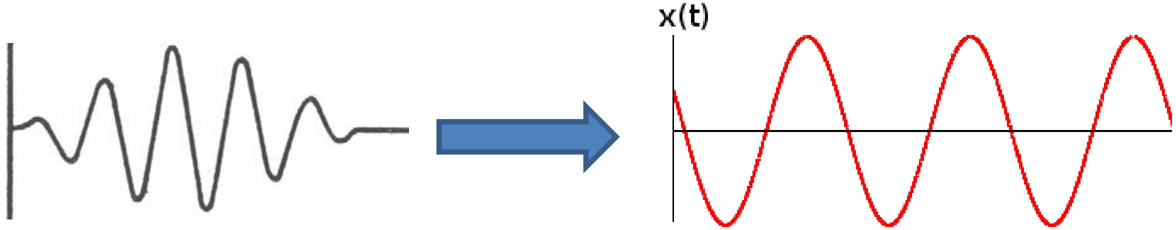
Amplitude:	*24 nV*
Onset phase:	*320^0*
p value:	*0.012*
Circle radius:	*19 nV*
EEG noise:	*10 nV*

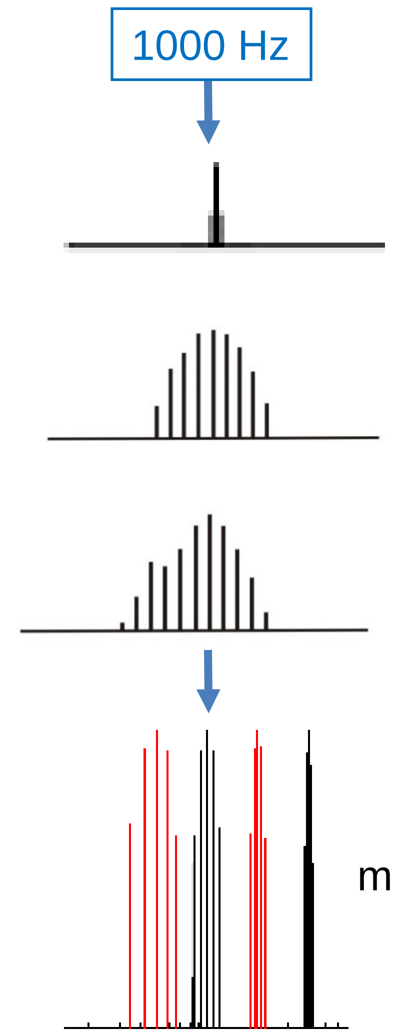
Stimuli & EEG parameters

Many types of "frequency-specific" ASSR stimuli

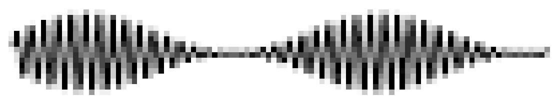
brief tones

continuous

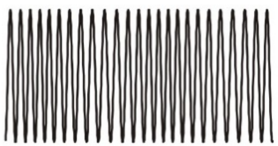




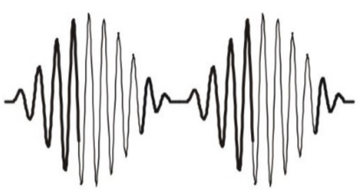
AM



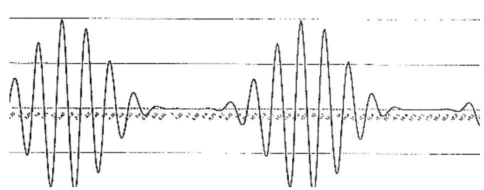
FM



AM/FM



AM²



multiple

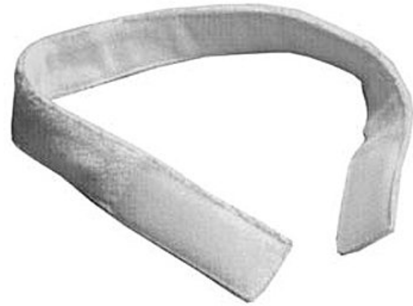
+ narrow-band chirps
-- previous presentation
with Dr. Y. Sininger

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

Bone oscillator coupling method in infants

least likely to wake infant

hand-held



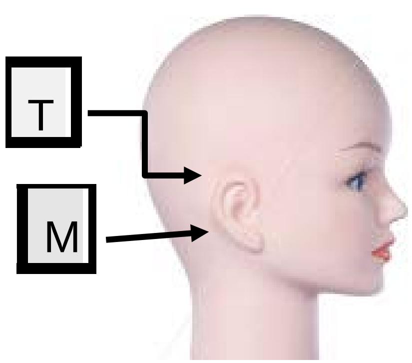
elastic head band

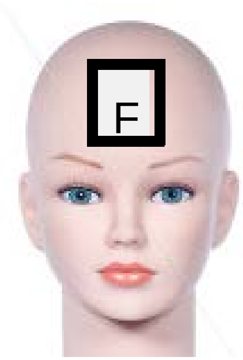
No significant differences (with training)

Recommend: Either

Bone oscillator placement

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:

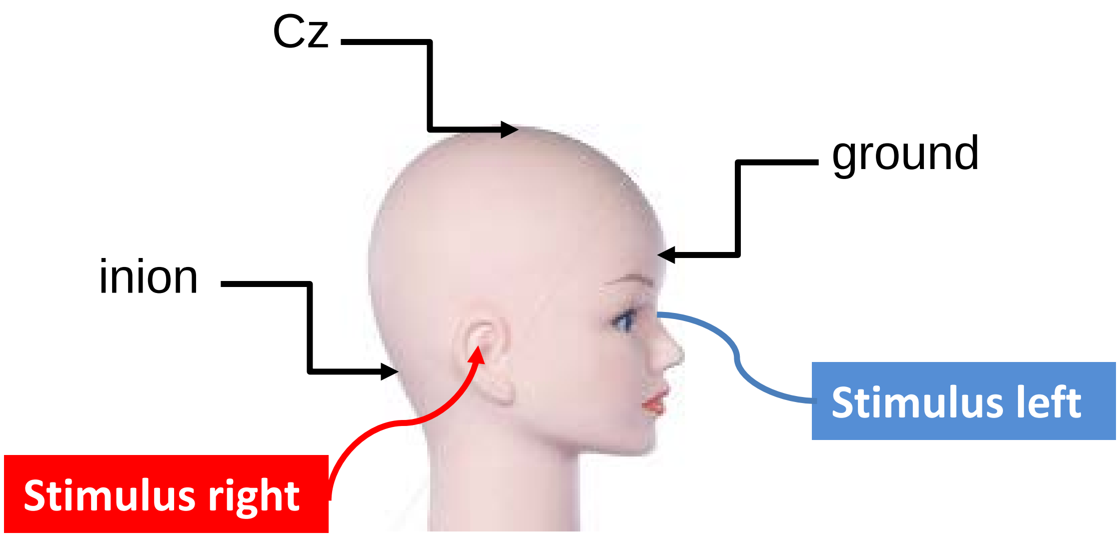
0-1 year: leave earphones in

1-2 years +: remove earphones (conservative)

EEG recording set up

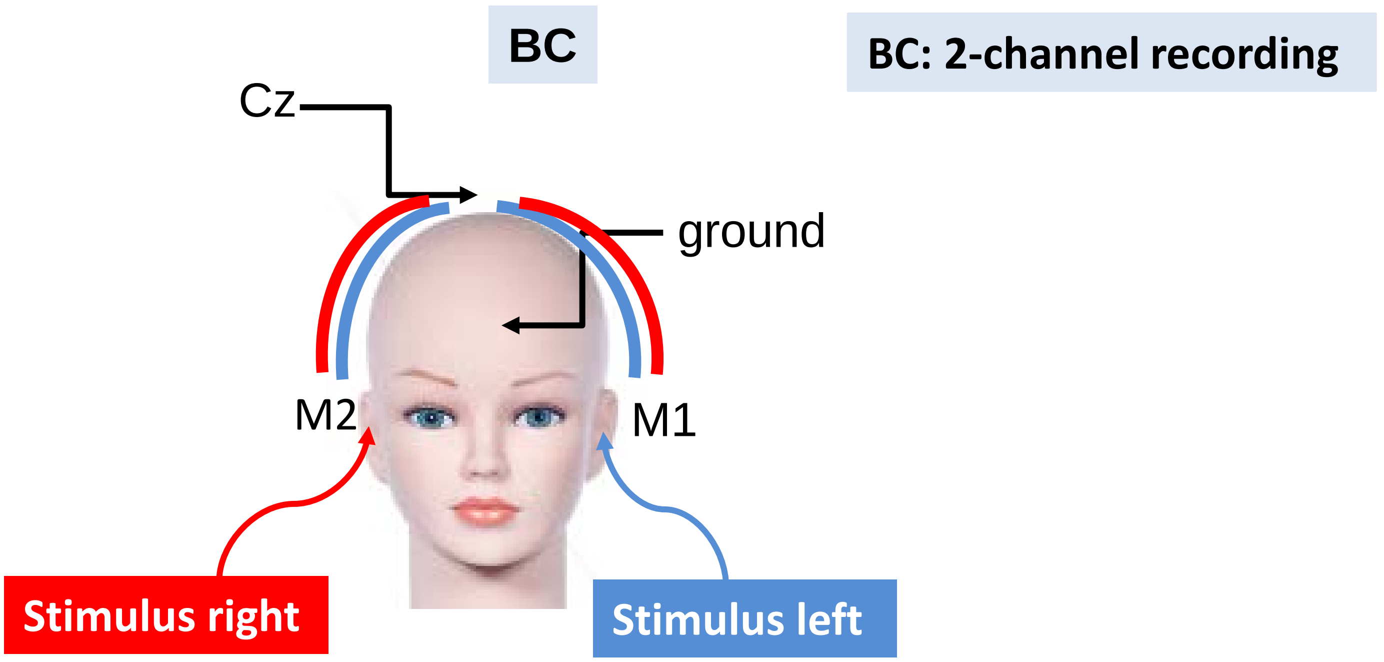
AC

AC*:* 1-channel recording



- 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**

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**

ABR threshold (dB nHL) — eHL correction (dB) = estimated behavioural threshold (dB HL)

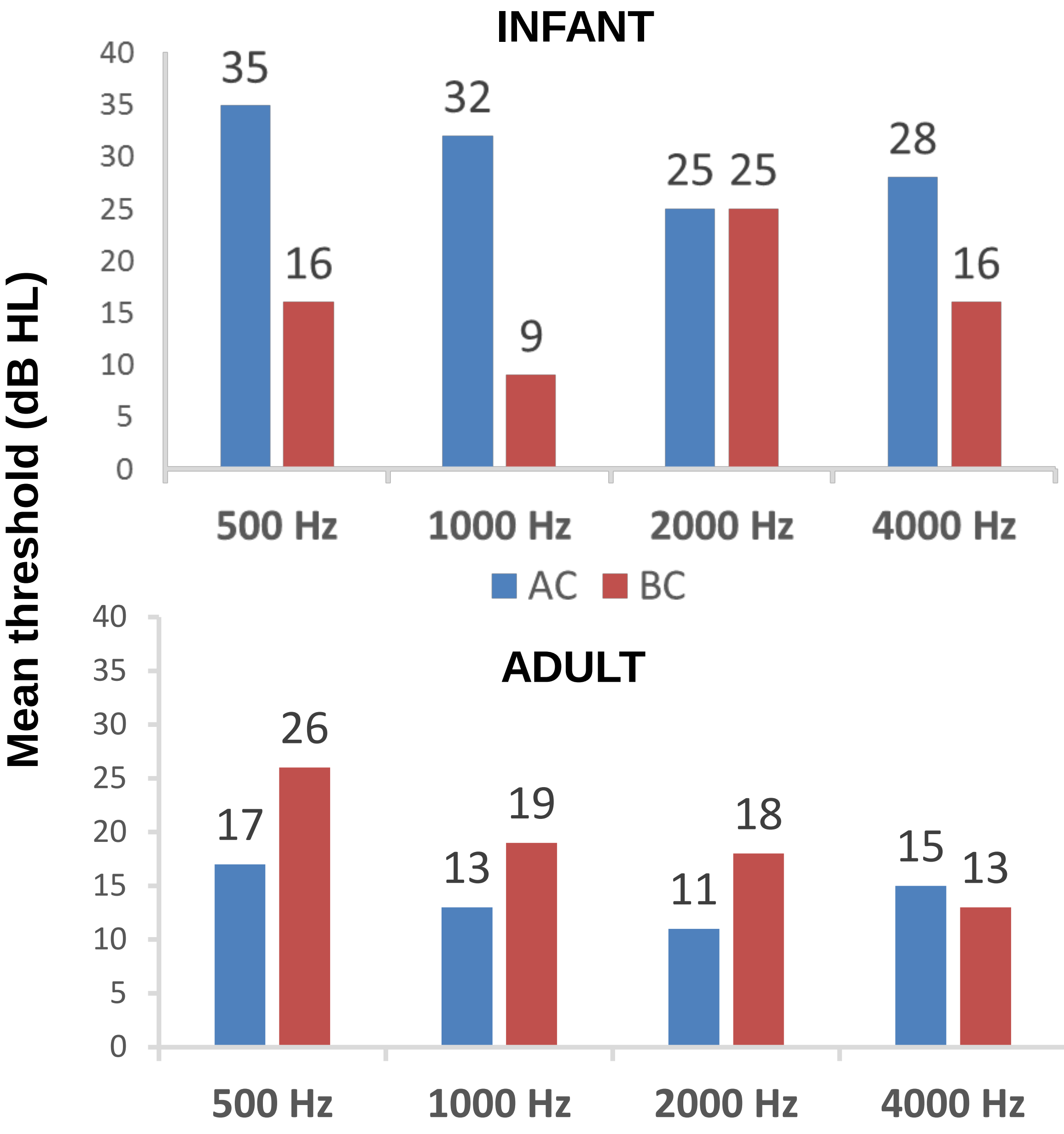
Normal ABR maximum levels & eHL correction for infants

Air- and bone-conduction ABR

	500 Hz		1000 Hz		2000 Hz		4000 Hz	
	AC	BC	AC	BC	AC	BC	AC	BC
BC EHP Normal ABR Max (dB nHL)	**35**	**20**	**35**	**na**	**30**	**30**	**25**	**na**
Range in literature	*30-35*	*20*	*30-35*	*na*	*20-30*	*30*	*20-25*	*na*
BC EHP eHL correction (dB)	**10**	**5**	**10**	**na**	**5**	**5**	**0**	**na**
Range in literature	*10-15*	*-5*	*5-10*	*na*	*0-5*	*5*	*-5-0*	*na*

(BC-EHP 2012, 2015; Small & Stapells, Ch. 21, 2017)

Mean AC & BC ASSR thresholds across 11 infant & 10 adult studies



AC: low > high frequencies

BC: low < high frequencies

➢ *Maturational air-bone gap*

(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 & BC: similar across frequency

-- tendency for BC 500 Hz to be greater than other frequencies

(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!

AM
AM/FM
COS^3
AM^2
(Ages:0-79 ms)

	500 Hz	1000 Hz	2000 Hz	4000 Hz
	AC	AC	AC	AC
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:

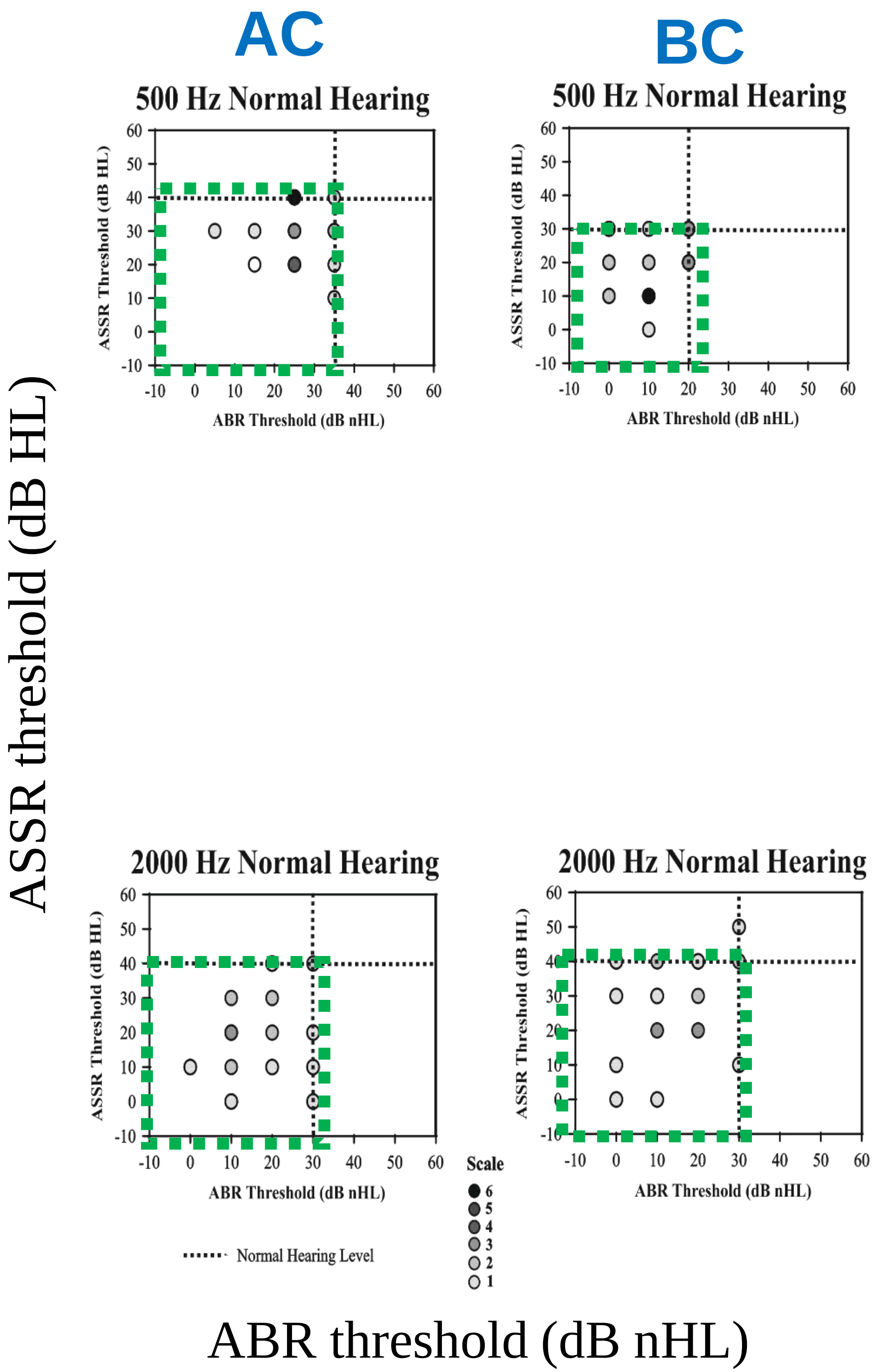
Adult (sensorineural & simulated)

- **.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**

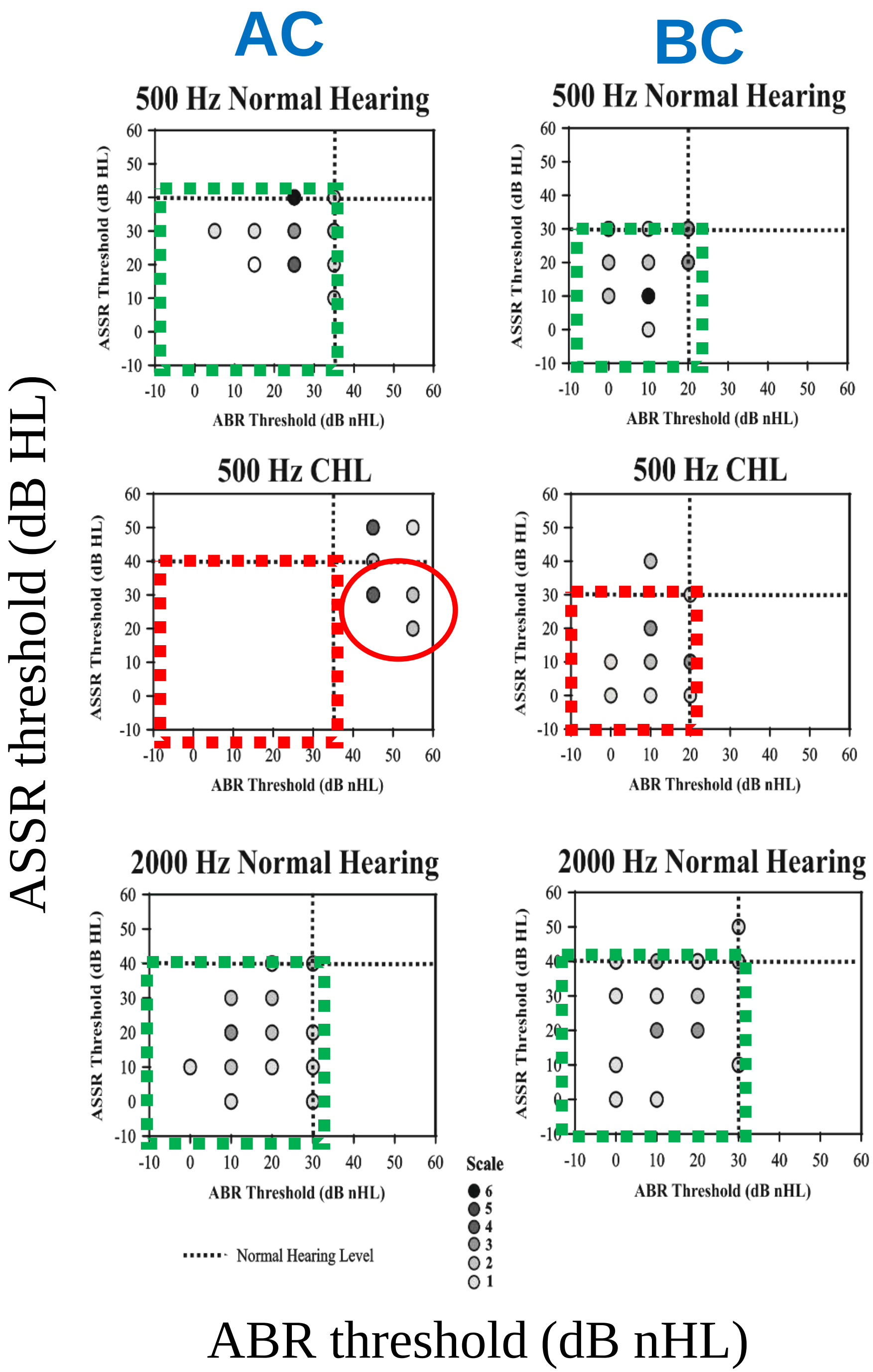
Valeriote & Small (in prep): Infant: normal hearing versus mild conductive loss at 500 Hz



Normal hearing (NH)

500 & 2000 Hz

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



Conductive hearing loss (CHL) (mild)

500 Hz

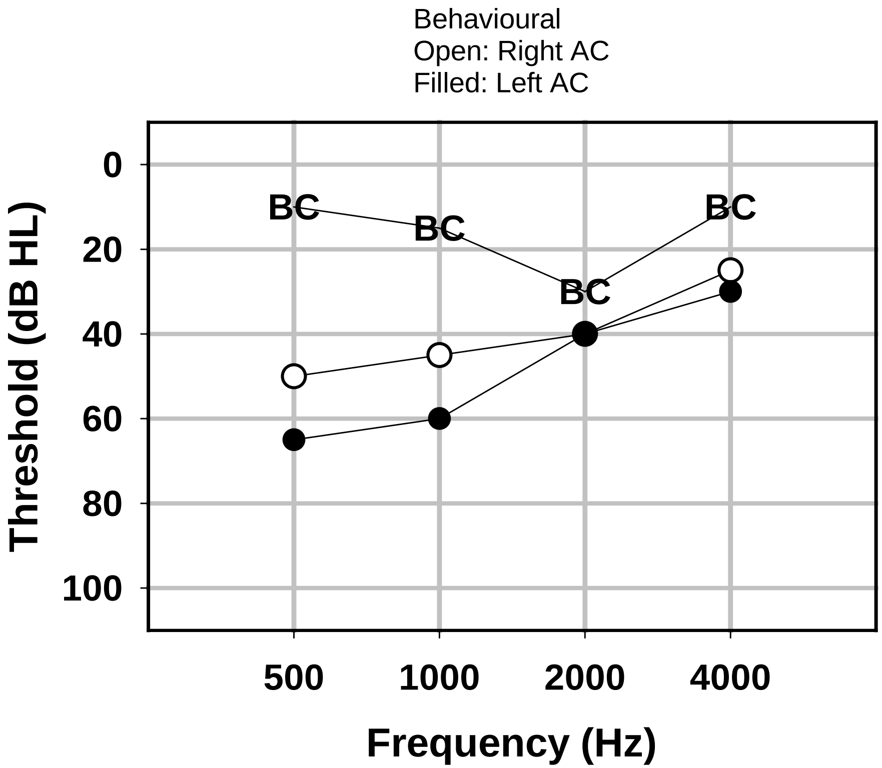
- ***AC: trend for elevated ASSR thresholds***

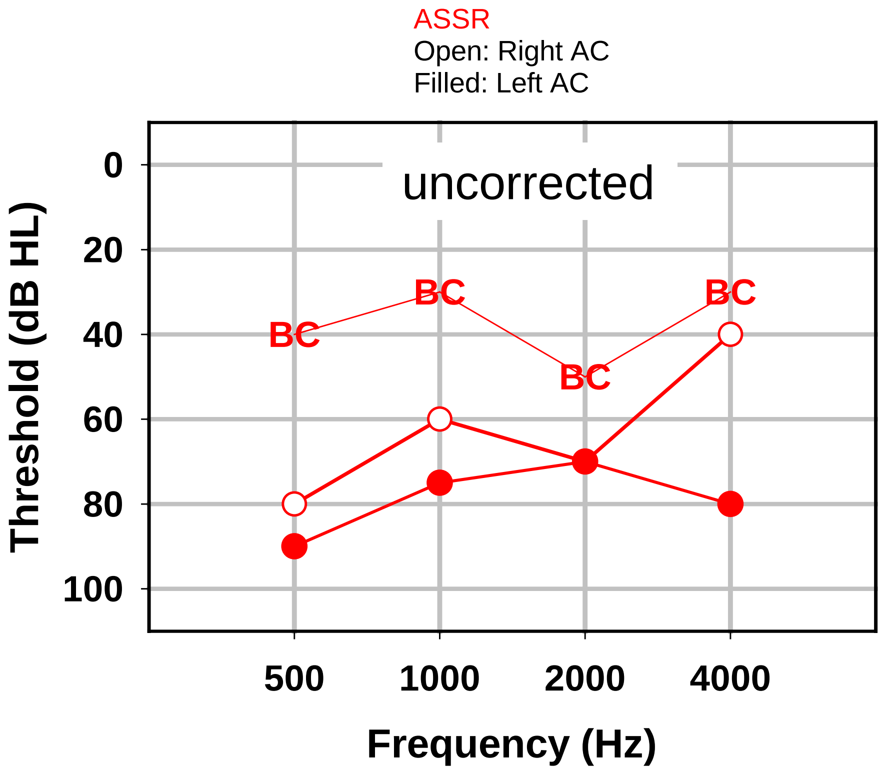
-- but overlap for NH and mild CHL for ASSR

- ***BC: CHL and NH did not differ significantly as expected***

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!

AM/FM

AM^2

	500 Hz	1000 Hz	2000 Hz	4000 Hz
	BC	BC	BC	BC
8 studies (0-24 mos) Normal ASSR Max (dB HL)	**30**	**20**	**40**	**30**
Range in literature	*30-40*	*10-30*	*30-40*	*10-40*
BC EHP eHL correction (dB)	**na**	**na**	**na**	**na**
Range in literature	*na*	*na*	*na*	*na*

(Small & Stapells, Ch. 21, 2017)

Are multiple ASSRs more or less efficient than single ASSRs?

NH infants @ 60 dB SPL

Amplitude	**Efficiency**
Single > Multiple	**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 same time in both ears to only one mode at a time in NH infants

AC: 2000 Hz AM tones (L: 111.4 Hz; R: 115 Hz)	simultaneous
BC: 500 Hz AM tones (L: 104.2 Hz; R: 107.8 Hz)	simultaneous
AC: 2000 Hz AM tones (115 Hz)	only stimulus
BC: 500 Hz AM tones (115Hz)	only stimulus

- 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)**

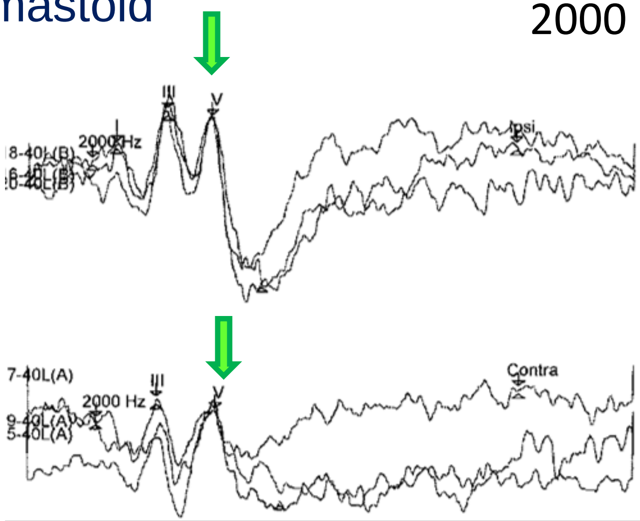
  [e.g., Foxe & Stapells, 1993; Stapells & Ruben, 1989; Stapells & Mosseri, 1991]

2000 Hz @ 40 dB nHL

BC left mastoid

Ipsi

Contra



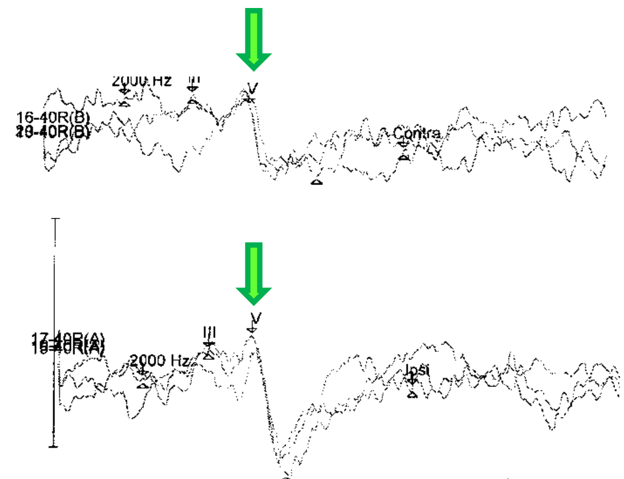
BC right mastoid

Left EEG Cz-M1

Contra

Right EEG Cz-M2

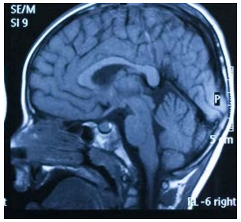
Ipsi



Amplitude: contra *smaller than* ipsi

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

(see for review: Small & Stapells, 2017)

- ***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**

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

	Frequency (Hz)				
	500	1000	2000	4000	
Infant	81	68	59	45	
Adult	66	63	59	55	
Infant minus adult difference (dB)	15 *	5 *		-10 *	

** 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
-- 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

** more work needed on isolation of test ear

Simultaneous AC & BC ASSRs

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

Questions?