Infant assessment using the auditory brainstem response (ABR) and auditory steady-state-response (ASSR): Updates for clinical practice

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CAA 2017, Ottawa, Ontario
October 11-14, 2017

NSERC CRSNG

Disclosure statement

BC Early Hearing Program (consultant): receive honorarium that contributes to my research program; Hamber Chair position: small contribution to research program; equipment on loan from Interacoustics

Other funding

UBC Faculty of Medicine

NSERC CRSNG Eric W. Hamber Professorship

SASS Seed Grant

TOPIC AREAS TO BE ADDRESSED

Overview of brainstem ABR & ASSRs

EEG parameters

Stimuli

Estimation of infant hearing thresholds

Isolation of test cochlea

Clinical implications/ Future research needed

Overview

Clinical goal for infant ABR & 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 ABRs?

- **Evoked potentials elicited to transient stimuli analyzed in the time domain: amplitude & latency characteristics of peaks/troughs in waveform**

For threshold estimation:

- **Wave V tracks close to threshold levels**
- **Subjectively interpret presence/absence of response using visual replicability with some objective tools (e.g., residual noise, SNR)**
- **Assess one ear and one frequency at a time**

- **Most commonly used clinical method to identify hearing loss in infants**

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)

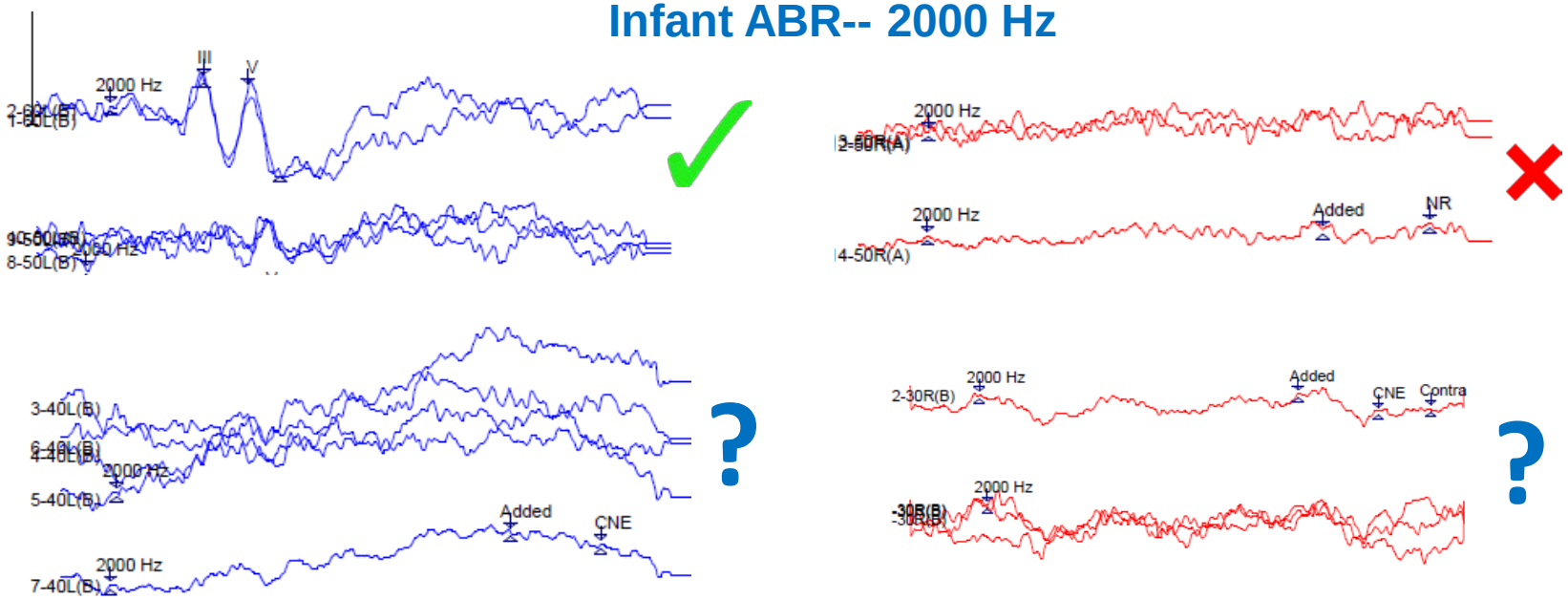
- Most research and clinical applications for infants
  - -- 40-Hz smaller in sleep in infants versus adults (Picton et al., 2003)
  - -- 80-Hz or "brainstem"– most of research & today's focus!
- Single- & multiple-ASSRs presented to two ears simultaneously
  - -- depends on equipment available (focus on multiple ASSRs)

- **Why consider ASSRs for the clinic when we have brief-tone ABRs?**

-- brief-tone ABRs require considerable training & skill to interpret:

- **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

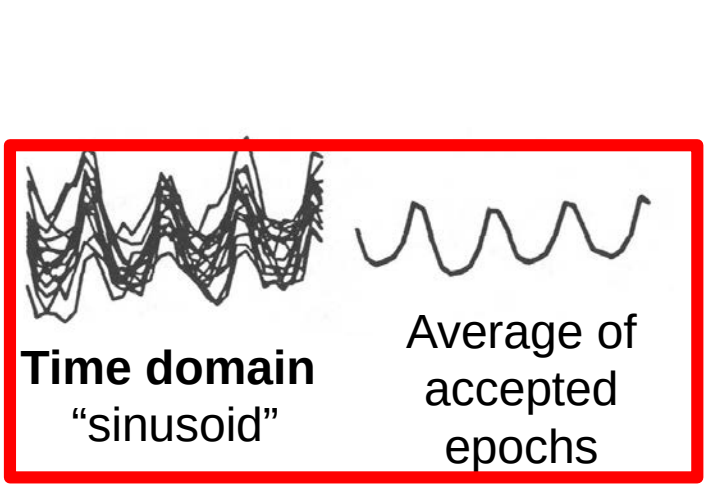
- efficient use of clinical time (2/3 time of ABR)

[van Maanen & Stapells, 2009]

One example of ASSR analysis

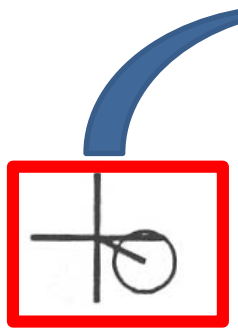
Comparison of response amplitude @ modulation rate to surrounding noise frequencies: F statistic ($p < .05$) (for review see Picton et al., 2003)

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



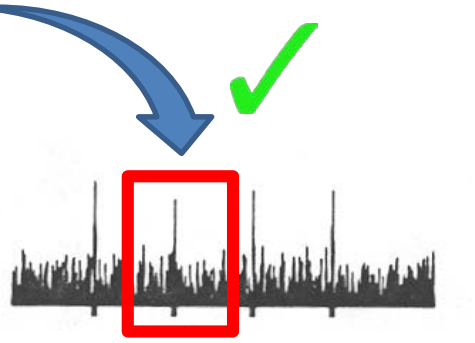
Time domain
"sinusoid"

Average of accepted epochs



Polar plot

- amplitude
- phase
- circle radius



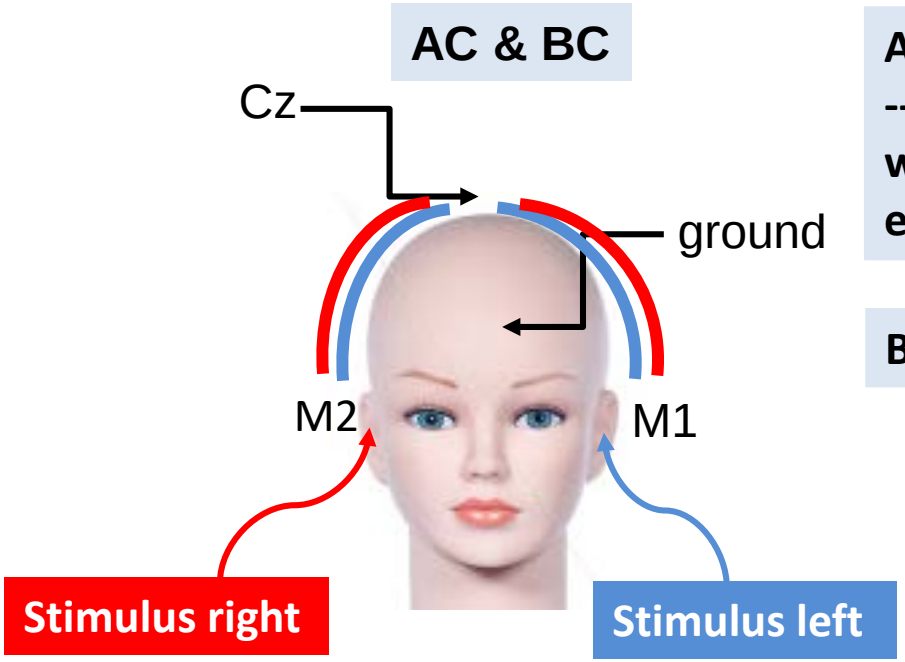
84.9 Hz

Frequency domain
Fast Fourier Transform

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

EEG parameters
- very briefly

ABR EEG recording set up



AC: 1-channel recording
-- 2-channel can be helpful when large asymmetries exist

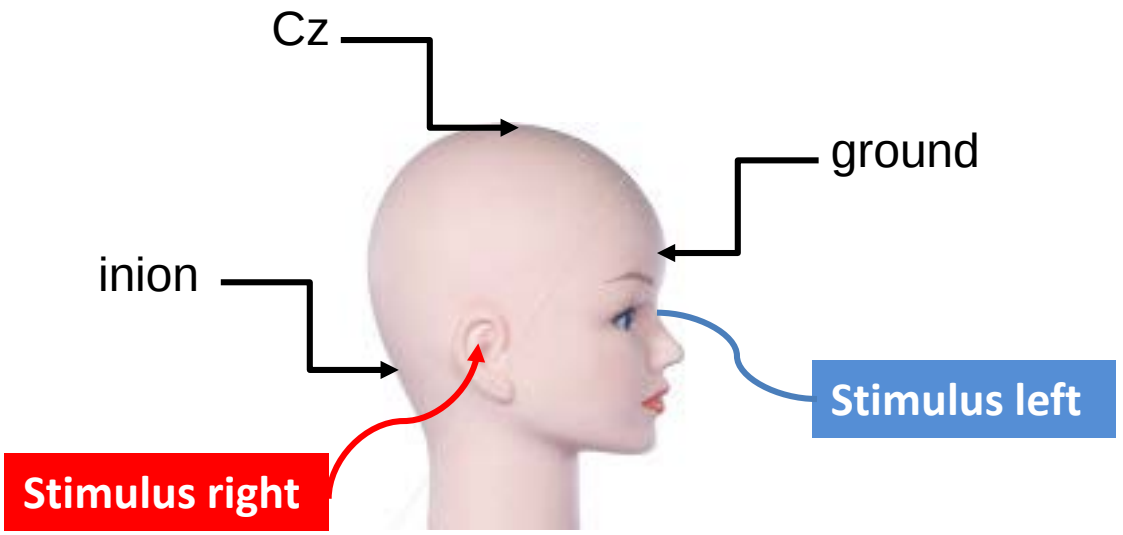
BC: 2-channel recording

- **Can record EEG ipsilateral & contralateral to mastoid stimulated to assist with isolation of the test ear (more later in presentation)**

ASSR EEG recording set up

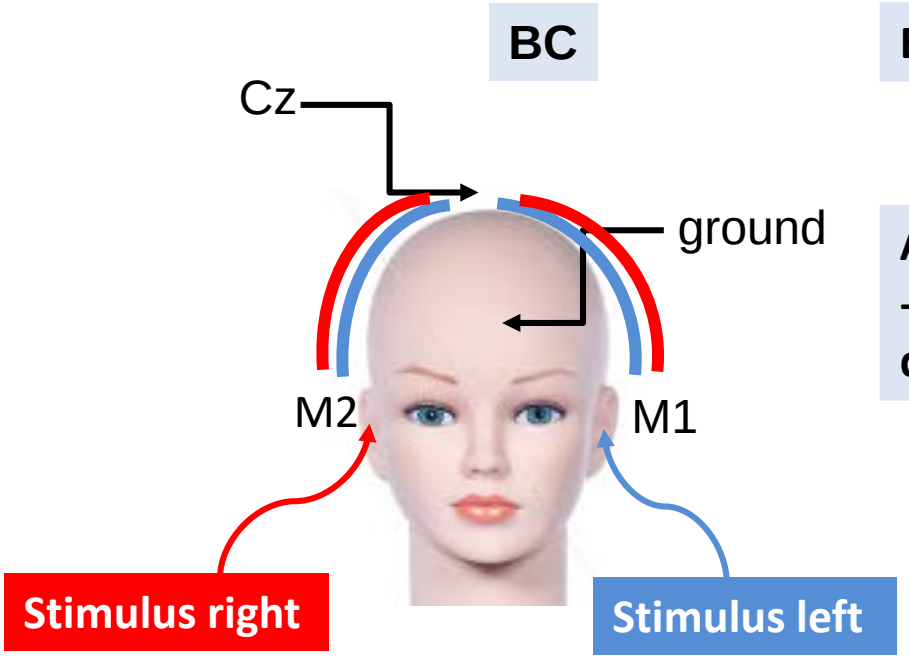
AC

AC: 1-channel recording



- can avoid post-auricular muscle response

ASSR EEG recording set up



BC: 2-channel recording

AC: 2-channel recording -- not aware of any clinical data

- **Can record EEG ipsilateral & contralateral to mastoid stimulated to assist with isolation of the test ear (more later in presentation)**

AC methodology

-- nothing new

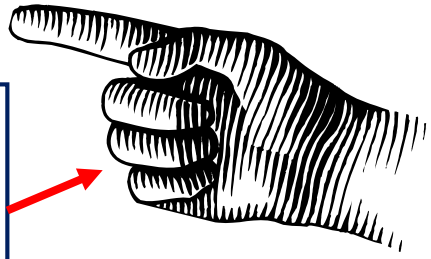
preferred- better for setting hearing aid targets

use as needed

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

Bone oscillator coupling method in infants

least likely to wake infant



hand-held

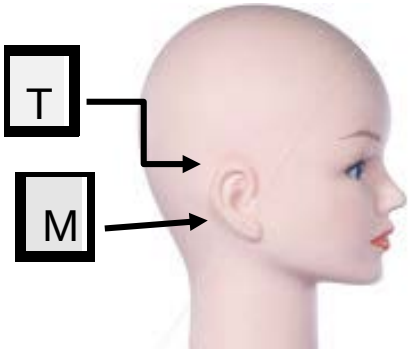
elastic head band

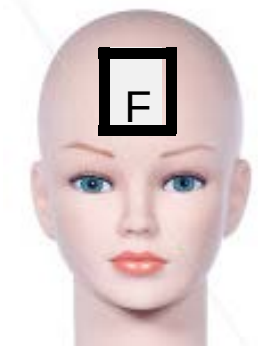
No significant differences (with training)

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)

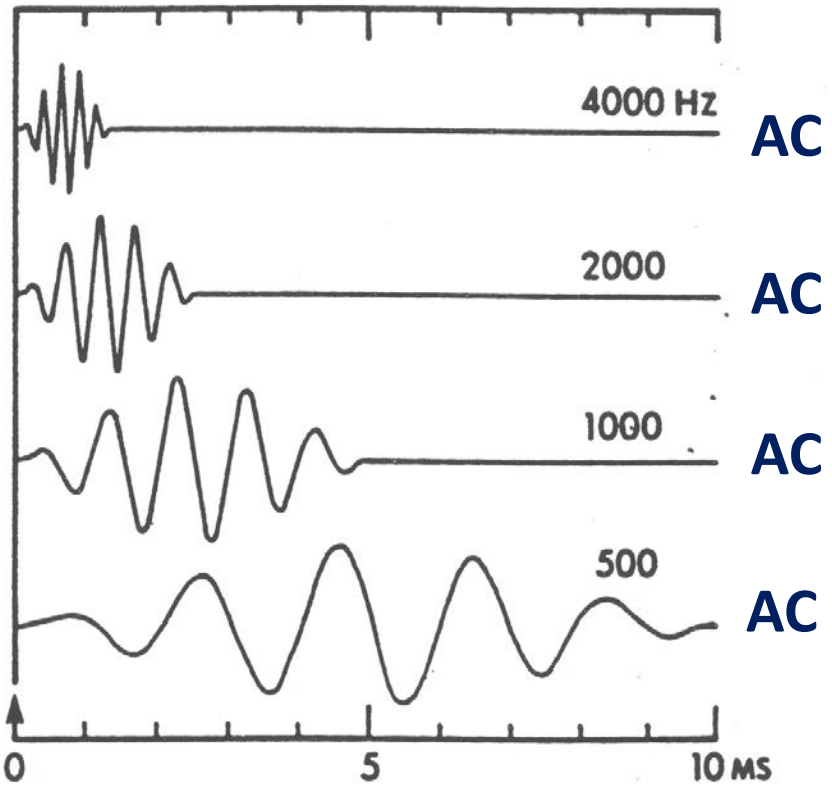
Stimuli

Frequency-specific ABR

brief tones

BC Under investigation

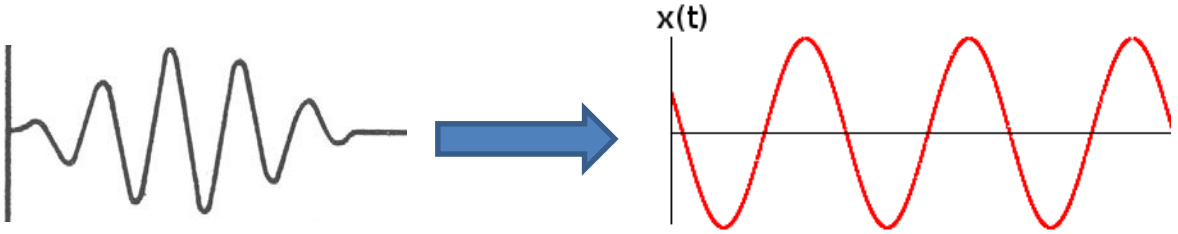
Typical stimuli used to elicit the ABR
(e.g., Davis et al., 1984)

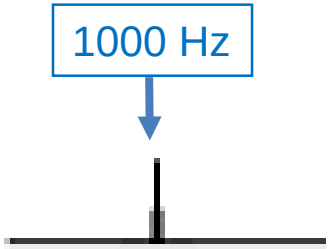


+ more recently: narrow-band chirps

Many types of “frequency-specific” ASSR stimuli

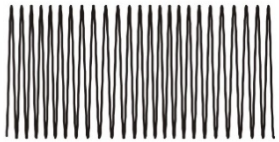
brief tones (~ COS^3) continuous

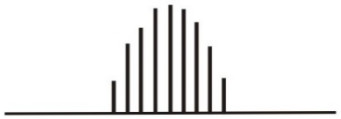




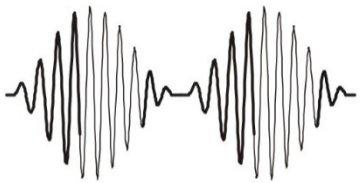
AM

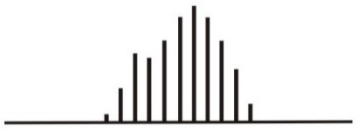
FM



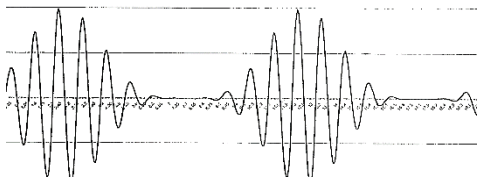


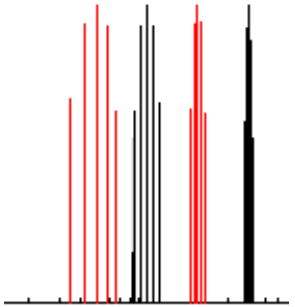
AM/FM





AM²





multiple

+ more recently: narrow-band chirps

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

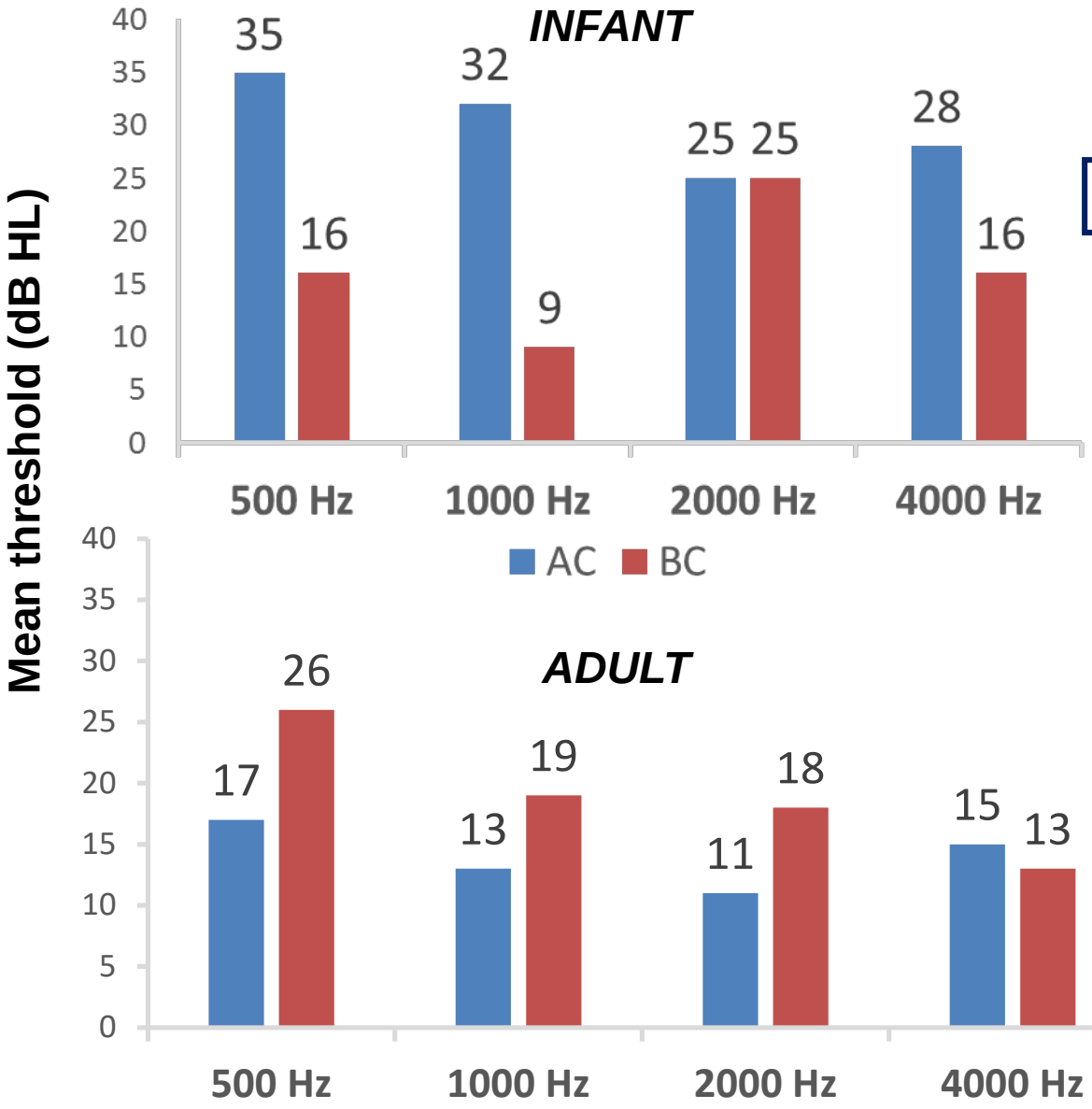
Air- and bone-conduction ABR

	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

AM; AM/FM; $AM^{2;}$ COS^{3}



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-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

- **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***

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

Bone-conduction ASSR

Preliminary & conservative!

	500 Hz	1000 Hz	2000 Hz	4000 Hz
AM/FM AM^2	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)

More recently…chirp stimuli

Why chirps?

- **Clicks/brief-tones do not compensate for temporal delays in frequency contributions when basilar membrane is activated**

Consequences:

(i) superimposition of responses from individual nerves is sub-optimal

- **some destructive interference-- reduces ABR/ASSR amplitudes**

- **Chirps are designed to compensate for basilar membrane travelling-wave delays (> compensation for low frequencies) (Shore & Nutall, 1985; Dau et al., 2000; Elberling et al., 2007)**

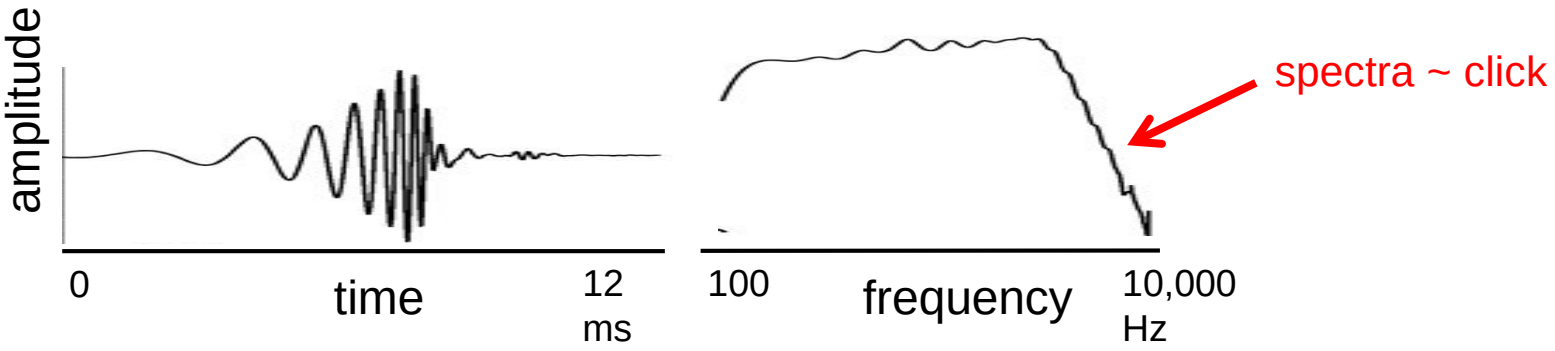
e.g., *CE-chirp (Broadband) (Elberling et al., 2007; Elberling, Don et al., 2007)

-- low-frequencies precede high-frequencies

-- maximizes synchrony of neural firing across frequencies

-- larger response amplitudes result

* registered trade name



For stimuli < 60 dB nHL:

- **ABR amplitude CE-chirp versus click: 1.5-2 X larger**

(e.g., Dau et al., 2000; Elberling & Don, 2008)

- **Advantage for screening purposes in infants (e.g., Cebulla et al., 2014)**

For CE-Chirps @ higher intensities (> 60 dB nHL):

- **there is upward spread of excitation by the individual frequency components of the chirp**
- **as level increases, area of cochlear excitation broadens & desynchronization occurs**
- **chirps can be modelled with different delays– most efficient design is to increase the delay for decreasing stimulus levels**
  - **-- stacked ABR data was used to model CE-Chirps**
    (Fobel & Dau, 2004; Elberling & Don, 2008; Elberling et al., 2010)

Note: refer to papers on Level Specific CE-Chirps for more information on optimizing CE-Chirps (e.g., Kristensen & Elberling., 2012)

- **Refer to the literature for more on "broad-band" CE-Chirp thresholds in infants & adults with normal hearing and hearing loss (ABR & ASSR)– presenting only more frequency-specific data today**

Chirps for frequency-specific threshold estimation? Specifically in infants?

Optimize response amplitudes?

Increase detectability? **Reduce testing time?**

Accurately predict behavioural thresholds?

- **narrowband chirp stimuli were designed (NB CE-Chirps)**

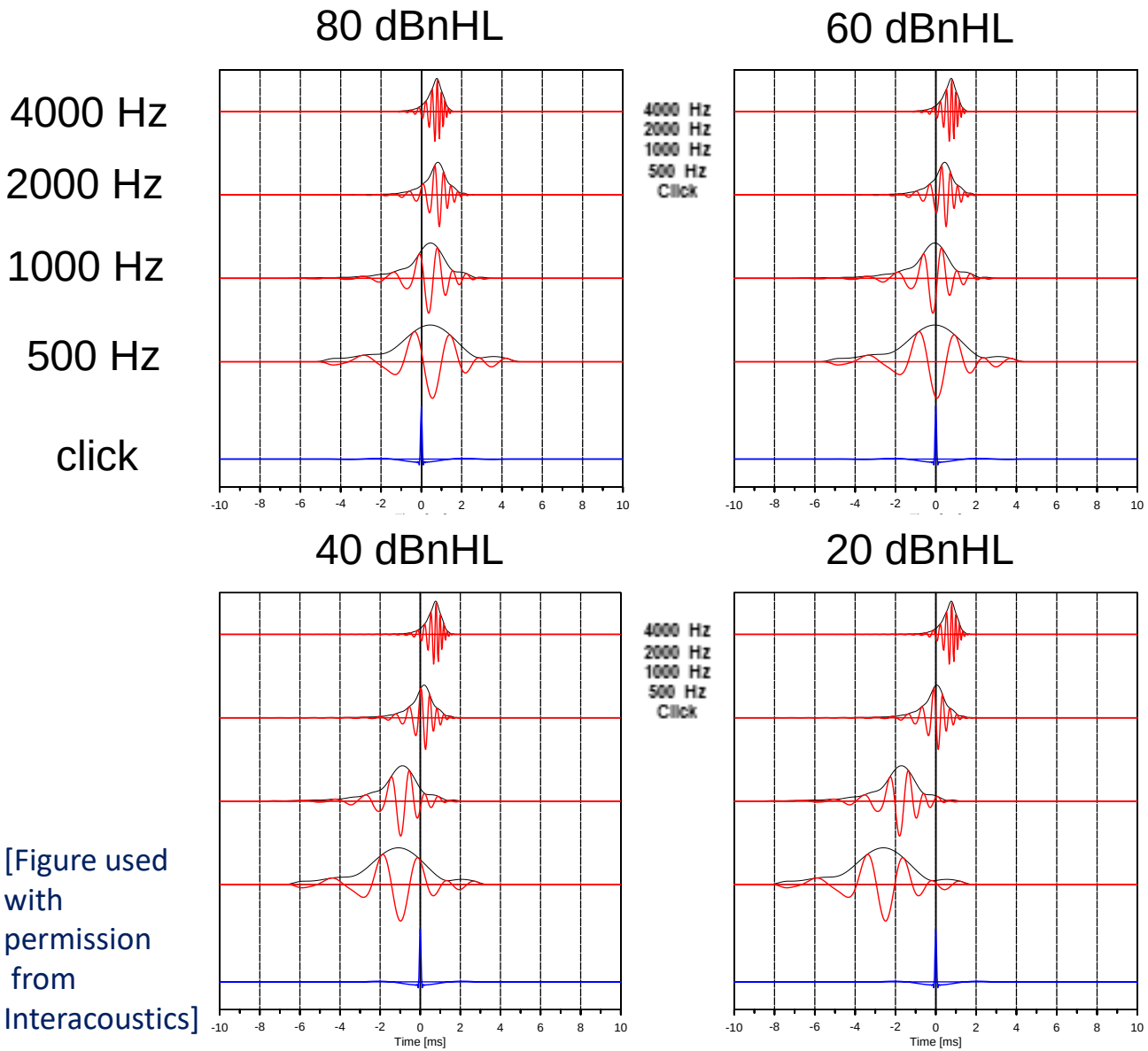
-- same compensation for travelling-wave delay but for much narrower range of frequencies

<u>Question</u>: Is the NB CE-Chirp better than brief-tones for <u>ABR</u> or other stimuli for <u>ASSRs</u> @ estimating threshold? Is the amplitude advantage also present for the NB CE-Chirps? For all test levels?

<u>Note</u>: Today's focus is frequency-specific stimuli & brainstem ABR/ (80-Hz) ASSR

NB CE-Chirps

(Elberling, 2011)



[Figure used with permission from Interacoustics]

Stimulus timing

NB-Chirps temporally adjusted

- **If stimulus onset is not adjusted, wave V latencies for the low frequencies are shorter for NB CE-Chirps than brief tones due to stimulus design**
  (e.g., Rodrigues et al., 2013)

- **Stimulus onset is adjusted to expected response latencies (same delay model for all levels)**
  (e.g., Interacoustics, 2012)

ABR
NB CE-Chirps versus brief tones
NH infants

ABR studies in NH infants: NB CE-Chirps versus brief tones

Study	Age (wks)	f (Hz)	Optimal stimulus level (dB nHL)	Level (dB nHL)	Ear phone	Greater Amp	% with >AMP	> AMP with increase in level
Ferm et al. 2013/15	0-12	500	**≤ 30**	**10-50***	TDH-39	**1.3 x**	**71**	**No**
N=30-39								

ABR studies in NH infants: NB CE-Chirps versus brief tones

Study	Age (wks)	f (Hz)	Optimal stimulus level (dB nHL)	Level (dB nHL)	Ear phone	Greater Amp	% with >AMP	> AMP with increase in level
Ferm et al. 2013/15	0-12	500	**≤ 30**	**10-50***	TDH-39	**1.3 x**	**71**	**No**
N=30-39		1000	**≤ 40**	10-45	TDH-39	1.6 x	98	Yes
		2000	**≤ 40**	0-40	TDH-39	1.5 x	93	Yes
		4000	**≤ 45**	0-40	TDH-39	1.6 x	100	Yes

- **NB CE-Chirp responses present at levels 10 dB < brief tones for 52-62 % of infants tested– less so for 500 Hz***

ABR studies in NH infants: NB CE-Chirps (NBCh) versus brief tones (BT)

Study	Age (wks)	f (Hz)	Optimal stimulus level TDH39 (dB nHL)	Level (dB nHL)	Ear phone	Greater Amp?
Rodrigues et al., 2013	4-12	500	**≤ 30**	**80**	ER3-A	**No BT>NBCh***
				60	ER3-A	**No NBCh~BT***
				20-40	ER3-A	Yes

- **500 Hz: only advantage seen is for low levels; no advantage for mid levels and disadvantage for high levels***

ABR studies in NH infants: NB CE-Chirps (NBCh) versus brief tones (BT)

Study	Age (wks)	f (Hz)	Optimal stimulus level TDH39 (dB nHL)	Level (dB nHL)	Ear phone	Greater Amp?
Rodrigues et al., 2013	4-12	500	**≤ 30**	**80**	ER3-A	**No BT>NBCh***
				60	ER3-A	**No NBCh~BT***
				20-40	ER3-A	Yes
		1000 - 4000	**≤ 40-45**	**80**	ER3-A	**No NBCh~BT***
		1000 - 4000	**≤ 40-45**	20-60	ER3-A	Yes

- **500 Hz: only advantage seen is for low levels; no advantage for mid levels and disadvantage for high levels***
- **1000-4000 Hz: advantage for low/mid levels but not for high level***

ABR studies in NH infants: NB CE-Chirps versus brief tones

Study	Age (hours)	f (Hz)	Optimal stimulus level TDH39 (dB nHL)	Level (dB nHL)	Ear phone	Greater Amp?
Cobb & Stuart, 2016	11-104 N=20-22	**500**	**≤ 30**	**30-60**	ER3-A	**No***
		4000	**≤ 45**	**60**	ER3-A	**No***

- **500 Hz: no advantage for low-mid levels***
- **4000 Hz: no advantage for mid levels***

ABR studies in NH infants: NB CE-Chirps versus brief tones

Study	Age (hours)	f (Hz)	Optimal stimulus level TDH39 (dB nHL)	Level (dB nHL)	Ear phone	Greater Amp?
Cobb & Stuart, 2016	11-104 N=20-22	**500**	**≤ 30**	**30-60**	ER3-A	**No***
		1000 2000	**≤ 40**	30-60	ER3-A	Yes
		4000	**≤ 40**	30-45	ER3-A	Yes
		4000	**≤ 45**	**60**	ER3-A	**No***

- **500 Hz: no advantage for low-mid levels***
- **4000 Hz: no advantage for mid levels***
- **4000 Hz: advantage for low levels**
- **1000-2000 Hz: advantage for low & mid levels**

Across NH infant ABR studies: NB CE-Chirps versus brief tones for frequency-specific threshold estimation

AC stimuli

Optimize response amplitudes?

- **NH : Yes, on average, amplitudes larger; greatest advantage 1000-4000 Hz for levels < 60-80 dB nHL**
- **However @ 500 Hz: amplitude disadvantage at 80 dB nHL, no advantage at 45-60 dB nHL, & may or may not show an amplitude advantage at 20-30 dB nHL**

Increase detectability?

- **NH infants: Yes, ~ 52-62% of cases**
- **Hearing loss: No data but expect less benefit with increase in stimulus level**

AC stimuli cont'd

Reduce testing time?

- **NH infants: Yes**
- **Milder losses: No ABR data but probably (more so at 1-4 kHz)**
- **Moderate/severe losses: No ABR data: maybe a disadvantage?**

Accurately predict behavioural thresholds?

- **Lack of ABR data for NB CE-Chirps in infants with hearing loss**
- **Ferm et al. recommended correction factors to dB eHL for NB CE-Chirps as 5 dB < brief tone correction factors**
- **Not yet verified in a clinical population**

BC stimuli

- **No published ABR data for NB CE-Chirp stimuli -- NH infants or infants with hearing loss**
- **Currently for clinic– no date to support estimation of frequency-specific BC thresholds using these stimuli**
  - **-- only one research group has looked at AC and BC ABRs in infants -- only for broadband CE-Chirps (Cobb & Stuart, 2016a, b& c)**
  - **-- we know there are frequency-dependent differences in infant BC thresholds so need to investigate BC ABRs to NB CE-Chirps**

ASSRs

NB CE-Chirps versus brief tones ABR/behavioural measures:

NH infants & infants with hearing loss

Adults with hearing loss

ADULTS WITH HEARING LOSS:

AC ASSR NB CE-Chirps & AM/FM versus behavioural

Study	Age	Correlation coefficient			
		500	1000	2000	4000
NB CE-Chirps versus behavioural					
Lee et al. (2016)	ADULTS N=19	.67*	.87	.76	.91
AM/FM sinusoid versus behavioural					
Lee et al. (2016)	ADULTS N=19	.67*	.81	.68	.80

Note: all correlation coefficients were statistically significant

- **Larger amplitudes for NB CE-Chirps for 1000-4000 Hz similar to ABR**
- **Slightly stronger correlation coefficients compared to AM/FM > 500 Hz**
- **no advantage at 500 Hz***

NORMAL HEARING INFANTS

AC ASSR NB CE-Chirps versus brief-tone ABR

Study	Age (mos)	Level at which 90% of infants have PRESENT responses (dBnHL)				Testing time (min)
		500	1000	2000	4000	
NB CE-Chirps						
Rodrigues & Lewis (2014)	NH neonates N=30	**35***	**28**	**13**	**15**	**21±5**
Brief-tone ABR						
Small & Stapells, 2017[a] Janssen et al. (2010)[b]	NH (across studies)	**30-35[a]***	**30-35[a]**	**20-30[a]**	**20-25[a]**	***49-58*[b]**

- **normal maximum levels: lower for NB CE-Chirps 1000-4000 Hz**
- **no advantage at 500 Hz***

INFANTS WITH HEARING LOSS:
AC ASSR NB CE-Chirps versus brief-tone ABR

Study	Age (mos)	Correlation coefficient*				Difference	dB nHL to dB eHL	Testing in min
		500	1000	2000	4000			
NB CE-Chirp ASSR versus brief-tone ABR [+]								
Michel & Foldager Jorgensen (2016) [+]	4-22 N=67	.90	.90	.96	.95	500-4000 Hz Mean: - 4-5 dB	5 dB < ABR	
NB CE-Chirp ASSR versus behavioural								
Venail et al. (2014)	2-12 N=32	.87	.91	.93	.86	500 & 2000 Hz Mean - 4 dB 1000 & 4000 Hz Mean: -1-2 dB		23±16
Brief-tone ABR versus behavioural								
Stapells et al., 1995[a], Janssen et al. (2010)[b]	4 N=188	.94[a]	--	.95[a]	.97[a]			***49-58***[b]

[+] infants with hearing loss only

similar

shorter testing time

Across infant ASSR studies: NB CE-Chirps versus AM/FM tones for frequency-specific threshold estimation

AC stimuli

Optimize response amplitudes?

Increase detectability?

- **No amplitude data provided in the two infant studies available (1 NH and 1 hearing loss)**
- **NH infants: Normal levels were slightly lower for 1000-4000 Hz but not 500 Hz (Rodrigues et al.; 2014)**
- **Hearing loss: One study with correlation data showed strong correlations but slightly less compared to brief-tone ABR data**

Reduce testing time?

- **NH and hearing loss: Yes, significantly**

Accurately predict frequency-specific behavioural thresholds?

Potential issues:

(i) Limited ASSR data for NB CE-Chirps in infants with hearing loss

- **No recommended correction factors to dB eHL**

(ii) No place/frequency specificity studies to explore whether the advantage of using NB CE-Chirps is due to compensation for basilar membrane travelling-wave delays OR stimulation of broader portion of the basilar membrane (i.e., less frequency specific)

BC stimuli

- **No published ASSR data for BC NB CE-Chirp stimuli in infants**

Spectral analysis: NB CE-Chirps versus 2-1-2 brief tones

Adjekum, Chan, Stapells & Small, in prep
- also Cobb & Stuart (2016)

Work in progress in my lab:
- investigating place specificity of NB CE-Chirps

Table 1: Characteristics of brief tone spectra: NB CE Chirps versus 2-1-2 tones (Interacoustics)

Nominal Frequency	0.5 KHz		1 KHz		2 KHz		4 KHz	
Stimuli	Chirp	2-1-2	Chirp	2-1-2	Chirp	2-1-2	Chirp	2-1-2
Geometric Mean	485	472	1006	973	2076	1945	3618	3764
Bandwidth	**560**	**302**	**1077**	**560**	**1229**	**1120**	**3015**	**2024**
Deviation (%)	3.03	5.64	0.63	2.74	3.79	2.74	9.56	5.90

Work in progress in my lab…

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)	
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

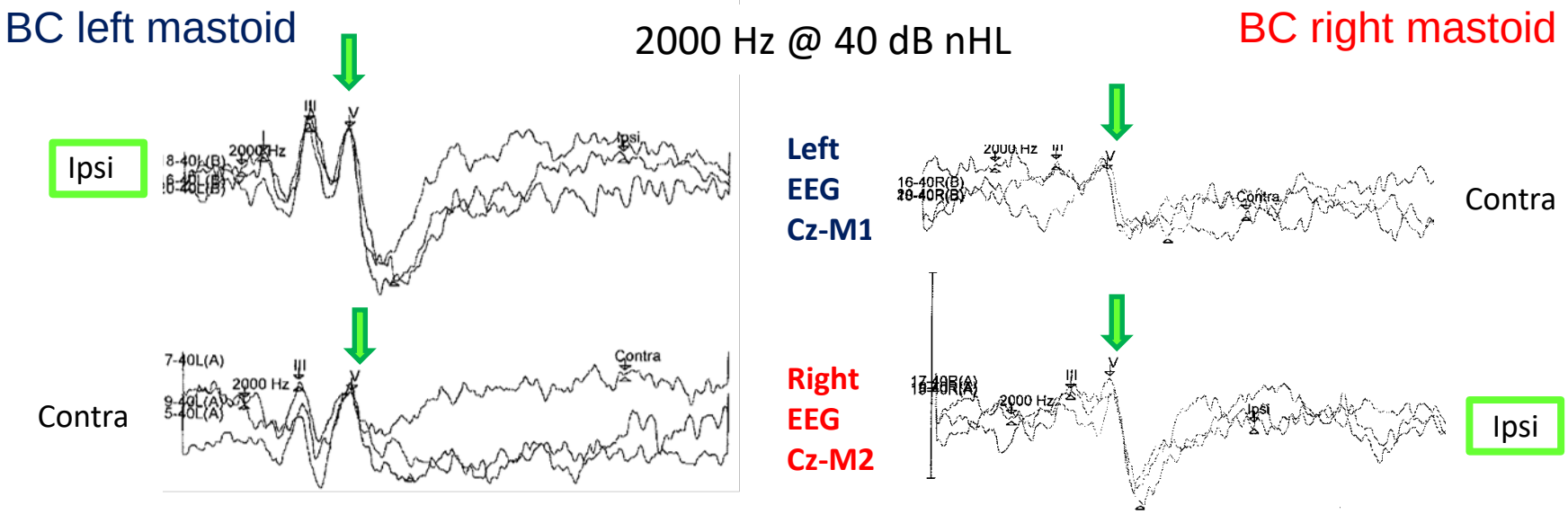
- **ABR– negative wave at ~ 3 ms at 95 & 110 dB nHL due to activation of the vestibular system– not auditory in nature but easy to identify in the waveform (Stapells, 2011)**
- **ASSRs can also be elicited from vestibular sources– cannot be differentiated from auditory responses – no time domain waveform 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]

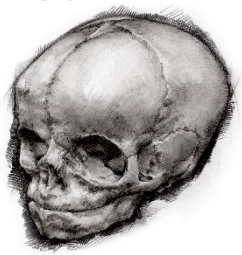


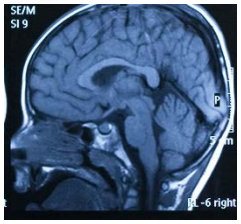
Amplitude: contra *smaller than* ipsi **Latency**: contra *later than* ipsi

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

[these data are currently being collected in my lab (Lau, M.Sc. thesis)]

- **We have 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
	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)

Threshold: Clinical Implications/Future Research

AC ABRs

Brief tones
well established

✓

NB CE-Chirps
- Need studies with large sample size and range of ages and types of hearing loss
-- verify benefit for more severe losses
-- establish eHL corrections

?

BC ABRs

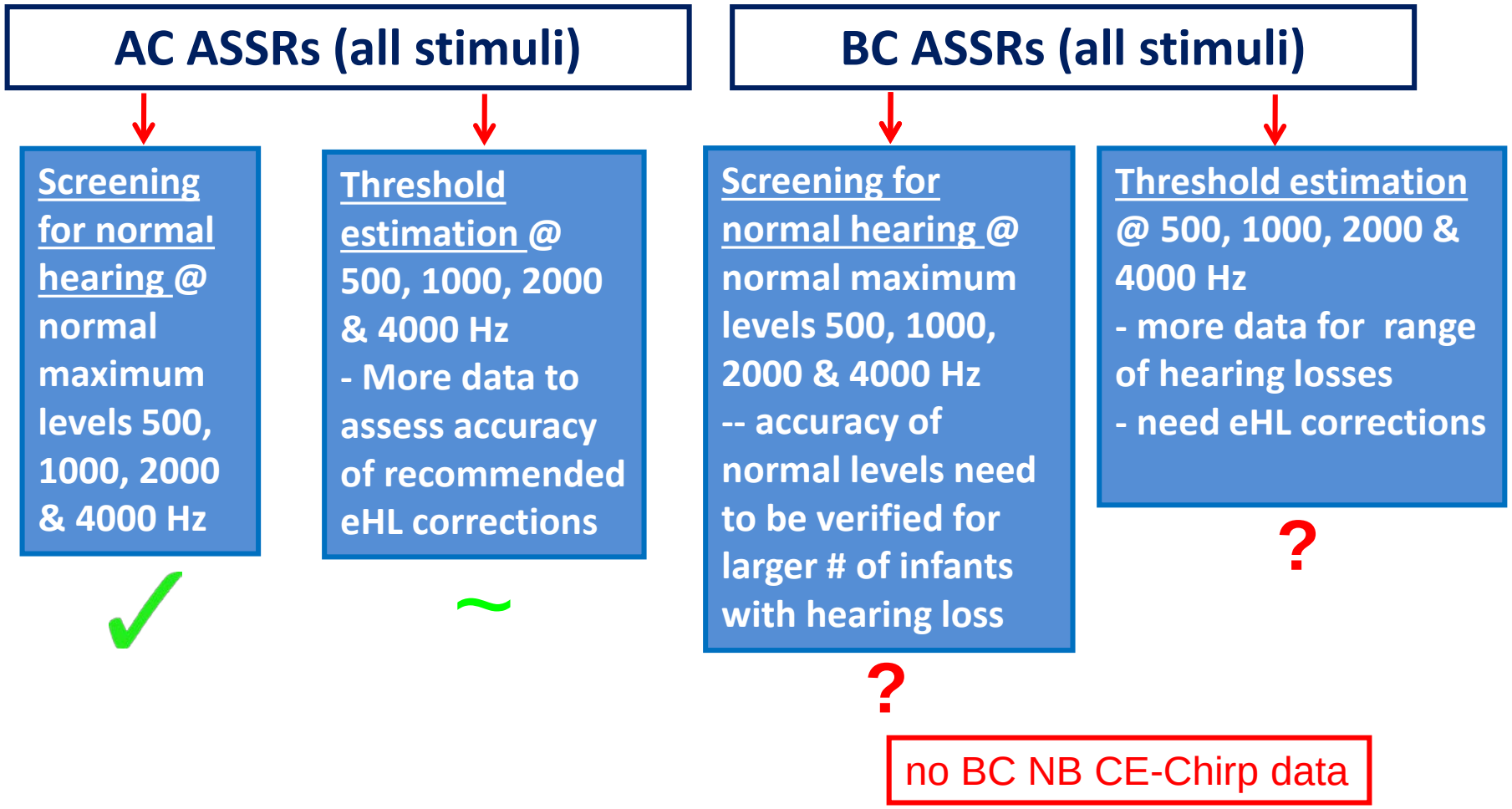
Brief tones
- normal levels well established @ 500 & 2000 Hz
- need eHL correction factors
- need EMLs

~ ✓

NB CE-Chirps
- Need studies with large sample size and range of ages and types of hearing loss
-- verify benefit for more severe losses
-- establish eHL corrections

?

Threshold: Clinical Implications/Future Research



More Future Research needed

BC ASSRs

↓

** more work needed on isolation of test ear

Simultaneous AC & BC ASSRs

↓

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

Questions?