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Auditory brainstem responses (ABR) to brief-tone bone-conducted (BC) stimuli

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Associate Professor
Hamber Professor of Clinical Audiology
University of British Columba
AudiologyOnline, June 15, 2016

NSERC CRSNG

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TOPIC AREAS TO BE ADDRESSED

BC ABR to brief-tones -- preamble

Overview of methodology

Estimation of infant hearing thresholds

Isolation of test cochlea

Case Study

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LEARNING OUTCOMES

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

1) Explain how to set-up clinical equipment to conduct brief-tone bone-conduction auditory brainstem testing in infants

2) Estimate bone-conduction hearing thresholds in infants with normal hearing and hearing loss using bone-conduction auditory brainstem testing

3) Explain how to isolate the test cochlea using brief-tone bone-conduction auditory brainstem testing

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BC ABR to brief tones-- preamble

Clinical goal for BC testing?

Accurate estimation of BC thresholds to determine type of hearing loss responsible for elevated air-conduction (AC) thresholds

Conductive? **Sensorineural?** **Mixed?**
- How much is conductive?

- **Standard practice for pure-tone audiometry**
- **Should be standard practice for infant ABR testing**

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Very Brief History of BC ABR testing:

- **In the late 1970s and 1980s, BC ABR research emerged (brief tones and clicks) – some technical issues arose but research continued**

Examples of early studies:

- ❖ **Mauldin & Jerger (1979) found that adult wave V latencies to BC clicks were longer than AC clicks**
- ❖ **Boezeman et al. (1983) found the same for 2000-Hz brief tones**
- ❖ **Cornacchia et al. (1983) compared AC & BC ABR wave V latencies in infants & adults; found that infant wave V latencies to BC stimuli were prolonged relative to adults**

-- Differences in AC vs BC ABR results and maturational effects emerging in ABR research

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Examples of early studies that focussed on clinical use of brief-tone BC ABR testing in infants:

Clicks:

- ❖ **Yang et al. (1987), Stuart et al. (1993, 1994), Gorga et al. (1993)**

Brief-tones:

- ❖ **Gravel et al. (1989), Stapells (1989), Stapells & Ruben (1989), Cone-Wesson (1995), Cone-Wesson & Ramirez (1997), Foxe & Stapells (1993) & Nousak & Stapells (1992); Sininger et al. (1997)**

Examples of more recent infant brief-tone BC ABR research:

- ❖ **Ferm et al. (2014), Hatton et al. (2012), Vander Werff et al. (2009), & Valeriote & Small (2015)**

(i) feasible to record brief-tone BC ABRs clinically

(ii) frequency- and mode- (AC vs BC) dependent infant-adult differences to be accounted for in their interpretation

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Joint Committee on Infant Hearing (2007)

"The audiological assessment should include:

… A frequency-specific assessment of the ABR using air-conducted tone bursts and bone-conducted tone bursts when indicated. When permanent hearing loss is detected, frequency-specific ABR testing is needed to determine the degree and configuration of hearing loss in each ear for fitting of amplification devices."

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Overview of methodology

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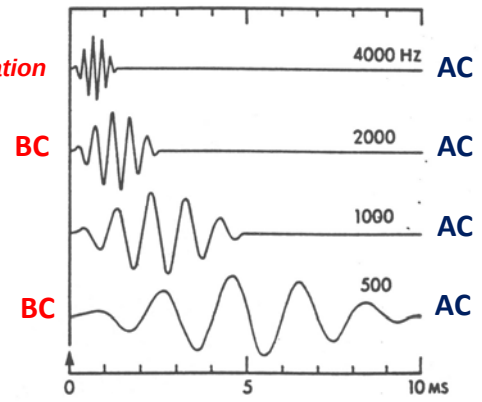
Under investigation

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



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Air- and bone-conduction brief tones
Stimulus parameters

"2-1-2" (cycles) linearly-gated tones; 5-cycle Blackman tones (no plateau)

500 Hz:	**AC/BC**	**4 ms rise/fall, 2 ms plateau; 10 ms**
1000 Hz:	**AC/BC**	**2 ms rise/fall, 1 ms plateau; 5 ms**
2000 Hz:	**AC/BC**	**1 ms rise/fall, 0.5 ms plateau; 2.5 ms**
4000 Hz:	**AC**	**0.5 ms rise/fall, 0.25 ms plateau; 1.25 ms**
	*** BC**	**1 ms rise/fall, 0.25 ms plateau, 2.25 ms**

**** to reduce ringing***

(Small & Stapells, 2003)

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Calibration

Supra-aural TDH49/ER3-A insert earphones/B71 transducer

UNITS: dB peak (peak hold) minus 3 dB = dB ppe x

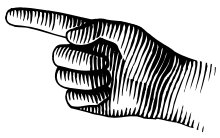
AC: dB ppe SPL ***BC: dB ppe re: 1 µN***

Acoustic calibration for 0 dB nHL											
500 Hz			1000 Hz			2000 Hz			4000 Hz		
AC TDH 49	AC ER3-A	BC	AC TDH 49	AC ER3-A	BC	AC TDH 49	AC ER3-A	BC	AC TDH 49	AC ER3-A	BC
25	**22**	**67**	**23**	**25**	**54**	**26**	**20**	**49**	**29**	**26**	**46**

(Small & Stapells, 2003)

ASSR: Bone oscillator coupling method in infants

- **Small et al. (2007) compared infant ASSR & adult behavioural thresholds obtained with elastic headband and hand-held coupling method (for trained individuals)**



hand-held

Elastic head band

➢ **No significant differences 500-4000 Hz**

Caveat: used trained individuals for both methods
-- We do not recommend that a parent couple the bone oscillator to their child's skull

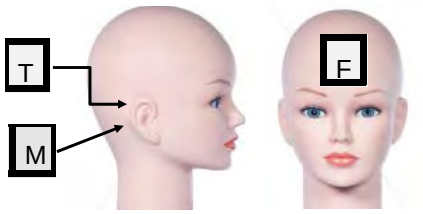
➢ **BC EHP: clinicians use hand-held method**
– least likely to wake up infant

CONTINUED

ASSRs: Bone oscillator placement

- Small et al. (2007) compared infant ASSR thresholds at different positions on the skull

No difference for T versus M position



Significantly poorer for F versus T or M position

- BC EHP: clinicians use the T position method
  - greatest range of intensities available
  - easier to maintain firm consistent placement than M position

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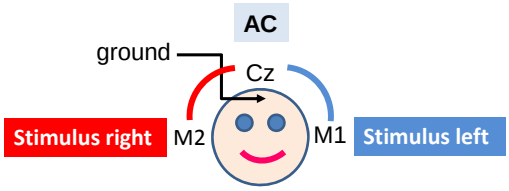
EEG recording parameters



AC: 1-channel recording

- ***Consider two-channel AC recordings if large asymmetry between ears***

Adapted from Stapells & Oates (1997)

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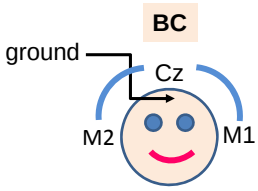
EEG recording parameters



BC: 2-channel recording

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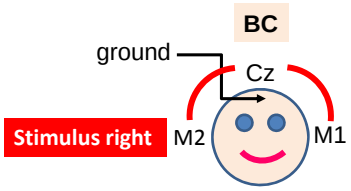
EEG recording parameters



BC: 2-channel recording

➢ ***Always use two-channel BC recordings***

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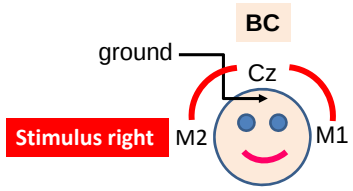
EEG recording parameters



BC: 2-channel recording

EEG filter:	High Pass: 20-30 Hz Low Pass: 1500-3000 Hz (Slope: 6 or 12 dB/octave, analog)
Artifact reject:	Trials exceeding ± 25 µV (equals Nicolet "50 µV") *-- can reduce this to optimize recording (balance with rejection rate)*
# of trials:	Typically 2000 per average
# of sweeps:	Two or more as needed to obtain good signal-to-noise ratio
Display Scale:	Avoid too large a scale close to threshold

Adapted from Stapells & Oates (1997)

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Air- and bone-conduction brief tones
Setting latency window for signal-to-noise ratio (SNR) & residual noise (RN)

	500 Hz	1000 Hz	2000 Hz	4000 Hz
	AC & BC	AC & BC	AC & BC	AC & BC
Start*	10.5	7	6.5	5
End	20.5	17	16.5	15

*Note: should shift 10 ms window later for higher presentation levels to avoid stimulus artifact

500 Hz BC stimuli > 30 dB re: 1 µN → 14 – 24 ms

(BCEHP, 2012)

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Interpretation of waveforms

✓ **Response present:**
- ✓ **SNR >1**
- ✓ **Wave V visually replicates**

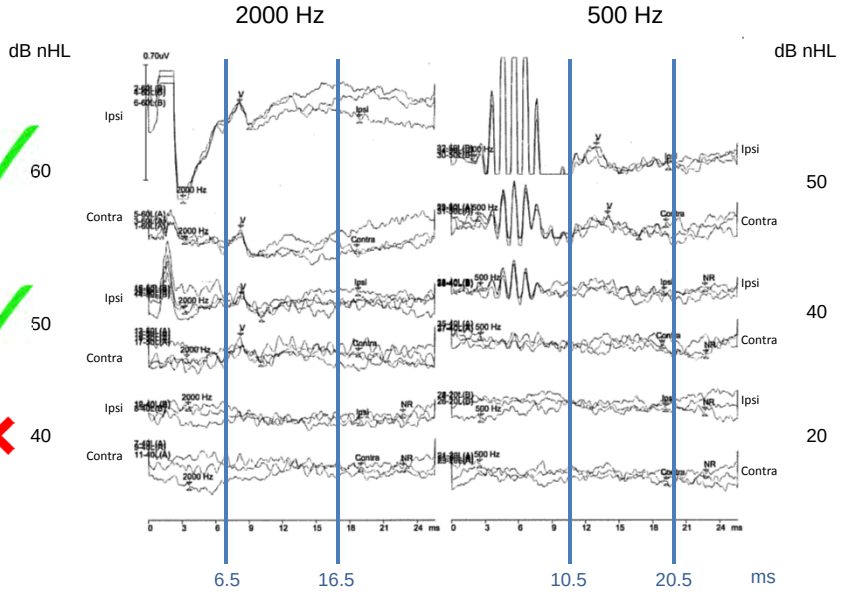
✗ **Response absent:**
- **SNR <<1**
- **Visually flat**
- **RN < 0.05-0.08 µV**

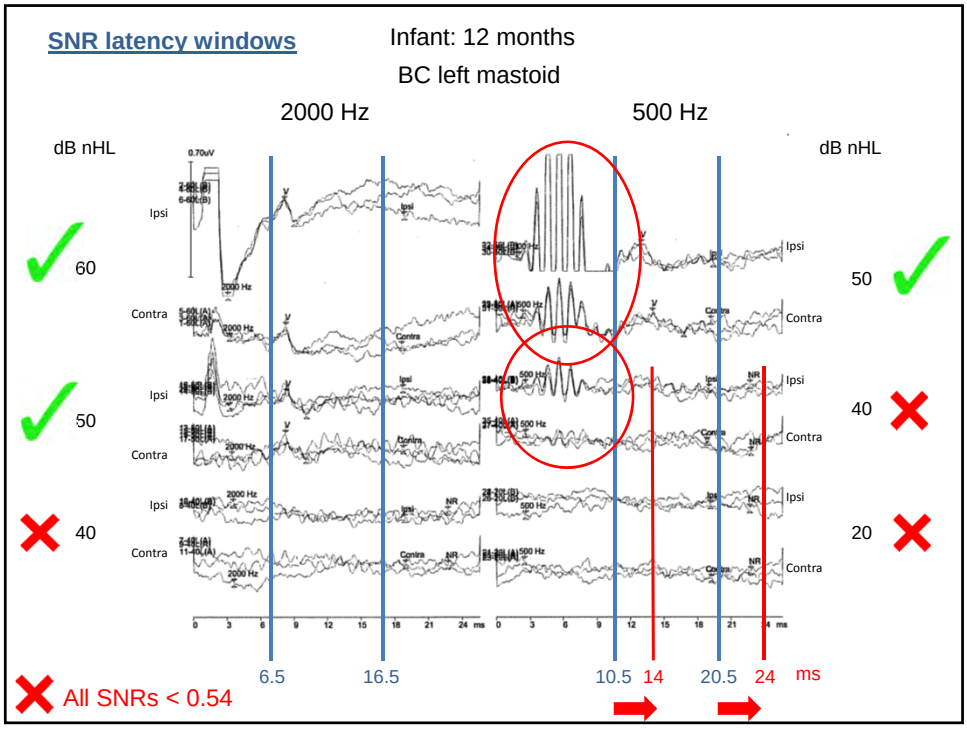
? **Cannot evaluate:**
- **SNR <<1**
- **RN > 0.08 µV**
- **No repeatable peaks**
- **Not visually flat**

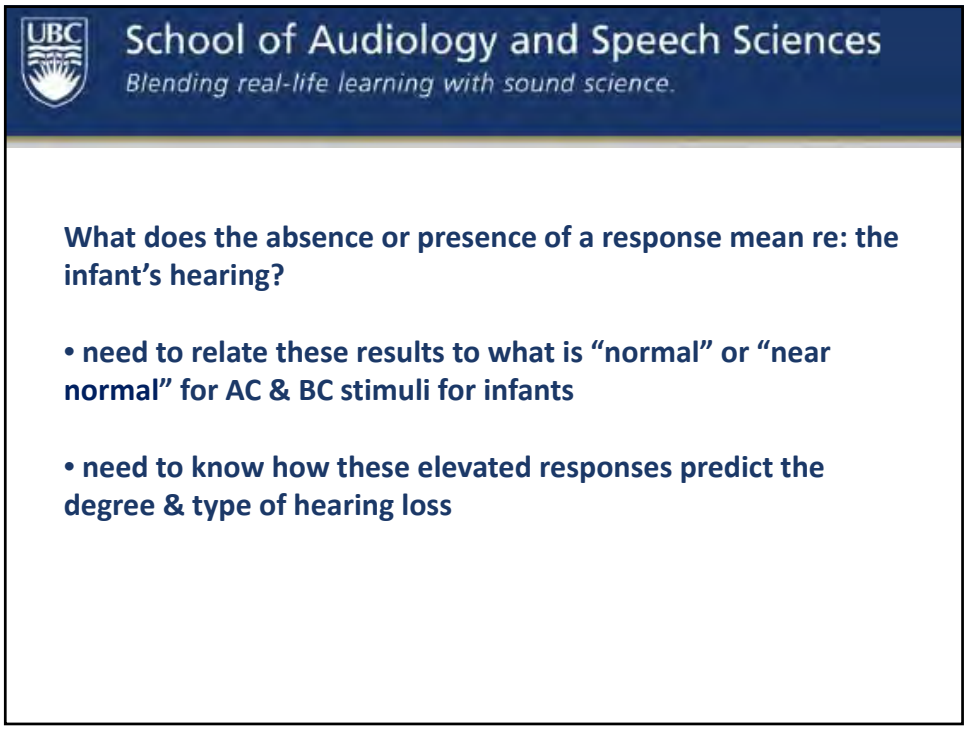
(BCEHP, 2012)

SNR latency windows

Infant: 12 months
BC left mastoid




SNR latency windows
Infant: 12 months
BC left mastoid
2000 Hz
500 Hz
dB nHL
dB nHL
60
50
40
50
40
20
Ipsi
Contra
6.5
16.5
10.5
14
20.5
24
ms
All SNRs < 0.54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What does the absence or presence of a response mean re: the infant's hearing?
• need to relate these results to what is "normal" or "near normal" for AC & BC stimuli for infants
• need to know how these elevated responses predict the degree & type of hearing loss

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Definition of terms (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 max**

***eHL correction*:**

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

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

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

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)

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Estimation of infant hearing thresholds

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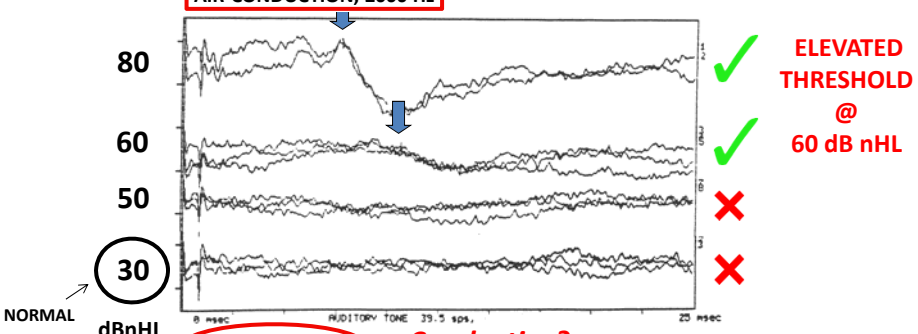
BABY X

AIR-CONDUCTION, 2000 Hz



ELEVATED THRESHOLD @ 60 dB nHL

Flat tympanogram
Absent OAE

Conductive?

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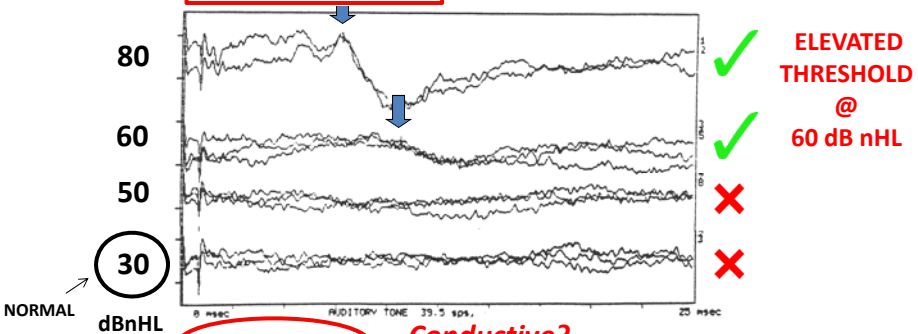
BABY X

AIR-CONDUCTION, 2000 Hz



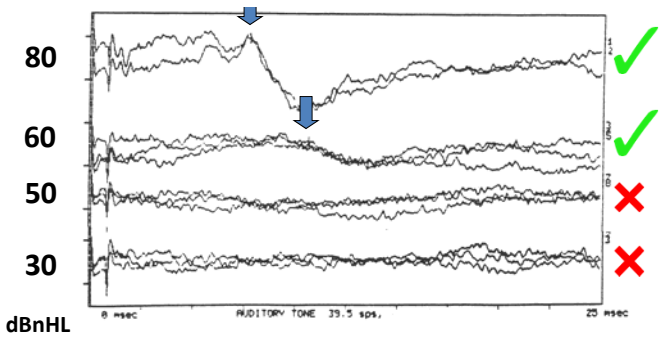
ELEVATED THRESHOLD @ 60 dB nHL

Flat tympanogram
Absent OAE

Conductive?
Could be sensorineural or mixed!
Need BC ABR testing to be sure!

BABY X

AIR-CONDUCTION @ 2000 Hz

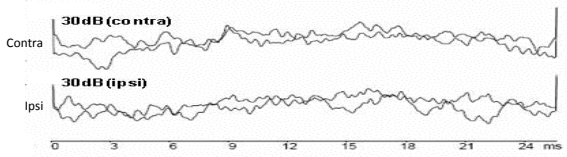


ELEVATED THRESHOLD @ 60 dB nHL

Flat tympanogram
Absent OAE

BONE-CONDUCTION @ 2000 Hz

2-channel BC @ 30 dB nHL



BC ABR ABSENT @ 30 dB nHL

➢ **sensorineural (or mixed) hearing loss**

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- **If audiologist conducts only AC ABR testing and tympanometry & otoacoustic emmissions (OAEs) to identify a conductive component**
  - ➢ ***May lead to error***
- **Tympanometry in very young infants:**
  - **may fail to identify middle-ear involvement**
  - **flat tympanogram does not assess amount of hearing loss attributed to the conductive component**
- **OAEs:**
  - **sensitive to middle-ear involvement but only helpful if present**

Only *BC thresholds* can distinguish between sensorineural, conductive and mixed losses
AND
determine magnitude of conductive loss

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How well do BC ABR results predict the nature of the hearing loss (conductive versus sensorineural loss?)

Data collected from BC EHP diagnostic follow up:

	Nature of loss is certain	All data (includes cases where assumptions made)
500 Hz	91.9% (65 cases)	81.2% (126 cases)
2000 Hz	94.2% (37 cases)	93.7% (49 cases)

(Hatton, Janssen & Stapells, 2012)

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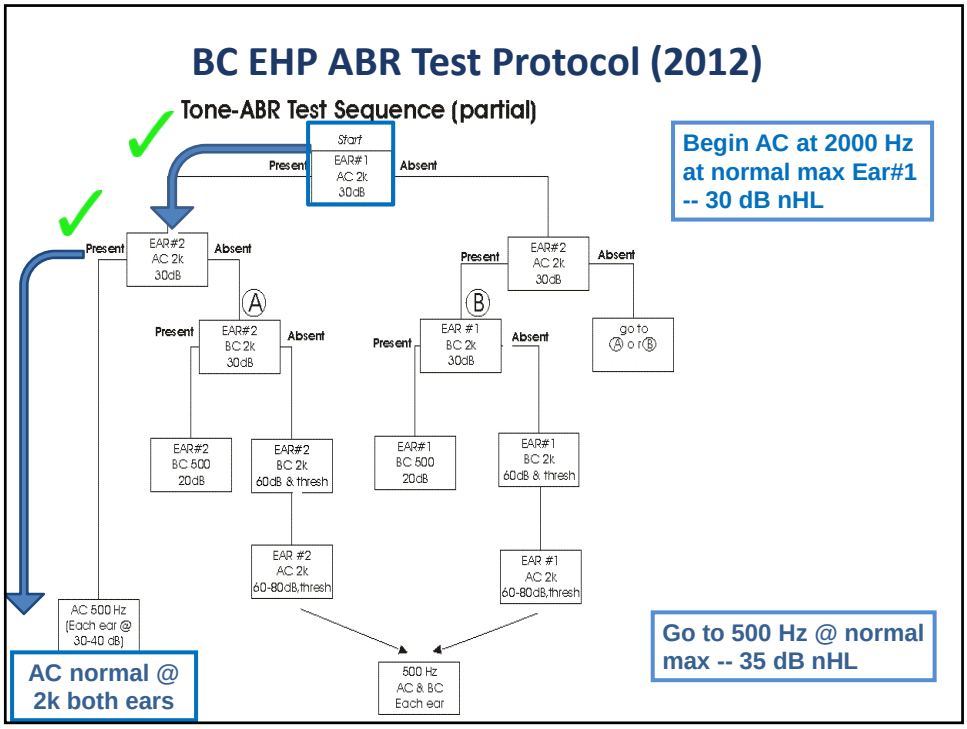
Where does BC ABR testing fit in the diagnostic protocol?

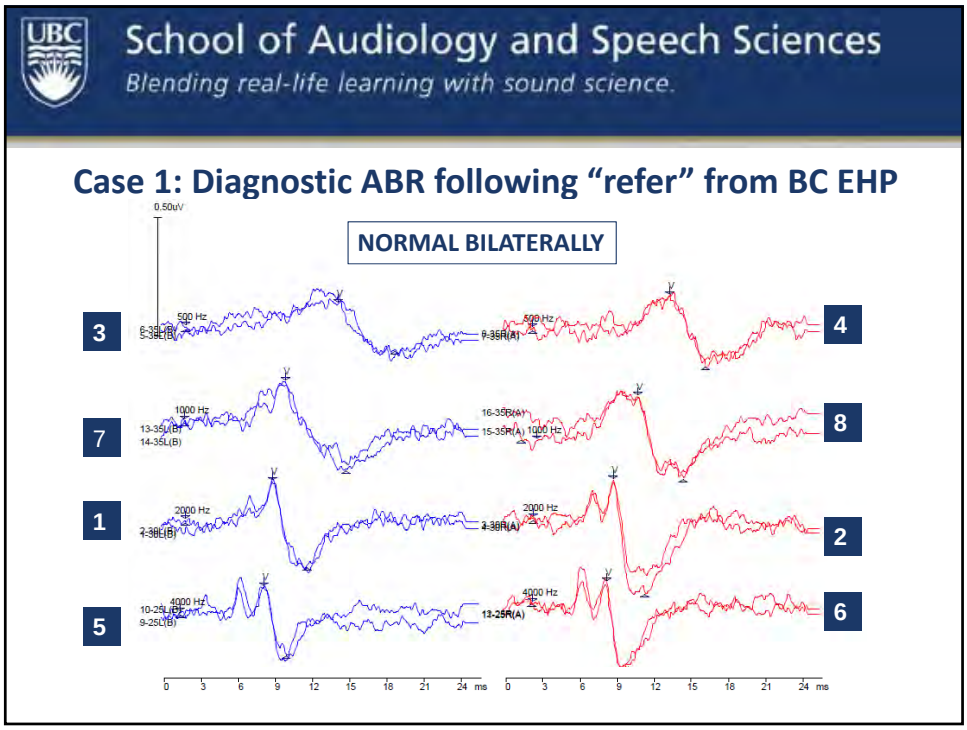
- ❑ After AC thresholds are established for both ears?
- ❑ After AC threshold search, tympanometry & OAEs?
- ❑ Before AC testing?
- ☑ As soon as AC thresholds are determined to be elevated?

➢ **Want BC ABR thresholds <u>early</u> in diagnostic testing to avoid delays in medical follow-up or intervention**

✓ **BC testing occurs after AC thresholds are shown to be elevated in at least one ear at 2000 Hz (> normal max) -- *before AC threshold search***

BCEHP, 2012


BC EHP ABR Test Protocol (2012)
Tone-ABR Test Sequence (partial)
Start
EAR#1 AC 2k 30dB
Present
Absent
EAR#2 AC 2k 30dB
EAR#2 BC 2k 30dB
EAR#2 BC 500 20dB
EAR#2 BC 2k 60dB & thresh
EAR #2 AC 2k 60-80dB,thresh
EAR #1 BC 2k 30dB
EAR#1 BC 500 20dB
EAR#1 BC 2k 60dB & thresh
EAR #1 AC 2k 60-80dB,thresh
go to A or B
AC 500 Hz (Each ear @ 30-40 dB)
500 Hz AC & BC Each ear
Begin AC at 2000 Hz at normal max Ear#1 -- 30 dB nHL
AC normal @ 2k both ears
Go to 500 Hz @ normal max -- 35 dB nHL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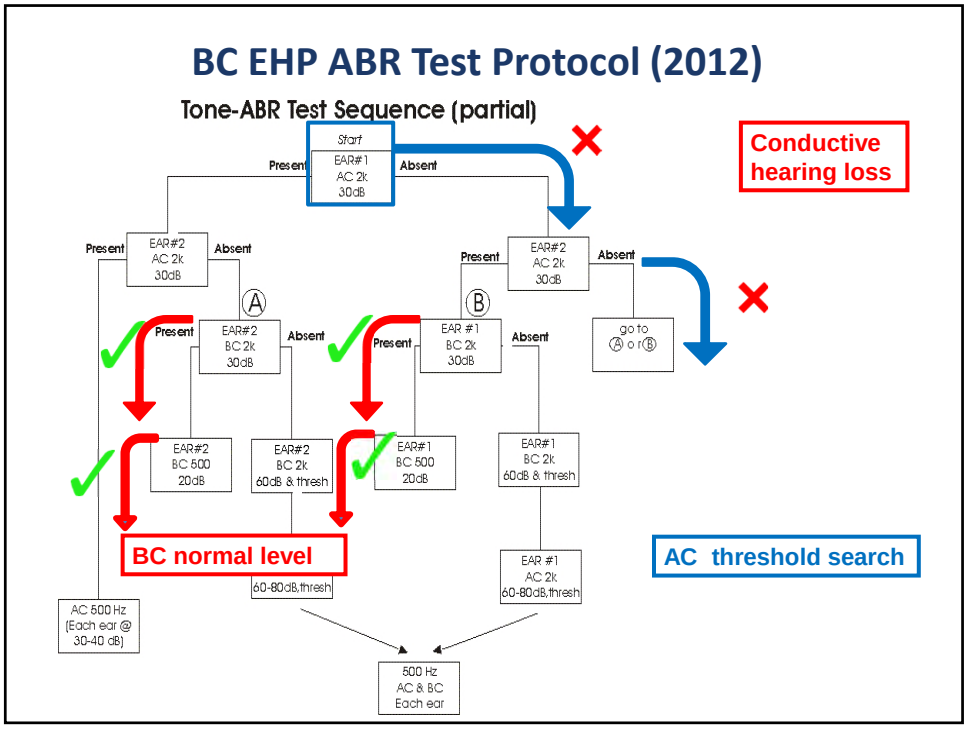
Case 1: Diagnostic ABR following "refer" from BC EHP
NORMAL BILATERALLY
3
4
7
8
1
2
5
6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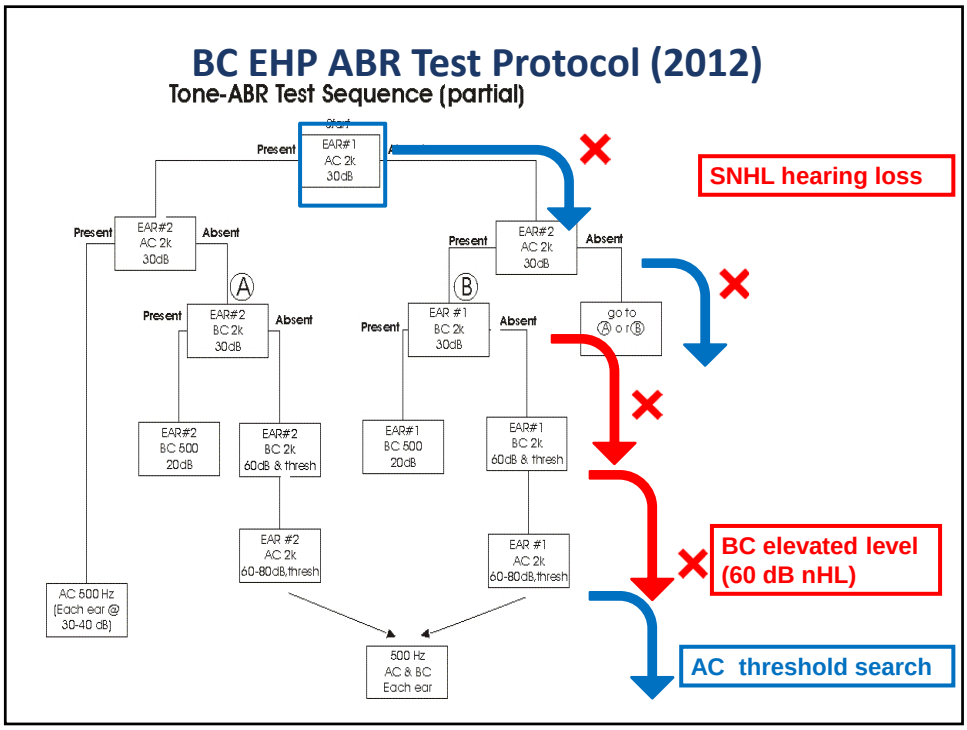
Absent
EAR#2 AC 2k 30dB
EAR#2 BC 2k 30dB
EAR#2 BC 500 20dB
EAR#2 BC 2k 60dB & thresh
EAR #2 AC 2k 60-80dB,thresh
AC 500 Hz (Each ear @ 30-40 dB)
EAR #1 BC 2k 30dB
EAR#1 BC 500 20dB
EAR#1 BC 2k 60dB & thresh
EAR #1 AC 2k 60-80dB,thresh
go to Ⓐ or Ⓑ
500 Hz AC & BC Each ear
Conductive hearing loss
BC normal level
AC threshold search


BC EHP ABR Test Protocol (2012)
Tone-ABR Test Sequence (partial)
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Present
Absent
EAR#2 AC 2k 30dB
EAR#2 BC 2k 30dB
EAR#2 BC 500 20dB
EAR#2 BC 2k 60dB & thresh
EAR #2 AC 2k 60-80dB,thresh
AC 500 Hz (Each ear @ 30-40 dB)
EAR #1 BC 2k 30dB
EAR#1 BC 500 20dB
EAR#1 BC 2k 60dB & thresh
EAR #1 AC 2k 60-80dB,thresh
go to Ⓐ or Ⓑ
500 Hz AC & BC Each ear
SNHL hearing loss
BC elevated level (60 dB nHL)
AC threshold search

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Isolation of test cochlea

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BC ABR: Isolation of test cochlea

INFANTS

- **Clinical masking?**

-- IA for AC stimuli are not known

-- IA for BC have been approximated with indirect measures (ABR & ASSR data)

-- effective masking levels for BC not know for ABR (BC ASSR data available)

-- are corrections for occlusion effect needed? (BC ASSR data available)

ADULTS

- **Use masking to isolate test ear as needed**

- interaural attentuation (IA) & effective masking levels for AC & BC stimuli are well established

- corrections for occlusion effect are known

Interaural attenuation of BC stimuli – indirect measures

Study	Method	Indirect measure	Age	Interaural Attenuation (dB)
Yang & Stuart 1987	ABR clicks	Wave V latency	Adult	0-10
			Neonate	**25-35**
			12 months	**15-25**

Interaural attenuation of BC stimuli – indirect measures

Study	Method	Indirect measure	Age	Interaural Attenuation (dB)
Yang & Stuart 1987	ABR clicks	Wave V latency	Adult	0-10
			Neonate	**25-35**
			12 months	**15-25**
Small & Stapells 2008	ASSR- AM/FM 500-1000 Hz Fc	Ipsi/contra asymmetries	Adult	0-10
			0-6 months	**10-30**

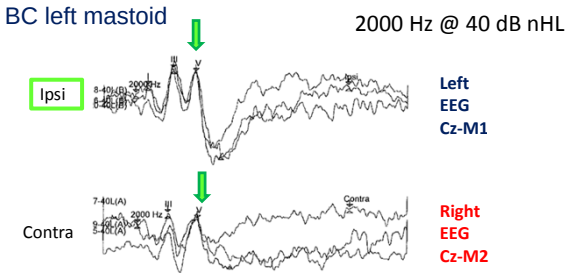
Interaural attenuation of BC stimuli – indirect measures

Study	Method	Indirect measure	Age	Interaural Attenuation (dB)
Yang et al 1987	ABR clicks	Wave V latency	Adult	0-10
			Neonate	**25-35**
			12 months	**15-25**
Small & Stapells 2008	ASSR- AM/FM 500-1000 Hz Fc	Ipsi/contra asymmetries	Adult	0-10
			0-6 months	**10-30**
Hansen 2010 (M.Sc. Thesis)	ASSR- AM/FM 1000 Hz	Effective masking levels (Binaural AC)	Adult	0
			0-7 months	**10-15**

- **Interaural attenuation for BC stimuli in infants is a minimum of 10-35 dB depending on the age**

Utilize ipsilateral/contralateral asymmetries?

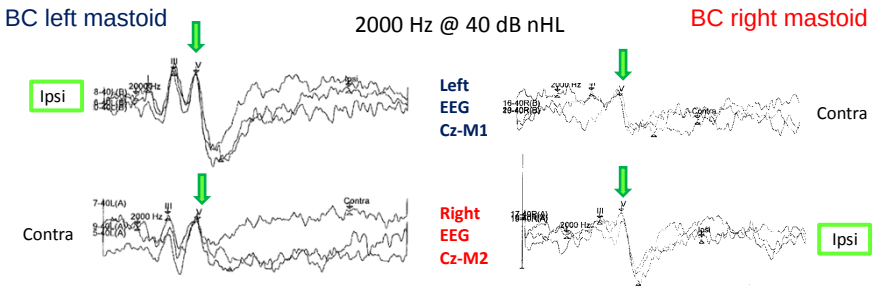
- Expected pattern for normal cochleae up to 102 years of age -- normal hearing or conductive loss (e.g., aural atresia)
  [e.g., Foxe & Stapells, 1993; Stapells & Ruben, 1989; Stapells & Mosseri, 1991]



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

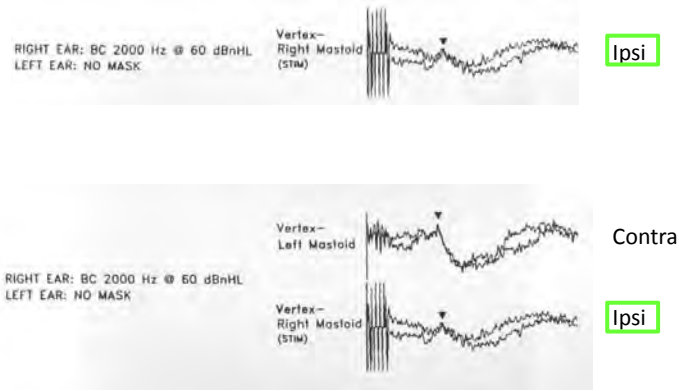
Utilize ipsilateral/contralateral asymmetries?

- Expected pattern for normal cochleae up to 102 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

Bone-conduction ABR



Contra >> IPSI

SEVERE UNILATERAL (RIGHT EAR) SNHL

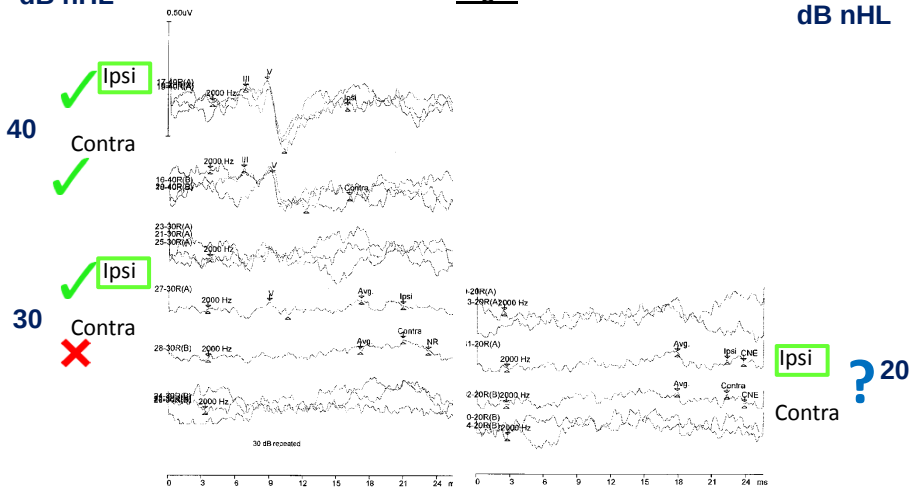
(Stapells, personal communication)

Ch A = right
Ch B = left

Case 2: 13 months – referred from NHS

2000 Hz BC Right Mastoid

dB nHL



dB nHL

30 & 40 dB nHL: Ipsi > contra

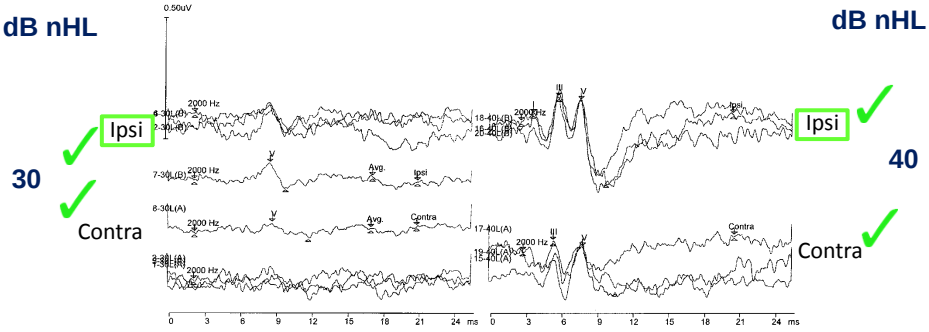
Which ear is responding? **Right ear!**

Ch A = right
Ch B = left

13 months – referred from NHS

2000 Hz BC Left Mastoid

dB nHL



dB nHL

Which ear is responding? **Left ear!**

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Factors contributing to ipsi/contra asymmetries?

1. Greater IA compared to adults due to unfused cranial sutures

2. Infant-adult differences in positioning of neural generators

Evidence: infant AC ABR/ASSRs show consistent ipsi/contra asymmetries; adult AC ABR/ASSRs do not show these patterns
(Reviewed in Small & Stapells, 2017)

➢ **Two-channel recordings are routinely used by our provincial program (BCEHP) for BC brief-tone ABRs**

***NOTE**: Can also use ipsi and contra EEG channel for AC if a large difference in thresholds between ears exists (and contra masking not used)*

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What if ipsi/contra asymmetries in BC ABRs are ambiguous?

➢ **Need clinical masking**

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

➢ **What do we know about EMLs for BC auditory evoked potentials?**

-- EMLs for infant BC ASSR stimuli were estimated for 500-4000 Hz using binaural AC masking (Hansen & Small, 2012; Small, Smyth & Leon, 2014)

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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)

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Is there an occlusion effect (OE) in infants?

- **Adults with normal hearing or a sensorineural hearing loss: occluding the ear canal results in a significant improvement in pure-tone BC thresholds**
- **Do we need to correct for an OE in infants when we obtain BC thresholds with earphones in place?**

We investigated this phenomenon in infants (2 studies):

(i) Small, Hatton & Stapells, 2007
- ***no occlusion effect for BC ASSR thresholds 500-4000 Hz***

(ii) Small & Hu, 2011
- ***Sound pressure ⬆ in ear canal when occluded: infants >> adults***
- ***% occurrence of OE:***
  - **Older infants: OE emerging at 500 & 1000 Hz**
  - **Young infants: OE absent at 1000 Hz (very small at 500 Hz)**

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Earphones in or out during BC testing?

- **Recommendations (conservative):**
  (i) Young infants: leave earphones in place
  (ii) Older infants: remove earphones

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Case Study

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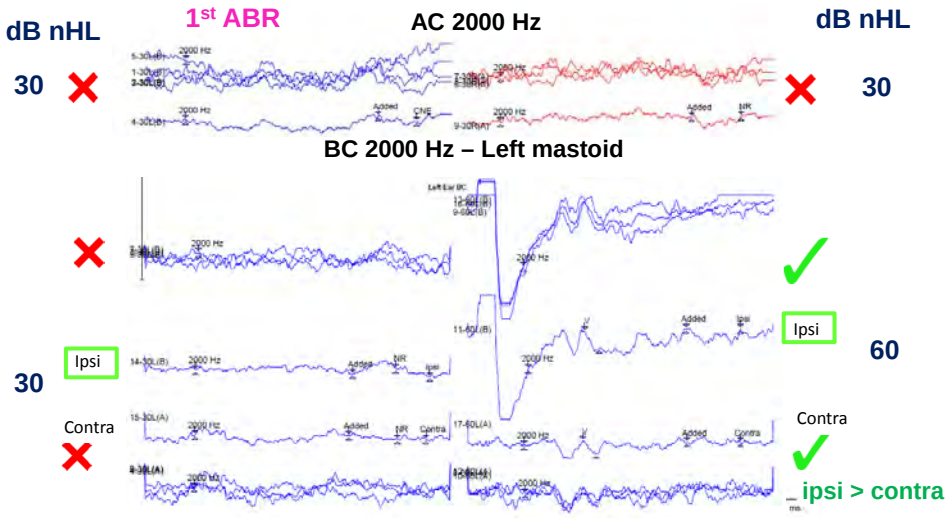
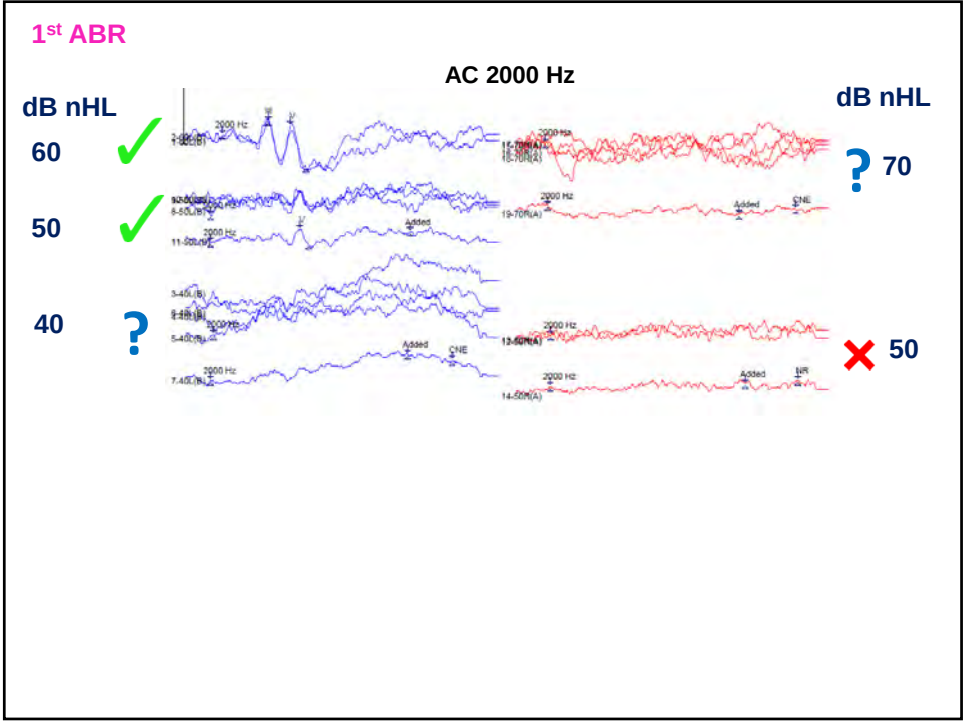
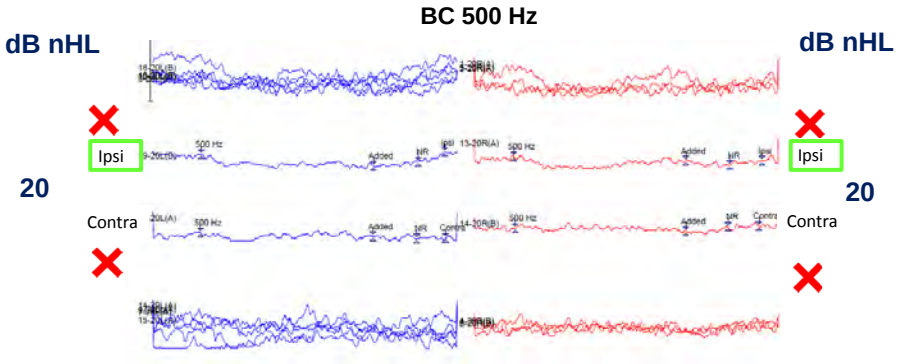
Case 2: Diagnostic ABR following "refer" from BC EHP

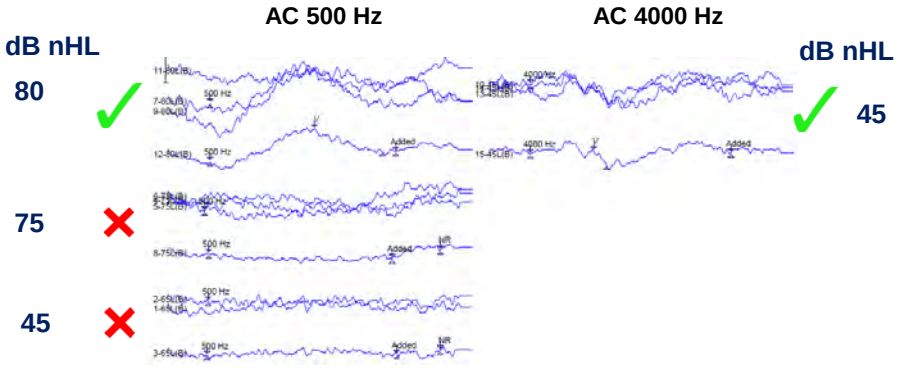




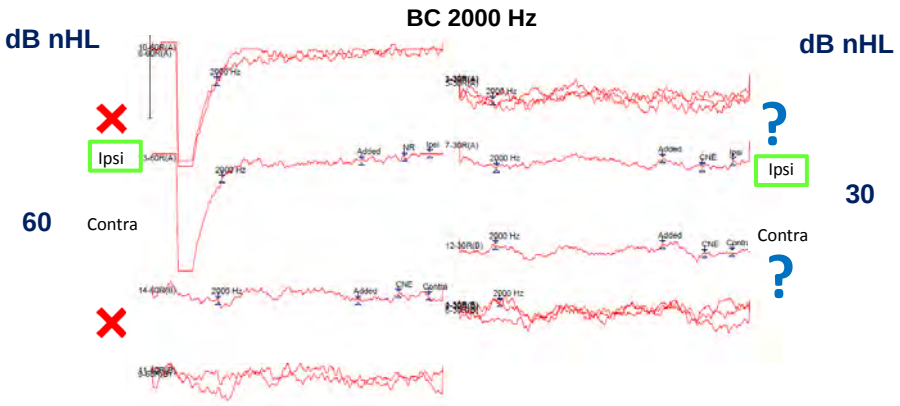
1st ABR



1st ABR



1st ABR

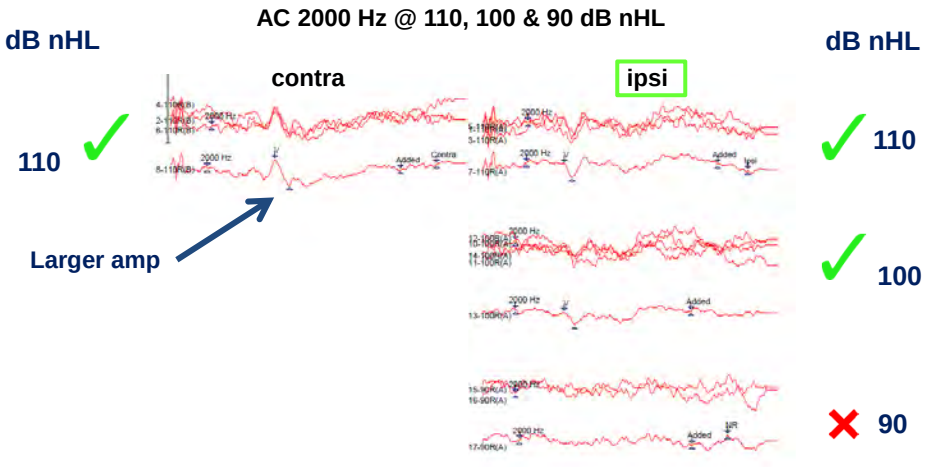


What we know so far: Elevated AC & BC both ears

- LEFT: severe SNHL at 500 Hz (threshold @ 80 dB nHL) rising to no worse than mild/moderate SNHL at 2000 & 4000 Hz
- RIGHT: at least a moderate SNHL at 2000 Hz

- need further ABR testing to fill in gaps – summarized in table on next slide

3rd ABR



Stimulus	ABR (dB nHL)		Estimated Behavioural Threshold (dB eHL)	
	RIGHT	LEFT	RIGHT	LEFT
AC – 500 Hz	> 100	80	> 110	70
BC – 500 Hz	> 20	> 20	> 25	>25
AC – 1000 Hz	> 100	≤ 55	> 110	≤ 45
AC – 2000 Hz	> 100	40	> 105	35
BC – 2000 Hz	> 60	35-60	> 65	30-55
AC – 4000 Hz	> 90	25	> 90	25

+ ipsi/contra asymmetries (BC & AC) support left ear responding

- **1st appointment: BC ABR established nature & severity of loss L & R**
- **2nd and 3rd appointment completed AC ABR testing:**
  - **-- L: thresholds at 500, 1000, 2000 & 4000 Hz**
  - **-- R: established profound loss**
- ***MRI/CT: confirmed absence of cochlear nerve on the R (click ABR– no clear signs of ANSD)***

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Thoughts?

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Thank you!