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Improving EHDI with CAEPs:

Clinical Assessment of the Cortical Auditory Evoked Potential in Children with Hearing Loss

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Disclosure

The HEARLab system was donated to Hearts for Hearing by Frye Electronics as part of an ongoing research project.

Learner Outcomes

As a result of this course, participants will be able to…

- List characteristics of a CAEP: P1-N1-P2 complex.
- Identify at least three populations for whom CAEP testing can assist in developing a plan of care.
- Make clinical management suggestions based on presence or absence of CAEPs

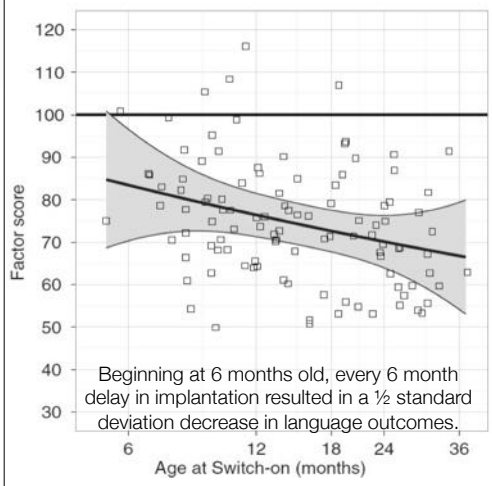
Agenda

- Early Hearing Detection and Intervention (EHDI)
- Cortical auditory evoked potentials (CAEPs)
  - Overview of the P_1-N_1-P_2 complex
  - Obtaining the measurement
  - Interpreting the measurement and developing a plan
  - Current literature regarding reliability
- Using CAEPs to make intervention recommendations
- Case studies from Hearts for Hearing

Early Hearing Detection and Intervention (EHDI)

Outcomes of Early- and Late-Identified Children at 3 Years of Age: Findings From a Prospective Population-Based Study

Teresa Y. C. Ching,[1,2] Harvey Dillon,[1,2] Vivienne Marnane,[1,2] Sanna Hou,[1,2] Julia Day,[1,2] Mark Seeto,[1,2] Kathryn Crowe,[1,2] Laura Street,[1,2] Jessica Thomson,[1,2] Patricia Van Buynder,[1,2] Vicky Zhang,[1,2] Angela Wong,[1,2] Lauren Burns,[1,2] Christopher Flynn,[1,2] Linda Cupples,[4] Robert S. C. Cowan,[3] Greg Leigh,[1,2] Jessica Sjahalam-King,[1,2] and Angel Yeh[1,2]



LOCHI Study; Ching et al., 2013

The "Black Hole" in Pediatric Audiology

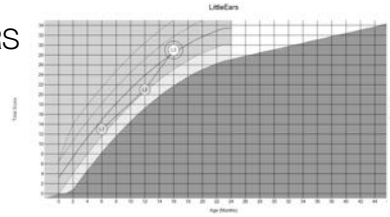
- ABR
- Hearing Aid Fitting

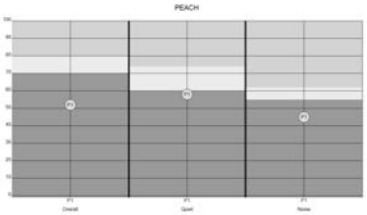
- Reliable Behavioral Audiometry

0-3 Months	4-7 Months	8-9 Months

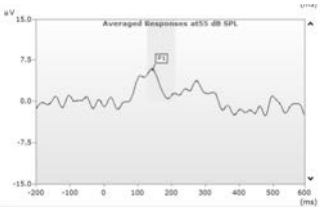
Filling the "Black Hole"

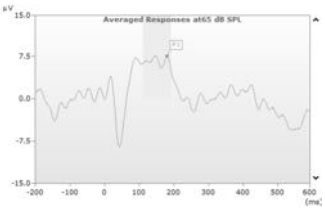
- Reports from Parents and Auditory Verbal Therapist
- Assessments of Functional Auditory Performance
  - LittlEARS
  - PEACH





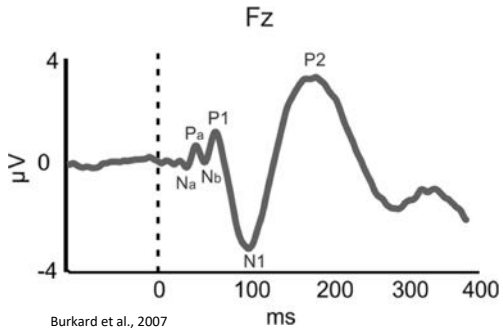
- Cortical Auditory Evoked Potentials (CAEPs): P_1-N_1-P_2 complex





CAEPs: P_1-N_1-P_2 Complex

- Complex can be elicited via click, tone burst, or speech stimuli
- Response occurs at 50-300 ms post-stimulus onset
- P_1 is generated by the primary auditory cortex
- P_1 is robust in children and N_1 and P_2 will develop at approximately seven years old



Burkard et al., 2007

Advantages of Speech-Evoked CAEPs

- Acoustics of speech stimuli are similar to the sounds the child will hear in daily life and are handled well by hearing aid signal processing
- CAEPs evaluate the integrity of the auditory pathway to the level of the auditory cortex; assesses detection, not discrimination
- CAEPs can be present in some children with auditory neuropathy spectrum disorder (ANSD)
- CAEPs can be recorded in awake infants when signals are presented at suprathreshold levels; responses are patient state dependent and "can be modified by auditory training."

Burkard et al., 2007, Punch et al., 2015

Advantages of Speech-Evoked CAEPs

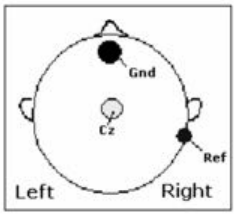
- Clinician
  - Provides additional information regarding auditory function
  - Identifies fittings that may need adjustments
  - Assists in the determination of optimal intervention
    - Hearing aid
    - Frequency-lower technology
    - Cochlear implant
- Family
  - Present aided CAEP provides reassurance that the child has access with current technology
  - Absent CAEP reinforces the need for consistent device use or the need to discuss further intervention

Australian Hearing 2014, 2016

Why aren't CAEPs routinely used in the clinic?

- Previously, CAEP measurements for research studies were completed with expensive, multi-channel equipment
- Clinicians may not feel comfortable analyzing CAEP waveforms
  - Morphology and latency of the waveform changes as a function of age and auditory exposure
- Clinicians may not feel comfortable calibrating CAEP systems, particularly for soundfield assessment
- Clinicians may not have access to appropriate CAEP stimuli
  - Tonal signals may produce artifact when processed by digital hearing aids
  - Many clinicians do not have the resources to generate speech signals

Frye Electronics HEARLab System



- The **Gnd** (ground) electrode is to be attached on the forehead
- The **Ref** (reference) electrode is to be attached to the left or right mastoid
- The **Cz** (active) electrode is to be attached to the vertex position

HEARLab System Operator's Manual

Advantages of the HEARLab System

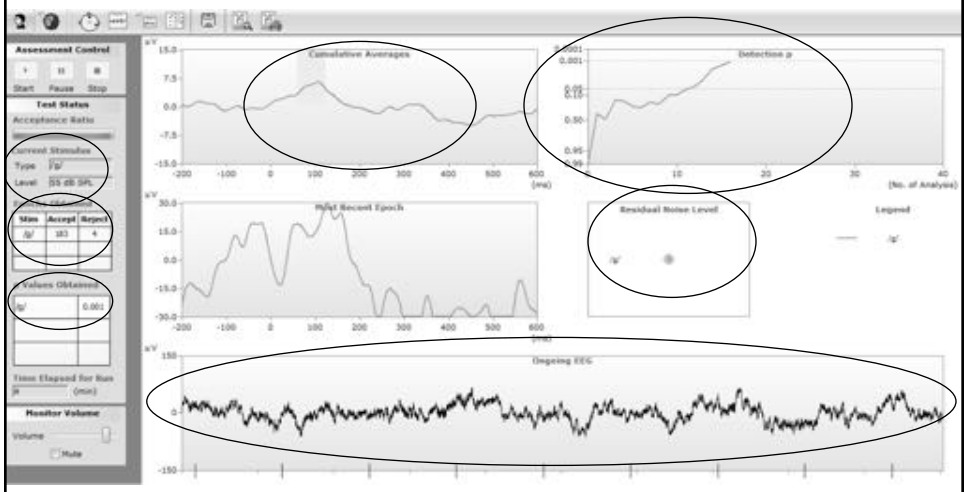
- Previously, CAEP measurements for research studies were completed with expensive, multi-channel equipment
- Clinicians may not feel comfortable analyzing CAEP waveforms
- Clinicians may not feel comfortable calibrating CAEP systems, particularly for soundfield assessment
- Clinicians may not have access to appropriate CAEP stimuli
- Allows for acquisition of CAEP with clinically-conducive single-channel recording
- Automatic response detection via statistical analysis and calculation of residual noise
- Simple procedure to calibrate stimuli for soundfield delivery
- Includes calibrated speech signals:
  - /m/ 500 Hz
  - /g/ 1250 Hz
  - /t/ 4000 Hz
  - /s/ 6-8000 Hz

Australian Hearing 2016

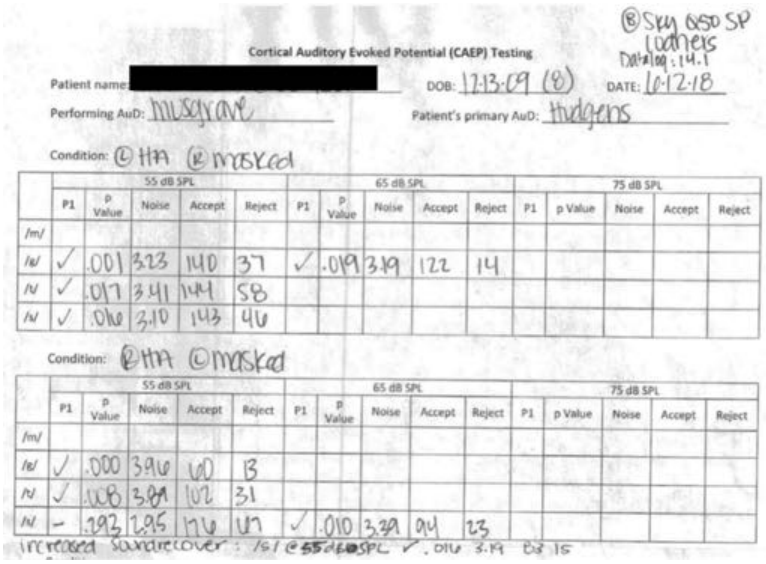
Prepping for CAEP Testing

Obtaining CAEPs

Interpreting CAEPs: P1



Interpreting CAEPs: P1



Cortical Auditory Evoked Potential (CAEP) Testing

Patient name: [redacted] DOB: 12-13-09 (8) DATE: 10-12-18

Performing AuD: Musgrave Patient's primary AuD: Hudgens

Condition: (L) HA (R) masked

	55 dB SPL					65 dB SPL					75 dB SPL				
	P1	p Value	Noise	Accept	Reject	P1	p Value	Noise	Accept	Reject	P1	p Value	Noise	Accept	Reject
/m/															
/ʃ/	✓	.001	3.23	140	37	✓	.019	3.19	122	14					
/v/	✓	.017	3.41	144	58										
/v/	✓	.016	3.10	143	46										

Condition: (R) HA (L) masked

	55 dB SPL					65 dB SPL					75 dB SPL				
	P1	p Value	Noise	Accept	Reject	P1	p Value	Noise	Accept	Reject	P1	p Value	Noise	Accept	Reject
/m/															
/ʃ/	✓	.000	3.96	60	13										
/v/	✓	.008	3.84	102	31										
/v/	–	.293	2.95	176	47	✓	.010	3.39	94	23					

increased sound cover: /s/ @ 55 dB SPL ✓ .016 3.19 63 15

Interpreting CAEPs and Developing a Plan

CAEP	Approximate Behavioral Threshold
Present at 55 dB SPL	No greater than mild hearing loss
Present at 65 dB SPL	Mild to moderate hearing loss
Present at 75 dB SPL	Moderate to severe hearing loss
Absent at 75 dB SPL	At least severe hearing loss

Australian Hearing 2016

Why might a CAEP be absent?

- High levels of noise in the recording
- Varying levels of alertness of the child
- Severe cases of auditory neuropathy spectrum disorder
- Future poor speech discrimination
- Cortex maturation
- Skull morphology and/or thickness of the cortical folds
- Stimulus is not audible
- Unknown reasons

Courtesy of Bram Van Dun

Chang et al., 2012 International Journal of Audiology

- Measured aided CAEPs
  - 18 infants with bilateral sensorineural HL
  - Mean age 6.7 months (SD 2.3)
- Estimated audibility was determined via VRA thresholds obtained at a later date
- Aided CAEPs were present in approximately 70% of infants with SNHL when the signal was presented at a positive sensation level

Van Dun et al., 2012 Audiology Research

- Measured aided CAEPs
  - 25 infants with sensorineural HL
  - Mean age 19 months (SD 8)
- Estimated audibility was determined via VRA thresholds obtained at a later date
- Aided CAEPs were present in approximately 80% of infants with SNHL when the signal was presented at a positive sensation level

Gardner-Berry et al., 2016 Seminars in Hearing

- Measured aided CAEPs
  - 29 infants with sensorineural HL
    - Mean age 6.6 months (SD 2.9)
  - 17 infants with auditory neuropathy
    - Mean age 11.2 months (SD 8.5)
- Measured behavioral thresholds via VRA
- CAEPs as a function of sensation level:
  - SNHL: present in approximately 70%
  - ANSD: present in approximately 80%

Kevin Munro 2016 Sound Foundation Conference

- 104 infants with normal hearing
  - Age range: 5-29 weeks
- Evaluated the following:
  - Presence of CAEP
    - All infants had a CAEP to at least one, and many two, stimuli
  - Ability to complete testing
    - Testing was completed 95% of the time
  - Duration required to complete testing
    - Average test duration was 27 minutes
      - 13 minutes prep and 13 minutes acquisition
  - Clinicians' and parents' perception
    - Parents reported all aspects of the test acceptable
    - Interviews revealed a positive experience

CAEP Clinic at Hearts for Hearing

- Auditory Neuropathy Spectrum Disorder (ANSD)
  - All children diagnosed with ANSD are seen for unaided CAEP testing to determine need for amplification and estimated behavioral thresholds.
- Cochlear implant track
  - Children moving toward implantation for whom reliable behavioral testing cannot be obtained are seen for aided CAEP testing to evaluate aided benefit with current hearing technology.
- Slight or mild sensorineural hearing loss
  - All children diagnosed with slight or mild sensorineural hearing loss are see for unaided CAEP testing to determine need for amplification.
- Hearing aid check (<9 months old or developmentally delayed)
  - All babies fit with hearing aids are seen for aided CAEP testing to evaluate aided benefit with hearing technology.

CAEP Clinic at Hearts for Hearing

- Total patients tested: 165
  - 22 could not be completed due to excessive artifact (13%)
- Sensorineural or Mixed HL: 52 (32%)
  - Bilateral: 41
  - Unilateral: 11
- Auditory Neuropathy: 68 (41%)
  - Bilateral: 52
  - Unilateral: 16
- Normal Hearing: 23 (14%)
- Total Patients Reliably Tested: 143
  - 126 of the patients tested had a CAEP to at least one stimulus (88%)

CASE STUDY #1

JM was referred to H4H due to referring on her NBHS in both ears.

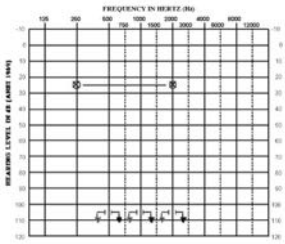
April 2014 – 5 months old, born at 25 weeks gestation, 143 day NICU stay, no family history of hearing loss

ABR testing confirmed bilateral ANSD

CASE STUDY #1

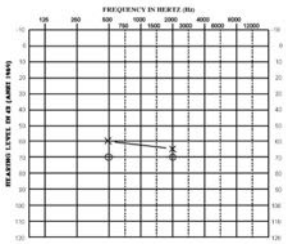
JM was followed at H4H for bilateral ANSD; no amplification.

August 2014 – 9 months old, parents denied concerns regarding auditory awareness



October 2015 – 1.10 year old, parents denied concerns regarding auditory awareness

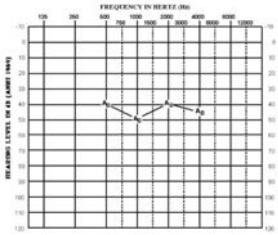
November 2015 – binaural hearing aid trial initiated



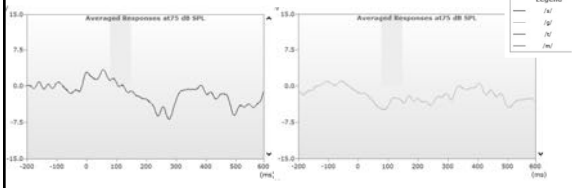
CASE STUDY #1

JM was followed at H4H for bilateral ANSD; bilateral hearing aids.

June 2016 – 2.7 years old, parents reported little-to-no aided benefit



August 2016 – 2.9 years old, parents reported little-to-no aided benefit



Were responses detected?

Right HA, left ear masked

	/m/	/t/	/g/	/s/
75 dB SPL	**0.008**	0.671	0.749	0.703
65 dB SPL	0.147	0.457		

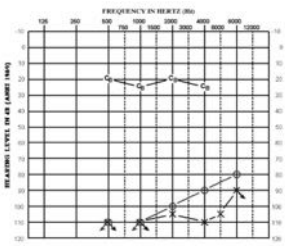
CASE STUDY #1

JM was followed at H4H for bilateral ANSD; bilateral cochlear implants.

September 2016 – 2.10 years old, simultaneous bilateral cochlear implantation

- 1 week post-op activation
- Parents reported immediate improvement in auditory awareness

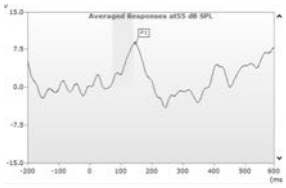
February 2017 – 3.3 years old, parents and auditory-verbal therapist report continued improvement in awareness and speech and language development

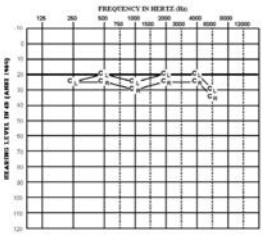


CASE STUDY #1

JM was followed at H4H for bilateral ANSD; bilateral cochlear implants.

March 2017 – 3.4 years old, five months post-cochlear implant activation





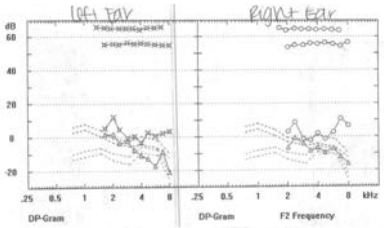
January 2018 – 4.2 years old

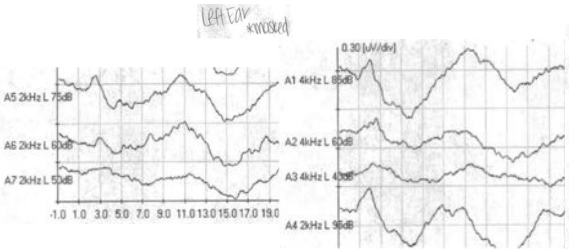
- LNT words at 60 dBA
- Right CI: 88%
- Left CI: 92%

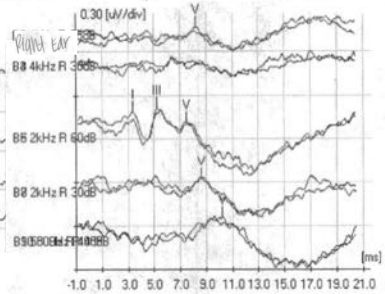
CASE STUDY #2

AS was referred to H4H due to referring on her NBHS in the left ear.

June 2016 – 2 weeks old, born full-term, no NICU stay, no family history of hearing loss



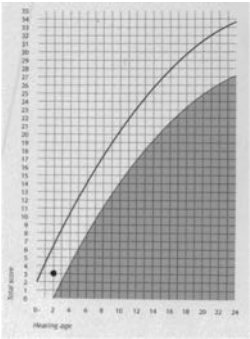


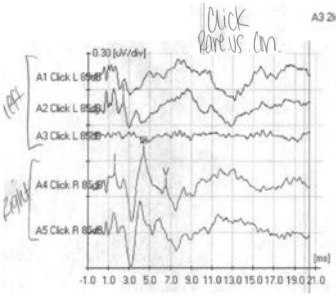


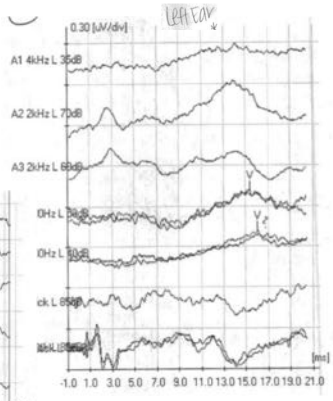
CASE STUDY #2

AS was referred to H4H due to referring on her NBHS in the left ear.

July 2016 – 2 months old,
parents reported some concerns
regarding auditory awareness







CASE STUDY #2

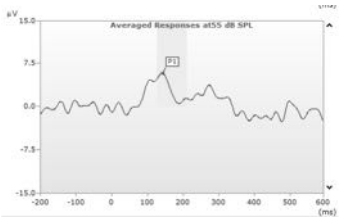
AS was referred to H4H due to referring on her NBHS in the left ear.

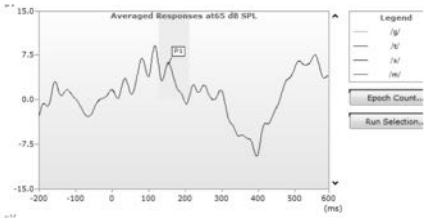
January 2017 – 7 months old,
parents reported improvement
in auditory awareness

Were responses detected?

Left ear, right ear masked

	/m/	/t/	/g/	/s/
65 dB SPL		0.001	0.039	
55 dB SPL	0.025	0.039	0.658	0.007

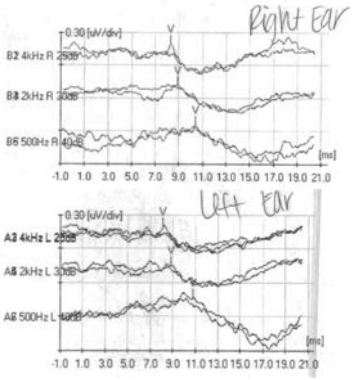


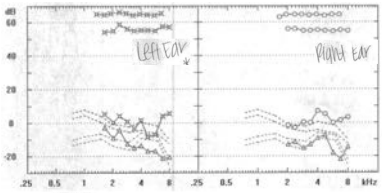


CASE STUDY #3

EP was referred to H4H due caregiver concern for hearing loss.

August 2016 – 9 months old, born full-term, suspected stroke in utero, 5 day NICU stay, passed NBHS in both ears





Right Ear

L1 (dB)	L2 (dB)	F1 (Hz)	F2 (Hz)	GM (Hz)	DP (dB)	NF (dB)	DP-NF (dB)
65.5	57.3	6563	8016	7253	5.6	-20.8	26.4
64.1	57.5	5531	6750	6110	3.9	-21.6	25.5
64.7	55.1	4641	5672	5130	-7.3	-17.3	10.0
64.8	55.2	3891	4734	4292	-8.5	-17.0	8.5
64.4	55.3	3281	3984	3616	1.4	-14.0	15.4
65.5	55.1	2766	3375	3055	-3.6	-15.4	11.8
66.1	56.1	2344	2859	2589	0.8	-12.8	13.6
65.3	58.5	1922	2344	2122	4.1	-4.5	8.6
64.6	55.0	1641	2016	1818	0.4	-9.2	9.6
64.8	54.1	1359	1641	1493	5.3	-3.2	8.5

Left Ear

L1 (dB)	L2 (dB)	F1 (Hz)	F2 (Hz)	GM (Hz)	DP (dB)	NF (dB)	DP-NF (dB)
64.7	55.0	6563	8016	7253	3.2	-14.6	17.8
64.5	55.4	5531	6750	6110	1.3	-22.0	23.3
64.0	54.4	4641	5672	5130	0.0	-18.2	18.2
64.7	55.0	3891	4734	4292	5.0	-7.5	12.5
64.4	55.3	3281	3984	3616	7.0	-9.2	16.2
64.9	54.9	2766	3375	3055	-0.2	-13.0	12.8
64.5	55.1	2344	2859	2589	0.4	-15.3	15.7
64.6	56.1	1922	2344	2122	-3.1	-11.7	8.6
63.2	55.9	1641	2016	1818	-1.4	-13.2	11.8

CASE STUDY #3

EP was referred to H4H due caregiver concern for hearing loss.

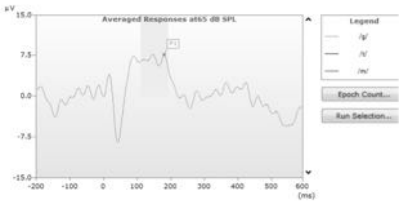
November 2016 – caregiver concerns persist for lack of awareness to sound and limited speech and language progress

- Tympanometry – Type A, good movement, bilaterally
- Distortion Product Otoacoustic Emissions – present bilaterally
- Cortical Auditory Evoked Potentials – present at 65 dB SPL to /m/, /t/, and /g/

Were responses detected?

Binaural soundfield

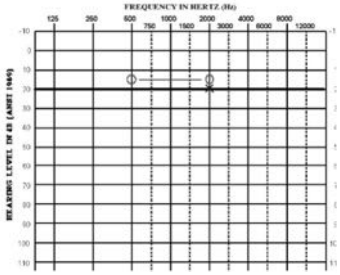
	/m/	/t/	/g/	/s/
65 dB SPL	0.005	0.013	0.002	



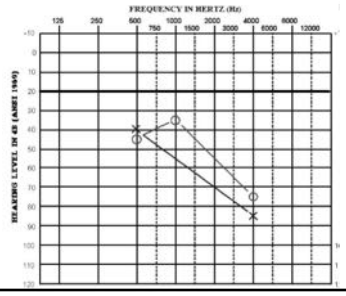
CASE STUDY #4

MP was referred to H4H due to speech and language concerns.

December 2014 – 2.7 years old, passed newborn hearing screening, no family history of hearing loss



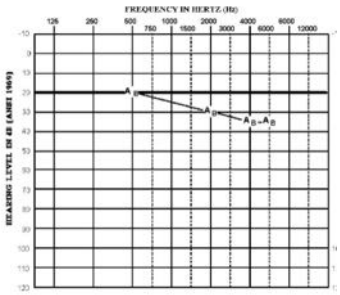
March 2015 – bilateral hearing loss confirmed via sleep-deprived ABR and behavioral audiometry



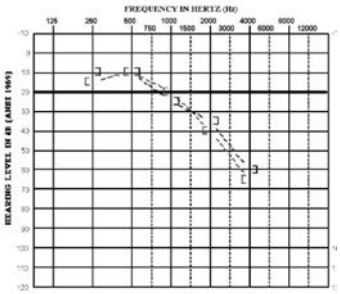
CASE STUDY #4

MP was followed at H4H for bilateral SNHL; bilateral hearing aids.

December 2015 – 3.7 years old



June 2016 – 4.1 years old



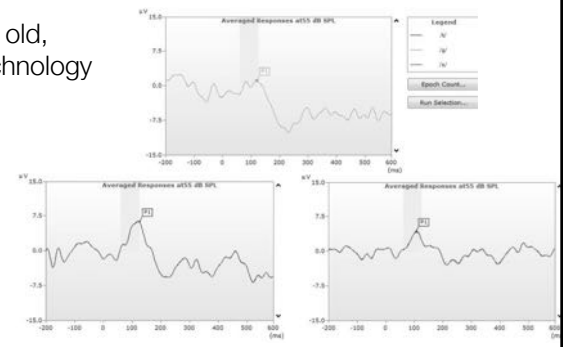
CASE STUDY #4

MP was followed at H4H for bilateral SNHL; bilateral hearing aids.

April 2017 – 4.10 years old,
Phonak Soundrecover2 technology

Were responses detected?

	/m/	/t/	/a/	/s/
55 dB SPL		0.002	0.001	0.027



January 2018 – 5.7 years old, PBK words at 60 dBA

Right HA: 100% (quiet) 76% (+10 SNR)

Left HA: 92% (quiet) 72% (+10 SNR)

Binaural HAs: 96% (quiet)

Recap: Clinical Applications for CAEPs

- Provides additional information regarding auditory function for individuals with sensorineural hearing loss and auditory neuropathy spectrum disorder
- Identifies patients that may need adjustments and/or a change in intervention
  - Hearing aid
  - Frequency-lower technology
  - Cochlear implant
- Comparing unaided and aided CAEPs may reinforce to a family the need for consistent device use

Australian Hearing, 2014, 2016

Recap: Clinical Applications for CAEPs

- CAEP testing should be completed with multiple stimuli and at multiple presentation levels
  - Absent responses in all conditions enhance the likelihood of stimulus inaudibility
- CAEP testing and intervention should been conducted in conjunction with other assessments
  - LittlEARS
  - PEACH
  - Behavioral audiometry
  - Parent and therapist input

Courtesy of Bram Van Dun

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