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Cortical Auditory Evoked Potentials in a Pediatric Practice:

Verification, ANSD & Norms for APD testing

Shanda Brashears, AuD, ABAC, PASC

Nemours Pediatric Audiologist

Shanda Brashears, AuD

Shanda Brashears began her career at the Kresge Hearing Research Lab and has been a Pediatric Audiologist at Nemours Children's Hospital since 2005. She has a Bachelor in Music Therapy from Loyola University and a Masters Degree in Communication Disorders from Louisiana State University Medical School. She received her AuD from the Central Michigan University / Vanderbilt Distance Learning Program in 2006. Dr. Brashears' primary focus within Audiology is electrophysiology and she is a member of the Delaware Early Hearing Detection and Intervention (EHDI) group. In addition, Shanda is committed to hearing conservation and she provides hearing conservation and custom in-the-ear products to musicians in the Delaware Valley through her sole proprietorship, Brashears Hearing Health Care.

Disclosures

- **Presenter Disclosure**: Financial: Shanda Brashears is an employee of Nemours Children's Hospital and received an honorarium for this course. Non-financial: Shanda Brashears has no relevant non-financial relationships to disclose.
- **Content Disclosure**: This learning event does not focus exclusively on any specific product or service.
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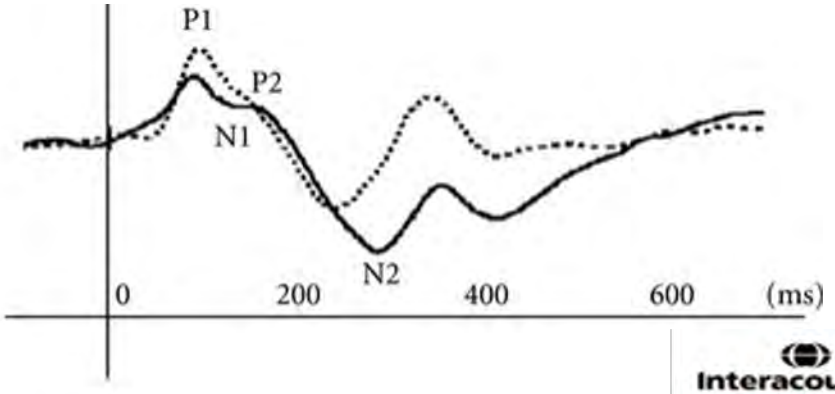
Learning Outcomes

After this course, participants will be able to:

- Identify how to apply protocols into their clinical practice in order to determine if a stimulus is detected by a patient's auditory cortex with and without hearing aid(s) or cochlear implant(s).
- Discuss how to utilize the Cortical Auditory Evoked Potential to estimate a speech awareness threshold in patients with Auditory Neuropathy Spectrum Disorder.
- Explain how to utilize normative data to assist in determining if Cortical Auditory Evoked Potential tracings are normal in quiet and in noise in pediatric patients with Auditory Processing Disorders.

Where will the Cortical Pathway Take Us Today?

- What is the Cortical Auditory Evoked Potential (CAEP)?
- Why use speech stimuli?
- Verifying technology
- ANSD
- Norms & correction factors
- APD patients
- Consider the efferents
- Addressing noise in noisy places on noisy people
- Future directions



Interacoustics Academy

What is the Cortical Auditory Evoked Potential

- The CAEP (1939) predates ABR and was first used to estimate hearing levels (1967).
- The CAEP is a late, near field, obligatory response.
- Reflects the ability of Heschl's gyrus (& nearby areas) to detect acoustic information.
  - Integrity of the auditory pathway through the level of the primary auditory cortex can be inferred.
  - Does NOT provide information on processing of sounds!
- Response morphology is dependent on stimulus and presentation parameters, state of arousal and age.
  - Awake and alert state that's constant throughout test
  - P1 is a biomarker for auditory maturity (Sharma et al., 2005).
    - Often present a birth, disappears and returns around puberty.

A Few Limitations of Note

- Too many acronyms - CAPE, LEAP, LAPE, P1/N1, N1/P2, N1/P2/N2
- CAEPs are often not as sensitive in children at low sensation levels.
- Can't bill on same day as ABR; same code: 92653– Neurodiagnostic with interpretation and report.
- Training is required to obtain, interpret and apply the data. This training can be challenging to obtain.

Advantages of Speech Stimuli

- Speech stimuli are the most real world!
  - CAEP stimuli are slower and can mimic phonemes.
- Aided / implanted benefit can be assessed in the soundfield.
  - Speech stimuli are handled optimally by hearing aid and CI signal processing.
  - High correlation between speech perception testing, validation scales & CAEP responses
  - Programming adjustments and features, such as frequency lowering, can alter recordings.

Advantages of Using CAEPs with HA / CI patients

- 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

VERIFICATION

Using CAEP to Obtain Estimated Thresholds

- Obtain unaided cortical thresholds when needed.
- Use frequency specific phonemes (at least one low and one high (e.g. - /m/ & /s/, no vowel)
- Verify amplification in the soundfield with your high and low frequency stimuli.
  - Most useful when patient can't perform behavioral testing
  - Used as cross check when aided performance doesn't match SII, validation measures, etc.
- Start with real world aided condition, then just right, just left as time and the child will allow.
  - Can use hearing aid powered off as a plug in the non-test ear.
  - Compare aided vs unaided at 80 dBnHL for latency and amplitude & / or obtain aided thresholds.
  - Expect amplitude to be affected more by decrease in intensity than latency.

High Correlation Between Speech Discrimination & CAEP Responses

- Automatic detection of cortical responses to aided soundfield stimuli in adult hearing aid users showed 91% agreement with the psychoacoustic perception of speech. (Durant et al., 2019)

- Older listeners showed better CAEPs in noise when utilizing HA directional microphone or remote microphone (RM) technology.
  - Biggest effect was with RM.
- Speech scores correlate highly with CAEP results. (Slugocki et al., 2020)

Validation and Cortical Hearing Aid Verification Are Well Correlated

- Functional performance as measured by PEACH validation scale assessed on 24 children.
- Ear specific, automatic detection of present cortical responses obtained on every child.
- There was a very high correlation between the two measures (p=.001).
- This high correlation was seen across all three groups.

N = 24
12 sensorineural
7 auditory neuropathy
5 multiply disabled

Gardner-Berry et al., 2015

CAEPs Used to Estimate Hearing Level

CAEPs as a function of sensation level

- CAEP detection rates increase with increasing audibility.
- Low cortical thresholds correlated well with functional performance in the booth.

Correction Factors

- 5 dB correction factor recommended for SNHL
- 10 dB correction factor more likely to correlate with behavioral thresholds for ANSD.

Gardner-Berry et al., 2015

Estimating Speech Awareness Threshold

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
Punch et al., 2016

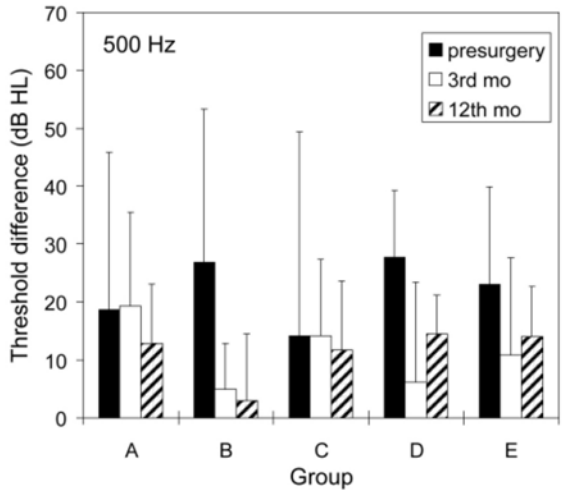
Establishing Early CI & Binaural Benefit in Young CI Recipients

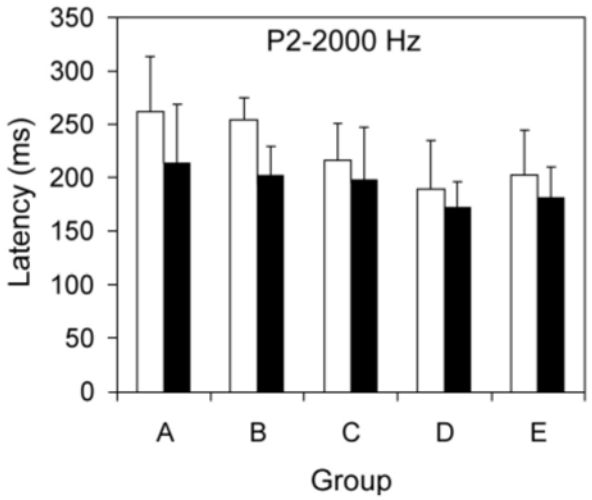
- Longer cochlear implant use is associated with shorter P1 latency.
- In children with sequential bilateral cochlear implants, P1 latency of 1st side improves when 2nd ear is implanted.
- The degree of central auditory maturation between 1st & 2nd side may better indicate likelihood of success than the timing between the two surgeries.
- Authors concluded that increased auditory experience improves central auditory pathway maturation. (Jeong et al., 2018)

- Three young CI recipients were followed for 2.5 years with CAEP and validation surveys.
  - All showed gradual improvement in both measures.
  - Two of 3 were age appropriate on survey by 9 months.
  - One of the 3 was normal on both by 9 months.
  - All had normal CAEP & surveys by 2 years post CI. (Paluch et al., 2019)

Cortical Improvements Over Time in CI Recipients

- 45 subjects 2 – 70 years old
- 5 groups homogeneously arranged by chronological age, age at onset of deafness, and age at implantation.
- Cortical P2 thresholds decreased from pre to post implant; all groups significantly by 3 months post activation.
- P2 latencies decreased from 3 to 12 months post-implantation in all groups.





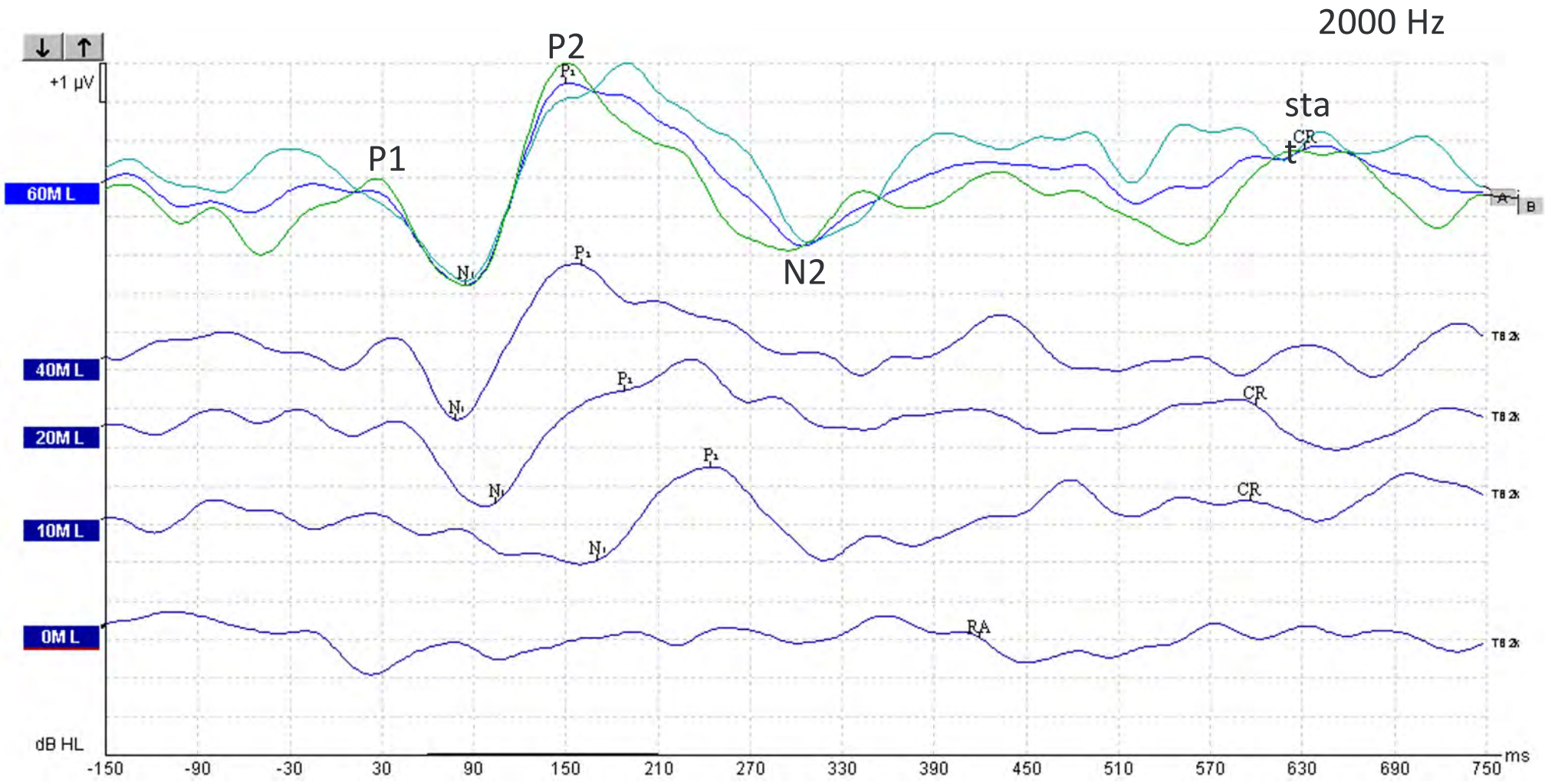
(Burdo et al., 2006)

CAEP & CI for Single Sided Deafness

- Case study showing the progression in auditory maturation in a 10-year-old:
- Morphological markers of a typical CAEP in implanted ear were first observed around 6 months post CI and fully mature by 14 months post activation.
- Contralateral, NORMAL ear CAEP also improved over time!
- MRI and EEG showed improved cortical activation concurrently with CAEP improvements.
- Scores on speech testing & validation scales improved along with the CAEP.
- Perceived listening effort decreased!

- At Nemours, we have started to implant this population generally when a risk factor for loss of hearing in the good ear is present.

Sharma et al., 2016



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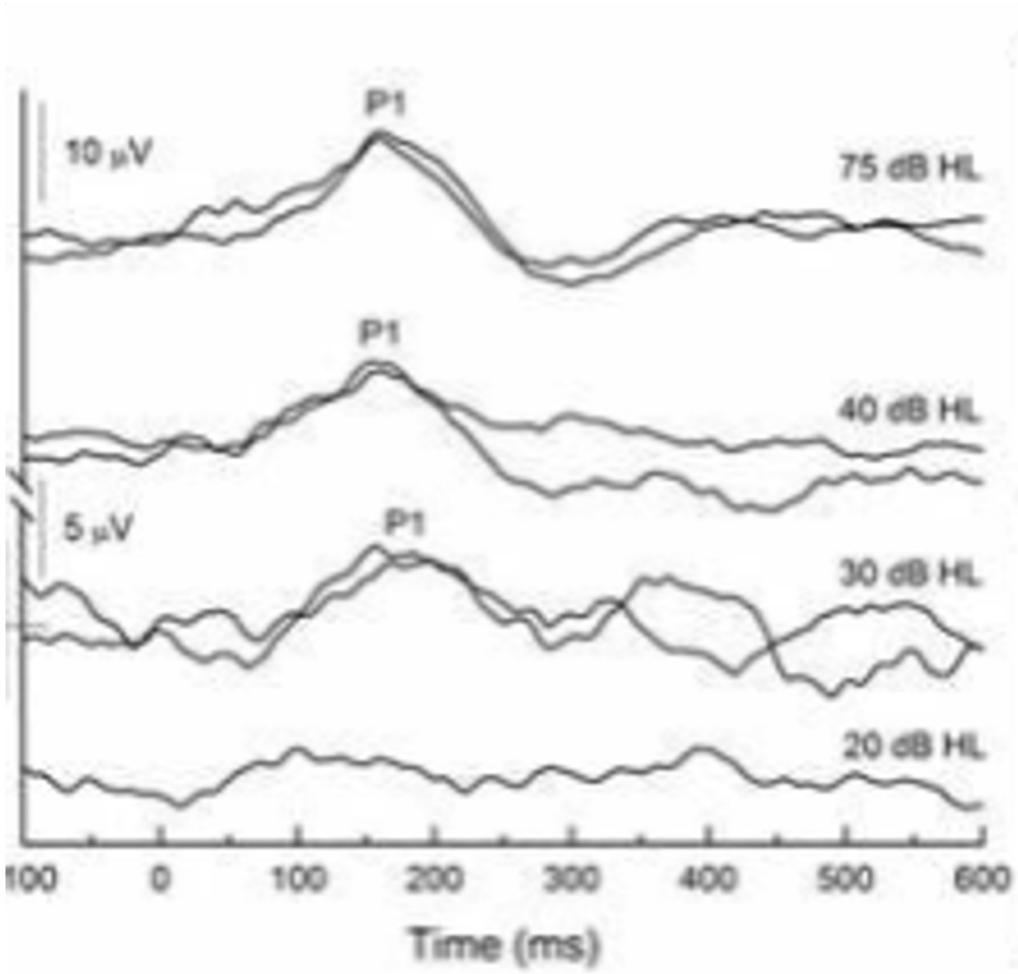
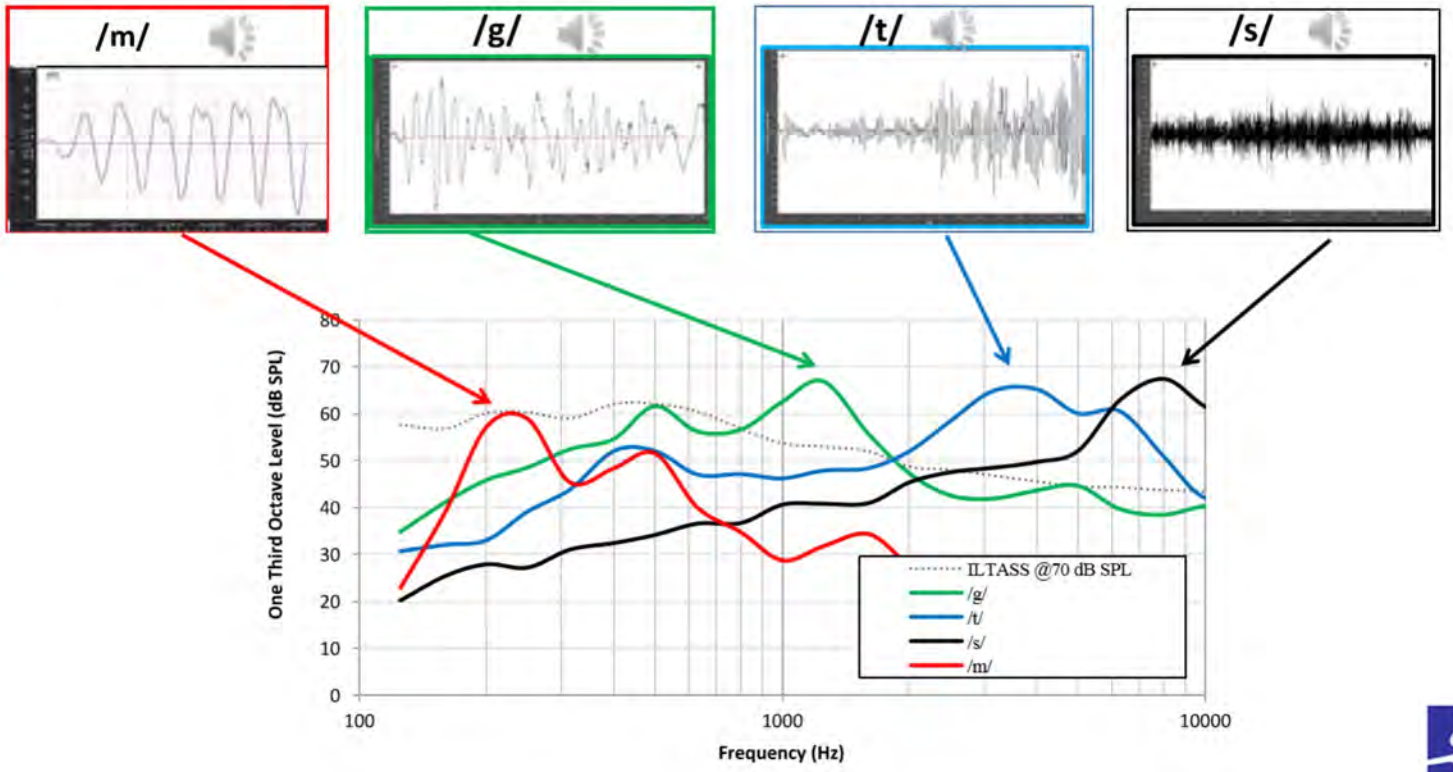
Normal Soundfield Threshold Search



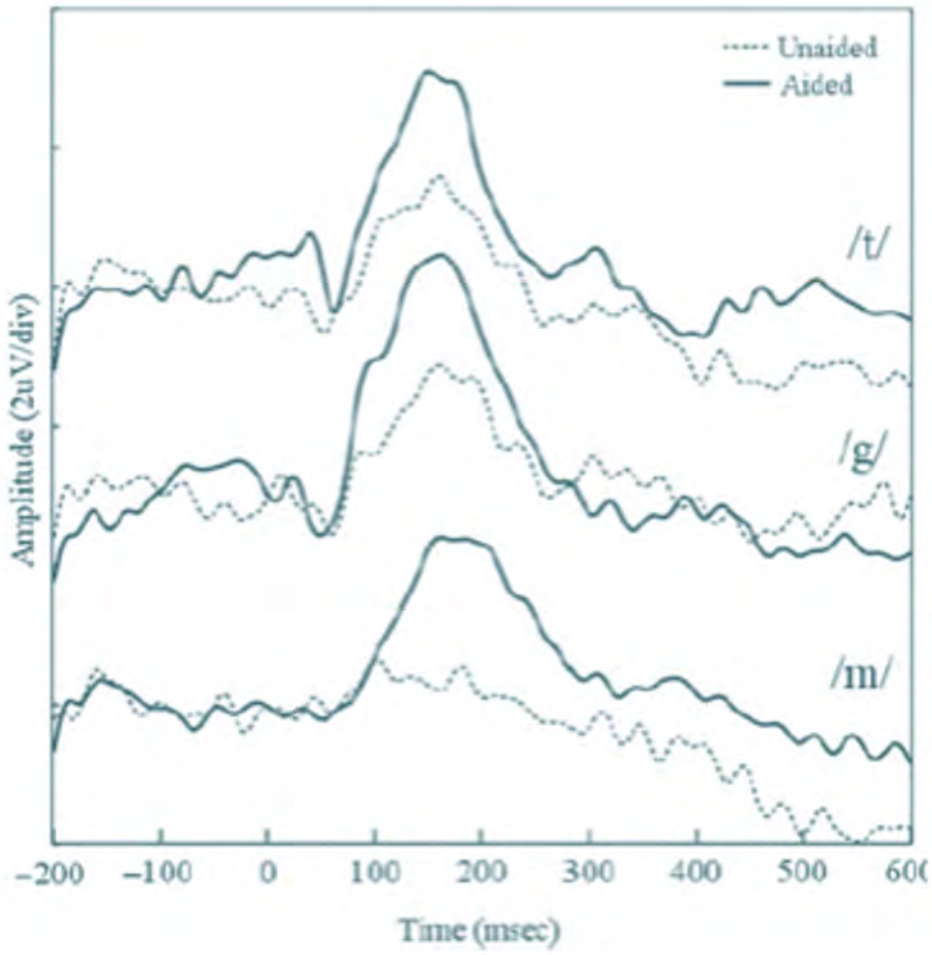
/da/

Frequency Specific Speech Stimuli

Stimuli for measuring CAEP



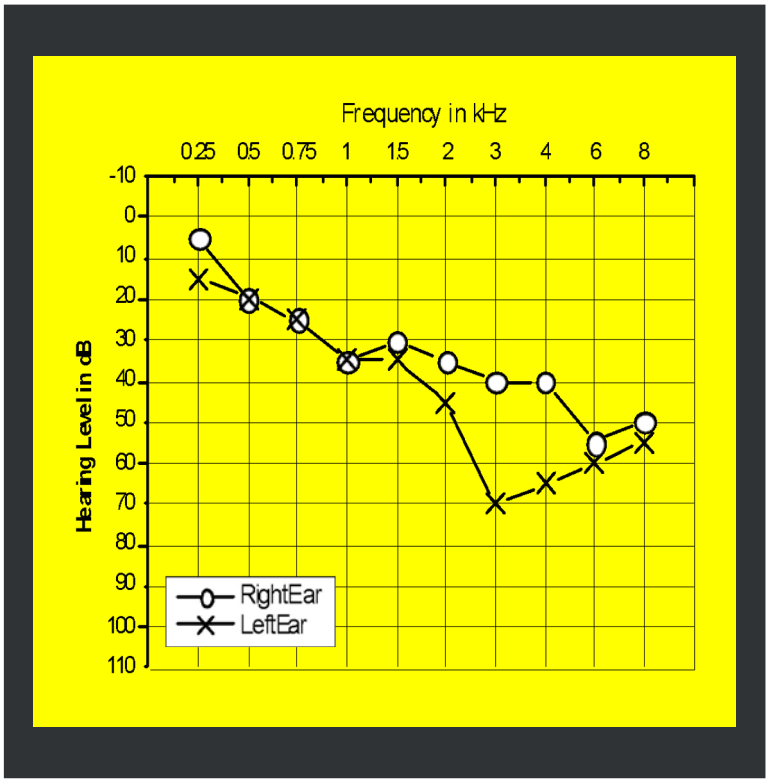
National Acoustic Laboratories



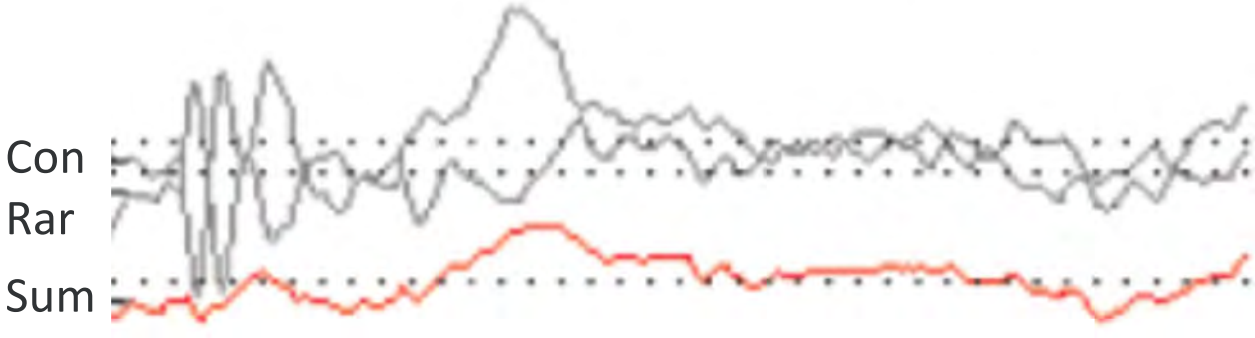
Corticals Shed Light on Little Ones with ANSD

- ABR and ASSR can't estimate behavioral thresholds in ANSD. (Lalayants et al., 2018)
- Because CAEP stimuli are much slower than ABR/ASSR, a patient with neural dyssynchrony will usually generate a response to CAEP stimuli, provided it's audible. (sensation level > 10 dB minimally).
- There's more redundancy in the pathway by the time you reach the cortex.
- Speech stimuli are even more highly recommended in cases of ANSD.
  - Tonal stimuli can have too narrow a frequency spread for the system to pick up.

Early Evoked Potentials don't give threshold information!



*Narrow band noise in behavioral testing may provide better reliability and agreement with SRT with ANSD *



Neural hearing loss

- can result in longer neural refractory periods.
- Each neural impulse may not be time locked to every stimulus ABR stimulus presented.
- There may be a response from the auditory brainstem, but you can't measure it because the system is not organized or fast enough.
- The cochlear microphonic is not a neural response, it's sensory and therefore polarity dependent. (Lalayants et al., 2018)

Correlation Between Validation and Cortical Hearing Aid Verification

- Children with ANSD who had a present P1 / P2 were more likely to score high on the IT-MAIS ($p < .01$).
- CAEP results were grouped into 3 categories:

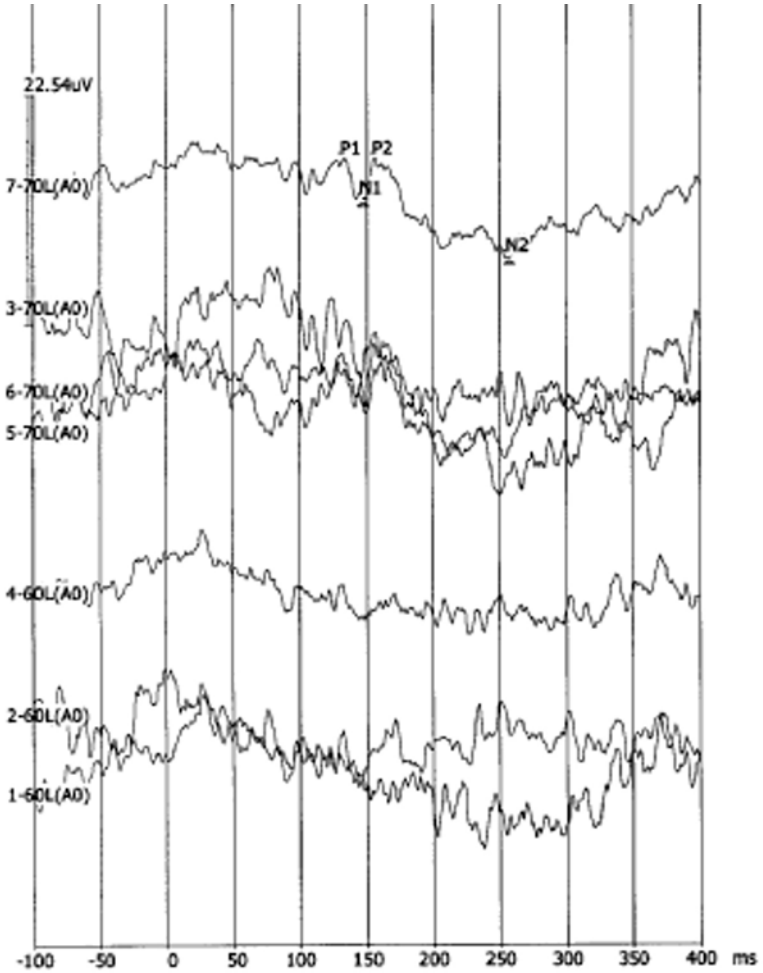
1. Normal P1 / P2
2. Delayed P1 / P2
3. Abnormal or absent P1 / P2

- Authors propose using the CAEP as part of a clinical test battery to help triage infants with ANSD.

1. No technology (or possible, cautious HA trial) - monitor closely
2. HA candidate
3. CI evaluation (to include HA trial)

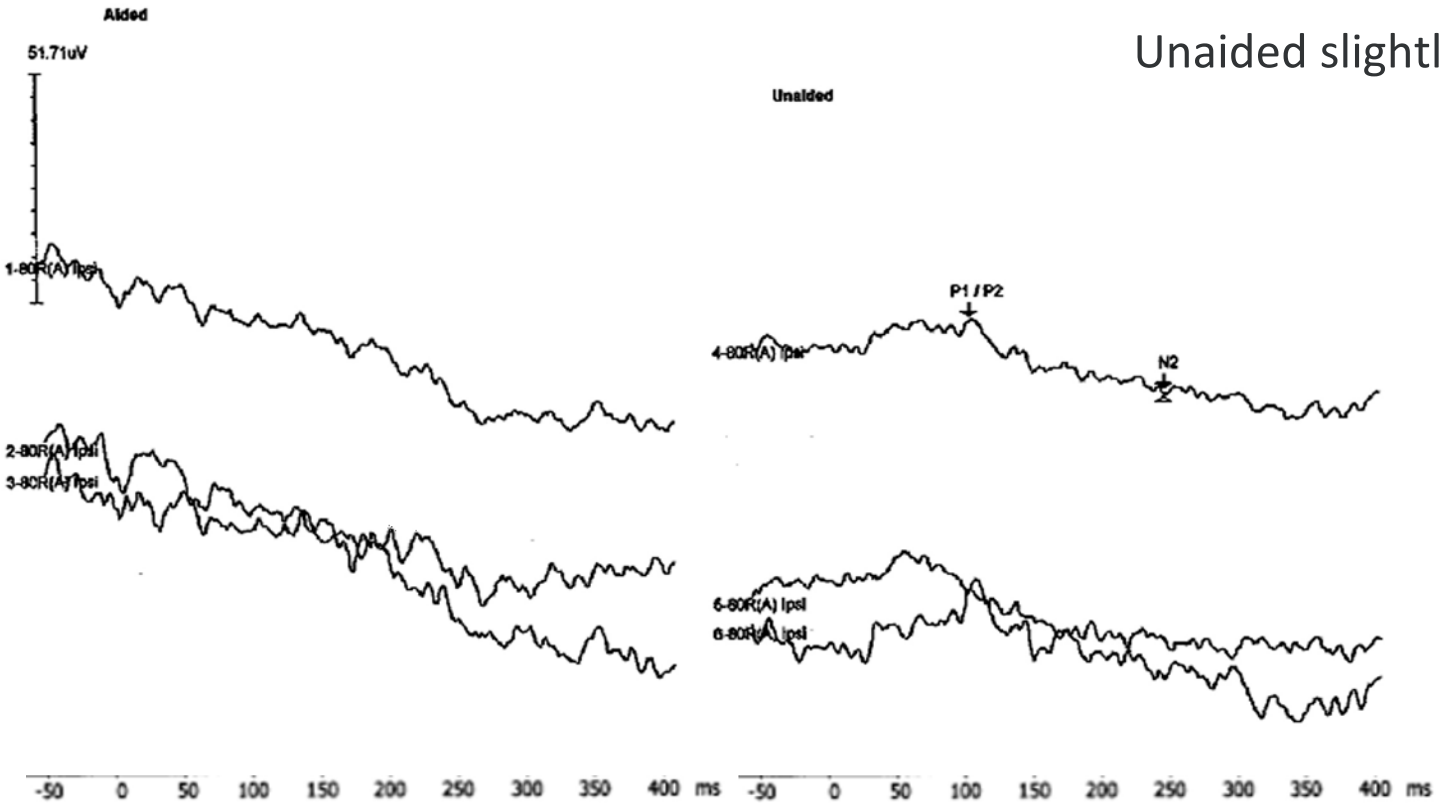
Sharma et al., 2011

Cortical Threshold to Obtain eSAT



Gardner-Berry et al., 2016

Aided vs Unaided



Unaided slightly better than aided???

NORMATIVE DATA
&
CORRECTION FACTORS

Published Norms via Scoping Review of Literature

- Newborns / Infants
  - P2 and N2 are broad in morphology and can vary across tests. P2 begins to be less variable 4 months of age.
  - P2 = 200-250 msec
  - N2 = 300-550 msec
- 16 months of age (toddlers)
  - P1/P2 complex = approximately 200 msec
  - N2 = approximately 450 msec
- 3-year-old children (3-4 years)
  - P1 = approximately 130 msec
  - N1 = approximately 250 msec
  - N2 = approximately 450 msec
- 5-6 year old children
  - P1, if present = approximately 85-95 msec
  - N1, if present = approximately 100-150 msec
  - P2 = approximately 140-210 msec
  - N2 = approximately 220-240 msec
- Adults (12 years+ / puberty+)
  - P1 = approximately 40-60 msec
  - N1 = approximately 100 msec
  - P2 = approximately 200 msec
  - N2 = approximately 250 msec

Wunderlich et al., 2006

Nemours Center for Pediatric & Speech Sciences Norms

Response	Left Ear (msec)	Right Ear (msec)
P2 Quiet	104.9 +/- 26.2 (52.5-157.4)	106.9 +/- 22.8 (61.3-152.5)
P2 Ipsi Noise	134.9 +/- 19.2 (96.5-173.3)	134.1 +/- 20.3 (93.5-174.7)
P2 Contra Noise	107.2 +/- 25.2 (56.8-157.6)	104.7 +/- 18.6 (67.5-141.9)
P2 Bin Noise	141.3 +/- 22.7 (95.9-186.7)	132.3 +/- 21.5 (89.3-175.3)
N2 Quiet	175.6 +/- 33.2 (109.2-242)	167 +/- 36.9 (93.2-240.8)
N2 Ipsi Noise	205.1 +/- 26.1 (152.9-257.3)	193.7 +/- 21.3 (151.1-236.3)
N2 Contra Noise	173.3 +/- 27.2 (118.9-227.7)	175.6 +/- 31.1 (113.4-237.8)
N2 Bin Noise	204.5 +/- 25.9 (152.7-256.3)	192 +/- 22 (152-240)

Ranges are +/- 1 & (2) standard deviations

Ages 7-12 years old
Typically developing, no APD symptoms
Stimulus = /da/
Noise = speech weighted noise

Morlet et al., 2019

Adult Norms Obtained in Nemours' Clinic

/M/ at 80 dB SPL

N of 10

	Latency in ms			
Right Ear	P1	N1	P2	N2
Mean	35	74	161	253
St Dev	5	18	21	37

	Latency in ms			
Left Ear	P1	N1	P2	N2
Mean	50	85	181	263
St Dev	22	31	33	47

/S/ at 80 dB SPL

Right Ear	P1	N1	P2	N2
Mean	39	79	193	280
St Dev	11	18	24	45

Left Ear	P1	N1	P2	N2
Mean	42	84	163	234
St Dev	14	9	30	34

/T/ at 80 dB SPL

Right Ear	P1	N1	P2	N2
Mean	40	88	166	269
St Dev	13	15	18	34

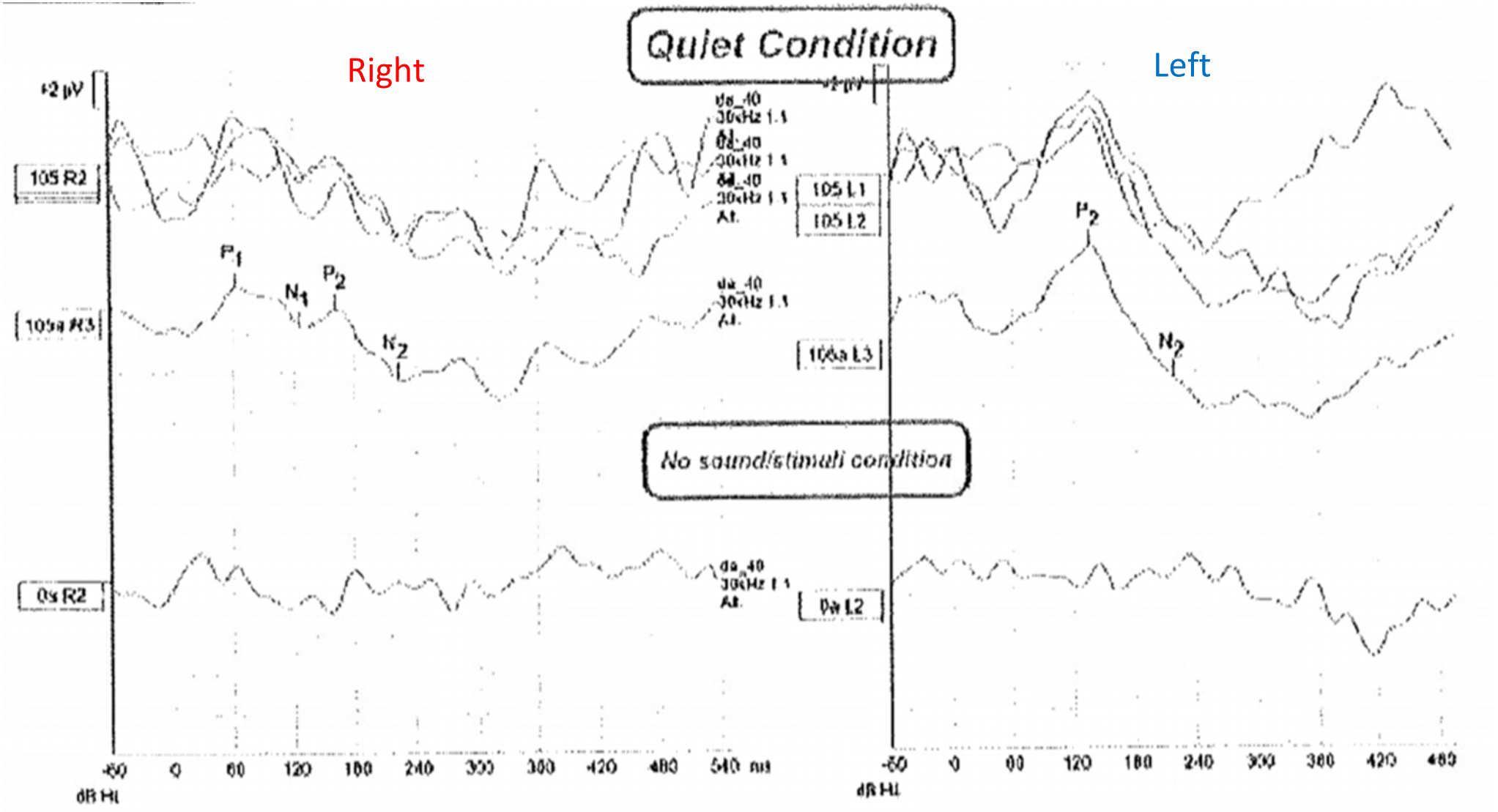
Left Ear	P1	N1	P2	N2
Mean	39	80	166	272
St Dev	14	12	25	37

AUDITORY PROCESSING DISORDERS (APD)

Morphological Markers

- Presence or absence of response
- Presence of P1 (auditory maturity) vs P1 / P2 complex
- Latency of P2 considered abnormal if more than 20 msec later than normative range (mean + 1 standard deviation).
  - Developed based on data spread within the norms
  - Consistent with cut-off for normal temporal awareness (RGDT)
- More important than norms is intersubject differences: R vs L, quiet vs noise, with vs without technology, pre vs post training, development over time (1-2 year follow up).
  - The same 20 msec cut-off applied for intersubject comparison.
- Looking for a pattern
  - Noteworthy to find P2 or N2 late (usually represents morphology difference)
  - Considered abnormal if P2 and N2 are late

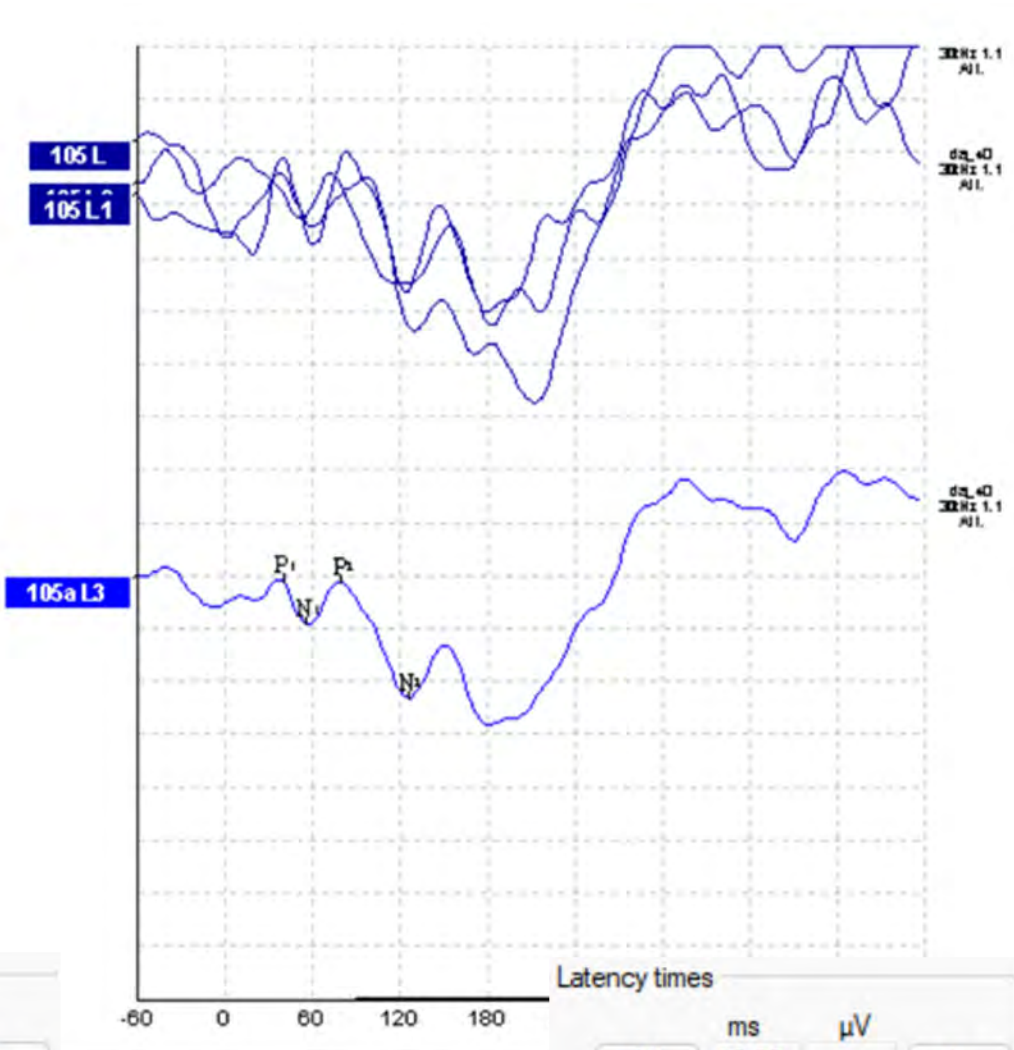
R vs L Morphological Difference



Quiet vs Ipsi Noise

Latency times

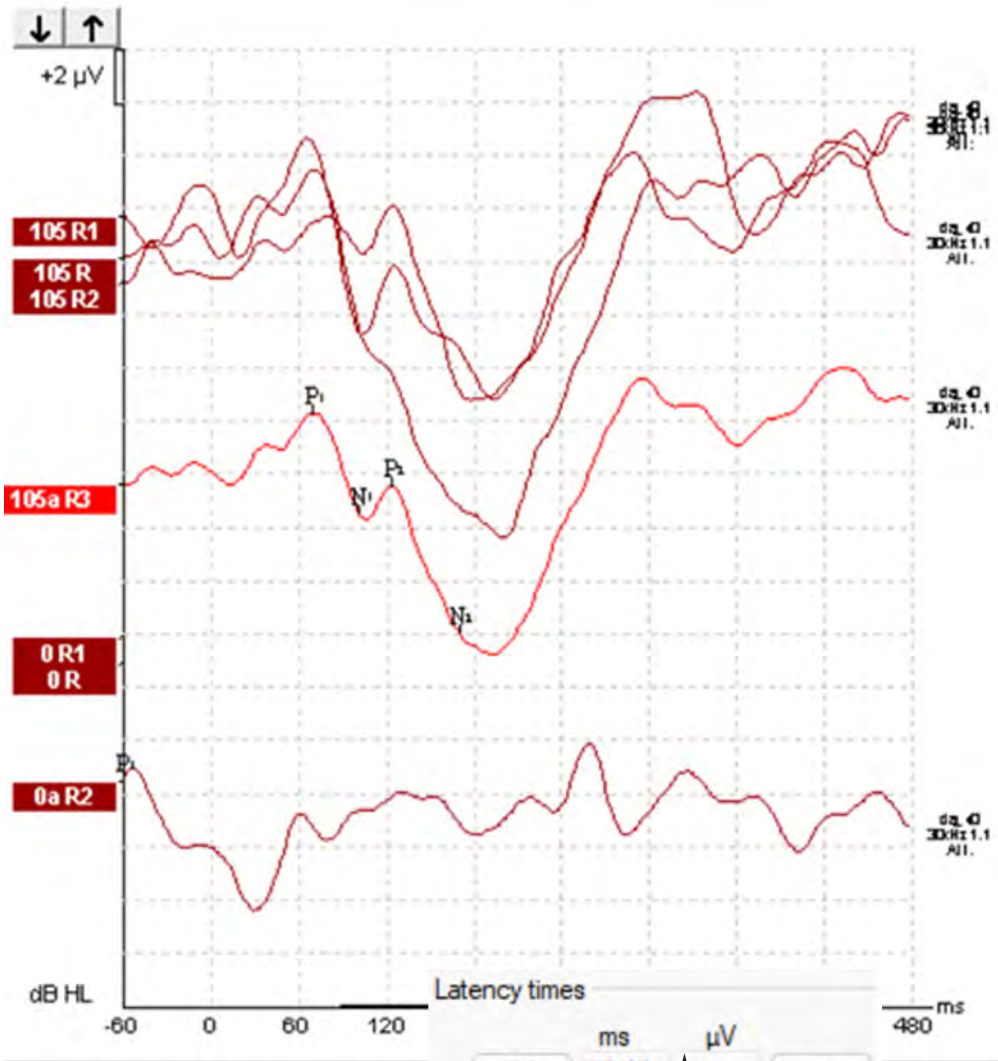
	ms	µV	
P1	34.00		tr
N1	68.00		tr
P2	86.00		tr
N2	128.00		tr
P3			tr



Latency times

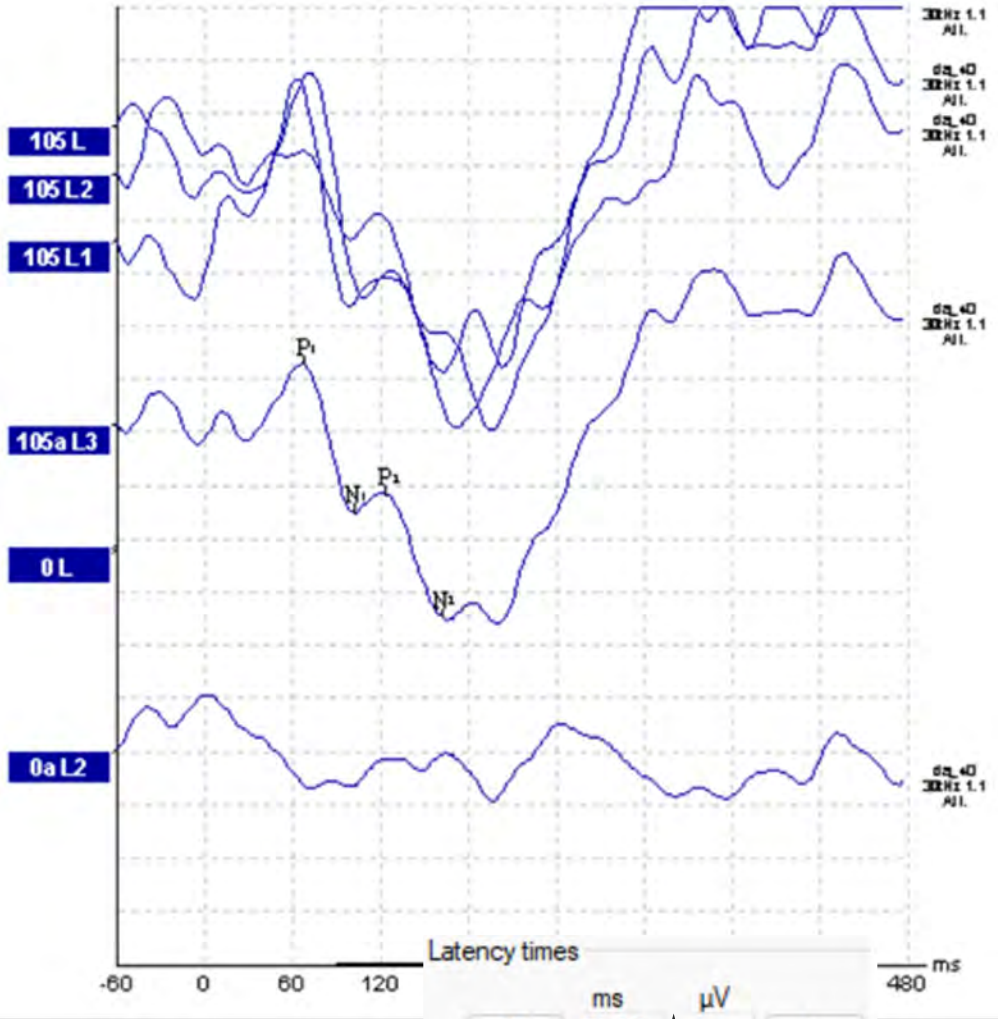
	ms	µV	
P1	40.00		tr
N1	56.00		tr
P2	80.00		tr
N2	126.00		tr
P3			tr

Quiet better than **Noise**



Latency times

	ms	µV	
P1	70.00		tr
N1	102.00		tr
P2	124.00		tr
N2	170.00		tr
P3			tr



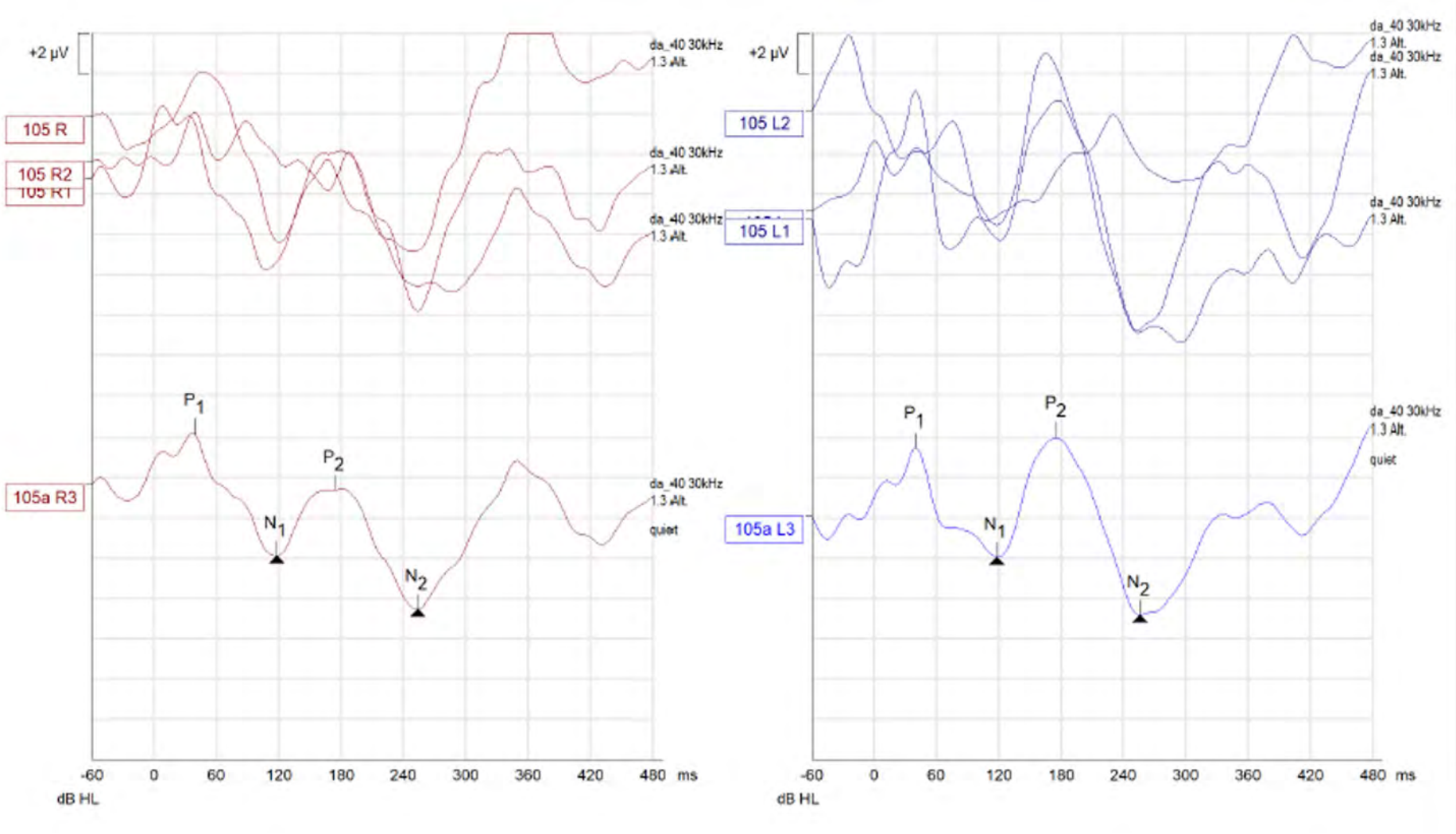
Latency times

	ms	µV	
P1	68.00		tr
N1	102.00		tr
P2	124.00		tr
N2	162.00		tr
P3			tr

Correction Factors & Other Notes

- 105 dBnHL = 80 dB SPL on our EP25 systems due to output of stimulus used (NAL stimuli)
  - Manufacturer and calibration company did not recommend changing calibration, but rather to apply correction factors.
  - Output verified, correction factors applied, and site-specific norms obtained
- 0 dB - no stim run used to help validate response
- Recording window (-60 to 480 msec)
  - Sufficiently long as to view delayed responses
  - It's nice to see some running EEG prior to the response.
  - You will want a line at 0 msec

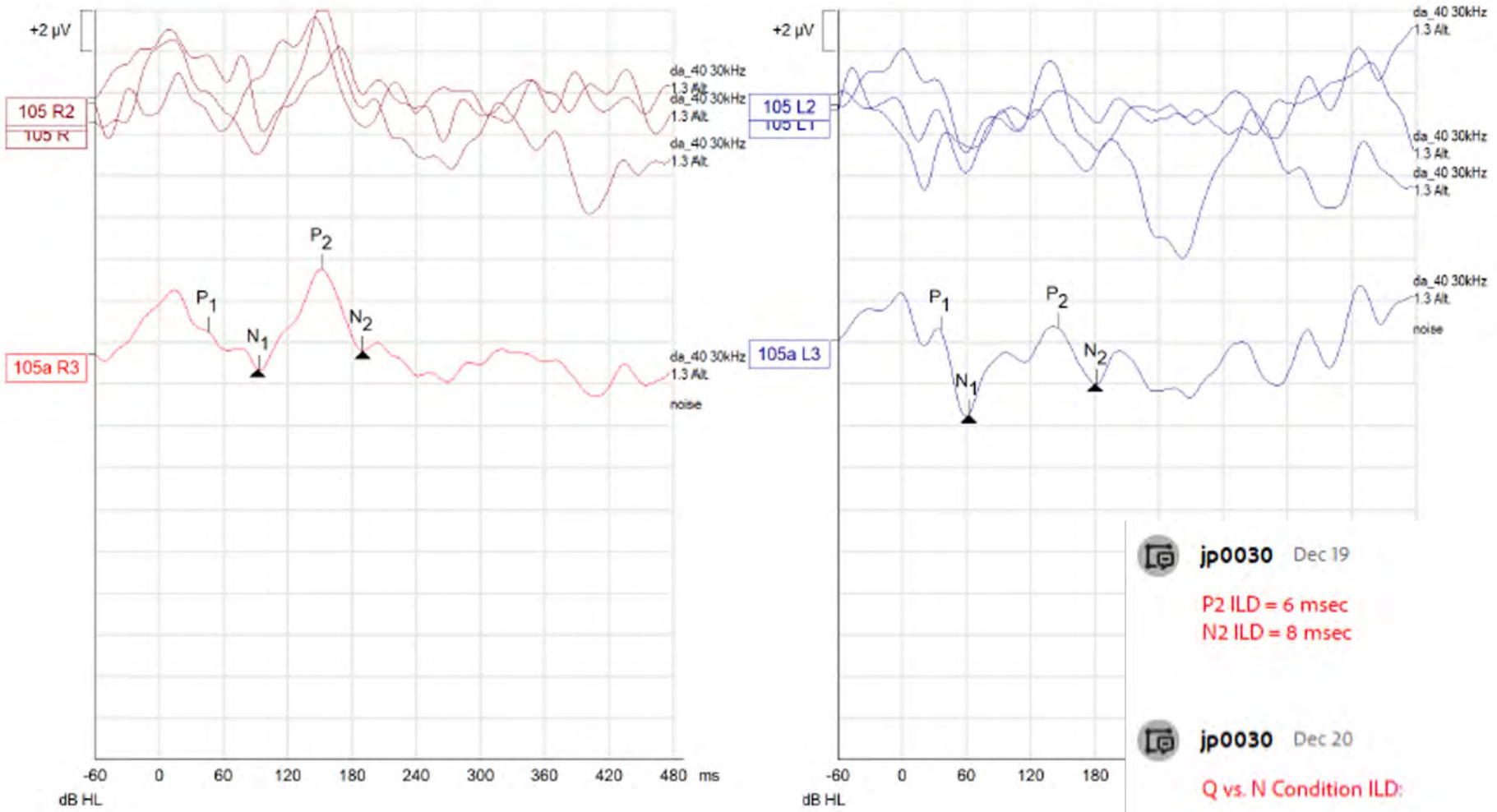
Quiet vs Ipsi Noise



jp0030 Dec 19

P2 ILD = 2 msec
N2 ILD = 2 msec

Noise better than Quiet



jp0030 Dec 19

P2 ILD = 6 msec
N2 ILD = 8 msec

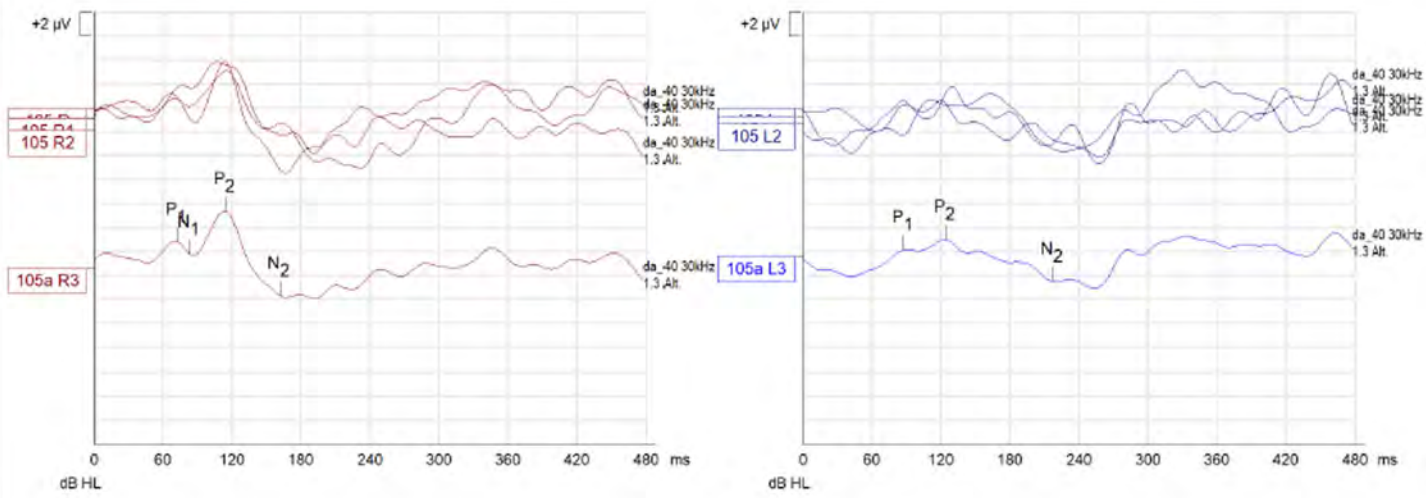
jp0030 Dec 20

Q vs. N Condition ILD:

Right:
P2= 30 msec
N2= (-)64

Left:
P2= 22 msec
N2= (-)74

Morphology Difference in **Quiet**



Curve	Latencies (ms)						
	P1	N1	P2	N2	P3	N1-P2 Lat	N1-P2 Amp
105 R							
105 R1							
105 R2							
105 L							
105a R3	72.00	84.00	114.00	162.00		30.00	-0.00
105 L1							
105 L2							
105a L3	88.00		124.00	218.00			

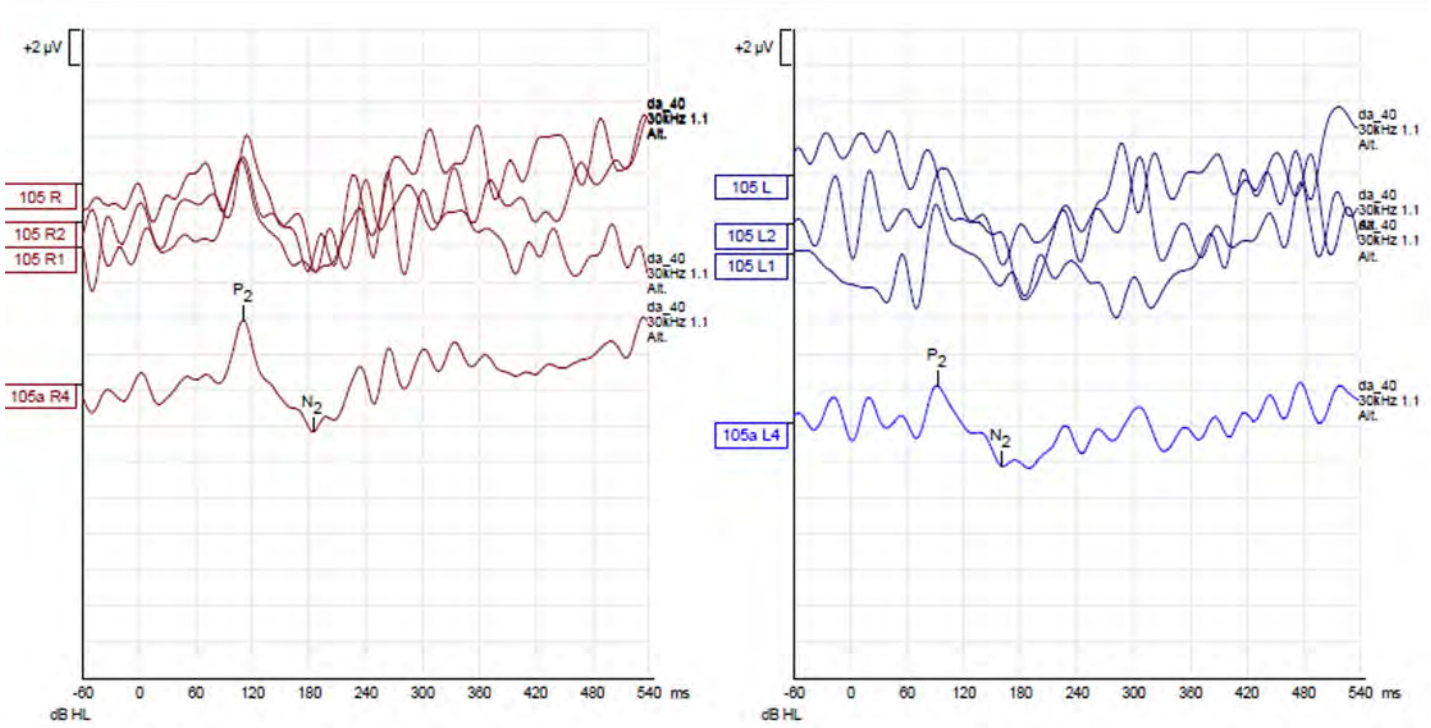
Difference between ears:
P2 - 10 msec
N2 - 56 msec ★

Difference between Q and N:

RIGHT EAR
P2 - 10 msec
N2 - 14 msec

LEFT EAR
P2 - 26 msec
N2 - 32 msec ★

Left Improvement in **Noise**



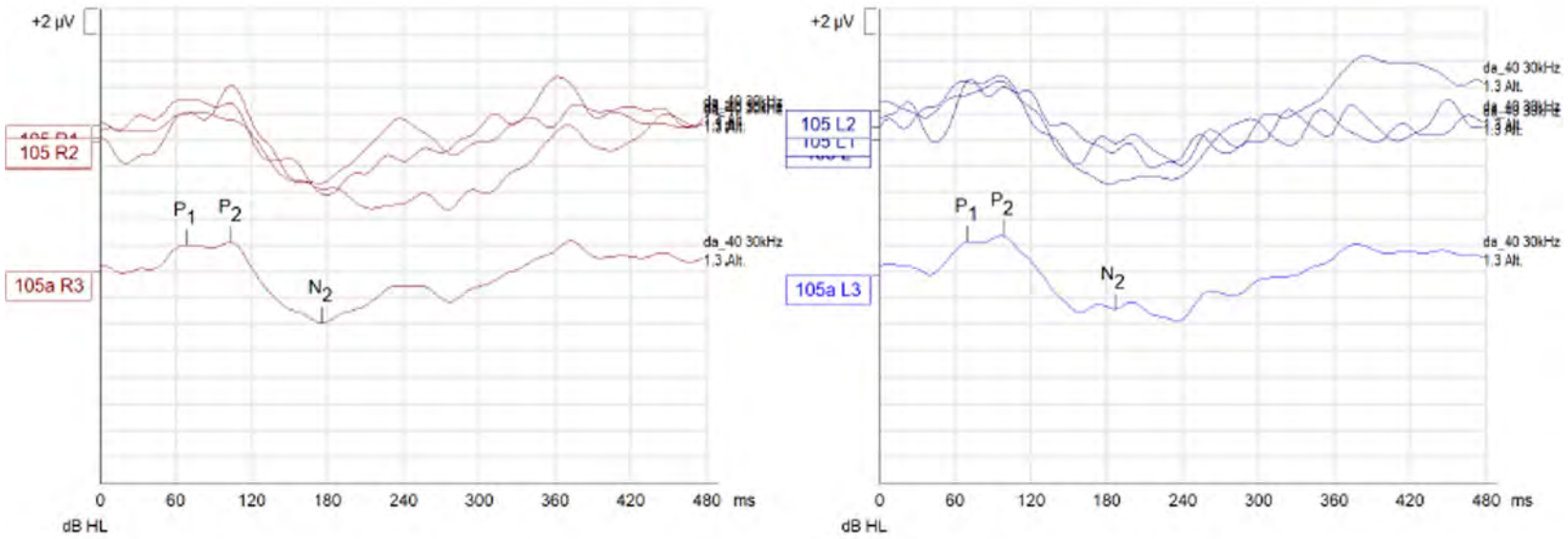
Curve	Latencies (ms)						
	P1	N1	P2	N2	P3	N1-P2 Lat	N1-P2 Amp
105 R							
105 R1							
105 R2							
105a R4			110.00	184.00			
105 L							
105 L1							
105 L2							
105a L4			92.00	160.00			

ILD: 18 ms ILD: 24ms ★

The Right Ear Advantage

- Left hemispheric dominance for speech processing
- Contralateral pathway to left language brain is more direct and efficient from the right ear.
- Farah et al. (2014) with imaging showed that children with APD have a disruption in fibers connecting the right ear to left cortex.
- Due to slower interhemispheric transfer, the right ear advantage (REA) is more pronounced in young children. (Keith et al., 1985).
  - By age 7, expect a CAEP that is mostly symmetrical to slightly better in the right.
  - REA is more likely to show up in behavioral tests of degraded speech than in the Cortical.
- Our EARS may perk up when we see a left CAEP significantly better than the right – “atypical ear advantage”

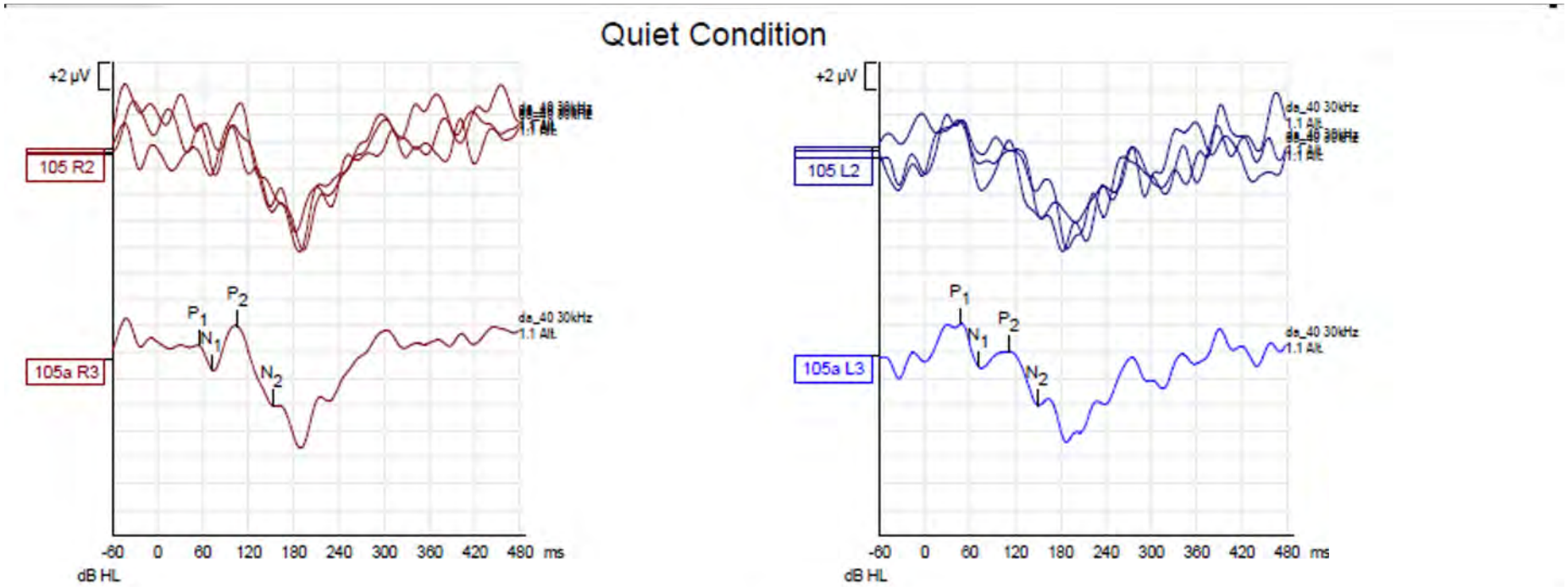
Emerging P1 in Quiet



Curve	Latencies (ms)						
	P1	N1	P2	N2	P3	N1-P2 Lat	N1-P2 Amp
105 R							
105 R1							
105 R2							
105 L							
105a R3	68.00		104.00	176.00			
105 L1							
105 L2							
105a L3	70.00		98.00	186.00			

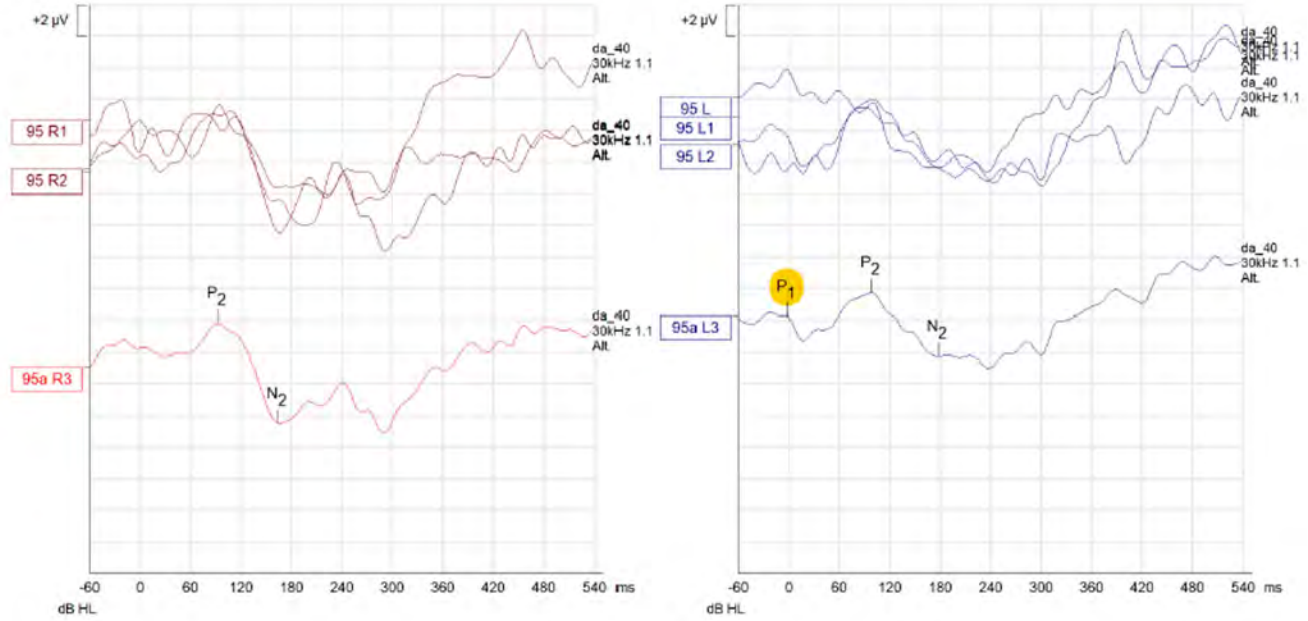
Difference between ears:
P2 - 6 msec
N2 - 10 msec

Be Consistent in Marking



Curve	Latencies (ms)						
	P1	N1	P2	N2	P3	N1-P2 Lat	N1-P2 Amp
105 R							
105 R1							
105 L							
105 L1							
105 L2							
105 R2							
105a L3	48.00	72.00	112.00	150.00		40.00	-0.00
105a R3	54.00	72.00	106.00	152.00		34.00	-0.00

Cross Check / Co-Sign Principle



Curve	Latencies (ms)						
	P1	N1	P2	N2	P3	N1-P2 Lat	N1-P2 Amp
95 R							
95 R1							
95 R2							
95 L							
95a R3			92.00	164.00			
95 L1							
95 L2							
95a L3	-2.0		98.00	178.00			

Ear Difference:
P2 - 6 msec
N2 - 14 msec

The Power & Limitations of CAEP in APD Population

- P2 and N2 latencies in quiet and in noise are significantly delayed in the pediatric APD population (Morlet et al., 2019 and others).
- Can lead to confidence in interventions such as binaural remote microphone system, listening therapies, etc.
- Amplitude is a soft sign and can be difficult to interpret.
- P2 / N2 amplitudes in noise are LARGER in the pediatric APD population (Morlet et al., 2019 & Liasis et al., 2003). Theories include:
  - High performing speech in noise (SIN) listeners require fewer neural resources in noise due to heightened efficiency.
  - Good SIN listeners have greater inhibitory control (efferents), allowing better suppression of unwanted background noise.
- The CAEP is part of a battery that includes behavioral ADP testing, language evaluations, psychoeducational testing, etc. and should not be used alone.

Consider the Medial Olivocochlear System (MOCS)

- Quiet vs. noise CAEP in part assesses the efferents
  - Modulation of the outer hair cells are a more direct window into the efferent pathway (95% of OHC neural innervation is efferent) – Suppression of OAEs
  - Cochlear modulation by the efferents enhance auditory sensitivity.
  - Efferent suppressions studies correlate robust suppression with both improved frequency resolution and speech discrimination in noise with (Marian et al., 2018 & Maison et al., 1997).
  - A left ear advantage in efferent suppression of OAEs has been described in the APD population (Burguetti & Carvallo, 2008).
  - Classically trained musicians show more robust suppression than non-musicians (Brashears et al., 2003).

Expect CAEP responses in noise to be as good or better than in quiet. Poorer in noise (>20 msec difference) is abnormal.

Triage with Tymps, OAEs Middle Ear Muscle Reflexes

- MEMR also reveal some info on the efferents
- MEMR are often absent or elevated (>95 dB) in APD population (Smart et al., 2019)
  - Abnormal MEMR with normal hearing and listening complaints may indicate need for APD testing.
  - Speech in quiet and in noise are recommended when reflexes are absent.
- Absent MEMRs and poor speech in noise may indicate further testing for ANSD is warranted.
  - We include a “rule out” ABR as part of our APD intake when indicated.
- Let’s be specific!
  - There is more than one acoustic reflex
  - Both evaluate the MOCS
    - Middle ear muscle &&&&

Efferent Suppression of OAEs

Fit the Physiology!

What does an OHC and a HA have in common?

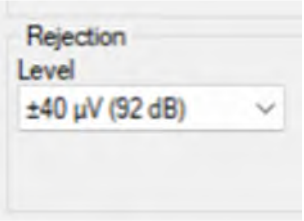
- Sensory
  - Thresholds generally better than 65 dB HL
  - Word rec and speech in noise are good (at sufficient sensation level)
  - OAEs absent / MEMR present
  - Can expect great hearing aid outcomes

WIDE DYNAMIC RANGE COMPRESSION!

- (Sensori)neural
  - MEMR are often absent or elevated
  - Would only expect OAEs in some cases of ANSD
  - Word rec is poor, even when presented well above speech threshold
  - Speech in noise may be VERY poor
  - HL with a neural component may require consistent use of remote mic technology for success
  - Maximize visual cues / manual communication
  - Possible CI eval

Combating Noise

- Electrical
  - Additional in-line power conditioner
  - Physical grounding
- Myogenic
  - Head should be at rest against seat back, reclined slightly.
  - Legs uncrossed
  - A silent video keeps them occupied & therefore more still. Employ sub-titles, giving added benefit of reading practice.
- Last resort - open up the reject filter
  - Letting more in more noise, so open judiciously
  - 80-99% accepted is the sweet spot.




0.3A Max

Future Directions

- Wider application of the CAEP to verify technology, evaluate severity of ANSD and support behavioral APD testing
- Consider P300 speech phoneme pairs for testing discrimination in ANSD
- Increase clinical prevalence of testing MEMR
- Because suppression of OAEs is difficult to obtain accurately in peds, we need a more direct test of the efferents that is easier to obtain.
- Frequency Following Response (FFR) / Continuous ABR to evaluate APD patients. Not all of Auditory Processing Dysfunction is Central!

A Big Thank You!

- Nemours Audiology Department
- Thierry Morlet, PhD and Nemours Center for Pediatric Auditory & Speech Sciences (CPASS), now at University of Memphis
- Tammy Riegner, AuD, Nemours APD aficionado

Congratulations!

- You've completed the course and can move on to the exam!
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