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Cortical Response Applications for Audiometric and Audibility Assessment

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Cortical Response Applications for Audiometric and Audibility Assessment

Samuel R. Atcherson, Ph.D.

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Agenda

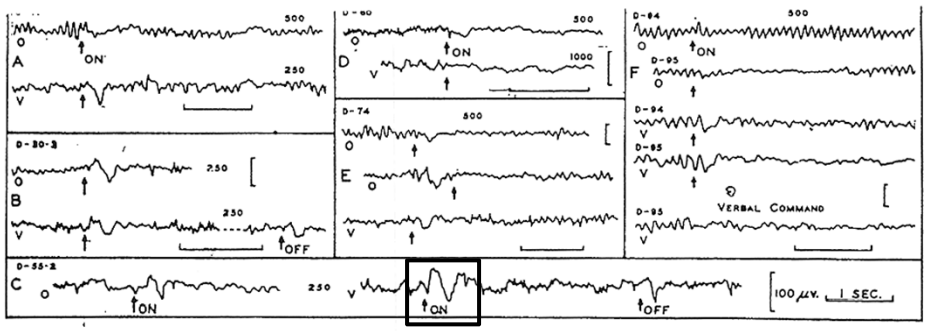
I. Background and introduction; underpinnings of threshold estimation and audibility testing with CAEP
II. Review of stimulus and recording parameters and considerations
III. Information about new and existing commercial systems related to CAEP testing; brief strengths and limitations
IV. Threshold estimation using CAEP, relevant literature and clinical examples
V. Audibility measures using CAEP, relevant literature and clinical examples
VI. Summary, Q & A

Background and Introduction

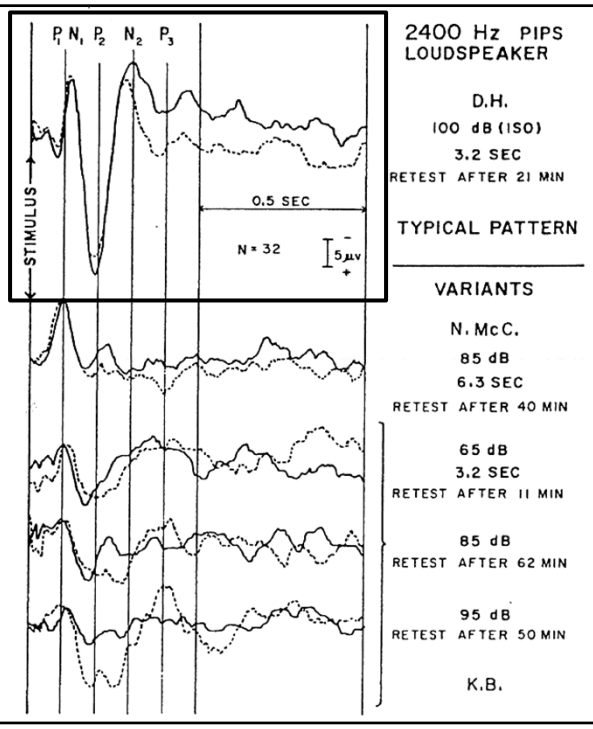
Where It All Began

Father of Auditory Evoked Responses

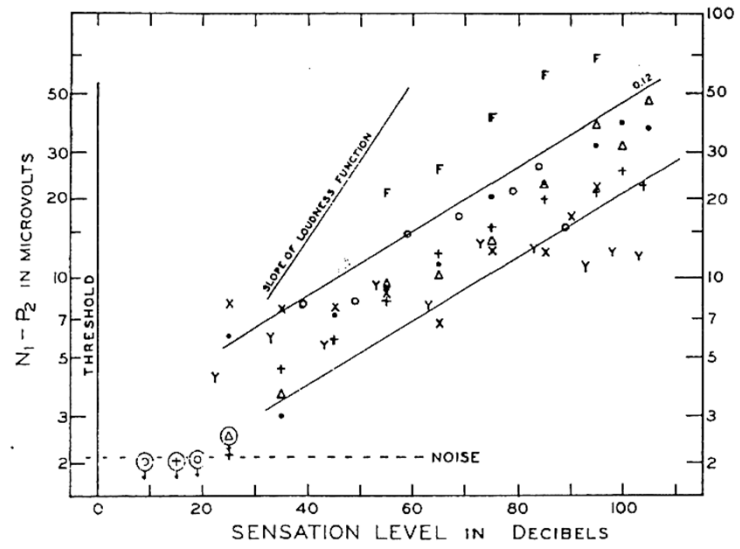
- Davis and colleagues recorded first human EEG in 1934
- Wife, Pauline Davis, discovered N1 potential in ongoing EEG in 1939
- Built his own signal averaging computer in 1963
- Relentless pursuit of “evoked response audiometry” technique in infants and young children beginning around 1965



Davis, P.A. (1939)



Davis, Mast, Yoshie, & Zerlin (1966)



Davis & Zerlin (1966)

In Current Clinical Practice

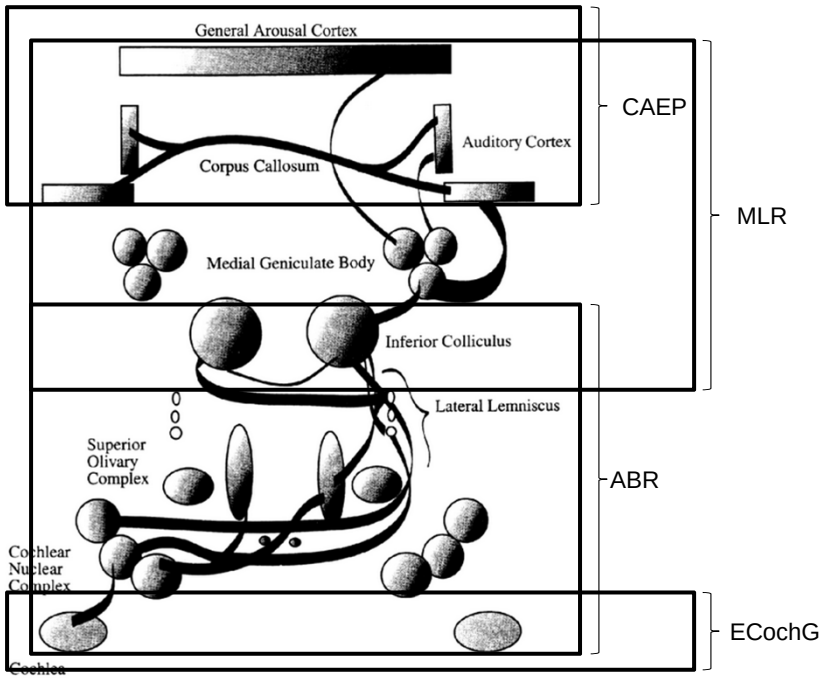
- Widespread
  - Click and Toneburst ABR
- Not as Widespread
  - ECochG
  - ASSR
  - MLR
  - LLR (CAEP)
  - P300

Table 5 Administration of Electrophysiologic Tests (n = 212)

Test	*%*
Evoked otoacoustic emissions	33
Electrocochleography	25
Auditory brainstem response	65
Middle latency responses	9
Late evoked responses	2
40-Hz potential	1
Mismatch negativity (MMN)	1
Cognitive (P-300) response	5
Electronystagmography	47
Other	7
Do not test	25

N = 212

Martin et al (1998); JAAA



With Permission from Herbert Jay Gould, Ph.D. (in Atcherson & Shoemaker, 2012)

WYSINWYG

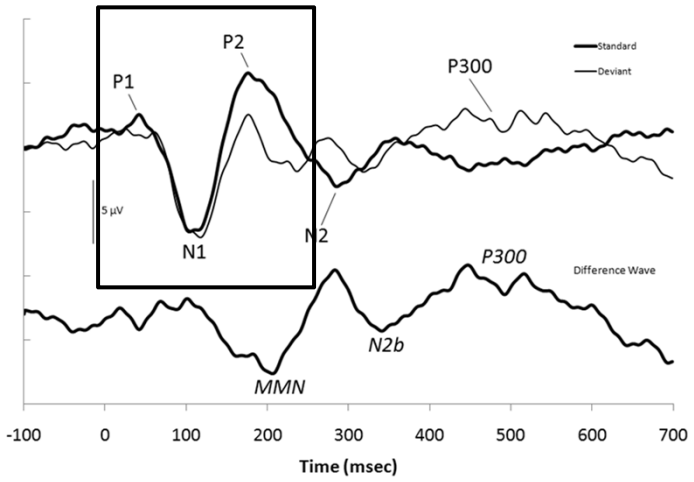
- Except for Wave I, no 1-to-1 relationship between peaks/valleys and auditory structures
  - Assumptions*:
    - Valleys = cell body activity (stationary sources)
    - Peaks = traveling action potential activity (moving sources)
    - Straight or bending pathways
    - Changes in conduction medium
    - Multiple generators beyond cochlear nucleus
- Parallel and crossed pathways
- Open and closed fields
- Changes from *action potentials* to *post-synaptic potentials* as we advance to the cortex

*See Moore (1987); Moller (1994); Eggermont (2007); Picton (2011)

First Things First

- Names: cortical auditory evoked potentials (CAEP), late auditory evoked potentials (LAEP), late auditory response (LAR), late-latency response (LLR); cortical event-related potential (CERP)
  - For this presentation, I will use CAEP which seems to be the most common and recent convention for the two measures discussed today
- Both exogenous and endogenous components (some more than others)
- Patient state needs to be awake and alert

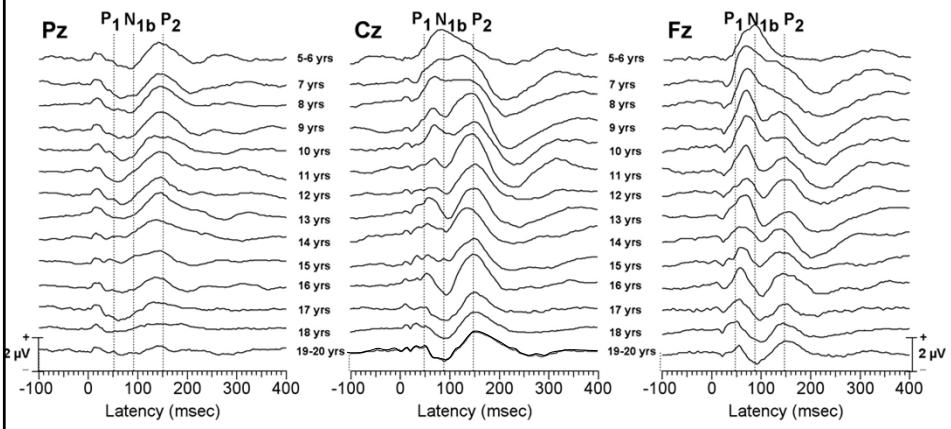
Family of CERPs

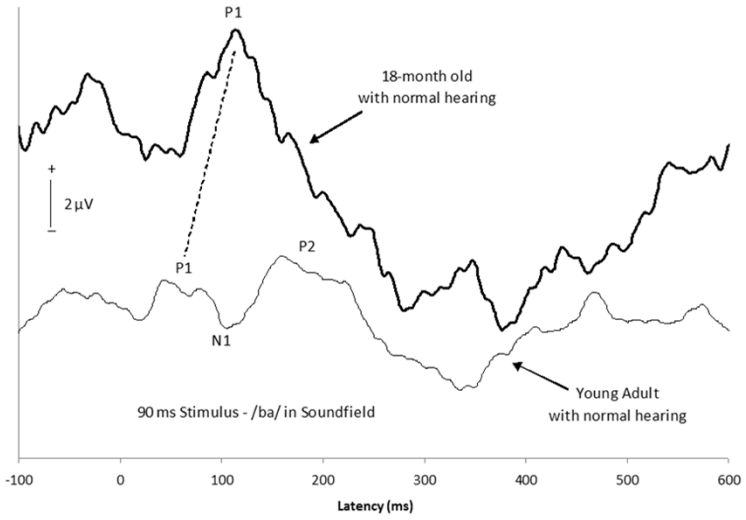


CAEP

- Occur between 50 and 250 ms (generally cannot see MLR and earlier waves)
- All "classic" components are obligatory
  - P1 (aka Pb or P50)
  - N1 (approximately 100 ms)
  - P2 (approximately ~180 ms, seen as early as 150 ms)
- Generators
  - Typically the auditory and association cortex, but not solely
  - May be influenced by reticular activating system and frontal cortex

Ponton et al. (2002)





White & Atcherson (2011)

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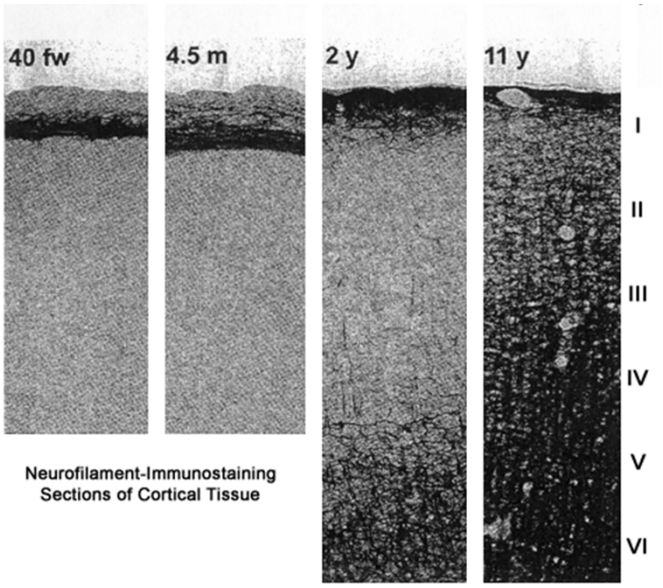

Neurofilament-Immunostaining
Sections of Cortical Tissue

Moore (2002). Ann Otol Rhinol Laryngol, 111, 7.

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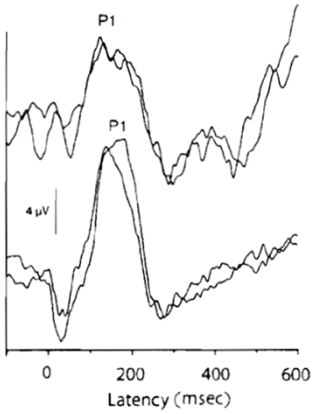
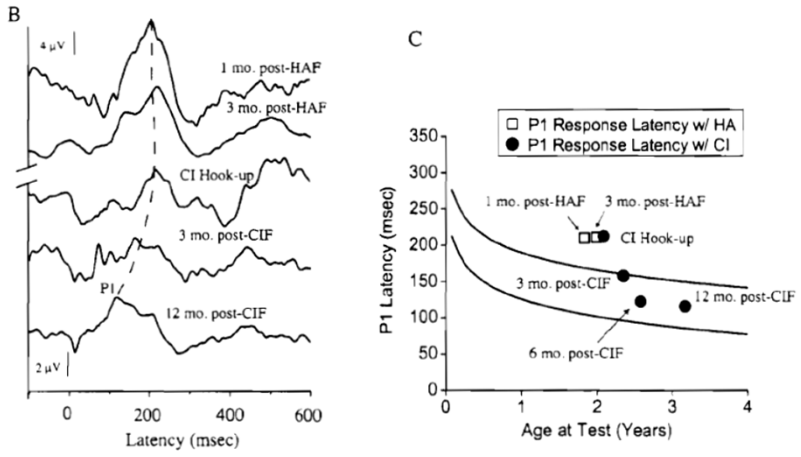
P1 Biomarker of Auditory Development

Hearing Aid

Cochlear Implant



Sharma et al. (2005)



Sharma et al. (2005)

CAEP Clinical Applications

Neurodiagnostic

- Cortical lesions
- Auditory processing deficits
- Auditory Neuropathy Spectrum Disorder (ANSD)
- Possibly tinnitus

Other

- Audiometric threshold estimation
- Audibility assessment (detection)
- Discrimination

Target Clinical Uses

- Biomarker of maturation (or lack thereof)
- Unaided versus aided
  - Benefit of amplification/implant devices
  - Signal processing features
- Threshold estimation (Cortical Evoked Response Audiometry; CERA)
  - Medico-legal cases (noise-induced hearing loss)
- Alternative response when ABR is absent
  - ANSD
  - Severe degrees of hearing loss

CAEP Stimulus and Recording Parameters

Test Protocol for CAEP

Parameter	Recommendation	Comments
Transducer	ER-3A Inserts, Loudspeaker	Threshold estimation Audibility
Mode	Monaural; Soundfield	Depends on purpose of CAEP
Stimulus Type	100 µsec Click, ~50 msec tone burst, Speech stimuli	Depends on purpose of CAEP
Rate	0.7 to 1.7/sec	High rates attenuate
Intensity	Variable	Depends on purpose of CAEP
Sweeps	200 to 500	Few as 50; as much as 1000

Test Protocol for CAEP

Parameter	Recommendation	Comments
Time Window	500 msec or more	Add -100 msec pre-stimulus; consider stimulus duration
Amplification	50,000x	
Artifact Rejection	±100 µV	May adjust specific to patient
Notch Filter	Off	
Filter Settings	0.1 to 100 Hz 1 to 30 or 40 Hz	Online filtering Offline filtering
Ocular Channel	Yes, if possible	At least one above or below 1 eye
Replication	Minimum of 2 runs	May be helpful to average replicated runs for analysis

CAEP Electrode Montage

- Montage:
  - (+)Non-inverting (active) at Cz or Fz
  - (-) Inverting (reference) at earlobe(s) or mastoid(s)
  - Ground (depends on the montage, if single channel – earlobe/mastoid, if multi-channel Fpz)
  - Ocular electrodes for eyeblink detection/rejection
- Selection of reference site will influence results
  - Non cephalic site? Nape of Neck
  - Linked earlobes? Not always recommended

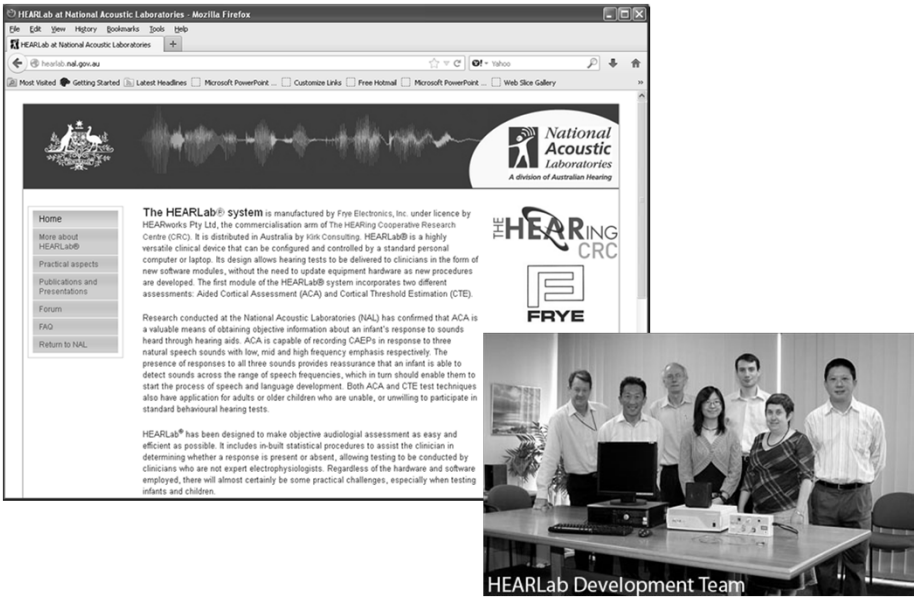
New and Existing CAEP Systems

What's Out There?

- Most commercial auditory evoked potential systems permit CAEP recordings
  - Too numerous to name all
- HEARLab System (Frye Electronics)
  - Aided Cortical Assessment
  - Cortical Threshold Estimation
- CERA (at Royal Liverpool University Hospital)
  - Research system developed and used by Dr. Guy Lightfoot and colleagues

HEARLab

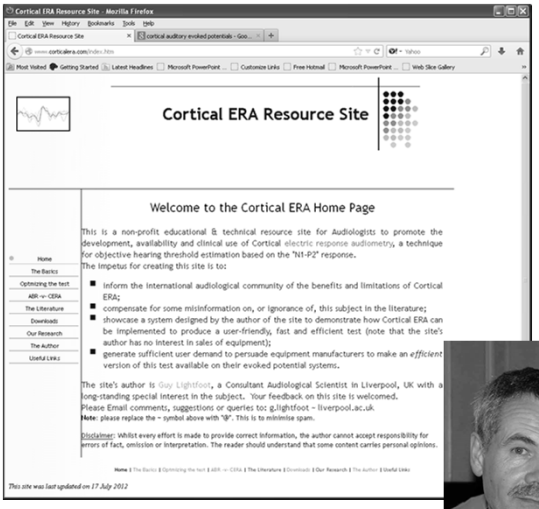
- Developed by National Acoustics Laboratory
- Manufactured by Frye Electronics, Inc.
- FDA approved since April 2013
- Cortical potential testing (P1/N1/P2)
  - ACA = aided cortical assessment (main feature)
  - CTE = cortical threshold estimation
- Uses statistical procedure (Hotelling's T^2) and *p*-value to objectively determine if response is present

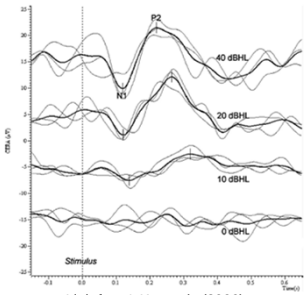


http://hearlab.nal.gov.au (Developers of the HEARLab)

CERA

- This is a research system developed by Dr. Guy Lightfoot and colleagues
- His website discussed many potential advantages for the CAEP, makes comparisons with ABR, demonstrates how the CAEP stimulus and recording parameters can be optimized, and have video examples
- Uses cross-correlation, calculates SNR, and yield *p*-value for likelihood of response

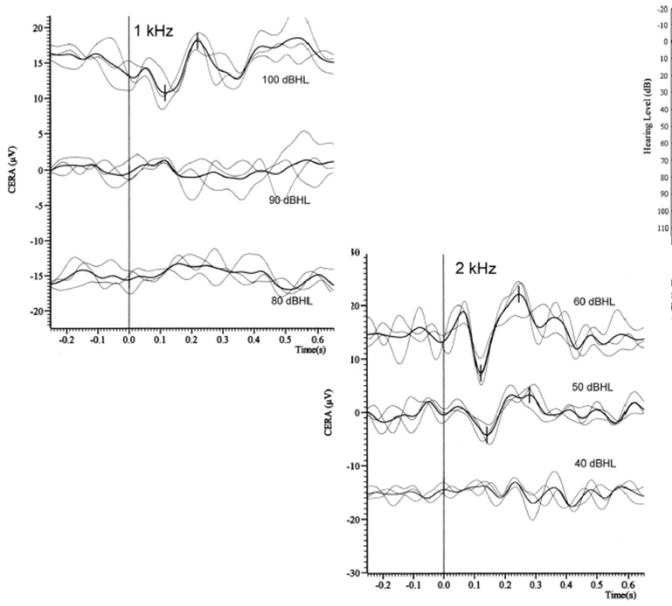




Lightfoot & Kennedy (2006)

http://www.corticalera.com (Dr. Guy Lightfoot's website)

CAEP Threshold Estimation



Pure-tone audiogram in case study 1. Bone conduction olds (not shown) indicated that the loss on the right was ineural in nature. Symbols: O, right ear air conduction;

Fig. 8. CERA waveforms of the right ear in case study 1.Top panel: 1 kHz, suggesting a threshold of 95 dB HL; bottom panel: 2 kHz, suggesting a threshold of 45 dB HL.

Lightfoot & Kennedy (2006)

EXAMPLE AT 0.5 AND 1KHZ WITH PROFOUND HEARING LOSS

Raven E. Brasseux, Audiology Capstone Project (2013)
Research Advisor: Samuel R. Atcherson, Ph.D.

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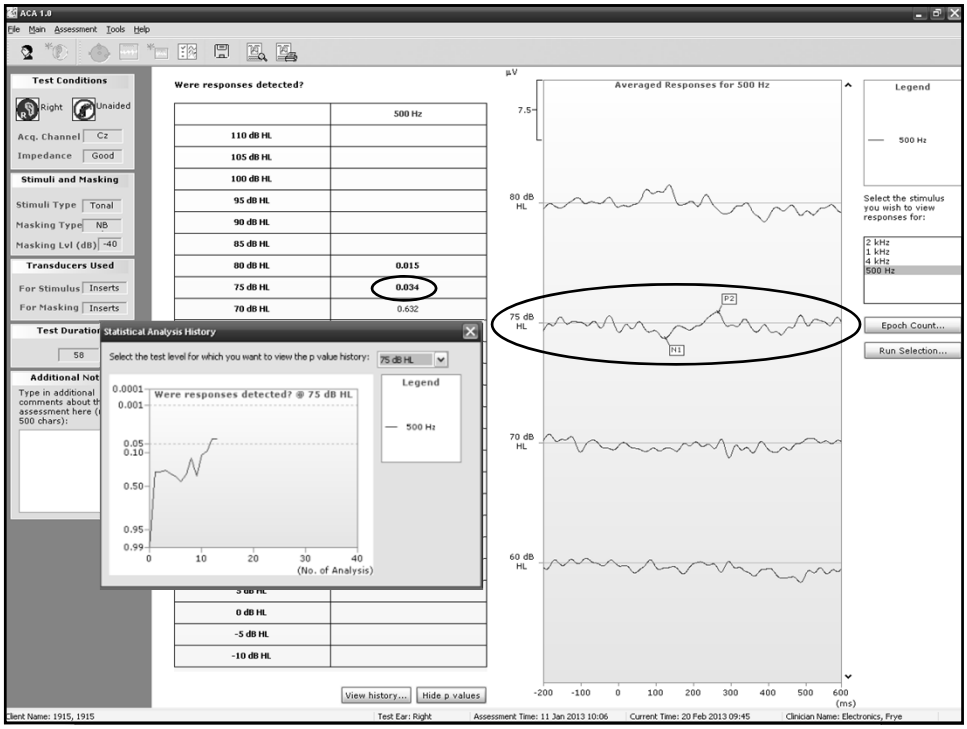
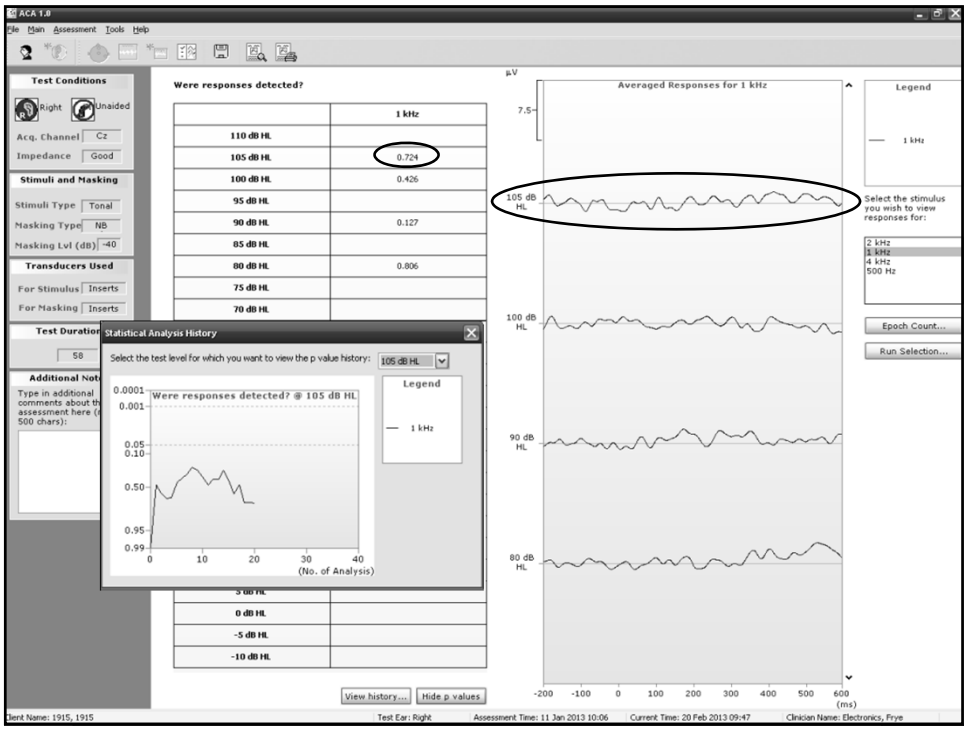

ACA 1.0
File Main Assessment Tools Help
Test Conditions
Right
Unaided
Acq. Channel Cz
Impedance Good
Stimuli and Masking
Stimuli Type Tonal
Masking Type NB
Masking Lvl (dB) -40
Transducers Used
For Stimulus Inserts
For Masking Inserts
Test Duration
58
Additional Not
Type in additional comments about th assessment here (500 chars):
Were responses detected?
500 Hz
110 dB HL
105 dB HL
100 dB HL
95 dB HL
90 dB HL
85 dB HL
80 dB HL 0.015
75 dB HL 0.034
70 dB HL 0.632
0 dB HL
-5 dB HL
-10 dB HL
View history...
Hide p values
Statistical Analysis History
Select the test level for which you want to view the p value history: 75 dB HL
Were responses detected? @ 75 dB HL
Legend
500 Hz
(No. of Analysis)
Averaged Responses for 500 Hz
µV
7.5
80 dB HL
75 dB HL
70 dB HL
60 dB HL
P2
N1
Legend
500 Hz
Select the stimulus you wish to view responses for:
2 kHz
1 kHz
4 kHz
500 Hz
Epoch Count...
Run Selection...
(ms)
Client Name: 1915, 1915
Test Ear: Right
Assessment Time: 11 Jan 2013 10:06
Current Time: 20 Feb 2013 09:45
Clinician Name: Electronics, Frye


ACA 1.0
File Main Assessment Tools Help
Test Conditions
Right
Unaided
Acq. Channel Cz
Impedance Good
Stimuli and Masking
Stimuli Type Tonal
Masking Type NB
Masking Lvl (dB) -40
Transducers Used
For Stimulus Inserts
For Masking Inserts
Test Duration
58
Additional Not
Type in additional comments about th assessment here (500 chars):
Were responses detected?
1 kHz
110 dB HL
105 dB HL 0.724
100 dB HL 0.426
95 dB HL
90 dB HL 0.127
85 dB HL
80 dB HL 0.806
75 dB HL
70 dB HL
0 dB HL
-5 dB HL
-10 dB HL
View history...
Hide p values
Statistical Analysis History
Select the test level for which you want to view the p value history: 105 dB HL
Were responses detected? @ 105 dB HL
Legend
1 kHz
(No. of Analysis)
Averaged Responses for 1 kHz
µV
7.5
105 dB HL
100 dB HL
90 dB HL
80 dB HL
Legend
1 kHz
Select the stimulus you wish to view responses for:
2 kHz
1 kHz
4 kHz
500 Hz
Epoch Count...
Run Selection...
(ms)
Client Name: 1915, 1915
Test Ear: Right
Assessment Time: 11 Jan 2013 10:06
Current Time: 20 Feb 2013 09:47
Clinician Name: Electronics, Frye

EXAMPLE AT 0.5 AND 4 KHZ WITH MODERATE HEARING LOSS

Raven E. Brasseux, Audiology Capstone Project (2013)
Research Advisor: Samuel R. Atcherson, Ph.D.

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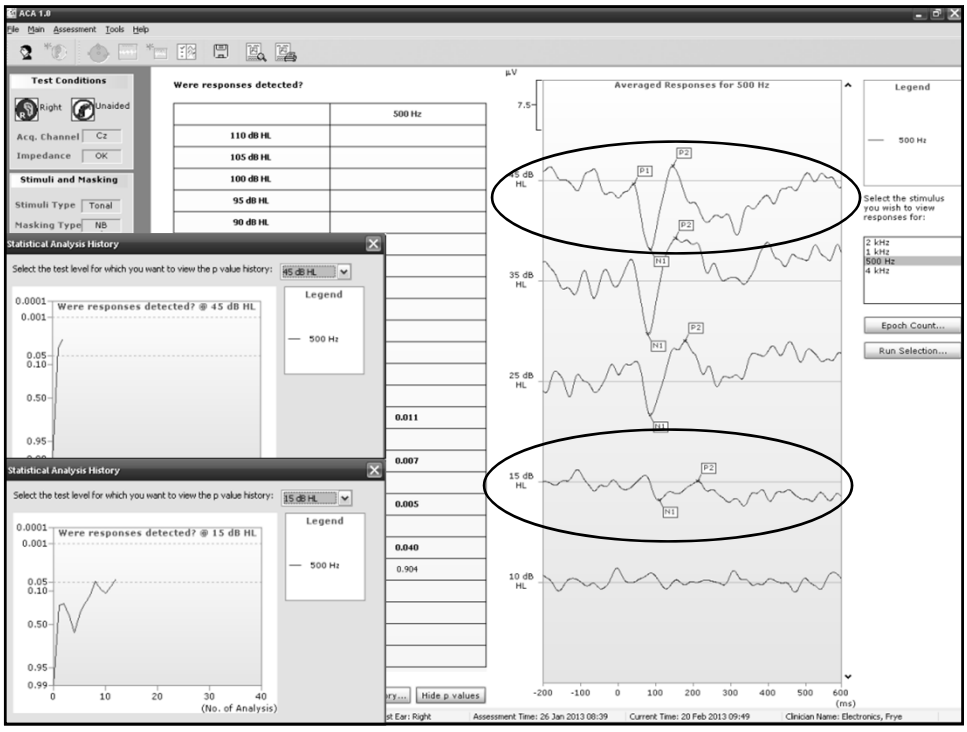
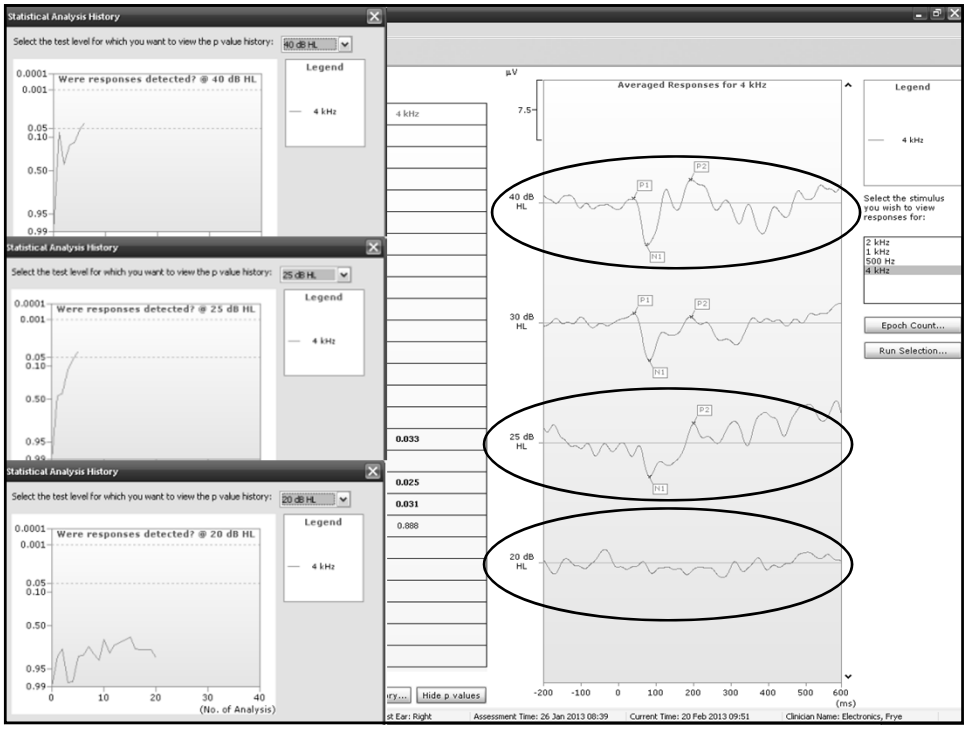
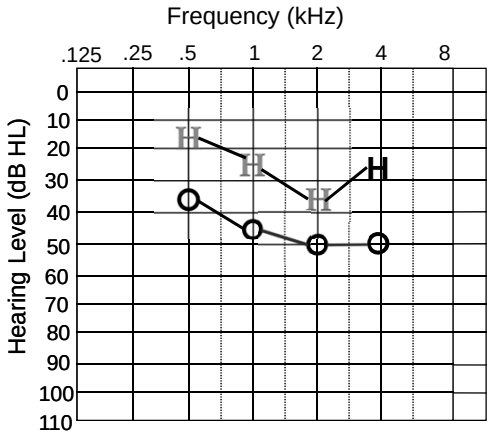




Worst Match



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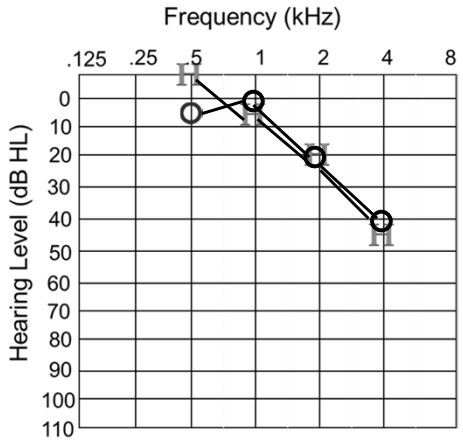
Research Advisor: Samuel R. Atcherson, Ph.D.

Best Match



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Research Advisor: Samuel R. Atcherson, Ph.D.

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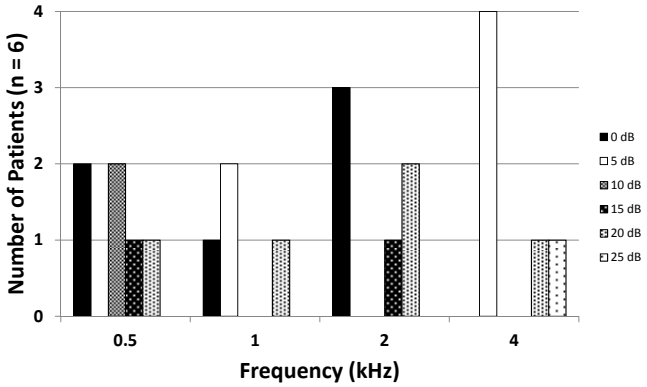
HEARLab to Behavioral Threshold Difference



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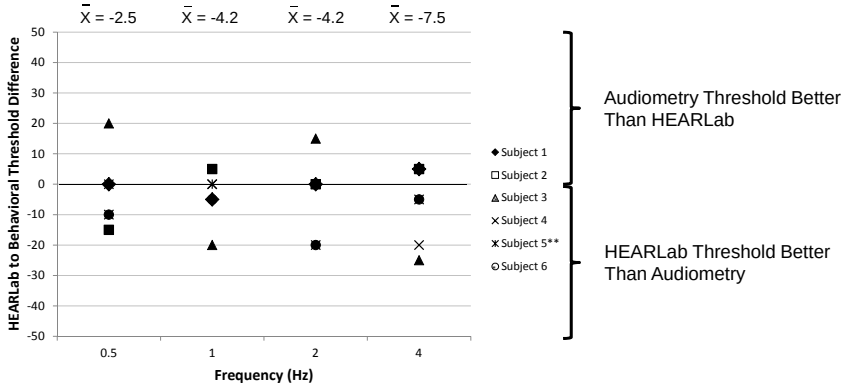
HEARLab to Behavioral Threshold Difference



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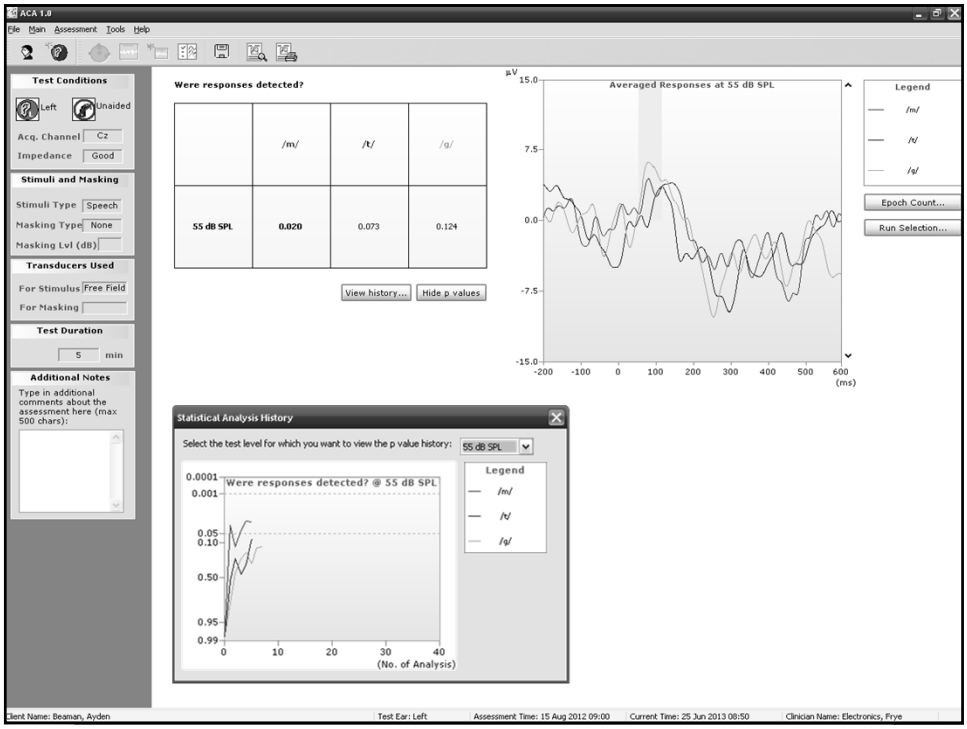
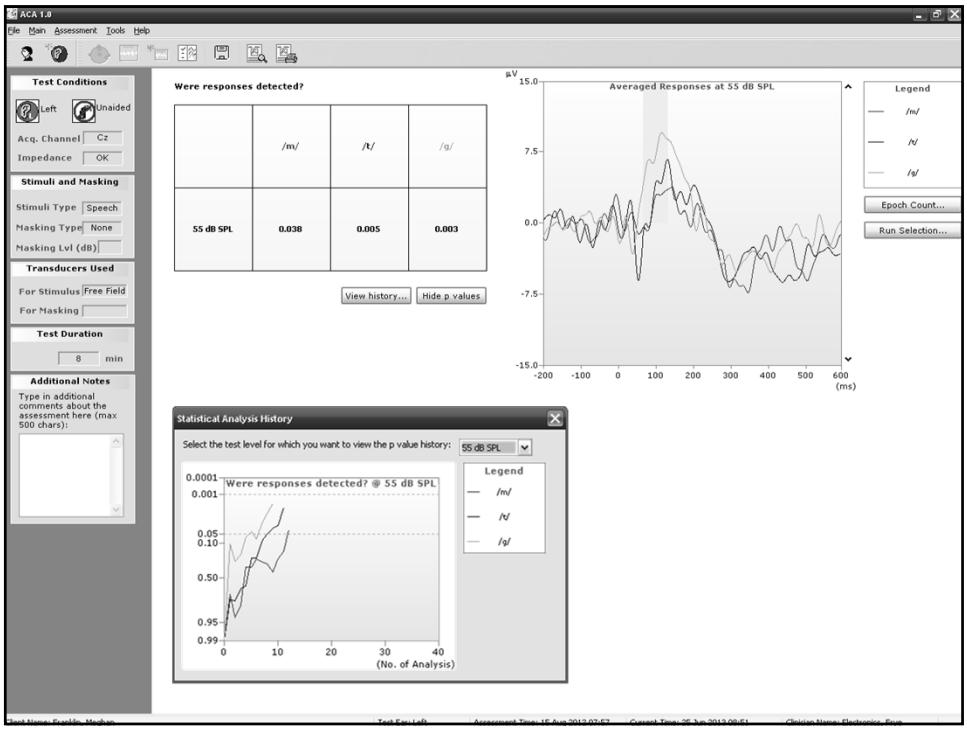
Research Advisor: Samuel R. Atcherson, Ph.D.

CAEP Audibility Assessment


ACA 1.0
File Main Assessment Tools Help
Test Conditions
Left
Unaided
Acq. Channel Cz
Impedance Good
Stimuli and Masking
Stimuli Type Speech
Masking Type None
Masking Lvl (dB)
Transducers Used
For Stimulus Free Field
For Masking
Test Duration
5 min
Additional Notes
Type in additional comments about the assessment here (max 500 chars):
Were responses detected?
/m/ /t/ /g/
55 dB SPL 0.020 0.073 0.124
View history... Hide p values
Averaged Responses at 55 dB SPL
µV
15.0
7.5
0.0
-7.5
-15.0
-200 -100 0 100 200 300 400 500 600
(ms)
Legend
/m/
/t/
/g/
Epoch Count...
Run Selection...
Statistical Analysis History
Select the test level for which you want to view the p value history: 55 dB SPL
Were responses detected? @ 55 dB SPL
0.0001
0.001
0.05
0.10
0.50
0.95
0.99
0 10 20 30 40
(No. of Analysis)
Legend
/m/
/t/
/g/
Client Name: Beaman, Ayden
Test Ear: Left
Assessment Time: 15 Aug 2012 09:00
Current Time: 25 Jun 2013 08:50
Clinician Name: Electronics, Frye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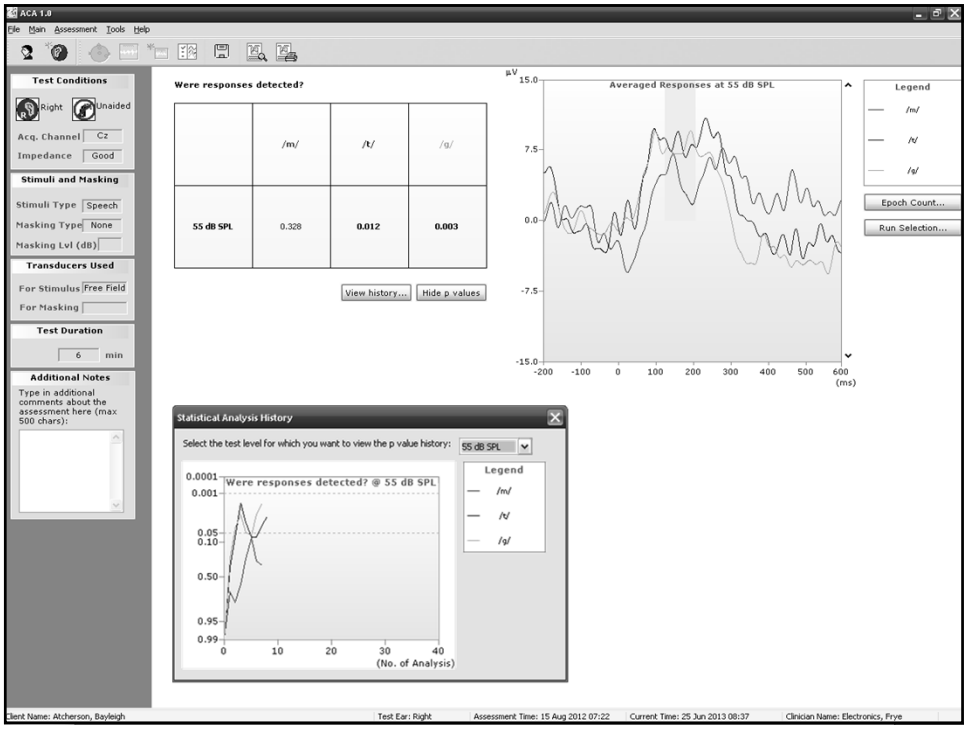
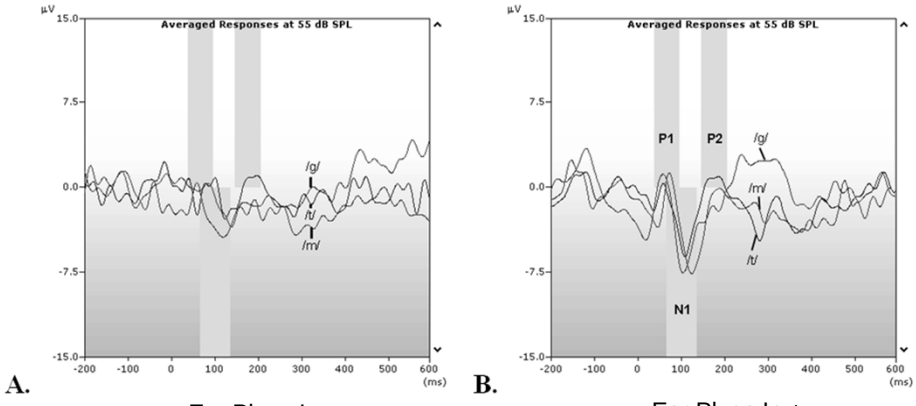
File Main Assessment Tools Help
Test Conditions
Left
Unaided
Acq. Channel Cz
Impedance OK
Stimuli and Masking
Stimuli Type Speech
Masking Type None
Masking Lvl (dB)
Transducers Used
For Stimulus Free Field
For Masking
Test Duration
8 min
Additional Notes
Type in additional comments about the assessment here (max 500 chars):
Were responses detected?
/m/ /t/ /g/
55 dB SPL 0.038 0.005 0.003
View history... Hide p values
Averaged Responses at 55 dB SPL
µV
15.0
7.5
0.0
-7.5
-15.0
-200 -100 0 100 200 300 400 500 600
(ms)
Legend
/m/
/t/
/g/
Epoch Count...
Run Selection...
Statistical Analysis History
Select the test level for which you want to view the p value history: 55 dB SPL
Were responses detected? @ 55 dB SPL
0.0001
0.001
0.05
0.10
0.50
0.95
0.99
0 10 20 30 40
(No. of Analysis)
Legend
/m/
/t/
/g/



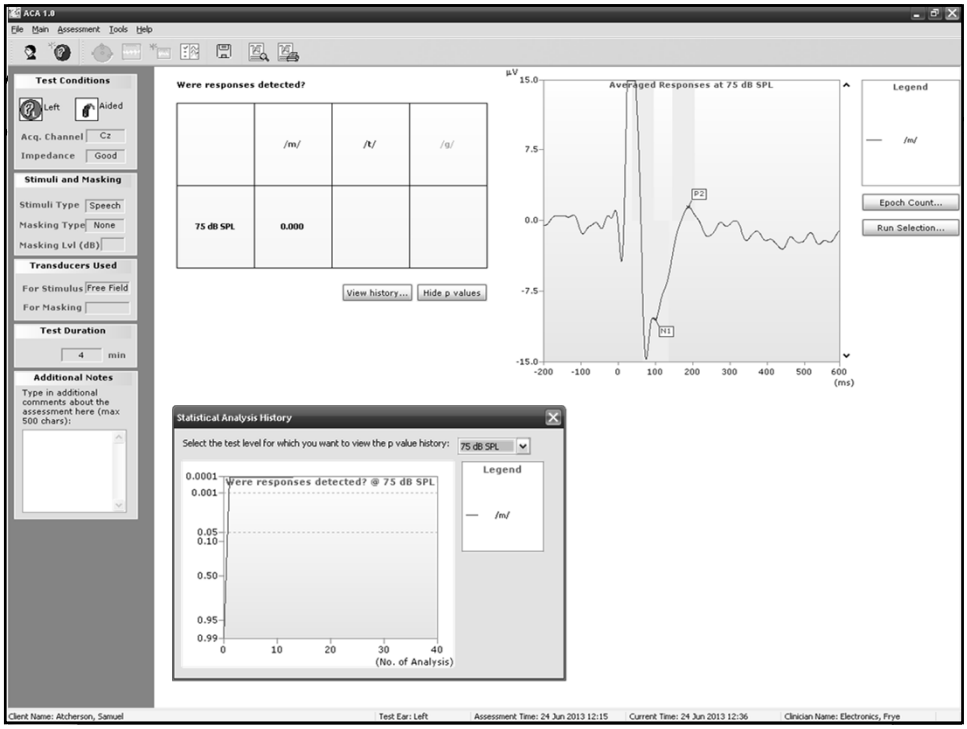
ACA Example (Audibility)

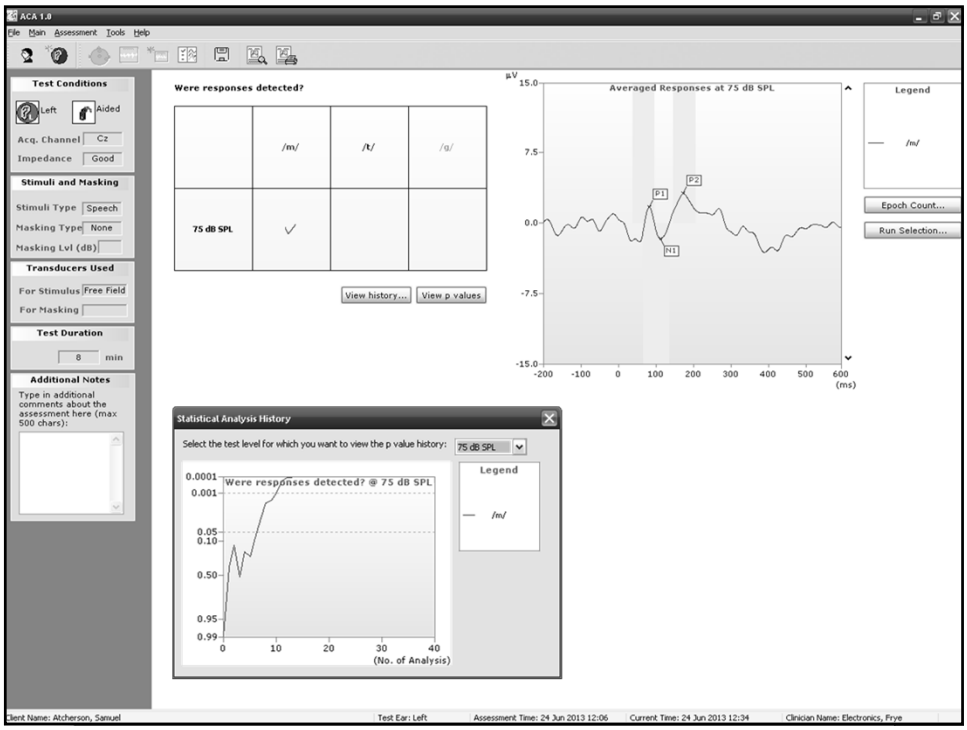


Ear Plugs In
(Simulated CHL)

Ear Plugs In +
Softband BAHA

Atcherson, Nicholson, Franklin, & Smith-Olinde (unpublished data)


ACA 1.0
File Main Assessment Tools Help
Test Conditions
Left
Aided
Acq. Channel Cz
Impedance Good
Stimuli and Masking
Stimuli Type Speech
Masking Type None
Masking Lvl (dB)
Transducers Used
For Stimulus Free Field
For Masking
Test Duration
4 min
Additional Notes
Type in additional comments about the assessment here (max 500 chars):
Were responses detected?
/m/
/t/
/g/
75 dB SPL
0.000
View history...
Hide p values
Averaged Responses at 75 dB SPL
µV
15.0
7.5
0.0
-7.5
-15.0
-200 -100 0 100 200 300 400 500 600
(ms)
P2
N1
Legend
/m/
Epoch Count...
Run Selection...
Statistical Analysis History
Select the test level for which you want to view the p value history:
75 dB SPL
Were responses detected? @ 75 dB SPL
0.0001
0.001
0.05
0.10
0.50
0.95
0.99
0 10 20 30 40
(No. of Analysis)
Legend
/m/
Client Name: Atcherson, Samuel
Test Ear: Left
Assessment Time: 24 Jun 2013 12:15
Current Time: 24 Jun 2013 12:36
Clinician Name: Electronics, Frye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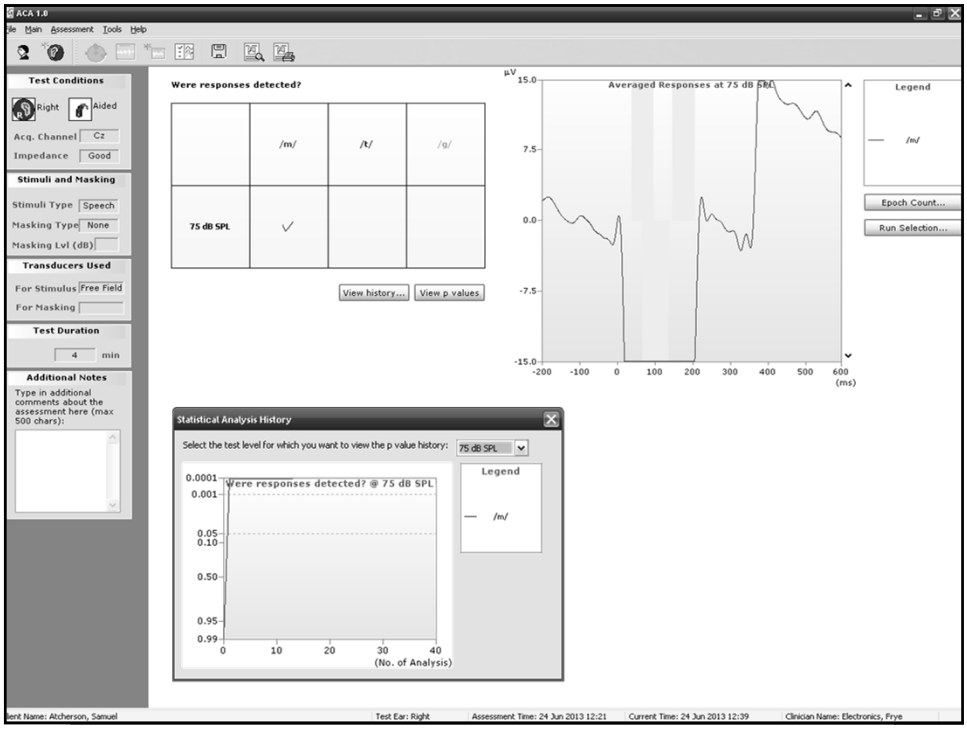
File Main Assessment Tools Help
Test Conditions
Left
Aided
Acq. Channel Cz
Impedance Good
Stimuli and Masking
Stimuli Type Speech
Masking Type None
Masking Lvl (dB)
Transducers Used
For Stimulus Free Field
For Masking
Test Duration
8 min
Additional Notes
Type in additional comments about the assessment here (max 500 chars):
Were responses detected?
/m/
/t/
/g/
75 dB SPL
✓
View history...
View p values
Averaged Responses at 75 dB SPL
µV
15.0
7.5
0.0
-7.5
-15.0
-200 -100 0 100 200 300 400 500 600
(ms)
P1
P2
N1
Legend
/m/
Epoch Count...
Run Selection...
Statistical Analysis History
Select the test level for which you want to view the p value history:
75 dB SPL
Were responses detected? @ 75 dB SPL
0.0001
0.001
0.05
0.10
0.50
0.95
0.99
0 10 20 30 40
(No. of Analysis)
Legend
/m/
Client Name: Atcherson, Samuel
Test Ear: Left
Assessment Time: 24 Jun 2013 12:06
Current Time: 24 Jun 2013 12:34
Clinician Name: Electronics, Frye



Atcherson, Damji, & Upson (2011)

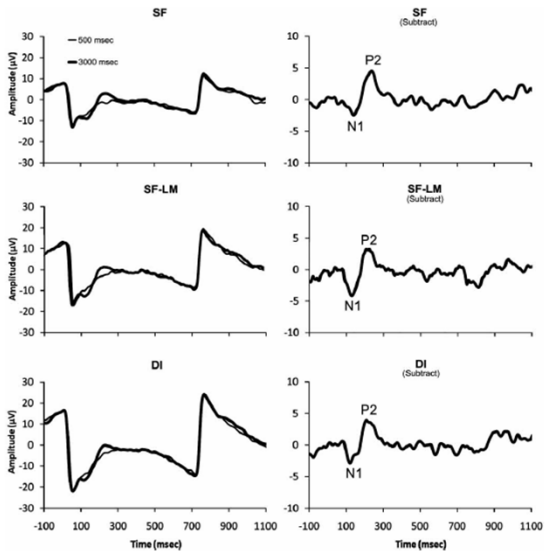


Figure 1 The unsubtracted (left column) and subtracted (right column) waveforms recorded in three different stimulus presentation setups: soundfield-only (SF), soundfield and direct-audio input with microphone (SF-LM), and direct input (DI). The CI artifact is clearly seen in the unsubtracted waveforms at stimulus onset (0 ms) and offset (656 ms). For unsubtracted waveforms, thick lines show responses to 3000 ms ISI and thin lines show responses to 500 ms. Subtracted waveforms are all quite similar despite some differences in the CI artifact magnitude seen in the unsubtracted waveforms. All waveforms were recorded at Cz.

Summary

- Most commercial systems (at the very least) will allow you to record CAEPs, and optimized systems with objective statistical tools can improve detection
- Know and understand the vary stimulus and recording parameters, and patient effects
- Lots of potential clinical uses for CAEP, but more research is required, and should not discourage clinical use
- Stay Tuned…with the literature

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  - Cliff Franklin, Ph.D.
  - Patti Martin, Ph.D.
  - Laura Smith-Olinde, Ph.D.

Recommended Reading

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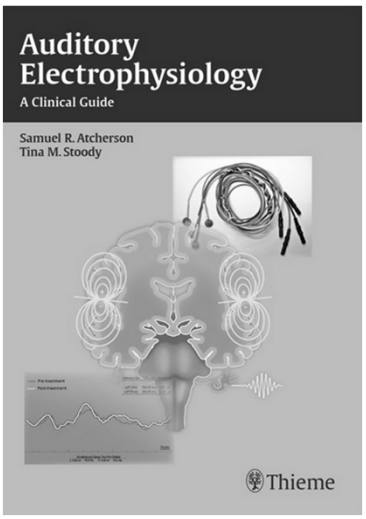
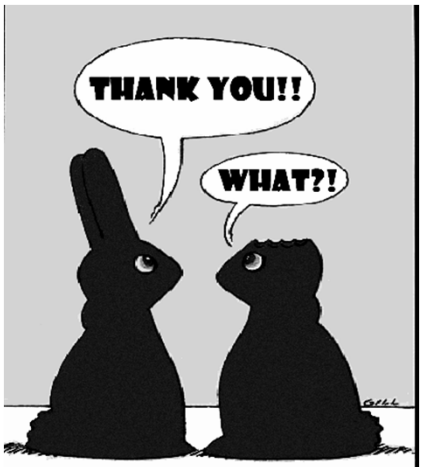
Questions?





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James W. Hall III, PhD

Clinical Applications of Electrocochleography in Audiology Today
James W. Hall III, PhD

Neurodiagnostic Auditory Evoked Responses Applications
Samuel R. Atcherson, PhD

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