Electrophysiological assessment of auditory function in infants and children

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4th Virtual Audiology Conference of Phonak
June 28-29, 2010

Overview of issues related to electrophysiology in paediatric audiology

- toneburst ABR
- use of click ABR for diagnosis of auditory neuropathy spectrum disorder
- use of cortical auditory evoked potentials for assessment of hearing aid function in infants
- electrophysiological findings in auditory processing disorder
Electrophysiological assessment of hearing

- Toneburst ABR recommended internationally for audiogram prediction
- In the absence of international or North American standard, differing values have been used for calibration and audiometric corrections
- ASSR an ‘emerging’ technique (ASHA, 2004; Stapells, 2010)
- Click ABR continues to have a key role in ANSD diagnosis
Toneburst ABR regarded as the gold standard, ASSR is ‘emerging’


“...chapter describes the two frequency-specific AEP methods currently considered appropriate for infant threshold measures: the tone-evoked auditory brainstem response (ABR), the current gold-standard measure, and the relatively new brainstem auditory steady-state response (ASSR).”
Toneburst ABR considerations

- Transducer
- Calibration values
- Conversion from ABR threshold to estimated pure tone threshold
- Response determination - determining whether the evoked potential recording consists of response plus noise or noise alone
• Insert earphones optimal for diagnostic ABR
• Benefits include more reliable placement, comfort, separation of stimulus artifact from wave I and cochlear microphonic, reduced need for masking, attenuation of ambient noise

http://www.audiomed.com/Audiomed.com/ResourcesEarPhones_files/ER-3A.pdf
Insert earphone case example, infant with ANSD: CM in right ear, negative *versus* positive polarity 86 dBnHL click ABR.
Artifactual results are possible for both ASSR & ABR

- For all evoked potential recordings use techniques to reduce stimulus artifact e.g., separating transducers & electrode cables, braiding electrode cables, good contact impedances, etc.
- Use insert earphones to separate cochlear microphonic from stimulus artifact
- Replicate traces
- Test at multiple intensity levels and include a baseline/control condition
- Only interpret evoked potential results when electrical noise is acceptably low
- Apply cross-check principle
Issues in use of ABR and ASSR for pure tone threshold estimation

• Calibration of brief stimuli using reference equivalent threshold levels (RETLs)
• Ensuring appropriate values are in the evoked potential instrument protocols
• Correcting from ABR (or ASSR) thresholds to estimated pure tone thresholds
• Not yet an international consensus
• Note that for screening ABR instruments, there is the further complication of different transducer types and calibration methods

- ...need to develop a standard for calibration of such devices for newborn screening applications
- ...prospect of missing the milder degrees of hearing loss

**Table 1.** Summary of measurement conditions and results.

<table>
<thead>
<tr>
<th>Manufacturer literature: muff on a flat plate</th>
<th>Results observed: muff on a flat plate</th>
<th>Results with Zwislocki coupler mounted on a flat plate</th>
<th>Zwicklocki coupler in a newborn manikin</th>
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<tbody>
<tr>
<td>Natus</td>
<td>{ER7 microphone}</td>
<td>{ER7 microphone}</td>
<td>{B&amp;K 4136 microphone}</td>
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<tr>
<td>Bio-logic</td>
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<td>75.2</td>
<td>82.8</td>
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<tr>
<td></td>
<td>~75.4</td>
<td>80.0</td>
<td>84.9</td>
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</table>

- ...call for an international initiative to address these challenging issues, lest we continue to work somewhat in the dark in this important area of health care
Differing ppe dB SPL reference threshold levels for tonebursts (ER-3A insert earphones)


- **NHSP** National Health Screening Protocols
  [http://hearing.screening.nhs.uk/audiologyprotocols#fileid16502](http://hearing.screening.nhs.uk/audiologyprotocols#fileid16502)

- **Stapells** 2010

<table>
<thead>
<tr>
<th></th>
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<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
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<tbody>
<tr>
<td>NHSP &amp; ISO 389-6:2007</td>
<td>Occluded ear simulator</td>
<td>23.5</td>
<td>21.5</td>
<td>28.5</td>
<td>32.5</td>
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<td>NHSP</td>
<td>2cc coupler, HA-2</td>
<td>19.5</td>
<td>16</td>
<td>20</td>
<td>23</td>
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<tr>
<td>Stapells (2010)</td>
<td>2cc coupler, HA-2</td>
<td>22</td>
<td>25</td>
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</table>
Guidelines for ABR audiometry


The signal to noise problem

http://www.courses.audiospeech.ubc.ca/haplab/aep.htm
Guidelines for determining whether ABR is clearly present (CR), absent (RA) or inconclusive (Inc.)


Decision about electrophysiological response presence should be based on evaluation of residual noise in trace, as well as presence of reproducible peak at appropriate latency range.

CAEP present
“clear response”

present?
“inconclusive”
Recommendations for optimising accurate response identification

- Follow procedures for optimising recording quality and minimising noise
- Replications at and below threshold
- 10 dB or 5 dB step size near threshold
- Appropriate response latency and morphology
- Ontario: peak-to-peak amplitude of the supposed response should be 3-4 times the size of the residual noise
- UK: peak-to-peak amplitude from III/V to following SN10 trough should be at least 3 times background noise level estimated by the average difference between traces
60 & 50 dB = CR, 45 dB = Inc., 40 dB = RA
Toneburst ABR pass at 30 dBnHL @500 Hz and 20 dBnHL @2kHz

Figure 15–5 Air conduction ABR recorded to 500 Hz (left) and 2000 Hz (right) tonebursts from a four-month-old infant with normal hearing. The time window differs between stimuli (25 milliseconds at 500 Hz versus 15 milliseconds at 2000 Hz). For tonebursts at 30 dB nHL, wave V occurs at ~12 milliseconds at 500 Hz and 9 milliseconds at 2000 Hz. This latency difference is expected based on cochlear travel times (Don, Eggermont, and Brackmann, 1979)

ABR → audiogram?

• Should a single correction factor be used to convert from ABR threshold to PTA threshold for each stimulus or should allowance be made for the nonlinear relationship between ABR and PTA thresholds (closer agreement at higher intensities?)

• Should there be a correction for the difference in stimulus intensity in an infant versus an adult ear canal?

• Having obtained an estimate of PTA, what is the confidence interval for that threshold estimate and how might this influence the approach to hearing aid fitting?
Stapells (2002) meta-analysis


<table>
<thead>
<tr>
<th>Infants with SNHL</th>
<th>Mean threshold difference (dB)*</th>
<th>Standard error (dB)</th>
<th>95% confidence interval (dB)</th>
<th>Number of individuals</th>
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<td>+4.9</td>
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<td>+2.4 - +7.3</td>
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<td>1.1</td>
<td>-1.6 - +2.7</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>-8.1</td>
<td>2.0</td>
<td>-12.1 - -4.1</td>
<td>35</td>
</tr>
</tbody>
</table>

*Threshold Difference = Tone-ABR threshold (in dB nHL) minus pure-tone behavioral threshold (in dB HL). Thus, “-10 dB” indicates the tone-ABR threshold (in dB nHL) is 10 dB lower (better) than the pure-tone behavioral threshold (in dB HL).*
Berlin et al. (2008) continuum of Auditory Neuropathy Spectrum Disorder (ANSD)


Recording cochlear microphonic (key diagnostic indicator of ANSD)

• Separate polarity, high level, click stimuli used to diagnose ANSD
• Important to distinguish stimulus artefact from cochlear microphonic using no-stimulus run (insert earphone tube clamped)
• Stimulus artefact occurs before acoustic stimulus reaches the eardrum, due to the insert tube delay

Rance et al. (2005)
Behavioural audiogram is variable – see unaided audiograms below of 7 children with ANSD, all with speech & language delay (aged 4-8 to 9-0 years, mean 6-7 years) [see also F-G Zeng et al., 1999]
Variable speech perception outcomes for children with ANSD receiving hearing aids or cochlear implants (Rance & Barker *Otology Neurotol* 2008 29:179-182)

Absent EABR
ABR cannot be used to predict the audiogram in ANSD

FREQUENCY (Hz)

500 1k 2k 4k 8k

0 10 20 30 40 50 60 70 80 90 100 110

OAEs

CM & abnormal ABR
Electrophysiological approaches to predicting audiological outcomes in ANSD (PTA, speech perception, auditory behaviour)

- **ABR**
- **ASSR**
- **ECochG – Cochlear Microphonic**
Electrophysiological approaches to predicting audiological outcomes in ANSD

- **ECochG – Summating & Dendritic Potentials**?
  - Gardner-Berry et al. (in preparation)

- **CAEP**
McMahon et al. (2008)

• N=14 diagnosed with ANSD at 3-24 months
• 2 main types of ECochG waveforms evoked by an 8-kHz tone burst

  (A) delayed latency summing potential waveform with or without a residual CAP
  (B) normal latency summing potential followed by a broad negative dendritic potential (DP*) waveform

*DP distinguished from N1 of the CAP by the lack of increase in latency with decreasing sound level
McMahon et al. (2008) results

- Group 1 no obvious dendritic potential (n=15 ears)
  - results consistent with a **presynaptic** lesion
  - latency of the SP waveform delayed
  - 7/8 subjects with this pattern had good EABR waveforms

- Group 2 dendritic potential present (n=11 ears)
  - results consistent with a **postsynaptic** disruption
  - SP latency within normal range
  - assumed that the DP waveform is local (non-neural) potential produced by the sum of EPSPs generated near the round window (close to ECoG recording electrode)
  - six of the subjects who showed ECochG waveforms with a normal latency SP and a DP present showed poor or absent EABR waveforms after cochlear implantation
ECochG waveform in ANSD

- Can be difficult to interpret due to presence/absence of CM, SP/APP, AP, DP
- One strategy for separating out neural from cochlear components is to increase stimulus presentation rate

Examples of ECoG recordings associated with ANSD and moderate hearing loss on pure tone audiometry
If this was a true neural response, expect to see a decrease in amplitude with the higher rate because the neural component would adapt.

This doesn’t appear to be happening so we may simply be seeing electrical potential associated with hair cell activity.

*Slide courtesy of Kirsty Gardner-Berry; this case had normal EABR*
Children with ANSD with cortical responses present have better speech perception.

Case Example: Better CAEP than ABR in ANSD

- Born at 24 weeks
- Prolonged oxygen therapy
- ABR thresholds
  - R at 2000 Hz 80 or >95 dB on different occasions (not due to middle ear)
  - L no response 500 Hz at 90 and no response 2000 Hz at 95 dB
- Aided VRA thresholds unclear but ≈65-85 dBA
- Cortical responses present bilaterally unaided at 65 dB SPL for speech sounds
Unaided (blue) versus aided (red) right ear cortical responses to 65 dB SPL speech sounds. Note that ABR thresholds indicate severe profound loss.

Cf. case examples in Pearce et al. (2007)
Case example: Poor ABR & poor CAEPs (Pearce et al., 2007)

- full term
- family history of two paternal relatives who used CIs
- diagnosed with ANSD at ten weeks of age
- initial ABR tests (and repeat testing), using click stimuli, showed no response at the maximum limit of 100 dB nHL for the left ear and
- repeatable wave V response at 100 dB nHL for the right
- clear CMs and robust DPOAEs bilaterally
- digital hearing aids at four months of age
Case example: Poor ABR & poor CAEPs (Pearce et al., 2007)

- poor auditory skills development
- despite high gain hearing aids, no repeatable CAEPs for 65 dB SPL speech sounds
- no inner ear abnormalities
- extensive family counselling
- received a cochlear implant at one year, four months
Objective evaluation of hearing aid fitting using cortical auditory evoked potentials (CAEP)

- Does the child have access to the full range of conversational level speech sounds when wearing their hearing aids?
Objective hearing aid evaluation using cortical auditory evoked potentials

Inadequate gain provided by hearing aids
- Absent CAEPs to 65 dBSPL speech sounds
- Increase overall gain, change amplification strategy

1. CAEPs now present

2. CAEPs still absent → CI

High powered hearing aid

CI
CAEP latency vs. age (NAL 2008 data & Anu Sharma et al.)

Function = $271 - 106 \log_{10}(12 \times X) - 7.8 (\log_{10}(12 \times X))^2 + 6.94 (\log_{10}(12 \times X))^3$
CAEPs

- Considerable maturational effects
- Can be elicited by short and long speech sounds
- Latencies reduce when children with hearing loss receive a CI, but this effect depends on duration of auditory deprivation prior to CI
- CAEP latencies and amplitudes affected by maturation, auditory deprivation, noise, auditory processing disorder
- CAEPs provide an objective measure of central auditory nervous system function
- Role in APD clinical diagnosis still unclear
Effect of noise at +3 dB SNR on /da/ CAEP for N=90 children (mean 9.8 yrs, SD 1.6) with suspected APD (N=65 confirmed) [Sharma, Purdy, Kelly, in preparation]

N90_Visit 1_quiet.avg
N90_Visit 1_noise.avg
Girl 9 years old: abnormal FPT, gap detection and supralinguistic abilities; passed DDT and compressed/reverb speech; normal performance IQ, phonological awareness, auditory comprehension.

Minimal change with addition of noise, immature cortical response.

P1

N$_{250}$

/dā/ noise

/dā/ quiet
CAEPs – clinical applications

- Aided CAEPs in children with hearing loss indicate speech sound detection
- May be indicative of auditory/oral prognosis in ANSD
- CAEPs in quiet versus noise an objective measure of auditory processing (e.g. to measure FM effectiveness)
- CAEP latencies are increased and amplitudes are longer in children with APD compared to control group children (Purdy et al., 2002 etc.)
- Sensitivity of measure to APD in individual children not established – main application likely to be for younger children in whom behavioural measures are unreliable
Summary

- ABR – need careful attention to protocols for accurate results
- ANSD – electrophysiological measures used to diagnose, but prognostic value not yet clear
- CAEPs – range of clinical applications

- Clinical utility of all measures depends on clinician’s ability to obtain high quality recordings using reliably calibrated equipment

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Suggested reading


Standards for ABR stimulus calibration

- IEC 60645-3 Ed. 2.0 (2007). Electroacoustics - Audiometric equipment - Part 3: Test signals of short duration