Infant Hearing Aid Evaluation Using Cortical Auditory Evoked Potentials

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Motivation for investigating aided auditory evoked potentials

Objective hearing aid validation techniques needed for young infants and difficult-to-test children
Overall Aim

To use obligatory cortical auditory evoked potentials (CAEP) to assess the effectiveness of hearing aids fitted to infants.
Specific Aims

• To show that CAEP can be reliably recorded in awake infants with normal hearing and in infants with hearing loss wearing hearing aids
• To show that CAEPs are sensitive to changes in stimulus and hearing aid frequency response characteristics
• To devise methods for using CAEPs to guide fine-tuning of hearing aids
Topics to cover

- Rationale for using cortical responses
- Characteristics of cortical responses
- Cortical responses in normal hearing adults and infants
- Cortical responses in hearing-impaired infants and children
- Future work
How do you get from hearing threshold assessment to speech perception?

- Hearing aid prescriptive procedures aim to make the full frequency range of speech detectable and comfortably loud to the hearing impaired child.
- Real ear measures such as insertion gain or the real ear to coupler difference (RECD) techniques can be used to ensure that prescriptive targets have been met.
from hearing threshold assessment to speech perception?

• Having met the hearing aid prescriptive target how do we ensure that speech is detectable and speech sounds can be discriminated in a very young infant or a child with a limited behavioral repertoire?
Types of auditory evoked response that have been used to objectively evaluate hearing aid function

- Auditory brainstem response (ABR)
- Auditory steady state response (ASSR)
- Obligatory cortical auditory evoked potential (CAEP)
Why are we using obligatory cortical responses to evaluate speech perception in infants?

• more likely to correlate well with perception
• can be elicited by a range of speech phonemes
• reliably present in awake young infants
• can be present in children with auditory neuropathy/dys-synchrony
An important distinction

• We are not trying to verify hearing aid fitting by measuring aided thresholds using evoked potentials.

• We are trying to validate the hearing aid fitting by showing that speech stimuli across the speech spectrum evoke a neural response at the level of the auditory cortex and therefore are likely to be perceived by the infant.
Some results of previous CAEP research
Cortical auditory evoked responses traditionally used for objective assessment of hearing thresholds in adults

• In 1965 Hallowell Davis showed good agreement between cortical and pure tone thresholds in children
• For many years cortical response audiometry has been regarded as the “gold standard” for objective electrophysiological hearing assessment
Maturational effects on cortical evoked response morphology: adult & infant responses differ

Cortical responses can be elicited by different speech phonemes in newborns.

D. Kurtzberg (1989) 
n=4 normal hearing infants
Effects of auditory deprivation and cochlear implantation in profoundly deaf children (Ponton et al, 1999)

- P1 development delayed by time without sound
- P1 & especially N1-P2 do not mature fully if time without sound is too long
Speech stimulus effects in adults

• Differences in cortical response morphology & latencies between speech stimuli
  – Koch et al 1997
  – Sharma & Dorman 1999
  – Kraus et al 2000
  – Power 2000
  – Ostroff et al 1998
Frequency specific ABR and aided CAEP in 7-month old (J. Gravel et al, 1989)
What do these studies tell us about CAEP?

- slow maturational time course
- dominated by a large positive “P1” peak in infants that becomes earlier and smaller with maturation as P2 appears
- present to a range of speech sounds at birth
- group differences in morphology between sounds
- deafness causes P1 latency delay that can be corrected if amplification is provided early
- aided cortical responses can be recorded
NAL research into cortical responses (initial work began in December 2000)
Methodology

- Participants are awake
- Loudspeaker-presented sounds
- Loudspeaker at 1.5 m and 45º (several milliseconds delay before sound reaches ear)
- Flat loud speaker response: 100 Hz to 10 kHz
- 1-2 test sessions (sometimes more for hearing-impaired subjects if hearing aids adjusted)
- Session length dictated by the child (can be 30 minutes up to 1.5 hours but typically 45 minutes)
Stimuli

- 750 ms interstimulus interval for initial studies, but changed this later to 1125 ms
- Tonebursts 20-20-20 ms rise-plateau-fall
- Speech stimuli
  - native Australian male speaker, excised out of running speech
  - stops include release and some transition
  - total durations 32 → 141 ms for /gae/ → /mae/
Recording

- Individual epochs and average files saved
- 100 responses per average
- Artifact reject +/- 100 µV in infants & +/- 75 µV in adults (includes eyeblink channel in adults)
- Time window -100 to +500 ms (later +600 ms)
- On-line filtering 0.1-100 Hz
- Off-line analysis: baseline correct, linear detrend, 30 Hz low pass filter
- 3-7 channels (always C3, Cz and C4)
Choice of Electrode Montage?

D. Kurtzberg (1989) found differences in CAEP at midline versus lateral electrodes.

Stimulus:
- /da/
- 85 dB SPL
- 170 ms long
- ISI = 2.7 s
Adult subjects

- N=14
- normal hearing (n=12) or slight (20-25 dB) hearing loss (n=2)
- mean age 36.7 yrs (sd 10.8 yrs)
- watching subtitled videos
- stimulus order randomized
- 8 stimuli (500, 1k, 2k, 4k Hz, dae, gae, kae, tae, mae)
Adult grand average waveforms at Cz

Time (ms)

-100 0 100 200 300 400 500

1.25μV

Speech

Tones
The most interesting findings with respect to applying these results to children

- Robust cortical responses were obtained to a wide range of real speech stimuli
- Different speech stimuli produced statistically significant differences in cortical response latencies and amplitudes
Three speech stimuli

mae

gae

tae
Research goals for infants with normal hearing

- to characterise cortical responses to supra-threshold speech and tonal stimuli
- to determine whether responses are sensitive to differences in stimulus characteristics
Infant subjects

Experiment 1: Stimulus Effects

• N=20 including two sets of girl twins (one identical, one non-identical)
• 8 boys, 12 girls
• Age 3 1/2 - 7 months (mean 5, sd 1 month)
• Full term except n=2
• Normal hearing based on parent report and bilateral TEOAE
• Listening binaurally
• Stimulus order randomized in 2 blocks x 5 stimuli (500, 2 kHz, /tae/, /gae/, /mae/)
Infant grand mean waveforms at Cz

+/tae/ black
+/gae/ blue
+/mae/ green
500 Hz red
2 kHz pink
Post-Auricular Muscle
One infant’s 4-channel /tae/ recording

- Channel /tae/
  - Recording between back of pinna and mastoid
## Infant repeated measures ANOVA results

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<th>Peak</th>
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<th>Montage</th>
<th>Stimulus x montage</th>
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So … significant group differences between stimuli

But … do individual participants have reliably different responses to different stimuli?
• Divide each record into 50 millisecond time bins
• Average voltages across data points within each time bin
• Use these averages as variables in MANOVA analysis
• Result is probability of two stimuli coming from different distributions
Number of infants (N=20) with significantly different cortical responses to pairs of stimuli

Based on MANOVA at C3, 101 to 500 ms post-onset, in eight bins each 50 ms
CAEP in Infants with Normal Hearing

Experiment 1 Conclusions

» responses reliably present
» significant latency and amplitude differences across stimuli
» significant differences in CAEP wave shape for /mae/ versus /tae/ and /mae/ versus /gae/ for most children
Experiment 2. Stimulus Duration

- N=11 (7 F, 4 M), 3-7 months (mean 5.1)
- /tae/ and /mae/ 141 versus 79 ms
  » duration not significant for latency or amplitude

Experiment 3. Inter-stimulus Interval

- N=10 (5 F, 6 M), 3-6 months (mean 4.4)
- interstimulus intervals 750, 1125, 1500 ms
  » trend for greater response amplitudes with longer ISI (p=.052), no change in latencies
Cortical responses in children with hearing impairment
Research questions for hearing-impaired infants & children

• Are aided cortical responses recordable in infants and children with moderate-profound loss?
• Are responses consistent with hearing loss and hearing aid characteristics?
• Do responses show consistent changes with altered hearing aid settings?
Key hypothesis

• CAEP recorded to speech stimuli while a hearing-impaired child wears a well-adjusted hearing aid are more like those recorded from normal-hearing children than are those recorded while the child is wearing a sub-optimally adjusted hearing aid.
Hearing Impaired Infants & Children

- N=40 aged 2 months to 18 years (31 right, 33 left ears)
- variety of etiologies
- one conductive ear, others sensorineural
- 40% had other disabilities such as autism or developmental delay
- stimulus 65, 75, or 85 dB SPL via loudspeaker at 45º azimuth
- hearing aids fitted using NAL-NL1 formula
% of ears tested with aided cortical response to 65 dB SPL speech stimulus

- mae: 13 moderate, 18 severe, 8 profound
- gae: 8 moderate, 10 severe, 7 profound
- tae: 13 moderate, 20 severe, 7 profound
Enhanced cortical P1 response to /gae/ with increased hearing aid gain where initially there was no response when hearing aid was set conservatively relative to the measured tone-burst ABR thresholds.
ANOVA: Age, hearing loss, electrode effects on latencies & amplitudes

- P1 amplitude declines with age at C3 and C4, increases with age at Cz (/tae/, electrode x age interaction, p=.015)
- P1 amplitudes greatest for contralateral electrode (/tae/, p=.025)
- /tae/ & /mae/ P1 & N1 latencies decrease with age (p≤.003) and increase with hearing loss (p≤.022)
Are cortical responses sensitive to hearing aid fine tuning changes?

Subjects: N=10 aided children, 6-12 years, moderate-severe hearing loss
Average cortical responses /mae/ vs. /tae/ for NAL-NL1 setting
Effect of filter response variation: MANOVA results for individual children

- 80% of children showed significant CAEP changes for slope changes of +/- 6 dB
- 60% of children had significant CAEP changes for slope changes of +/- 3 dB
- Not all children had aid fittings that matched NAL targets, therefore better results are possible
An electrophysiological equivalent of the Ling (1976, 2002) sound test?

Katrina Agung (MAud thesis)
Ling-plus study

- Original 5 Ling sounds (ee, oo, ah, s, sh) plus “or” [poor], “u” [put] & “m”
- N=20 (aged 3-9 months)
- Awake
- Listening binaurally via loudspeakers
- Recording electrode Cz
- -100 to 600 ms time window
- Artifact reject +/- 150 μs
- Two runs of 50 averages
- 100-ms natural (female) speech tokens
Individual infant’s results showing robust responses across stimuli
Grand Average n = 16 infants
Individual infants’ MANOVA results (N=20)

• The most consistently different responses (75% of infants) were to /ss/ versus /oo/ 

• The least consistently different responses (15% of infants) were to /ss/ versus /sh/
Summary

• CAEP present in most aided infants and children with moderate-profound hearing loss

• Different stimuli often lead to different response shapes within individual hearing-impaired children

• Aided CAEP are consistent with and sensitive to changes in hearing aid characteristics in many hearing impaired children
Case study
Case A @ 5-months

• Initial aid fitting based on toneburst ABR when he had effusion, conservative gain settings
  - CAEP show poor low-frequency /mae/ response, good /tae/ response

• Grommets inserted, improved behavioral responses, gain reduced →
  - enhanced /mae/, poorer /tae/ response
  - likely that combination of grommets plus reduced gain appropriate for low frequencies but too much gain reduction in high frequencies
Aided cortical responses /mae/ and /tae/

Response of brother with normal hearing
N=20 normative data
Case A @ 5 months
Aided CAEP to /mae/ and /tae/

1st appointment, middle ear effusion
Response of same-age brother with normal hearing
N=20 normative data
Case A @ 5 and 7 months
Aided CAEP /mae/ and /tae/

- 1st appointment, middle ear effusion
- 2 months later after aid adjustment and grommets
- Response of same-age brother with normal hearing
- N=20 3-7 month old infants’ normative data

/mae/

/tae/
Practical suggestions and conclusions
Practical aspects

• Infants need to be happy and awake (timing of appointments and mother/child-friendly test set-up very important)
• Distraction needs to be engaging but not exciting (if baby is too active recording will take too long and/or will be too “noisy”)
• Individual runs last about 4 minutes
• Need to pause if baby too vocal
• Monitor infant’s state closely
Effect of suddenly falling asleep on CAEP in one infant (3 month old, /tae/)

Notice that the post-auricular muscle response (PAMR) from the brainstem is attenuated but still present during sleep.
Practical aspects: Electrodes

- Ask family not to use cream or hair conditioner on baby’s head as electrodes will slide off
- Electrode application needs to be fast, painless, and secure
- Drape electrodes away from face and hands
- Impedances < 5 kOhms preferable
- Skin “sandpaper” & wet gel electrodes work well
- May need traditional electrodes on top of head if there is lots of hair (only rarely, usually OK if you can flatten hair to reveal scalp)
- Remove electrodes with lanolin-based cream
Interpreting results: Types of abnormal responses

- Absent
- Reduced amplitude
- Prolonged latency
- Unusual morphology (?)
Applications of CAEP in pediatric hearing aid evaluation

• Determining the audibility of speech sounds
  – aided or unaided
  – for clients who can’t respond reliably for behavioral testing e.g., infants, children with developmental delay
  – results may suggest the need to consider alternative management

• Guide to fine tuning of hearing aids
  – reasonable, but yet to be fully validated
  – increase low-freq gain if /mae/ response absent
  – increase high-freq gain if /tae/ response absent
  – technique cannot indicate excessive gain
Our next goals

- Assess hearing aid responses by both behavioral and electrophysiological methods in the same children to cross-validate the methods.
- Assess whether the outcomes of early electrophysiological tests can predict later speech outcomes for children with auditory neuropathy/dys-synchrony.
- Incorporate stimuli and statistical procedure (MANOVA) into an easy-to-use clinical device.
CAEP…. a promising new (old) technique for hearing aid assessment

Thank you
😊 Participants & families
😊 Gladesville Baby Health Centre
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😊 Royal Institute for Deaf and Blind Children
😊 Sydney Cochlear Implant Centre
😊 The Deafness Centre, Children’s Hospital at Westmead