Evaluating hearing aid effectiveness in infants using evoked cortical responses

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Evaluation of aided functioning in infants

Universal new born screening

Early fitting of hearing aids

Need for an evaluation method

Confirmation of fitting

Fine-tuning needed

Cochlear implant needed
So baby, how does it sound?

Objective hearing aid evaluation for:
- young infants
- difficult-to-test people

Why the rush?
Language ability 6 months after implantation

Language at 6 months after implantation
Wilks’ lambda = .71507, R^2(2, 28) = 5.5785, p = 0.00914

Covariate means:
MonFit: 10.97917

Diagram showing PLS-4 standard scores over implant age category.
Why use *cortical* responses?

Why cortical responses to evaluate hearing aid fitting in infants?

- Reliably present in awake young infants
- More likely to correlate well with perception
- Can be elicited by a range of speech phonemes – close to desired outcomes
- Stimuli handled reasonably by hearing aids
- Can be very frequency specific if needed
Where do cortical responses come from?

The end of the road
Cortical responses in adults with normal hearing
Adult grand mean waveforms at Cz

Speech

Tones

1.25μV

Time (ms)
Cortical responses in infants
Maturational effects on cortical evoked response morphology

- N=8-16 per grand mean
- Cz site
- stimulus = 10 click train, 2 ms ISI @ 65 dB SL
- rate = 1.3/s


- Fewer neuro-filaments in young children, especially in more superficial cortical layers thought to generate N1

(Ponton, Moore & Eggermont 1999)
Children with CI (Sharma, 2002) and NAL aided hearing impaired infants/children (N=40) using speech stimuli presented at 65 dB SPL.
Maturation with time “in sound”

Ponton and Eggermont (2007):
Latency matures consistent with the time “in sound”

Sharma (2002):
Provided implantation occurs by 4 years of age

Auditory system maturity
Cortical responses in infants to different speech sounds

Grand Average n = 16 infants
Why *not* obligatory cortical responses?

- variable shape across ages
- variable shape with auditory experience
- variable shape from person to person
- variable shape from time to time (state of person, especially sleepiness)
- stimulus
- Inter-stimulus

An automated method of response detection and response differentiation.

high skill level needed to read responses
Automatic detection of cortical responses

Desirable characteristics

- No reliance on a template
- Able to use information from contributing portions of waveform
- Able to discount non-contributing portions of waveform

\[ \text{Hotellings } T^2 \]
Analysis using Hotellings $t^2$ statistic

- Divide each record into 50 ms time bins
- Average data points within each time bin
- Use these averages as variables in Hotellings $t^2$ analysis
- Result is probability of the waveform being random noise

$$X = a_1X_1 + a_2X_2 + \ldots + a_9X_9$$

Test: is there any set of weighting coefficients for which $X \neq 0$?

Presentation of average response in series
Receiver Operating Characteristics – Expert judges

In-series - 60 presentations

ROC – 200 repetitions; adults with normal hearing to moderate loss
For hit rate of 80% and false alarm rate of 5%, \( d' = 2.5 \).
Infants: Hotellings versus experts

Normal hearing infants aged 7 to 16 months

Growth of amplitude with SL
adults; tonal stimuli
Loudness growth above threshold

Hellman & Meiselman, 1990

Effect of response amplitude on detectability

100 epochs
Adults, tonal
10, 20, 30 dB SL

z-level A = -0.5956 - 0.6753 * x

P < 0.05
Detectability (adults; tonal stimuli)

Significant responses – normal hearing and hearing impaired

Adults; tonal stimuli (n=100 or 200)
Proportion with responses present - adults

Normal hearing
Hearing Impaired

p < 0.05

Normal hearing
Hearing Impaired

p < 0.05

Normal hearing
Hearing Impaired

p < 0.05

Normal hearing
Hearing Impaired

p < 0.05

but infants move around!
### Residual noise level

\[
\text{rms noise} = \frac{\text{standard deviation}}{\sqrt{n}}
\]

### Residual noise levels (for 100 epochs)

**Awake adults**

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**Awake infants**

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But also larger responses.
Detectability versus residual noise

Proportion with responses present (p<0.05) – normal hearing infants; 100 epochs

Sensation level (dB)

- Noise <3.4 uV
- Noise >3.4 uV

Include condition: "SL"=30
Cortical responses and functional performance

Do cortical responses tell us about real-life auditory performance?

Parent’s Evaluation of Aural/oral performance in Children (PEACH) Questionnaire

- Parents are asked to describe their baby’s aural/oral skills based on real-life experiences (listening in quiet and in noise and alertness to environmental sound).

- Scores are assigned based on the number of observed behaviors and how frequently these occur.

- Final overall score of 0 – 40 can be calculated (and reported as a percentage).
Functional deficit vs number of cortical responses present at

![Graph showing functional deficit vs number of cortical responses](image)

- **N = 24; p = 0.001**
  - 12 sensorineural
  - 7 auditory neuropathy
  - 5 multiply disabled

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**Functional deficit versus cortical score**

- **All aided children**
  - $r_s = 0.60; n=24; p = 0.001$

- **SN only**
  - $r_s = 0.61; n=12; p = 0.02$

- **MD only**
  - $r_s = 0.82, n=5; p = 0.04$

- **AN only**
  - $r_s = 0.36; N=7; p = 0.22$
Cortical responses as evidence of speech sound discrimination?

Multivariate Analysis of Variance

- Divide each record into 50 ms time bins
- Average data points within each time bin
- Use these averages as variables in MANOVA analysis
- MANOVA finds the combination of variables that best distinguishes two or more stimuli
- 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 Cz, 101 to 500 ms post-onset, in eight bins each 50 ms

Are /tae/ & /mae/ cortical responses different in hearing impaired children?

- 10 subjects (5 with poor hearing aid progress), 14 ears
- 8 infants 6-20 months, 2 children 4 & 10 years
- 4 moderate, 8 severe, 2 profound ears
- 64% had different responses based on individual ANOVA

- 9 subjects, 9 ears
- 6-12 years
- sloping, mild-severe hearing loss
- hearing aids fitted to NAL-NL1 but not optimally
- 55% had different responses
Grand Average n = 16 infants

Number of subjects (out of 20) with significant differences between responses

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**Conclusion:** Cortical responses to sounds presented in isolation are better suited as indicators of detection.

**Future work:** Cortical response to change, as a measure of discrimination

**Reducing measurement variability**
(random electrical signals)

→ Speeding up measurements
→ Increasing validity of interpretation
Active electrodes

Capacitive Coupling 50 Hz

Passive Electrodes
Capacitive Coupling 50 Hz

Active Electrodes

Capacitive Coupling 50 Hz

Passive Electrodes  Active Electrodes
Finding thresholds with cortical responses

What does an absent cortical response mean?

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
Davis (1965) Cortical evoked potential versus behavioural thresholds

Clinical applications and implications

Clinical applications of corticals

- For finding thresholds (when awake)
- Determining whether speech sounds are audible
  - aided or unaided
  - for patients who can’t respond reliably by behavioral testing e.g., infants, multiply disabled people.
Clinical implications of corticals

Significant response is obtained to speech at 65 dB SPL

- Morphology normal for age → All is well
- Morphology abnormal for age → Repeat test

No significant response is obtained to speech at 65 dB SPL or to speech at 75 dB SPL

- Low residual noise → Re-check fitting; Consider all options
- High residual noise → Draw no conclusion!

Clinical implications of corticals (cont)

Mixed results (and noise is low)

- No /t/ response → Review HF gain or loss estimate
- No /g/ response → Review mid-freq gain or loss estimate
- No /m/ response → Review LF gain or loss estimate

Mixed results (and noise is high) → Draw no conclusions from missing response!
Hearing loss at birth ….. for parents

Parental denial

Unaided testing at conversational levels

Working towards a solution

Aided testing at conversational levels

Pessimism and hopelessness

Practical implementation of cortical testing: HearLab

Disclosure: NAL will get a royalty for each unit sold.

Thank you: The HearLab development team – Teck Loi, Barry Clinch, Isabella Tan, Dan Zhou, Scott Brewer, Ben Radzyn
Aim

To make available to clinicians:
- Stimuli - m, t, g (pure tones)
- Statistical tests (Hotellings $t^2$, MANOVA)
- Age appropriate norms
- Residual noise monitoring
- Active electrodes
- Future NAL developments

To supplement revenue available for research
Corticals for more advanced measurements

To summary
Application for auditory neuropathy spectrum disorder (AN)

- 15% of babies found to have hearing loss at birth in NSW have AN
- Management unclear (no device, hearing aid or cochlear implant)
- Rance showed close relationship between cortical response in older children and benefit from hearing aids
- Cortical responses more indicative than ABR of behavioural thresholds

Case Study 2

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ABR NR

28/8/03 - NR
Case Study 2

**ABR**
- 28/8/03 - NR
- 15/3/04 - NR

**CAEP**
- 14/10/03
- 30/3/04

**ECochG**
- 15/3/04
**Case Study 2**

Applying auditory neuropathy spectrum disorder (AN)

- 15% of babies found to have hearing loss at birth in NSW have AN
- Management unclear (no device, hearing aid or cochlear implant)
- Rance showed close relationship between cortical response in older children and benefit from hearing aids
- Cortical responses more indicative than ABR of behavioural thresholds
- Gap detection worse in people with AN
- Investigating gap detection by cortical responses
/Ah/ 2 second duration

Indicator of binaural functioning

N1 and P2 cortical amplitudes for /a/ in noise are enhanced when 700 μs inter-ear delay is introduced to noise in normal listeners (N=8, 19-32 years)
Summary

Cortical responses
- For checking the audibility of speech sounds
- Indicate the maturity of the auditory system
- Automatic detection as good as experts
- Residual noise size critical
- For checking hearing thresholds when the patient is awake

Thanks for listening

www.nal.gov.au
Auditory System: Central Pathways

Perception

SC: Visual spatial map

VNLL: Fed by contralateral CN

AVCN: Frequency analysis,
PVCN: Timing well preserved
DCN: Inhibitory circuits, pinna cue detection?
Parallel processing
Needs to be fed to develop & maintain

Adult P1 amplitude: smaller than infant P1, stimulus effects, no montage effect.
N1, P2 amplitude

- N1, P2 amplitude advantage at Cz in adults for all stimuli