Australian Hearing has introduced the use of Cortical Auditory Evoked Potential assessment into the paediatric clinical pathway. It also has application in the management of certain adult clients.

This document contains two sections:

1. Background:
   - Provides an overview of the role of aided cortical auditory evoked potential assessment (ACA) in infant habilitation programs and the validation of the HEARLab equipment;
   - Provides information to help understand and interpret the data

2. Clinical practice:
   - Explains Australian Hearing’s protocols for undertaking aided cortical auditory evoked potential tests.
   - Outlines protocols for fine-tuning hearing aids based upon the results of ACA.

BACKGROUND:

(i) What are Cortical Auditory Evoked Potentials?

Cortical auditory evoked potentials (CAEPs) are brain responses that are evoked by sound and processed in or near the auditory cortex. CAEPs can be recorded using an electroencephalogram (EEG) by placing electrodes on the person’s scalp in appropriate positions. The responses must be recorded when the subject is awake.

Nearly all types of stimuli evoke CAEPs, ranging from long tone bursts to short speech sounds. The response waveform appears irrespective of whether the person receiving the sound attends to the sound or completely ignores it. For an adult, the response waveform is characterized by a small positive peak (P1) about 50 ms after stimulus onset, a large negative peak (N1) about 100 ms after stimulus onset, and a second large positive peak (P2) about 170 ms after stimulus onset. The shape is very different, and more variable, for infants, often comprising just a single broad peak around 200 ms after stimulus onset. The shape changes as the auditory cortex matures, right through the teenage years up to early adulthood (see Appendices 4 & 5).

(ii) CAEPs and aided evaluation.

Cortical auditory evoked potentials are applicable to infant hearing aid evaluation. While it is feasible to use Auditory Brainstem Responses (ABR) and Auditory Steady State Responses (ASSR) to assess hearing aid fitting when behavioural measures cannot be employed, recording Cortical Auditory Evoked Potentials (CAEPs) for this purpose has several benefits over recording the early latency electrophysiological measures. First, the acoustic features that are relevant for speech detection and perception can be presented as stimuli (Kurtzberg et al, 1988). Second, the integrity of the response pathway through to the cortex can be assessed (Kraus et al, 1998). There may also be additional advantage in some cases of Auditory Neuropathy Spectrum Disorder (ANSD), as a cortical response may be observed (Pearce et al 2007) while the ABR cannot, and hence ABR results alone may be misleading. CAEPs can be reliably recorded in young awake infants with normal hearing when stimuli are presented at conversational levels (Cone-Wesson and Wunderlich, 2003). They have also been recorded to verify the audibility of stimuli presented at conversational level in infants fitted with hearing aids or in infants who are under evaluation for hearing aid fitting (Cone-Wesson and Wunderlich, 2003). Additional differences between CAEP and ABR/ASSR are: the CAEP shows up much later after the stimulus onset; signal amplitudes are much larger and thus fewer repetitions are necessary; and the presence and absence of CAEPs correlate better with perception.
(iii) Validation of HEARLab as a tool for Aided CAEP assessment.

Nearly a decade ago, the NAL Research Development Team commenced work on a Computer-Based Audiological Test Suite, which is commercially available as the HEARLab™ system. The first module of the HEARLab instrument has been implemented for CAEP assessment. The introduction of state-wide universal newborn hearing screening in NSW in 2002, as well as NAL’s encouraging results with CAEP research at the time, were the impetus for prioritising software development for assessing CAEPs in the sound-field (Aided Cortical Assessment Module, or ACA Module). The HEARLab system also allows assessment in response to tonal stimuli, by air or bone conduction (Cortical Threshold Estimation, or CTE Module).

Evaluation of the HEARLab system was undertaken in two stages. The first part of the study was a literature review, in which each component of HEARLab’s software specifications (e.g., stimulus types and characteristics, transducers and response parameters) were justified, with regard to earlier scientific findings. In 2007 the second part of the evaluation took place. This involved a clinical study in which recordings using HEARLab’s two modules were compared with responses recorded simultaneously from a second device (i.e., Neuroscan™) that is widely used for clinical and research purposes.

Participants in this study were: 14 adults, 6 with normal hearing, and 8 with hearing loss (CTE evaluation), and 13 infants, for 6 of whom complete data sets were analysed. When infant and adult-generated responses from the two systems were compared, very few significant differences were found between systems. This provided evidence that the HEARLab system results are as accurate as those obtained with recording systems that have been in wide clinical and research use.

(iv) CAEPs and unaided evaluation for Auditory Neuropathy Spectrum Disorder (ANSD).

CAEPs that are recorded in response to stimuli that are presented free field have limited value where clear consistent unaided evoked potential information is received as it is known that there is good correlation between ABR or ASSR results and behavioural hearing thresholds. However, where there are discrepancies with the initial evoked potential results and ANSD is diagnosed, unaided cortical results may give further indication about behavioural hearing levels.

The decision about whether to aid and the amount of amplification prescribed for ANSD can only be made on the basis of behavioural test results (King et al 2005, Northern 2008). For very young babies this relies on Behavioural Observation Audiometry and is very highly dependent upon the infant’s test state. More recently, research into CAEPs with children with ANSD shows that where there is detection of the stimuli at low levels shown by a CAEP, there is likelihood that behavioural testing will show hearing at normal levels or a mild hearing loss. (Pearce et al 2007). There has also been shown to be a strong correlation to scores on the Parent Evaluation of Auditory-oral performance in Children (PEACH) (Ching & Hill, 2007) which is a measure of functional hearing (Golding et al 2007) so both of these measures should be employed for children with a diagnosis of ANSD.

The presence of (unaided) CAEPs at a level of 55dBSPPL allows the audiologist to eliminate all but a mild hearing loss.

What data does HEARLab provide?

The Aided Cortical Assessment (ACA) module is used to evaluate whether speech is audible to the wearer of a hearing aid. Three speech stimuli with low (/m/), medium (/g/), and high (/t/) frequency emphasis are each presented in the free-field at input levels of 55, 65 & 75 dB SPL. These signals have a presentation time long enough to activate the compression circuits of a hearing aid, making it an effective tool for determining whether the amplification produced by the hearing aid provides a signal that is actually detectable at the cortical level of the listener. The unaided response can also be measured, and results can be compared with the aided cortical responses.

A statistical analysis* of each response (a "p-value") is automatically calculated to determine the likelihood that a CAEP has been detected in response to the test signal. The audiologist can verify this analysis by visually examining the measured cortical response (waveform).

*Australian Hearing
A study conducted by NAL found that Hotelling’s $T^2$ was at least equal to, if not better at detecting cortical responses than the average human expert (Golding et al., 2007).

Clinical Applications of Aided CAEP testing

Aided CAEP results are an extremely useful addition to the paediatric hearing aid evaluation test battery.

- CAEP assessment can add information to more traditional assessment techniques, such as Behavioural Observation Audiometry, as a means of confirming that sounds of low, mid, and high-frequency emphasis are audible to the aided child.
- For many children, particularly those with moderate to severe hearing loss, CAEPs can be used to demonstrate aided benefit to parents, which may help encourage consistent hearing aid use.
- Where some CAEPs are absent, the pattern of results (considering both stimulus type and presentation level) can give a general guide to adjusting a child’s hearing aid in order to obtain audibility for speech at conversational levels.
- Where CAEP responses are repeatedly absent, even after increases to the gain-frequency response of a child’s hearing aids, results may help parents and professionals in considering moving to cochlear implant evaluation (Ching et al, 2013).

Reports from NAL researchers and Australian Hearing Audiologists indicate that parent’s reaction to the assessment is generally extremely positive.

Cochlear implant evaluation

Studies at NAL and by other researchers have shown that the implant can produce electrical signals (“artefacts”) that adversely affect the CAEP waveform. Until these modifications are released, testing of children wearing cochlear implants is not recommended. Note: actually performing CAEP testing will cause no harm to the CI wearer, however, the results cannot be interpreted.

Interpretation of Results

Spectral content of the stimuli

The peak emphasis of the current speech stimuli in HEARLab is:

/M/ 250 Hz
/G/ 1250 Hz
/T/ 3250 Hz

When $p<0.05$ this is reported as a response being present for that test stimulus and presentation level. For further explanation of significant $p$-values see Appendix 1.

Use of other information available to the clinician

Important! In interpreting CAEP assessment results, the clinician should take other clinical information about the child into account, as well as the child’s state and other test conditions during the assessment. If there is doubt about interpretation, repeating the CAEP assessment may be helpful. In particular, PEACH results are a useful adjunct. Another NAL study (Golding et al, 2007) showed that, for a group of 31 aided infants and young children, there was a statistically significant correlation between the presence/absence of CAEPs and PEACH results.
CLINICAL PRACTICE:
Aided Cortical Auditory Evoked Potentials now form part of the Australian Hearing clinical pathway for initial hearing aid fittings for children and other clients whose hearing aid prescription has been based upon an audiogram that was estimated from evoked potential tests such as Auditory Brainstem Responses (ABR) and Auditory steady state Response (ASSR).

CLINICAL PATHWAY - for a summary refer to Appendix 2.

Aided cortical potentials form part of the initial fitting program for
- Clients whose hearing aid fitting has been based upon an audiogram estimated from evoked potentials. (This will mostly refer to infants referred from Universal Newborn Hearing Screening).
  - ACA is not a priority for children who have a unilateral hearing loss (normal hearing in one ear) or a loss that is estimated to be <45dBHL since these children are expected to detect the test stimuli in both the aided and unaided conditions. It may be considered if required to help parents accept their child’s hearing loss.
- children who have Auditory Neuropathy Spectrum Disorder
  - Both aided and unaided CAEPs are used in the management of ANSD

The test is also applicable for:
- Clients who have additional disabilities which have led to a fitting based upon minimal behavioural information or which have made it difficult to evaluate the benefit of their hearing aid fitting.
- Clients who are being considered for cochlear implantation due to poor speech perception performance or speech/language development
- Unaided testing of children who have ANSD.

At what stage of the clinical pathway should the test be performed?

When conducted as part of an initial fitting program, aided cortical assessment should be planned to occur after the first follow up appointment. This allows us to provide support and encouragement to the family in their management of their child’s hearing aids before embarking upon the evaluation. Ideally aided cortical assessment will occur within 6 weeks of the first follow up, when the family agrees. Other clients should be referred as appropriate to their program management.

Prior to referring a client for aided cortical assessment the audiologist will ensure that:
- The audiogram used to prescribe the gain, frequency response and maximum power output has been placed on file (King, 2010)
- Tone burst ABR results have been converted from dBnHL to dBHL to generate an estimated behavioural audiogram for the purposes of hearing aid fitting. Australian Hearing currently recommends using correction factors based on Vander Werff et al. (2009) recommended correction figures.
- The hearing aid frequency response has been matched as closely as possible to the NAL-NL2 prescription targets for 50, 65 and 80dBSPL input levels, and the MPO targets for the estimated audiogram.
  - The target Speechogram results for 55 and 65dBSPL inputs (the HEARLab test levels) have been generated using the NAL NL2 software and put on file.
- The client’s earmoulds are comfortable and the aids are not feeding back.
- The family understands what is involved in the HEARLab test and where it will be performed (if not at the home centre), and agrees to testing. A parent information sheet is available.

When conducted to help decide whether to fit amplification to infants who have ANSD, cortical assessment should be performed without hearing aids, and the results considered as part of a test battery in conjunction with the results of functional assessment using the PEACH and, if cortical potentials are not present, with results of Behavioural Observation Audiometry.
Aided Cortical Evoked Potential test protocol

Initial test run

1. Check the frequency response of the hearing aids with a new battery in the hearing aid.
2. Check tympanometry (if the child is known to be distressed by tympanometry it may be preferable to leave the test until after the CAEP assessment).
3. Insert both hearing aids into the ears and turn the aids on.
4. Present the three stimuli at 65dBSPL with the child facing the speaker (0º azimuth).
5. If a response to a 65dBSPL stimulus is obtained, reduce the level of that stimulus to 55dBSPL and retest.
6. If no response is obtained, increase the stimulus level to 75dBSPL and retest.

Notes:

As with any infant assessment, the audiologist should consider the state of the child and the information required, to determine whether it is most appropriate to start with a monaural aided test or binaural testing. Monaural aided testing is performed simply by turning off the hearing aid in the non-test ear.

Testing without the hearing aids may also be useful when the hearing loss is 55dB or greater for demonstrating aided benefit to parents or other professionals.

Interpretation of results (refer also to flow chart in Appendix 2) & aid adjustment.

1. If a result is obtained at 55 and 65 dB SPL, no change to hearing aids is required.
2. If there are responses as expected to a 65dBSPL input, but there is no response at 55dBSPL input level (and this would be expected based upon the speech-o-gram for a 55 dBSPL speech signal)
   a. Re-estimate thresholds for the frequency/ies which no response was obtained, assuming they are 1 SD above the original frequency, as in step 3.
3. If there is no response at 65 dBSPL, but a response at 75 dB SPL, re-estimate the thresholds for the frequency/ies in question from which the required 2 cc coupler targets were derived. Assume thresholds are 1 SD above the original at the corresponding frequency (increase of 10 dB HL).
4. If there is no response at 65 dB, or at 75 dB SPL re-estimate the audiogram from which the required 2 cc coupler targets were derived.
   i. Assume the new threshold/s to be 1.5 SD above the original at the corresponding frequency (increase of ~15 dB HL).
   ii. If there is still no response, refer to the (75dBSPL input) aided speech-o-gram for the latest estimated audiogram. If it suggests that one would not expect detection of the speech spectrum in the frequency range under consideration then the result is consistent with expectations.
5. If no responses are recorded to any of the stimuli and the audiogram has been re-estimated to be 1.5SD above the average, use the PEACH and/or TEACH to determine whether there are any behavioural responses to sound in the child’s real-life environment. This will help to understand whether the child falls into that small group of children whose aided cortical responses do not reflect their hearing capacity. Consider whether referral for cochlear implant candidacy is appropriate.
Please Note:

1. These recommendations assume that gain targets have been matched as closely as possible at all 3 input levels.
2. ACA does not indicate over amplification.
3. Australian Hearing does not recommend reducing the gain of the aid if ACA results indicate that a sound is audible despite the target speech-o-gram suggesting this should not be the case.
4. If ACA assessment has shown that certain frequency ranges are inaudible despite aid adjustment, these frequencies should be prioritised when commencing Visual Reinforcement Orientation Audiometry (VROA) testing.

Repeating the Aided Cortical Assessment

The aim of this assessment is to determine whether aid adjustments have improved audibility of the speech spectrum. In the interests of time, repeat the assessment only at those frequencies where changes were made. Similarly the starting presentation level will depend upon original test results (for instance if the aim of adjustment was to increase audibility for low level speech sounds, as in point 2 above, it would make sense to retest for a 55 dB input and not repeat testing at higher intensity levels.

REPORTS:

Audiological reporting should explain the reason that the testing was undertaken, what the test results were on the day, factors that may have affected the results, interpretation of the results, implications of the results obtained for further audiological management.
References:


APPENDIX 1: SIGNIFICANT P-VALUES

A significant p-value provides a level of confidence that the infant perceives the particular test stimulus at the level being presented. For example, where p = 0.001, there is only one chance in 1000 that the displayed waveform is the result of random electrical activity (or “noise”). At the level of p = 0.05, there is one chance in 20 that the response is the result of random noise. That is, the smaller the p-value, the more confidence there is that a CAEP is actually present (and consequently, that the sound is audible to the child).

When a significant response is detected, even when it is a single recording using a single stimulus, the following degrees of confidence can be placed in the significant (p < 0.05) presence of a cortical response:

- **p** smaller than 0.05 but greater than or equal to 0.01: ‘borderline’ response. A cortical response is very likely present, but a chance still exists it might be a ‘false detection’.
- **p** smaller than 0.01 but greater than or equal to 0.001: very high chance the response is genuine.
- **p** smaller than 0.001: it is next to impossible this response is originating from anything else but a genuine cortical response.

If results from two intensities are available, one can even rely on an additional pattern that appears in about 80% of the cases (Van Dun et al, 2012):

- When testing above the subject’s hearing threshold, the p-values of speech sounds tested at a higher intensity are generally **smaller** than the ones tested at a lower intensity.
  
  For example, one can observe the pattern below.

<table>
<thead>
<tr>
<th></th>
<th>/m/</th>
<th>/g/</th>
<th>/t/</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>75 dB SPL</strong></td>
<td>p = 0.001</td>
<td>p = 0.015</td>
<td>p = 0.25</td>
</tr>
<tr>
<td><strong>65 dB SPL</strong></td>
<td>p = 0.02</td>
<td>p = 0.16</td>
<td>p = 0.42</td>
</tr>
</tbody>
</table>

- Conversely, if a response is ‘borderline’ at for example 65 dB SPL, and not significant (p ≥ 0.05) at 75 dB SPL, chances are that the response at 65 dB SPL is a ‘false detection’, which is a possibility when using objective measures like a p-value.

In other words, one would expect that if a measured response genuinely reflects audibility of the speech stimulus, then as the intensity of the stimulus increases, the response becomes stronger and consequently the p value reduces.

**Non-significant p-values**

A non-significant p-value, where recording conditions are good (i.e., there is little residual noise in the recording—evidenced by a “green traffic light” indicator, and the child is in a suitably alert state for testing), strongly indicates that the test stimulus is either below, at, or only very slightly above behavioral threshold.

If recording conditions are less than ideal (i.e., there is significant residual noise, indicated by a “red or yellow traffic light” indicator, or the child is drowsy/medicated) it is possible that the sound is audible but the CAEP waveform is being masked by some one of these factors. **Bear in mind that an absent cortical response to a sound is not a certain indication that the child cannot perceive that sound.** Several studies have shown that a small proportion of people (both infants and adults) do not exhibit a strong CAEP even when the stimulus is audible. Clinical studies conducted by NAL, using HEARLab with unaided and aided infants (Van Dun et al., 2012), have shown that in some separate cases (in the order of 25%) a significant p-value was not obtained even when the stimulus is known to be audible, as confirmed using behavioural measures. **Although this number of absent responses seems high, the introduced level of uncertainty is reduced by combining the results for the same subject for other speech sounds and intensities.**

For example, when testing three stimuli /m/, /g/, and /t/ at the same intensity, the chance of having none of these stimuli appearing as significant while they are still audible drops to less than 2% (= 25/100 * 25/100 * 25/100).
To rephrase, if the p value is not significant for any of the three stimuli /m/, /g/, and /t/ when the presentation level is at 75 dB SPL, there is a high probability (>98%) that the stimuli are inaudible at the highest testable stimulus level.

Because there are many factors that can affect the ability to measure a CAEP and influence test results clinical management should consider the child’s state during testing and a test battery approach should be used when results are inconsistent.

Regardless of what is stated above, an absence of a CAEP, even with an isolated speech sound at an individual intensity, is still a strong indication the presented speech sound is below the behavioural threshold of the child.

CAEPs = suprathreshold measurement

It is also important to remember that the ACA assessment should generally be regarded as a suprathreshold measure - the presentation level at which a response is detected is not an indicator of the child’s aided threshold (although in occasional instances, it may coincidently be so). The clinician may, however, be able to make some inferences about the likely range in which threshold (for a given test stimulus) is likely to fall, if assessments are made at all three possible presentation levels, and the pattern of results is considered in combination with results from other assessments.
APPENDIX 2 – CLINICAL PATHWAY FOR AIDED CORTICAL ASSESSMENT

- **Sensorineural Hearing Loss**
  - Fitting aids based upon ABR, ASSR.
  - Match NAL NL2 targets for input levels of 50, 65 and 80 dBSPL
  - Follow up
  - Aided CAEPs + aid adjust if required

- **Auditory Neuropathy Spectrum Disorder**
  - Fitting for ANSD based on behavioural tests, PEACH and unaided CAEPs.

Timeline:
- **2 WEEKS**
- **4-6 WEEKS**
APPENDIX 3 – AID ADJUSTMENT.

Response to 65dBSPL

Y

Response to 55dBSPL

Y

Aid settings appropriate.

N

Does speechogram predict audibility?

Y

Re-estimate audiogram and retest if desired

N

Performance is as expected.

Response to 75dBSPL

Y

Increase estimate of threshold by 1 SD & adjust aid

Retest @65 if desired.

N

Increase estimate to 1.5 SD and adjust HA.

Response to 75dBSPL

Y

Retest @65 if desired.

N

Undertake PEACH or TEACH

Indicates hearing responses?

Y

Don’t adjust aid any further. Monitor closely

N

Discuss Cochlear Implant referral

Response to 55dBSPL

Y

Increase estimate of threshold by 1 SD & adjust aid

Retest @65 if desired.

N

Performance is as expected.

Y

Retest @65 if desired.

N

Increase estimate to 1.5 SD and adjust HA.

Y

Retest @65 if desired.

N

Undertake PEACH or TEACH

Indicates hearing responses?

Y

Don’t adjust aid any further. Monitor closely

N

Discuss Cochlear Implant referral
Waveforms to a variety of stimuli are shown in normal hearing Infants and Adults. A post auricular muscle response (PAMR) is evident in the infant responses to two stimuli. It is a somomotor response with a latency ~ 25 ms, which precedes the cortical response. These waveforms were obtained from research at National Acoustic Laboratories.
APPENDIX 5 – MATURATION OF CAEP’S

The graph below shows that the latency of P1 reduces with age. The morphology of the CAEP response also changes with age.

Source: graph compiled by NAL (Dillon, Van Dun, Carter, Gardner-Berry), based on research data from NAL and data published by Anu Sharma.