Optimising the test protocol for Cortical ERA

There are three main practical problems with the clinical application of Cortical ERA on conventional ERA systems that can be improved by appropriately designed software:

- The manual manipulation of waveforms (combining & superimposing sub-averages and the creation of intensity series are examples) and other predictable tasks are both tedious and time consuming.
- Long test sessions, especially using a predictable stimulus, lead to a diminution of the response, degrading accuracy and even further extending test time.
- Response identification is highly subjective and therefore vulnerable to error or bias.

The test can be improved in terms of ease of use, speed and accuracy by addressing these issues. The most obvious and productive measure is to ***automate all predictable tasks*** normally undertaken by the operator.

Other components of an efficient Cortical ERA system (as implemented in the author's system) include:

Pseudo-alternate binaural stimulation*.* In order to disrupt the monotonous predictable stimulus normally used in averaging, both ears may be tested using a P300-like oddball paradigm but where right and left ears are the "rare" and "frequent", and have ***equal*** likelihood. This random presentation is very "attention-grabbing" and difficult to ignore, slowing the habituation process somewhat. It is also efficient in that the user interaction required to assess the waveforms and select the next test intensity is less than twice that required in monaural tests. The intensities may differ for each ear, though this form of averaging is not appropriate if masking is required to prevent cross-hearing.

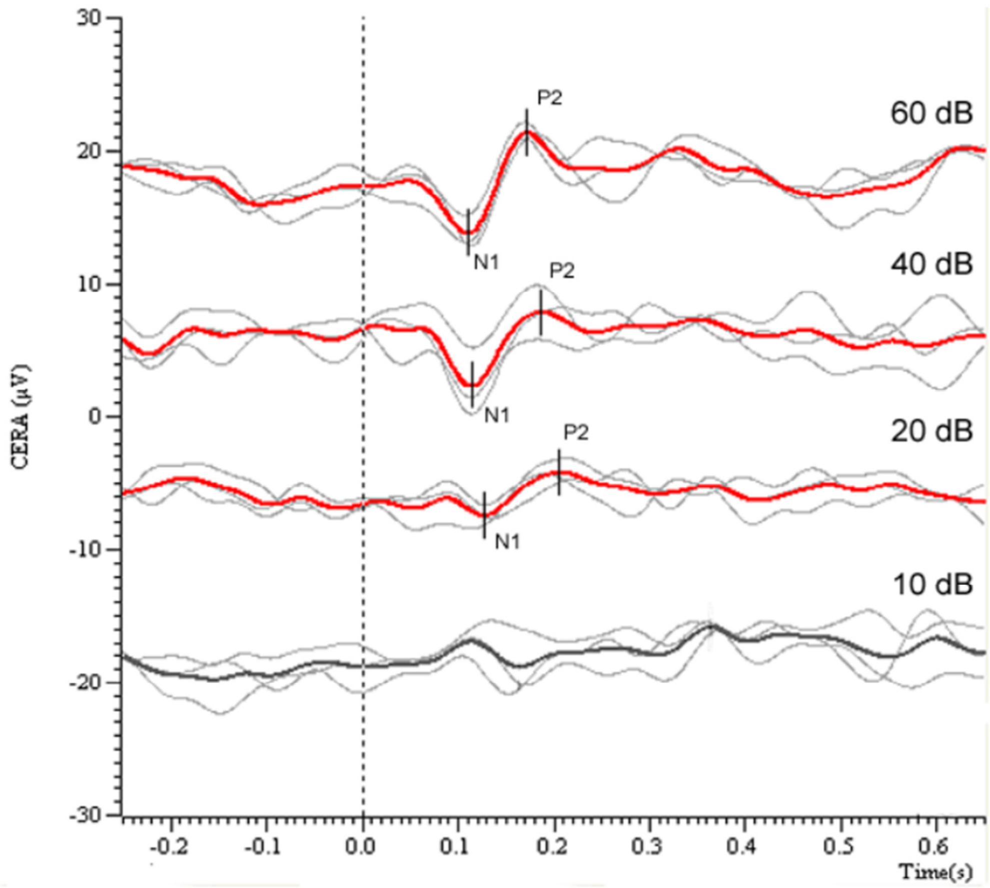
Non-rhythmical stimulus presentation*.* A further measure that may be applied in an attempt to arrest the decline in response magnitude and to make the stimulus less monotonous is to introduce some variability into the stimulus repetition rate. A mean value of 0.7 Hz with 30 % variability is recommended but a slower rate with greater variability is sometimes helpful in patients with a poor quality or small N1-P2 response.

Automatic per-stimulus replication**.** To assess response status, replicates are needed. Rather than manually recording several averages consecutively (which may differ as the patient’s arousal level or myogenic status changes) 3 replicates can be constructed pseudo-simultaneously. The 3 sub-averages A, B & C each receive an evoked response sweep in turn (ABCABC etc) until 15 stimuli have been delivered (5 into each sub-average). A grand average (red for right, blue for left - see below) is then computed and the 4 averages are superimposed for operator subjective visual assessment. Further sets of 15 stimuli may be delivered for near-threshold or indistinct responses, but a 10s stimulus-free period is given before the averaging resumes to allow the response to recover. These processes are automatic and therefore fast, requiring no laborious waveform manipulation.

Digital filtering of individual sweeps ***prior*** to averaging is possible when very fast processing is available.

Automatic cursor placement on N1 & P2 within pre-set latency limits speeds waveform assessment.

Objective response detection or assessment of response quality and residual noise. A number of methods have been applied, including cross-correlation, template-matching and a variety of measurements related to signal to noise ratio (SNR or S/N). An example is shown below. Following automatic cursor placement on N1 and P2, the response amplitude is computed and divided by a measurement of residual noise (RN, in this case the average gap between replicates) to calculate the S/N. The cross correlation between pair of replicates over a latency range centred on the response is also computed. These can be combined and compared to reference no-stimulus data to arrive at a p-value for each test level, as shown below.



Level dB HL	Sweeps	N1 (msec)	N1-P2 Amp (µV)	RN (µV)	Corr	S/N	p
60	15	110	7.5	1.43	0.84	5.25	<0.001
40	15	114	5.5	1.80	0.32	3.05	0.003
20	30	127	3.3	1.07	0.48	3.08	0.003
10	30	–	–	0.91	0.02	1.63	0.222

Automatic intensity sorting of waveforms when viewing an "intensity series" obviates laborious and time consuming manual waveform manipulation. The waveforms above (suggesting a 10 dBHL threshold in both ears) were acquired and analysed in 6 minutes.

Continual display of the ongoing EEG assists identification of excess EEG alpha and myogenic activity. In addition to the usual artefact rejection, a manual pause facility that withdraws the stimulus carries two benefits: (a) the user can use this means to introduce greater variability in the stimulus when required, and (b) when the test is paused because the patient is restless or noisy, unexploited stimuli do not habituate the response whilst waiting to resume averaging.

Note that no single feature detailed above is crucial for successful N1-P2 recording but together they combine to enhance speed, precision and ease of use.

Speed

One of the chief practical problems with Cortical ERA is that of test time. In order to take advantage of the superb frequency specificity of the test, one is frequently asked to re-construct a major portion of the audiogram. For example, in medico-legal cases, there is a requirement to obtain threshold estimates at those frequencies used in the calculation of disability (typically 3 or 4 frequencies in both ears by air conduction). In addition, issues of causation make the objective identification of an acoustic "notch" attractive, requiring 6kHz and 8kHz.

Bone conduction tests, with masking, may be needed at one or more frequencies. Test session can therefore become protracted. Since the response declines over time, this poses a very serious issue and if standard equipment is used, it is not uncommon for patients to have their tests split over two sessions if a comprehensive range of tests is sought. Conventional CAEP (that is, performed on a standard auditory evoked potential system) typically takes about 90 minutes for 8 thresholds (Hyde, 1997).

Using the author's "optimized" Cortical ERA system, in tests on 56 patients upon whom air conduction thresholds were estimated in both ears at between 3 and 6 frequencies, the average time taken to establish each threshold was 3.2 minutes using typically 3–5 intensities. Most 4-frequency, 2-ear air conduction tests took about 30 minutes. This is the "earphone on" time. Clearly, additional time is needed for electrode attachment, interview, otoscopy, tympanometry etc. Nevertheless, the test time with this system is substantially less than that using a conventional system. Since the response degrades with time, a faster test is likely to yield somewhat better accuracy.

Ease of use

This is one of the other benefits of an optimized system, since almost all of the mundane aspects of user interaction are removed, the software calling for tester involvement only when judging a response or specifying the next test intensity etc. Audiologists experienced in Cortical ERA on conventional equipment have been most impressed with the simplicity and ease of use of a system developed specifically for this application.

Other design features of the system

In addition to the pseudo-simultaneous bilateral air conduction cortical ERA threshold test, I have included the following features to make it a comprehensive clinical and research tool:

- A monaural air conduction cortical ERA threshold test with contralateral narrow band masking
- A bone conduction cortical ERA threshold test with contralateral narrow band

masking

- A user-friendly daily subjective calibration check program to ensure correct system function
- A program to facilitate periodic objective stimulus calibration using standard audiological calibration equipment
- A "review" facility to allow previously recorded waveforms to be viewed and printed off-line
- Full user control of all major test parameters within sensible limits
- Provision to employ non-standard stimulus waveforms (e.g. speech sounds) for research purposes

Implementation

Since there is no currently available evoked potential system with full user-programming capabilities (unlike the old Nicolet Pathfinder), this system was developed from scratch using the following elements:

- A standard desktop personal computer
- A clinical audiometer (Interacoustics AC30) operating under RS232 control from the computer, to provide stimulus attenuation & routing together with narrow band noise
- Cambridge Electronic Design hardware and software:
- CED 1902 isolated low-noise EEG amplifier
- CED Power (or Micro mk II) 1401 signal processor
- CED Signal software (running specially written scripts)

Whilst the CED system is available (officially for research use), this is NOT a hard-sell exercise and the author would like to see similar software developed by existing ERA equipment manufacturers.
Harvey Dillon and Australian colleagues worked on a system (HearLab) for the recording of infant cortical responses for habilitative purposes. It also has an adult threshold test and objective response scoring, based on Hotelling's T^2 statistic. A study describing and validating the statistical method is in press. It is great to see another cortical system possibly being made available to audiologists. Perhaps the major manufacturers will eventually take the hint and produce some decent software for the popular EP systems.

Sermon over! If you have read this far then thank you for your interest.
Still curious? Have a look at the CAEP-v-ABR page to compare the two methods.
Please feedback any comments or queries you may have using the Contact Us form.