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Cortical auditory evoked potential testing in infants and young children

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Background

The implementation of universal newborn hearing screening programmes throughout the world has increased the need for reliable, objective techniques for fitting and evaluating hearing aids in young infants. For infants found to have a hearing loss as a result of newborn hearing screening intervention, including hearing aid fitting, is typically occurring by age 6-8 weeks. It is difficult to assess hearing aid effectiveness using behavioural techniques in such young infants. Auditory evoked potentials provide an objective measure of the brain's response to sound and are a tool that can be used to assess aided as well as unaided auditory function in infants.

Why not use ABR to assess aided hearing in infants?

There was considerable interest in using the auditory brainstem response (ABR) to assess hearing aid effectiveness during the 1980s (Beauchaine et al, 1986; Bergman et al, 1992; Davidson et al, 1990; Gerling, 1991; Gorga et al, 1987; Hecox, 1983; Kiessling, 1982; Kileny, 1982; Mahoney, 1985). These studies demonstrated some problems with the use of ABR to assess amplification. Stimuli (clicks and brief tonebursts) suitable for ABR recordings may be too brief to activate a hearing aid's compression circuitry (Brown et al, 1999). Click stimuli have a very high peak level compared to the rms (root mean square) level of the stimulus. Consequently a hearing aid activated by the stimuli typically used for ABR testing may perform differently than it would for a speech stimulus. Contamination of the early latency response by stimulus artefact is also a problem due to electromagnetic pickup of the loudspeaker and hearing aid transduced signal by the recording electrodes.

Middle latency and steady state evoked potentials

The middle latency response (MLR) can be reliably recorded in infants at suprathreshold levels if recording and stimulus parameters are optimised (Tucker & Ruth, 1996). The MLR can be used to assess hearing sensitivity but is more affected by subject state and is more variable across and within subjects than ABR. Because of these limitations MLR is not normally used for threshold estimation (Kraus & McGee, 1993). In adults the peaks in the MLR waveform occur at intervals of about 25 ms and hence the MLR waveform has a periodicity of about 40 Hz. When the MLR is recorded with stimuli presented at 40 Hz a "steady state response" is generated since successive MLR waveforms are superimposed and as a result MLR amplitude is enhanced (Galambos et al, 1981).

A steady state response can be generated at faster stimulus presentation or stimulus modulation rates of about 70-100 Hz. Fast rate steady state evoked potentials (SSEP) were initially thought to result from superimposition of the slow wave of the auditory brainstem response (the low frequency component of the ABR), which has a peak latency of about 10-12 ms for tonal stimuli. Recent evidence suggests, however, that midbrain and cortical auditory pathways also contribute to the high rate SSEP (Kuwada et al, 2001). SSEPs are measured in the frequency domain as a peak in the amplitude spectrum of the electrical activity recorded from the scalp corresponding to the modulation rate of the stimulus and/or some measure of non-random phase behaviour of the response such as phase coherence (Picton et al, 2001). SSEPs generated by amplitude-modulated sinusoids can used to measure unaided and aided hearing thresholds in hearing impaired children with reasonable accuracy (Perez-Abalo et al, 2001; Picton et al, 1998).

Cortical auditory evoked potentials

The slow “obligatory” cortical auditory evoked potentials (P1-N1-P2) occur between 50 and 300 ms after stimulus onset. The slow cortical response is referred to as obligatory because it is primarily determined by the physical properties of the stimulus (see review by Hyde, 1997). Cortical potentials are affected by both arousal level and attention and therefore should be recorded when the subject is awake and alert. The main clinical application of obligatory cortical potentials is assessment of hearing sensitivity in adults. P1-N1-P2 response thresholds agree very well with audiometric thresholds determined behaviourally (Davis, 1965; Ross et al, 1999). Because babies are usually tested when they are asleep, ABR is a more suitable tool for assessing hearing sensitivity in infants, unless there is a concern about the infant’s central auditory processing.

From birth up to about 7 years of age the CAEP response is dominated by a large, late P1 response (eg, Kurtzberg et al, 1984; Ponton et al, 1996). CAEPs may be a good electrophysiological tool for assessing hearing aids because they are reliably present in infants (Kurtzberg et al, 1984; Pasman et al, 1991) and they can be recorded using relatively long duration stimuli (Hyde, 1997). A few case studies reported in the literature have shown that cortical evoked potentials can be used to demonstrate the benefits of amplification in children and infants (eg, Gravel et al, 1989; Rapin & Graziani, 1967).

Stimulus and recording parameters for CAEP testing

CAEP can be elicited using both tonal and speech stimuli. Speech stimuli have better face validity for hearing aid evaluation but unfortunately are not available in most clinical evoked potential systems. Tonal stimuli are widely used for CAEP threshold evaluation in uncooperative adults (eg, Ross et al, 1999). In adults, stimulus duration is not critical provided duration exceeds about 30 ms. Rise times of 10 ms or more and total durations of 30-75 ms are recommended (Hyde, 1997). A slow repetition rate of about 1 per second is needed to avoid neural refractory effects on CAEP amplitude (Budd et al, 1998). Stimulus onset polarity should be alternated to minimize stimulus artefact effects on the recording.

Because relatively long duration stimuli are used for CAEP testing, behavioural thresholds for the CAEP toneburst stimuli will approximate those obtained using conventional pure tone audiometry. Thus the audiometer standards for earphone and soundfield testing can be used for stimulus level calibration (ISO 389–1, 1998; ISO 389–2, 1994; ISO 389-7, 1996). Additional behavioural calibration using a group of normal listeners is recommended, however, to verify that the calibration is correct for the individual system and test environment (IEC 60645–3, 1994).

A bandpass filter of about 1-30 Hz is typically employed for CAEP recording. This is below the passband used for ABR and MLR recordings. Because CAEPs are considerably larger than ABR or MLR (approximately of 5 V peak-to-peak on average versus 0.5-2 V for ABR/MLR) a lower gain/sensitivity setting is needed. CAEP can be contaminated by eyeblinks, which cause large electrical voltages to be detected by the electrodes on the scalp. Eyeblinks can be minimized in adults by having them fixate on a point but this is not possible if subjects are reading or watching a video during recordings. In clinical evoked potential instruments artefact rejection can be used to eliminate CAEP recordings contaminated by eyeblinks or other muscle activity. An artefact reject setting of ±50 V is ideal but is often not possible when trying to record CAEP within a reasonable time frame. We have obtained CAEP recordings of acceptable quality in infants using artefact rejection values as high as ±150 V.

Test parameters that could be used to record CAEP in both adults and infants are displayed in Table 1. The suggested test parameters are similar to those recommended by Hyde (1997).

Stimulus	**Recording**
Stimuli: 500, 1000, 2000 Hz	*Electrode montage:* Cz-earlobe/mastoid*
Duration: 20-20-20 ms (rise-plateau-fall)	*Filter setting:* 1-30 Hz
Repetition rate: 0.8 - 1.2 per second	*Artefact rejection:* ± 50 – 150 V
Intensity level: 60-70 dB HL	*Prestimulus baseline:* 50-100 ms
Onset polarity: alternating	*Time window:* 500 ms post stimulus
Transducer: loudspeaker	*Number of averages:* 50-100
	Subject state: awake, quiet, alert

Table 1. Suggested stimulus and recording parameters for recording aided versus unaided CAEP infants. Higher test intensities may be required if responses are not present at moderate input levels. *If more than one recording channel is available C3 (left hemisphere) and C4 (right hemisphere) electrode locations are also recommended.

Examples of CAEP recordings

Responses to 500 and 2000 Hz tonebursts (60 ms duration, 750 ms interstimulus interval) recorded at Cz in an infant aged 6 months and an adult aged 24 years are displayed in Figure 1. The infant had normal transient click evoked otoacoustic emissions bilaterally and the adult had normal pure tone thresholds. Stimuli were presented via a loudspeaker at 65 dB HL. There is about 100-150 ms P1 latency delay between adults and 3-7 month old infants. Research is currently underway at National Acoustic Laboratories to determine the normative characteristics of CAEP in young infants and to investigate aided CAEP in infants and young children who have a hearing loss.

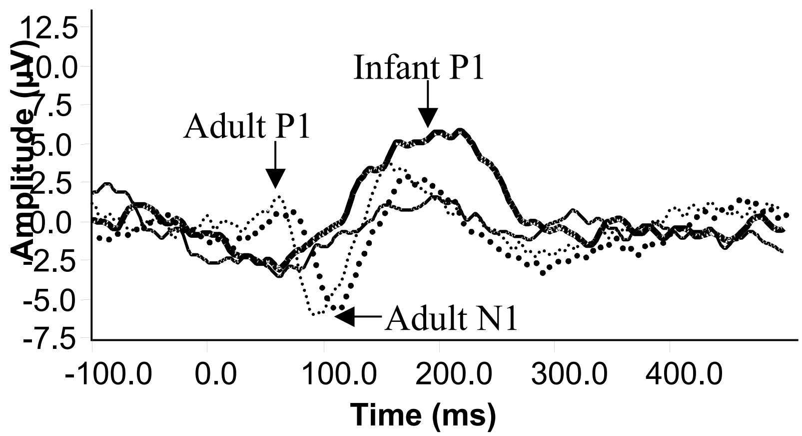

Figure 1. CAEP waveforms recorded in a 6 month old infant (solid lines) and a 24 year old adult (dotted lines), both with normal hearing. Stimuli were 65 dB HL 500 Hz (darker lines) and 2000 Hz (lighter lines) tonebursts. The adult waveform has P1, N1 and P2 peaks at about 50, 100 and 150 ms respectively. The infant waveform consists of a broad positive peak (P1) with a latency of about 200 ms.

Figure 2 shows aided versus unaided waveforms recorded using a Biologic evoked potential system at Starship Children's Hospital in a 3½.year old child with severe developmental delay. Toneburst air conduction thresholds are consistent with a moderate-severe low frequency loss and a mild high frequency loss. Bone conduction ABR thresholds are normal (10 dB nHL) at all frequencies. The conductive hearing loss in this case is due to congenital middle ear pathology. This child wears bilateral high-powered hearing aids. No unaided response was obtained but, as illustrated in Figure 2, a cortical response was obtained while the child was wearing the hearing aids. The test stimulus in this example was an 80 dB SPL toneburst at1000 Hz delivered binaurally. In this case there is no other evidence that the hearing aids are providing any benefit because behavioural testing is not possible and the child has not developed any speech. Cortical evoked potential testing was helpful in demonstrating that the hearing aids are amplifying sufficiently to produce neural activity at the level of the auditory cortex and therefore at least loud sounds should be perceived.

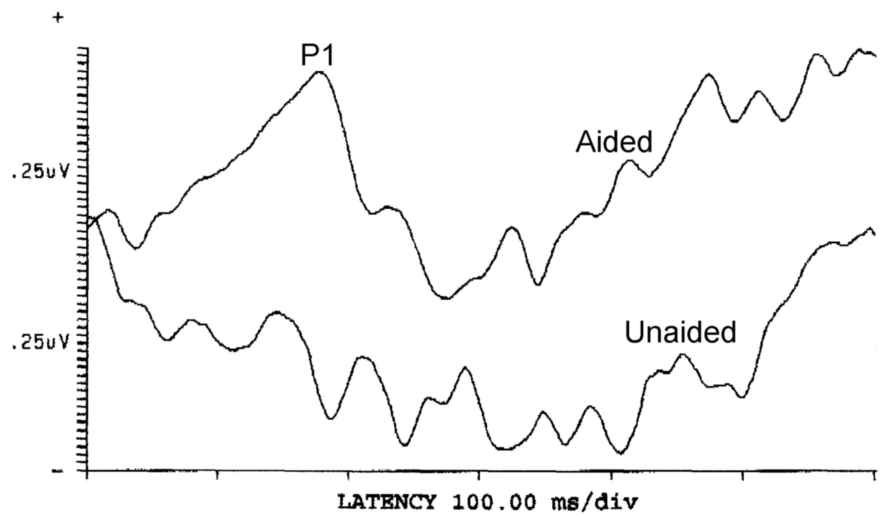

Figure 2. Unaided and aided cortical thresholds recorded in a 3½.year old child with a moderate-severe low frequency and mild high frequency conductive hearing loss. The stimulus was a 1000 Hz toneburst at 80 dB SPL delivered binaurally.

Conclusion

CAEP can be reliably recorded in young infants and therefore provide a useful tool for objectively evaluating hearing aid success in this population and in children who are difficult to test behaviourally. Clinical evoked potential systems can be used for this purpose with the addition of a good quality loudspeaker (and external amplifier) to deliver the stimuli to the hearing aid.

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