Precise determination of residual hearing in prospective cochlear implant candidates is essential. As the minimum age of implantation for young children has reduced, the use of objective measures of hearing has become more important. At the University of Melbourne Cochlear Implant Clinic, steady state evoked potential (SSEP) assessments are routinely carried out on all candidates under the age of 5 years using a microcomputer and custom-designed hardware in the manner described by Cohen et al. [1].

Steady state evoked potentials are scalp potentials elicited in response to sinusoidally amplitude and/or frequency modulated tones. The resulting potential is periodic, and is phase locked to the modulation envelope of the stimulus.

Good estimations of behavioural thresholds have been reported across a range of carrier frequencies (250-4,000 Hz), in both normal and hearing-impaired awake adults using SSEP testing techniques at repetition rates of 40 Hz [2, 3]. In addition to these findings, Cohen et al. [1] demonstrated that the response can be elicited by stimuli at low sound pressure levels in sleeping adults if modulation rates above 70 Hz are used. We have also successfully employed these high modulation frequencies to test sleeping neonates, obtaining results consistent with those seen in awake and sleeping adults, and suggesting that this technique is suitable for use as a measure of hearing acuity in sleeping children [4]. Furthermore, Rickards et al. [5] showed good agreement between SSEP thresholds and tone pip elicited ABR thresholds to stimuli at 500 and 4,000 Hz, in a group of 20 neonates.

This paper presents the preliminary findings for a study examining the relationship between the SSEP thresholds observed in a group of young cochlear implant candidates, with thresholds obtained behaviourally. Data from a similar study involving hearing-impaired adults is also included.

Methods

Subjects in this study were 25 severely/profoundly hearing impaired children (12 male and 13 female). The median age of this group was 28 months with a range of 10-58 months at the time of the SSEP evaluation. In addition, the results of 35 adults (23 male and 12 female) with mild to severe degrees of hearing loss are also presented. None of the subjects showed any evidence of middle ear, and, in the case of the adults, retrocochlear dysfunction.

Subjects' hearing sensitivity was assessed behaviourally using a standard clinical procedure, with pure or warble tones and a clinical audiometer. Results were obtained in the free field or under headphones as dictated by the age of the child.

At the time of the SSEP data collection, the adults were in natural sleep, and the children were either sedated with chloralhydrate, or under a general anaesthetic. This assessment was typically carried out on the occasion of the child's CT scans.

Stimulus generation, recording procedures and waveform analysis were the same as described previously by Cohen et al. [1]. The presence or absence of a response was determined automatically using a detection criterion which looked for non-random phase behaviour in regular samples of the scalp potentials. The stimuli, presented via mu-metal screened TDH-39 headphones, were pure tones amplitude and frequency modulated at a rate of 90 Hz. Carrier frequencies from 250 Hz to 4,000 Hz were tested (typically in octave increments). The maximum sound levels of the stimuli were 104 dB HL for the 250 Hz carrier, and 120 dB HL for the 500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz carrier frequencies.

Results

Figure 1 shows the plot of SSEP thresholds (Y) versus clinical behavioural thresholds (X) obtained for all of the subjects using a 1-kHz stimulus together with the appropriate linear regression line. The slope of less than unity and positive intercept reflects the better threshold accuracy seen in ears with a greater degree of hearing loss. Regression lines drawn for other carrier frequencies followed a similar pattern.

A comparison of actual and predicted SSEP thresholds was carried out for each of the carrier frequencies. In 395 of the 412 comparisons (96%),
Fig. 1. Regression line analysis of threshold estimation using the SSEP technique in sleeping subjects to 1,000-Hz tones amplitude and frequency modulated at 90 Hz. Shown are the SSEP thresholds versus behavioural thresholds for 25 profoundly hearing impaired children, and 35 adults with mild to severe losses.

The observed SSEP threshold was found to be within 10 dB of that predicted by the regression line. Discrepancies of greater than 10 dB were only seen at the 250-, 500-, and 1,000-Hz carrier frequencies.

Of the 25 cochlear implant candidates included in this study, 14 showed only low frequency residual hearing (<1 kHz) when assessed behaviourally. SSEP testing carried out in the high frequencies on these subjects revealed no response to the stimuli at maximum levels indicating that artifactual responses were not contaminating the results.

In many cases the SSEP thresholds in the low frequencies were less than the behavioural thresholds in the octave frequency above, confirming that the responses to these frequency specific stimuli are likely to be originating from the appropriate place in the cochlea.

Discussion

The preliminary results presented in this paper suggest that a linear regression analysis can be used to predict behavioural thresholds from steady state evoked potential thresholds. Our data has shown that the use of the regression line will enable prediction of behavioural thresholds across a range of carrier frequencies, to within 10 dB accuracy on 96% of the occasions.

Threshold estimation using the SSEP technique, offers a number of advantages over other frequency specific evoked potential procedures in the assessment of young cochlear implant candidates. Middle latency and slow cortical responses for example, have been shown to be unreliable in young subjects due to maturational and sleeping effects.

Recent work using auditory brainstem responses to short duration tones in notched noise, has shown that threshold estimates in awake adult subjects can also be made with reasonable accuracy [6]. The evoked potential thresholds obtained from the normal and hearing impaired subjects in this paper were, however, more variable than those we obtained using the SSEP technique. Their results did show the improved accuracy with hearing impairment, and higher stimulus frequency seen in this study.

Another disadvantage of the ABR technique is that like all brief stimuli procedures, the equivalent dBHL levels at which it can test are limited. The continuous modulated tone used in the SSEP technique can be presented at levels as high as 120 dBHL, whereas click or brief tone stimuli are typically restricted to levels less than 100 dBnHL. This limitation is obviously a significant disadvantage when testing implant candidates with profound to total hearing losses.

Another advantage which the SSEP procedure has over transient evoked response techniques is that it does not require subjective waveform analysis. The periodicity of the potential allows automated response detection systems such as the one used in this study, to be employed. This approach may in part account for the small variability in threshold estimates that we have observed.
In summary, this test has shown a high degree of accuracy in the determination of hearing thresholds. The SSEP procedure is well suited as a measure of residual hearing in young cochlear implant candidates in that it can provide accurate thresholds to frequency-specific stimuli presented at high levels.

References

Surgical Techniques


Multichannel Implants in Postmeningitic Ossified Cochleas

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Loss of hearing is a frequent complication of meningitis, having an incidence of between 8 and 24% [1, 2]. It is generally permanent, symmetrical, bilateral and, depending on the extent of injury, ranges from mild to profound. The infection from the brain-cerebrospinal fluid passes through the cribose areas of the internal auditory canal or the cochlear aqueduct and contaminates the inner ear fluids. The resulting labyrinthitis damages the organ of corti with loss of the hair cells. In addition, most cases develop labyrinthine neo-ossification (fig. 1) [3]. In the past 10 years, those unfortunate individuals who were so profoundly deafened that they were unable to benefit from amplification have had some degree of hearing restored by the electrical stimulation of auditory neurons using cochlear implants. The surgical insertion of these devices necessitates an open passageway through the scala tympani [4–7]. However, ossification of the cochlea may preclude the complete insertion of the cochlear-stimulating electrodes resulting in only a portion of the array being implanted (fig. 2).

This study reviews a series of 22 postmeningitic profoundly deaf children who had cochlear implants. The degree of cochlear ossification observed at surgery was compared with that detected on preoperative CT scans. The impact of ossification on the surgical insertion of the cochlear electrodes was analyzed. In cochleas that were obliterated by bone growth, the operative technique for inserting cochlear electrodes was reviewed.

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