Steady-State Evoked Potentials (SSEPs): An Objective Measure of Residual Hearing in Young Cochlear Implant Candidates

Department of Otolaryngology, University of Melbourne, Parkville, Australia

Abstract - The use of objective measures of residual hearing in young cochlear implant candidates has become more important as the minimum age of implantation has reduced. This paper examines the use of the steady-state evoked potential (SSEP) technique in the assessment of these children. SSEP thresholds were obtained using frequency specific stimuli at octave frequencies between 250 Hz and 4000 Hz in 25 children with moderate to severe hearing losses. These levels, determined automatically by a computerized detection system, were then compared with thresholds obtained behaviorally. Data was also collected from a group of 35 adult subjects with varying degrees of sensorineural hearing loss. Results indicate that the steady-state evoked potential procedure can provide accurate, frequency specific estimates of hearing thresholds in ears with even profound or total hearing losses.

INTRODUCTION

The accurate assessment of hearing thresholds in prospective cochlear implant candidates is essential. As the minimum age of implantation has reduced, audiologists have been faced with the complicated task of obtaining this information in children whose limited development may severely restrict the audiometric assessment process. Clearly the use of objective measures of residual hearing to confirm thresholds obtained behaviorally can in this instance offer an important safeguard in the pre-operative evaluation of these young children. At the University of Melbourne Cochlear Implant Clinic, steady-state evoked potential (SSEP) assessments are carried out on all children under the age of 5 years using a micro-computer and custom-designed hardware in the manner described by Cohen et al. (1).

Steady-state evoked potentials are electrophysiological responses elicited by sinusoidally amplitude and/or frequency modulated tones. These responses which are measured on the scalp are periodic, and are phase locked to the modulation envelope of the stimulus. The underlying processes which generate the steady-state potential are not completely understood, but they are thought to be the result of the overlaying of series of transient responses which merge together when the stimuli are presented at a sufficiently high rate.

SSEPs generated by tones modulated at a rate of 40 Hz have been shown to provide good estimates of behavioural thresholds in both normal and hearing impaired adults (2, 3). Furthermore, Cohen et al. (1) demonstrated that the response could be recorded at low sound pressure levels in sleeping adult subjects when modulation rates in excess of 70 Hz were used.

A number of studies have also shown that high modulation rate SSEPs can be reliably recorded in sleeping neonatal subjects (4, 5). These findings indicate that the technique is suitable as a measure of hearing acuity in subjects of all ages.

This paper presents the preliminary findings for a study examining the correlation between the SSEP and behavioural thresholds obtained from a group of young cochlear implant candidates. Also included are results collected in a similar study involving a number of adult subjects with varying degrees of sensorineural hearing loss.

METHODS

Subjects in this study were 25 children with moderate to profound hearing losses. They were aged between 10 and 58 months at the time of the SSEP evaluation. The median age of the group which included 12 males and 13
35 adults (23 male and 12 female) aged 24-82 years with audiometric thresholds ranging from normal to profound levels also participated.

Behavioural pure tone audiograms were established for the adult subjects using the standard audiometric procedure and a clinical audiometer. The children were assessed either in the free field or under headphones using techniques appropriate to their developmental level.

At the time of the SSEP assessment the adults were in natural sleep. The children were either in natural sleep, sedated with chloralhydrate, or under a general anaesthetic. In the case of the children, this evaluation typically took place on the occasion of their C.T. scans.

Stimulus generation, waveform analysis and acoustic equipment were the same as described previously by Cohen et al. (1). The presence or absence of a response was determined automatically by the system which looked for non-random phase behaviour in regular samples of the EEG signal.

The stimuli presented via mu-metal screened TDH-39 headphones, were pure tones amplitude and frequency modulated at a rate of 90Hz. Carrier frequencies from 250Hz to 4000Hz were tested for each subject, in each ear separately. The maximum presentation levels of the stimuli were 104dBHL for the 250Hz carrier, and 120dBHL for the 500-, 1000-, 2000- and 4000Hz carrier frequencies.

To obtain SSEP thresholds, the level of the stimulus was decreased in 10dB steps until no response could be detected. It was then increased in 5dB steps until it could again be identified. Threshold was defined as the minimum level at which the response could be automatically detected by the system.

RESULTS

Figure 1 shows the plot of SSEP thresholds (y) versus behavioural thresholds (x) obtained for all of the subjects using a 2kHz stimulus. Of note is the small spread of data about the regression line. Similarly small variances were observed for each of the carrier frequencies. A comparison of the actual and predicted SSEP thresholds across all of the data in fact showed that in 395 of the 412 cases (96%), the observed SSEP threshold was within 10dB of the level predicted by the regression line.

Figure 1: Regression line analysis of threshold estimation using the SSEP technique in sleeping subjects. Responses elicited by a 2000Hz tone were amplitude and frequency modulated at a rate of 90Hz.
Also of note in this figure is the regression line gradient of less than unity. This finding, which was again consistent across carrier frequencies, reflects the better threshold accuracy observed in ears with greater degrees of hearing loss. Table 1, which shows the steady-state evoked potential and behavioural thresholds obtained at octave frequencies between 250Hz and 4000Hz for three subjects with varying degrees of sensori-neural hearing loss, also demonstrates this finding. The correlations seen here between the results obtained with the two threshold techniques are typical of those observed in the subjects that we tested, that the evoked potential thresholds more closely follow the pattern of the loss as its degree increases.

<table>
<thead>
<tr>
<th>Category</th>
<th>Technique</th>
<th>250Hz</th>
<th>500Hz</th>
<th>1000Hz</th>
<th>2000Hz</th>
<th>4000Hz</th>
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<td>Normal Hg.</td>
<td>Behavioral</td>
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<td>50dBHL</td>
<td>50dBHL</td>
<td>50dBHL</td>
<td>50dBHL</td>
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<tr>
<td></td>
<td>SSEP</td>
<td>50dBHL</td>
<td>50dBHL</td>
<td>50dBHL</td>
<td>50dBHL</td>
<td>50dBHL</td>
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<tr>
<td>Moderate Hg.</td>
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<td>65dBHL</td>
<td>70dBHL</td>
<td>70dBHL</td>
<td>65dBHL</td>
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<tr>
<td></td>
<td>SSEP</td>
<td>80dBHL</td>
<td>80dBHL</td>
<td>80dBHL</td>
<td>80dBHL</td>
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<tr>
<td>Profound Hg.</td>
<td>Behavioral</td>
<td>95dBHL</td>
<td>100dBHL</td>
<td>NR (120dBHL)</td>
<td>NR (120dBHL)</td>
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</tr>
<tr>
<td></td>
<td>SSEP</td>
<td>105dBHL</td>
<td>110dBHL</td>
<td>NR (125dBHL)</td>
<td>NR (125dBHL)</td>
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</tr>
</tbody>
</table>

The third of these examples describes the levels obtained in a three year old cochlear implant candidate. The absence of SSEP responses at 2000Hz and 4000Hz is significant. In the fourteen subjects who showed no high frequency residual hearing (>1kHz) when assessed behaviourally, SSEP testing also failed to elicit a response to stimuli presented at maximum levels. This finding indicates that artificial responses were not contaminating the results.

DISCUSSION

The preliminary results presented in this paper indicate that a linear regression analysis can be used to predict behavioural thresholds on the basis of SSEP levels with some confidence. The small spread of evoked thresholds particularly in subjects with significant hearing losses, enabled prediction of behavioural thresholds across a range of carrier frequencies to within 10dB accuracy on 96% of occasions. This small variability may in part be due to the automatic response detection system that we used.

Although masking noise was not included in our test paradigm to ensure the frequency specificity of the evoked potentials, the overall pattern of results gave the impression that its presence was in fact reasonably frequency specific. In cases such as the audiograms presented in Table 1 for example, the SSEP levels in the way that they mirror the patterns of the behavioural thresholds, suggest that appropriate regions of the cochlea were being stimulated by the frequency specific tones. Further evidence for this specificity was observed in cases such as the third of these audiograms, where the SSEP threshold levels (SPL) for the low frequencies were in fact lower than the behavioural thresholds in the octave frequencies above.

The steady-state evoked potential procedure is particularly well suited to the task of providing objective estimates of residual hearing in young cochlear implant candidates. If modulation rates in excess of 70Hz are used, the SSEP technique does not suffer the reliability problems often reported with middle latency or slow cortical...
potentials in sleeping subjects [6, 7, 8]. High modulation rate SSEPs also appear to be unaffected by maturational factors making the test suitable for children of all ages.

Recent work using auditory brainstem responses to tones in notched noise has demonstrated that frequency specific threshold estimates can be made with reasonable accuracy. The major disadvantage of this and other techniques which employ short duration stimuli is however, that they are limited in the equivalent dBHL levels to which they can be used. The continuous modulated tones used in the SSEP procedure can be presented at levels as high as 120dBHL. Click or brief tone stimuli on the other hand, are typically restricted to levels less than 100dBHL. This is obviously a serious limitation when assessing implant candidates with profound to total hearing loss. As Brookhouser et al. [9] demonstrated in their study of click evoked ABR assessments of this population, there are a a significant number of profoundly, or even severely hearing impaired children who show no response at maximum presentation levels on an ABR assessment, and yet have sufficient residual hearing to provide them with good access to the speech spectrum with appropriate hearing aids.

In summary, our data indicated that the steady-state evoked potential procedure can provide a high degree of precision in the determination of auditory thresholds, particularly in subjects with significant hearing losses. It is well suited as a measure of residual hearing in young cochlear implant candidates in that it can provide accurate threshold estimates at frequency specific stimuli presented at high levels.

REFERENCES

G. Ranz, Department of Otolaryngology, University of Melbourne,
East Melbourne, Vic. 3002 (Australia)