K. J. Lee: Essential Otolaryngology and Head and Neck Surgery (IIIrd Ed)

Chapter 3: Electric Response Audiometry

During the past 10 years electric response audiometry (ERA), particularly brain stem audiometry, has become an important clinical tool. In this chapter the basic principles of electric response audiometry are reviewed. We then describe the various techniques emphasizing their clinical applications.

Basic Concepts of Electric Response Audiometry

The aim of electric response audiometry is to record the potentials that arise in the auditory system as a result of sound stimulation. The basic principles of recording the electric potentials from the auditory system are the same regardless of the potential that is of particular interest. The recording is made difficult by the fact that the potentials generated in the auditory system are minute in comparison with the background or electric impulses from other parts of the body (brain, heart, and muscles). The development of the average response computer has made it practical to record these potentials in the clinical setting.

The apparatus for electric response audiometry is shown in simplified block diagram in Fig. 3-1. The stimulus is an acoustic impulse of very short duration termed a click, tone pip, or tone burst. This brief stimulus produces a synchronized discharge in the auditory system. The stimulus is attenuated and then presented to the test ear through either a free-field loudspeaker or a headphone. Depending on the technique employed, the active electrode is applied to the ear lobe, mastoid prominence, ear canal, promontory, or scalp vertex. An appropriate reference electrode also is applied. The minute signal these electrodes pick up is differentially amplified first in a preamplifier and then further enlarged in an amplifier before being delivered to the averaging computer.

The average response computer consists of a series of memory units, each receiving information a fraction of a second later than the one just before it. We like to think of each point as a small calculator capable of addition and subtraction.

The computer is triggered to begin its sequential process of analysis each time a stimulus is delivered to the ear. The signal is said to be time-locked to the averager. In other words, the response repeatedly occurs in the same group of memory locations. In this way the potentials from the auditory system that singly would be impossible to identify are extracted from the background noise, which is reduced by the averaging. The averaged response is then transferred to permanent recording paper for analysis.

The basic principles for recording are the same in all electric response audiometry. The techniques vary depending upon the response to be measured.

Auditory Evoked Potentials

The most important auditory evoked potentials and their probable sites of generation are outlined in Table 3-1. In considering these responses it is important to point out that the measurements obtained from ERA methods are generally not measures of hearing per se.

Hearing is a perceptual process that involves the entire auditory system and cannot be measured in terms of electric responses unless those responses can be shown to relate directly directly to perception. The clinical value of ERA lies in the correlation of electric responses with auditory pathology and/or performance.

Table 3-1. Potentials Evoked in the Auditory System by Sound Stimulation, Their Probable Sites of Origin, and Typical Latencies

I.   Cochlea (hair cells).
Cochlear microphonic.
Summating potential.

II.   Auditory nerve.
(eight nerve action potential (wave I) 2.0 msec.

III.   Brain stem

Wave II	-	cochlear nucleus 3.0 msec.
Wave III	-	superior olive 4.1 msec.
Wave IV	-	lateral lemniscus 5.3 msec.
Wave V	-	inferior colliculus 5.9 msec.

Frequency following response - unknown.
Slow negative 10 (SN-10) - unknown 10.0 msec.

IV.   Middle responses (auditory cortex).

N0	-	8 to 10 msec (variable).
P0	-	13 msec.
Na	-	22 msec.
Pa	-	34 msec.
Nb	-	44 msec.

V.   Vertex potential (auditory cortex).

P1	-	50 msec (variable).
N1	-	90 msec.
P2	-	180 msec.
N2	-	250 msec.

Sustained cortical potential.
Late positive component.
Contigent negative variation.

Types of Electric Response Audiometry

Three techniques for recording the auditory evoked potentials have been described: electrocochleography (ECoG), auditory brain stem response audiometry (ABR), and cortical electric response audiometry. A comparison of these techniques is presented in Table 3-2.

Electrocochleography

Electrocochleography is the measurement of the potentials arising within the cochlea and the auditory nerve: cochlear microphonic, summating potential, and eight nerve action potential. In most cases a needle electrode is placed through the tympanic membrane onto the bone of the promontory to make these recordings.

Table 3-2. Comparison of Techniques of Electric Response Audiometry

Technique	Electrode	Effect of Anesthesia	Portion of Auditory System Tested	Reliability
Electrocochleography	Promontory	None	Peripheral	Excellent
Auditory brain stem response	Surface	None	Brain stem	Good
Cortical evoked response audiometry	Surface	Marked	Entire	Fair.

Electrocochleography is the most accurate of the electric response audiometric techniques by virtue of the close proximity of the electrode to the generator sites. Accuracy also is enhanced because the peripheral auditory system is unaffected by sedation or even general anesthesia.

An obvious disadvantage of this technique is the requirement for tympanic membrane penetration. Another disadvantage is that it measures only the response of the most peripheral portion of the auditory system and, therefore, cannot be equated with hearing as such. Although relatively rare, there are cases in which the cochlea and auditory nerve function normally, but brain stem or central defects produce hearing loss.

Auditory Brain Stem Response Audiometry

Auditory brain stem response audiometry utilizes surface electrodes to measure the potentials arising in the auditory nerve and brain stem structures. The active electrode is placed on the scalp vertex. , and the reference electrode is attached to the mastoid prominence of the test ear. The opposite mastoid is used as a ground. The events that occur during the first 10 msec following sound stimulation are recorded.

The advantage of auditory brain stem response audiometry is that because surface electrodes are used, anesthesia is not requird. In practice, however, either basal narcosis or anesthesia is often required in children to prevent excessive movement which interferes with accurate recordings. Auditory brain stem response audiometry, like electrocochleography, is not influenced by basal narcosis or general anesthesia.

Cortical Electric Response Audiometry

Cortical electric response audiometry involves the measurement of the potentials that arise in the auditory system above the brain st em (the middle and slow potentials). The electrode configuration is the same as for auditory brain stem response audiometry.

An advantage of cortical electric response audiometry is that in measuring the most central responses, the entire auditory mechanism is tested. Responses can thus be best equated with clinical hearing. This is particularly important when there is a question of a central disturbance.

A major disadvantage of cortical electric response audiometry is that the potentials also are affected by sleep and sedation. Because of these factors, cortical electric response audiometry is more difficult to perform in a clinical setting.

Electrocochleography

Stimulation Techniques

The stimulus most commonly used in electrocochleography has been wide-band click stimulus. Acoustically the click comprises a large number of frequencies which stimulate the entire cochlea. With a flat hearing loss, the click is a good predictor of the audiometric threshold. With sloping hearing losses, however, one cannot predict the type of audiogram using click stimuli.

Eggermont has used tone bursts for electrocochleography. Frequency-specific tone bursts are more accurate indicators of hearing levels at different frequencies and predict the behavioral audiogram quite accurately.

Recording Techniques

A standard Teflon insulated electromyographic recording needle is positioned onto thebone of the promontory after induction of anesthesia of the tympanic membrane by means of iontophoresis or topical phenol application. Responses are filtered below 30 Hz and above 3200 Hz. The computer is set to measure over a 10 msec window.

Measurable Potentials

Electrocochleography is a measure of the potentials arising within the cochlea and the auditory nerve: cochlear microphonics, summating potential, and eight nerve action potential.

Cochlear Microphonic

The source of the cochlear microphonic is the hair-bearing surface of the hair cells. Its onset is immediate and it mimics the wave form of the acoustic stimulus. Because the response recorded from the promontory is diffuse and gives no definite information regarding specific populations of hair cells, most investigators do not find the cochlear microphonic clinically useful.

Gibson and Beagley are an exception and have used the cochlear microphonic to aid in differentiation of cochlear from retrocochlear lesions. They find a tendency toward a reduction in microphonics in cochlear lesions, whereas in acoustic tumors the cochlear microphonic is often normal.

The eight nerve action potential is of primary interest in electrocochleography. This can be recorded free of the interfering cochlear microphonic by cancelling the microphonic by alternating the phase of the click or tone burst stimulus.

Summating Potential

The summating potential also is generated by the hair cells and is a direct current shift of the baseline of the recording, which is almost always negative for all frequencies and intensity levels in man (Fig. 3-2). This potential is thought to represent asymmetry in the basilar movement resulting from a pressure difference between the scala tympani and the scala vestibuli during sound stimulation. The source of this dc shift is also the hair cells. As we shall see later, this potential may be a means of studying hair cells in Ménière's disease and other cochlear disorders.

Since the summating potential appears superimposed upon the eight nerve action potential, its measurement is sometimes difficult. One technique for separating the summating potential from the eight nerve action potential is to increase the click rate. As the rate of the click is increased, the eight nerve action potential diminishes because the individual neurons do not have time to recover from their refractory period to again respond to the new stimulus. The summating potential is unaffected by click rate. A recording is first done at a low click rate and the response, which comprises both the summating potential and the eight nerve action potential, is stored in computer. A second recording is then done with a high click rate. The response obtained represents primarily the summating potential and is used as a measure of that response. The second response can then be subtracted from the first response in the computer and the derived response will represent primarily the eight nerve action potential devoid of the contaminating summating potential.

Compound Action Potential

The eight nerve action potential is the averaged response of the discharge pattern of many auditory neurons. Cochlear dynamics which influence the shape of the compound action potential are extremely complex and beyond the scope of this discussion. The reader is referred to Eggermont's chaper on electrocochleography in the *Handbook of Sensory Physiology* for a current review of this subject.

In addition to the normal compound action potential, Portmann and Aran have described four types of electrocochleographic response in patients with sensorineural hearing impairment: dissociated, recruiting, broad, and abnormal. Only the normal response will be described here.

Normal response. In patients with normal hearing an action potentical can be elicited to within 5-10 dB of the patient's behavioral threshold in most cases. At high intensity the potential is large, consistent, easily recordable, and reproducible. Action potentials are described by three parameters: latency, amplitude, and wave form.

Latency is defined as the time interval from the onset of the click to the maximal negative deflection in the action potential. Latency normally decreases systematically from approximately 4 msec at threshold to 1.5 msec at high intensity. Amplitude, on the other

hand, characteristically increases in two steps. There is a gradual rise to the level of approximately 40-50 dB HL, where there is a plateau, and then a second more rapid increase in amplitude above that level.

By convention, latency and amplitude (as a percentage of maximal amplitude) are plotted in relation to stimulus intensity. The maximal amplitude and representative wave forms are plotted on the recording (Fig. 3-3).

Clinical Applications of Electrocochleography

There are three clinical uses for electrocohleography: threshold testing, the study of Ménière's disease, and the study of acoustic neurinomas.

Threshold Testing

Electrocochleography is the most accurate of the objective audiometric tests. Thresholds to the click are an indication of the audiometric threshold in the 3000-4000 Hz range. The electrocochleographic threshold predicts the behavioral threshold to within 5-10 dB at this frequency to almost all cases. As stated before, however, one cannot predict the audiogram using clicks only.

There is a much better correlation to the subjective audiogram using tone bursts rather than clicks. The best correlation is the frequencies of 1, 2, and 4 kHz, but correlation remains excellent at 500 and 8000 Hz.

The disadvantage of using electrocochleography for threshold determination is the necessity for transtympanic needle placement. At the Otologic Medical Group, Inc, we currently use auditory brain stem response audiometry for threshold determination.

Ménière's Disease

The summating potential and the compound action potential are of interest in the study of Ménière's disease.

Summating potential. Eggermont has found an increased negative summating potential during periods of hearing loss in the fluctuant hearing stage of Ménière's disease. He attributes this findings to either a mechanical displacement of the basilar membrane, which causes nonlinearities in its movement as a result of the presumed endolymphatic hydrops, or a metabolic disturbance resulting in a larger endolymphatic potential. As fixed hearing loss develops, the summating potential decreases. This indicates a loss of hair cells. Measurement of the summating potential may, therefore, be an indication of reversibility of the hearing impairment in Ménière's disease.

Compound action potential. Compound action potentials in Ménière's disease are generally of the broad type, most likely because of the contribution of a large negative summating potential.

In approximately 50% of the patients with Ménière's disease whom we studied, a

distinctive type of eight nerve action potential was found characterized by a tendency to form multiple negative responses. We have not seen this type of response in other types of sensorineural hearing loss, and this may be a means of distinguishing endolymphatic hydrops.

Acoustic neurinomas. The potential of most interest in acoustic neuroma study is the compound action potential. Gibson and Beagley also have studied the cochlear microphonic as previously mentioned.

The compound action potential in acoustic neuromas is much broader than the normal potential. In our study by electrocochleography of 50 patients with acoustic neuromas we found an abnormal action potential in 85%.

As observed in the following section, brain stem audiometry is a more accurate predictor of acoustic tumors, and we use it exclusively for this problem at the present time.

Future applications of electrocochleography. Because of the necessity of penetrating the tympanic membrane for electrocochleography, auditory brain stem response audiometry has replaced it in most clinics. Threshold testing is nearly as accurate with auditory brain stem response audiometry as with electrocochleography. Auditory brain stem response audiometry is a more accurate predictor of retrocochlear pathology than is electrocochleography.

The future of electrocochleography lies in the study of cochlear and eight nerve physiology and pathophysiology. Changes in cochlear microphonics and summating potentials are an indication of hair cell disease. As outlined above, study of the summating potential and compound action potential are means of assessing the state of the end organ in Ménière's disease.

Moffat has reported changes in these potentials during glycerol dehydration in patients with Ménière's disease. Gibson, Ramsden, and Moffat also have demonstrated changes in these potentials with the administration of intravenous vasodilators. Electrocochleography is, therefore, a powerful new tool in the study of cochlear disease which will have great future application.

The disadvantage of electrocochleography is the necessity for transtympanic needle electrode placement. Because of this, surface recording techniques have become much more popular in the USA.

Auditory Brain Stem Response Audiometry

Stimulation Techniques

As in electrocochleography, the stimulus most commonly used for auditory brain stem response audiometry is a wide band click stimulus. This stimulus presents the same limitations in brain stem audiometry as in electrocochleography in that the entire cochlea is stimulated, and one cannot predict the audiogram except in cases of flat hearing impairment.

The majority of sensorineural losses are sloping with the loss greater in the higher

frequencies. Errors, therefore, might occur in predicting a more severe loss than is actually present because of preservation of low tone hearing.

Relatively frequency-specific stimuli (tone bursts, tone pips, filtered clicks) may also be used to elicit the brain stem responses. These stimuli give more frequency-specific information regarding the cochlea and may be used to estimate audiometric thresholds as described later.

The addition of high-pass noise with various cutoff frequencies simultaneously with click stimulation is a means of assessing contributions from different areas of the cochlea. With this technique a good estimation of the audiogram can be made. This technique is detailed below.

Recording Techniques

Standard electroencephalographic disk electrodes are attached to the vertex and both mastoids of the patients to be tested. The vertex electrode is the active lead, with the mastoid on the stimulated side as the reference electrode and the mastoid of the unstimulated ear as the ground electrode. Band-passing of the system occurs at 30-3000 Hz with an overall amplification of 100.000. A time window of 10 msec is used.

Sedation is not used in adults or in small infants, who often sleep during the procedure. Uncooperative children are sedated as follows: 1 mL/25 lb intramuscularly of a combination of meperidine (Demerol) (25 mg), promethazine (Phenergan) (6.25 mg), and chlorpromazine (Thoraxine) (6.25 mg) per 1 mL. A maximum of 1 mL is used. Chloral hydrate (500 mg/5 mL) in an oral dose of 1-2 mL/10 lb may be used in place of the injectable medication.

Normal Brain Stem Responses

A series of seven waves may be recorded from the scalp vertex during the first 10 msec following sound stimulation. These waves are thought to represent successive synapses in the auditory pathway with wave V most likely representing the inferior colliculus. Of these various responses wave V is the one that is most consistent and is used in the clinical assessment of hearing (Fig. 3-4).

Frequency Following Responses

Similar to the cochlear microphonic response, the frequency following response follows the frequency of tonal stimulation. It is distinguished from the cochlear microphonic by its onset latency of about 6 msec. This has led to the general consensus that its origin is in the region of the inferior colliculus. Some researchers are still investigating whether or not the frequency following response could possibly be a repeated wave V of the transient brain stem response.

Recently Davis and Hirsh, and Suzuki and coworkers, have described another response at around 10 msec after stimulus onset. Davis and Hirsh have labeled this the SN-10 response and believe the generator is the primary auditory cortex.

The first appearance and latency of wave V are the measures most used in brain stem audiometry. Wave V latency is dependent upon stimulus intensity: as the intensity of the stimulus is increased, there is a systematic shortening of the latency from about 8.5 msec at threshold to 5.5 msec at the 60 dB hearing level.

Clinical Applications of Auditory Brain Stem Response Audiometry

There are three major clinical uses of brain stem audiometry: (1) threshold testing of infants, young children, and malingerers, (2) diagnosis of acoustic neurinomas, and (3) diagnosis of brain stem lesions.

Threshold Testing

Brain stem audiometry is used in all cases in which standard behavioral audiometric techniques fail. This technique allows identification of hearing impairment in infancy so that rehabilitation can be started. As described above, wideband click stimuli stimulate the entire cochlea, and one cannot predict the audiogram except in cases of flat hearing impairment. Despite this deficiency, this is a valuable technique for early identification of hearing loss. If an error is made, it is usually in predicting a greater hearing loss than is actually present. In either case, early rehabilitation is begun.

Kodera et al have shown good correlation between the behavioral audiogram and brain stem audiometry using tone burst stimuli. As with the electrocochleography, the correlations are better for the high frequencies than the low. Use of these stimuli better predicts the pure tone audiogram than does use of broad-band click stimuli. This technique, however, is still deficient in accurately predicting low-frequency hearing.

Some studies have shown good correlation of the frequency following responses to low-frequency hearing thresholds. The disadvantage of the use of this response is that its amplitude is very small and it is difficult to separate artifact from the response. Some researchers have questioned the area of the cochlea from which this response is initiated at moderate to high levels of stimulation. Thus, even though this response shows promise of aiding in the assessment of low-frequency hearing, may questions remain unanswered regarding its clinical applicability.

Recently we have applied a technique which involves the use of high-pass masking noise which can reasonably reconstruct the pure tone audiogram. This technique was first introduced in animal work by Teas, Eldredge, and Davis and later applied to electrocochleography by Elberling.

The High-Pass Masking Technique

Don and Eggermont, and Parker and Thornton have demonstrated that the whole of the basilar membrane contributes to the brain stem response to a broad-frequency click. The technique of deriving the contribution initiated from each portion of the basilar membrane is illustrated in Fig. 3-5. In this figure the cochlea is rolled out flat and marked off in sections A through F. Section A represents the area of the cochlea whose maximum sensitivity is 8 kHz and above. Section B represents the region from 4-8 kHz. Section C represents the region

from 2-4 kHz; section D, from 1-2 kHz; section E, from 0.5-1 kHz; and section F, the region below 5000 Hz.

A click stimulus presented at moderate hearing levels and above will stimulate the entire cochlea because of its broad-band nature. The brain stem response R-1, seen in line 1 of Fig. 3-5 represents the sum of brain stem activity initiated by stimulation of the whole cochlea (i.e. from sections A through F). Next, as seen in line 2, the level of continuous broad-band noise that is sufficient to desynchronize and thereby obliterate the response to the click is determined. This masked activity is denoted as MR.

After the appropriate noise level has been determined, the noise is steeply high-pass filtered at 8 kHz (the high-frequency component of the noise above 8 kHz is allowed to pass), and the clicks are presented in this noise. As seen in line 3 of Fig. 3-5, the brain stem response (R-2) obtained under these conditions results from click-synchronous activity initiated from the region below 8 kHz. The subtraction of this response, R-2, from the response obtained without any masking noise, R-1, in the computer results in the derived narrow band response, DR-1, seen in line 4. This subtraction procedure eliminates the common contributions from regions below 8 kHz (stippled area in line 4) and results in the contribution from the cochlea that was masked by the 8 kHz high-pass noise (section A).

Next the high-pass cutoff of the noise is lowered by an octave to 4 kHz, and the clicks are presented in this noise. The brain stem response is recorded, R-3, shown in the line 5 of Fig. 3-5, results from click-synchronous activity from the unmasked portion of the cochlea, that is, the region below 4 kHz. Subtraction of the response (R-3) from that obtained with the 8 kHz high-pass noise (R-2) eliminates the common contribution from the region below 4 kHz (stippled area, line 6). The response derived from this subtraction (DR-2) is initiated from the narrow band region of the cochlea that is not masked by 8 kHz high-pass noise, but was masked by the 4 kHz high-pass noise (section B). In similar fashion, by successive subtraction of the responses, one obtains the derived narrow band contribution to the brain stem response for the other sections of the cochlea. This procedure is repeated for different click intensities and in this manner the contribution from each portion of the basilar membrane at each intensity is derived.

In patients with normal hearin, contributions to the brain stem response to the click can be detected down to the 30 dB sensation level for the 8 kHz and above region and 500 kHz and below regions of the cochlea. Contributions to the brain stem response from 4, 2, and 1 kHz octave-wide regions can be detected down to at least the 10 dB sensation level.

To estimate the hearing loss at a given audiometric frequency, these data have been used to derive the following simple formula:

Xf = LPf - LNf where

Xf = the amount of hearing loss at audiometric frequency (in kHz) for the patient.

LPf = the lowest click level where wave V is detected in the patient's derived response for frequency region f.

LNf = the lowest click level where wave V is detected in normal hearing subjects' derived responses for frequency region f.

For example, if for the derived responses from the 4 kHz region (f=4) in a patient, wave V can last be detected at a click level of 40 dB HL (i.e. LP4=40 dB) and from the data of normal hearing subjects the lowest level is 10 dB (i.e. LN4-10 dB), then the hearing loss at 4 kHz is X4=40 dB - 10 dB = 30 dB loss.

This technique estimates the hearing impairment at specific frequencies quite accurately in all types of hearing loss. There are two disadvantages to the technique, the time required to complete the test, and the sophisticated, expensive equipment necessary. To perform this analysis expeditiously, a computer system with storage capability is necessary. Even then testing of one ear requires approximately 1.5 hours. To complete the analysis without the capability of data storage would require at least twice as long. Nevertheless, this is a small price to pay for a technique which can accurately assess hearing function in the very young or otherwise difficult-to-test patient.

Use of a Combination of Techniques

Davis and Hirsh have proposed that a combination of techniques be used to approximate the pure tone audiogram. They use auditory brain stem responses to 2 and 4 kHz tone pips to estimate the audiogram at those frequencies. The later SN-10 response to 1 and 0.5 kHz tone pips is used to estimate the hearing at those frequencies. Moushegian et al have proposed that the auditory brain stem responses be used to assess the more basal portions of the cochlea and the frequency following response, the apical region.

Current Status of Threshold Testing

At the prewsent time, we are using broad-band click stimulation to elicit the brain stem responses. From this we estimate the hearing in the 3-4 kHz region of the cochlea. We estimate the low-frequency hearing with the use of impedance audiometry. The presence of an acoustic reflex to a low-frequency stimulus indicates preservation of hearing in the lower frequencies. This finding with an absent auditory brain stem response to high-frequency click stimulation would indicate a sloping type high-frequency hearing loss and would be an indication for caution in fitting of a hearing aid. In such a case we might well prescribe a low-gain hearing aid with high-frequency emphasis.

On the other hand, the absence of an acoustic reflex to a low-frequency stimulus combined with an absent brain stem response to a high-intensity click implies a profound hearing impairment and indicates the need for a high-gain hearing aid.

The use of the frequency-following response, the SN-10 response, and the high-pass masking technique, require further study and clinical verification. Some combination of these techniques give promise of accurate prediction of the pure tone audiogram with objective measuring techniques.

Acoustic Neurinoma Diagnosis

Auditory brain stem response audiometry has proved to be the best audiometric test for acoustic tumor detection. The success of ABR depends upon the fact that acoustic tumors stretch or compress the auditory nerve, producing a delay in the response latency which ABR can detect. This delay may occur in an ear with normal hearing. Conversely, cochlear lesions have little effect on the brain stem response latencies for high-intensity stimuli until the hearing loss becomes rather severe.

There are several techniques in which the latency of wave V is used for detection of a retrocochlear lesion. The first is to measure the absolute latency of the wave and compare it to normals. The normal latency for wave V is between 5-5.7 msec. Because of this rather large variability among normal patients, we have not found the measure of the absolute latency of wave V to be very useful in acoustic neurinoma diagnosis.

Another approach has been to measure the interval between the first and fifth waves. This so-called measure of central conduction time has the advantage of removing the error which occurs when there is a high-frequency sensorineural hearing impairment producing a cochlear delay, as described below. Prolongation of the wave I-V interval should reflect only the delay of propagation of the nerve impulse along the auditory nerve secondary to tumor compression.

The difficulty with the use of this technique is that patients with either sensory hearing loss or an acoustic tumor often do not have a recordable wave I. Thus, this technique cannot be used. Coates has increased his ability to use this method by doing simultaneous recordings with an ear canal electrode and scalp electrodes. The ear canal electrode more frequently detects the first wave, while the surface electrodes are used to record the fifth wave. This procedure, however, requires the placement of an ear canal electrode and also necessitates equipment which is capable of simultaneous recording.

Another difficulty in using central conduction time as the only measure of a retrocochlear lesion is that a tumor may cause delay in wave I; wave I-V latency would be normal with all of the waves delayed.

The technique which we use for acoustic tumor detection is to compare the patient's nonsuspect ear with the ear with the suspected acoustic tumor. With this technique, the patient acts as his own control to reduce the variability seen between normal patients.

Interaural Latency Differences in Patients with Normal Hearing

Brain stem responses to an 83 dB HL broad-band click are recorded. The nontest ear is masked by 78 dB white noise. The responses are studied for the detection and latency of wave V which is the largest and most recordable of the peaks. The latency between the two ears (IT5) is compared. In studying a group of normal patients, we found no more than a 0.2 msec difference between the wave V latencies for the two ears.

Interaural Latency Differences in Patients with Unilateral Hearing Loss

Nontumor Cases

Patients with hearing impairment greater than 75 dB at either 2 or 4 kHz are excluded because they do not give reliable brain stem responses. When the hearing loss is less than 55 dB at 4 kHz, there is an insignificant effect on the wave V latency. As the hearing loss at 4 kHz increases above 50 dB, wave V latency gradually increases at the rate of about 0.1 msec/10 dB, and it is necessary to introduce a correction factor to decrease the number of false-positive responses.

The correction factor was determined which would eliminate the majority of the false-positive responses without creating any false-negatives (tumor missed), which is a much more serious error. A correction factor of 0.1 msec is subtracted for 4 kHz pure tone hearing loss of 55 or 60 dB, and 0.2 msec is subtracted for hearing loss of 65 or 70 dB. The data are recorded as illustrated in Fig. 3-6.

Tumor Cases

One-half of the patients with acoustic neurinomas have no detectable wave V regardless of the degree of hearing impairment. We consider this indicative of an acoustic neurinoma.

Ninety-six percent of 150 tumor patients have shown an adjusted interaural difference (IT5) of greater than 0.2 msec. Comparing ABR with the other standard neuro-otologic tests, we find that ABR is the most accurate of these tests and also has the lowest false-positive rate (Tabel 3-3). Brain stem audiometry has, therefore, become an important part of our evaluation of acoustic tumor suspects.

Prediction of Tumor Size

Large acoustic tumors press against the brain stem. If significant pressure is exerted on the auditory tracts in the brain stem, abnormalities in the brain stem response are detectable when testing the opposite (nontumor) ear. This effect is best detected by measuring the interval between the third and fifth waves. Normally, this interval, T3-5, will be 1.9 ± 0.1 msec. A T5-3 of 2.1-2.8 msec has been found in 71% of 55 patients having tumors larger than 3 cm. Thus brain stem audiometry may not only predict the presence of an acoustic tumor, but also the general size of the tumor.

Conductive Hearing Losses

One word of caution is in order. Conductive hearing impairments will produce latency shifts that mimic an acoustic tumor. Standard audiometric tests to rule out conductive losses should first be performed.

Current Use of ABR in the Neuro-Otologic Evaluation

Our routine evaluation of a tumor suspect includes petrous pyramid x-rays, electronystagmography, and an acoustic reflex test. If the x-rays show definite enlargement of the internal auditory canal on the suspect side, a constrast study is obtained, usually computerized tomography with air contrast if necessary, followed by a small-dose polytome Pantopaque study if the diagnosis remains in doubt after computerized tomography.

If the findings on x-ray are not definite, but the ENG or acoustic reflex test suggests a tumor, we obtain ABR. If that is positive, the contrast studies as described above are performed.

Table 3-3. Four Screening Tests' Failures Listed as Percentages of Tests Performed

	ABR	X-ray	ENG	ART
Percent false-negative (tumor missed)	4	11	23	30
Percent false-positive (false alarm).	8	27	28	28

Recently we have used ABR as a primary screening test more often. In some cases the ENG and acoustic reflex test have been omitted because of ABR. The ABR is a significant addition to the acoustic tumor detection test battery which is being used with increasing frequency.

Nonacoustic Cerebellopontine Angle Tumors

Twenty-eight patients with cerebellopontine angle tumors, not acoustic tumors, have been studied with brain stem audiometry. Brain stem audiometry has identified the tumor in cases where there has been pressure on the cochlear nerve. Because some nonacoustic lesions of the angle do not produce pressure on the cochlear nerve, the detection rate for non-acoustics is not as good as for acoustic neurinomas (Table 3-4).

Table 3-4. Detection Rate for Nonacoustic Cerebellopontine Angle Tumors (#28)

Wave V	-	Absent or delayed	75%
Wave V	-	Normal	25%
	-	3 of 10 meningiomas	
	-	1 of 5 cholesteatomas	
	-	2 of 4 facial nerve neurinomas	
	-	arachnoid cyst.	

Brain Stem Lesions

Brain stem audiometry is of distinct value in the diagnosis and localization of brain stem lesions. Intra-axial pontine masses which impinge upon the auditory tracts produce loss

of brain stem responses. The level of the mass can be predicted on the basis of the presence or absence of succeeding brain stem responses.

Absence of brain stem responses is an early indication of multiple sclerosis in a large percentage of those patients. Lesions in the auditory tract produce desynchronization of the responses which make them nondetectable despite the presence of normal pure tone and speech audiometry in many cases.

Cortical Electric Response Audiometry

At the present time we are not using the cortical responses in our clinical practice. Nevertheless, a brief review of possible clinical application of these potentials is presented.

Slow and Late Potentials

Initially, the vertex potentials were explored for threshold testing. Some reasons for recording these potentials are: (1) they represent activity of higher central levels and, therefore, are apt to reflect more of the "hearing process", (2) stimuli more frequency specific than clicks (i.e. tone bursts) can be used to elicit a response, (3) the responses are relatively large and require only a small number of trials.

However, after a few years of research and application, it was evident that vertex potentials do not result in accurate threshold testing. They seem to correlate well with the audiogram (within 10 dB of threshold) in waking adults, but they are affected by the patient's physiologic state and by medications and anesthesia. More importantly, these responses are not reliable in children, the population most in need of an ERA technique. In general, the slow and late cortical potentials may be reliable in waking adults; in children these responses are unreliable either because they vary or, as with "expectation waves", they require some behavioral interaction. Thus, these responses can occasionally be used for gross testing but must be interpreted with great caution.

Middle Components

After the slow and late cortical responses lost their appeal, electric responses in the 12-50 msec range began to be examined. Unlike the slow and late cortical potentials, middle components remain stable whatever the subject's state - alert, asleep, even lightly sedated. However, they are affected by anesthetic levels of sedation. With use of filtered clicks or tone pips, middle components are better for predicting thresholds of various frequencies than the slow cortical potentials.

One major disadvantage of responses in this middle time domain is contamination by the myogenic responses. For threshold testing, whether the response is myogenic or neurogenic may be irrelevant as long as both responses are mediated by the auditory pathway. However, at high-stimulus levels, some of these myogenic responses from the scalp muscles are thought to be mediated by other portions of the labyrinth. The claims are that the middle responses will yield threshold estimates within 10 dB of the behavioral threshold in the waking state and about 20 dB in the sleeping state. This suggests that sleep has an effect on thresholds. Moreover, the amplitudes are smaller in infants and yield thresholds of about 30

dB normal hearing level (nHL). It is difficult to determine when middle responses should be the ERA method of choice, as many of their advantages over slow and cortical responses are the same advantages of brain stem and ECoG methods. It also should be noted that some researchers have had difficulty recording and using the middle components in children, while others have apparently had success. Perhaps middle responses can be used to provide information on some level (primary cortex?) of processing and thereby aid in assessing central problems.

Because of the difficulties in recording these later responses, the earlier surface-recorded brain stem responses are of much greater clinical usefulness.

Conclusions

Electric response audiometry is an exciting new development with broad implications in the fields of otology, audiology, and neurology. At the present time it is the best objective audiometric test for predicting hearing thresholds in infants or uncooperative patients.

Electrocochleography offers a means for study of the function of the inner ear and for differentiation of types of sensorineural hearing impairment. Auditory brain stem response audiometry is a valuable addition to the audiologic test battery for acoustic tumor diagnosis. It also offers a means of studying brain stem function in a variety of neurologic disorders.