USEFULNESS OF AUDITORY BRAINSTEM RESPONSE TO IDENTIFY RETROCOCHLEAR PATHOLOGY-A TUTORIAL

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Register No: 10DNA002

An Independent Project Submitted in Part Fulfillment of

PG Diploma in Neuroaudiology

University of Mysore,

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MANASAGANGOTHRI

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JUNE, 2011

DEDICATED TO

ALMIGHTY ALLAH

AND

MY DEAR PARENTS

CERTIFICATE

This is to certify that this independent project entitled **"Usefulness of Auditory Brainstem Response to identify Retrocochlear Pathology - A Tutorial"** is a bonafide work in part fulfillment of degree of Post Graduate Diploma in Neuroaudiology of the student registration no: 10DNA002. This has been carried under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore

June 2011

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CERTIFICATE

This is to certify that this independent project entitled **"Usefulness of Auditory Brainstem Response to identify Retrocochlear Pathology- A Tutorial"** has been prepared under my supervision and guidance. It is also certified that this independent project has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore
June 2011

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DECLARATION

This is to certify that this dissertation entitled **'Usefulness of Auditory Brain Stem Response to identify Retrocochlear Pathology - A Tutorial'** is the result of my own study and has not been submitted earlier to any other university for the award of any degree or diploma.

Mysore **Register Number: 10DNA002**

June, 2011

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INTRODUCTION

Auditory brainstem response (ABR) audiometry is a neurologic test of auditory brainstem function in response to auditory stimuli. It was first described by Jewett and Williston in 1971.

ABR audiometry refers to an auditory evoked potential evoked by a brief click or tone burst or any other transient acoustic stimulus from an acoustic transducer in the form of an insert earphone, headphone, or bone vibrator. The evoked response is measured by surface electrodes typically placed at the vertex of the scalp and ear lobes. The amplitude (micro voltage) of the signal is averaged and charted against the time (millisecond). A normal ABR waveform is characterized by five to seven vertex-positive peaks that occur in the time period from 1.4 to 8.0 ms after the onset of a stimulus. The 'waves' or 'peaks' of the ABR represent sums of neural activity from one or more sources at various discrete points in time. Responses are usually displayed with positive peaks reflecting activity toward the vertex (vertex-positive), and these peaks are labeled with Roman numerals I through VII and the negative troughs following each positive peak. The most prominent vertex-positive peaks in the ABR waveform are I, III, and V.

Each wave is thought to have different origin across the auditory nervous system. According to Moore (1987) origin of each waveform components in human are:

Wave I: The response is believed to be originated from the distal portion of the auditory nerve (cranial nerve VIII) i.e. away from Cochlear nucleus and close to the cochlea.

Wave II: is generated by the proximal part of the VIII nerve, or close to the Cochlear nucleus.

Wave III: The ABR wave III arises from the activity of second-order neuron (beyond cranial nerve VIII) in or near the cochlear nucleus.

Wave IV: It often shares the same peak with wave V, and is thought to arise from pontine third-order neurons mostly located in the Superior olivery complex, but additional contributions may come from the cochlear nucleus and nucleus of lateral laminiscus.

Wave V: Generation of wave V is believed to be from the vicinity of the Lateral laminiscus and Inferior colliculi. The second-order neuron activity may additionally contribute in some way to wave V.

Wave VI and VII: Thalamic (Medial geniculate body) origin is suggested for generation of waves VI and VII, but the actual site of generation is uncertain.

The latencies of the waves in the normal ABR are highly replicable providing a powerful basis for judging abnormality. ABR audiometry is of great interest today in the field of audiology, otology, and neuro otology and is probably one of the most exciting advances in evoked response audiometry (ERA). The degree of peripheral hearing sensitivity can be estimated and it is often used to cross check behavioral threshold. ABR can also be used to estimate the hearing threshold of infants, young children and other uncooperative subjects (Jerger & Hayes, 1976; Pratt & Sohmer, 1978; Davis & Hirsh, 1979).

ABR is considered to be an effective tool in the evaluation of suspected retro cochlear pathology such as an acoustic neuroma, demylinating disease etc. With the

ABR test it is possible to obtain diagnostic information regarding the status of the eighth cranial nerve and brainstem. ABR is a cost-effective approach for evaluating patients with suspected retro cochlear lesions. However, an abnormal ABR finding suggestive of retro cochlear pathology indicates the need for MRI of the cerebellopontine angle.

The importance of utilizing ABR in the evaluation of retrocochlear lesions have been emphasized by Selters and Brackman (1977). However, it was thought that the Auditory Brainstem Response may not be sensitive to detect small acoustic tumors. Don et.al (1997) proposed stacked ABR test which can be used to identify acoustic tumor when an MRI needs to be justified due to cost, or MRI facilities are unavailable.

Thus, Auditory brainstem response (ABR) audiometry has a wide range of clinical applications, including identification of space occupying lesions, diffuse lesions, demyelinating disorders and functional abnormalities. Due to wider range applications of ABR, a consolidation of all these information is required and a tutorial for this purpose would be extremely useful. Though there are a few comprehensive textbooks on ABR, a lot of information on ABR is available in various other sources. This tutorial makes an attempt to compile information available in the literature on various aspects of ABR.

The word **'tutorial'** as defined by scientific and English dictionaries refers to an 'instruction book' or 'intensive instruction in some area'. It provides step by step information in presenting a concept or learning unit. It is one method of transferring knowledge and may be used as a part of a learning process. More interactive and

specific than a book or a lecture; a tutorial seeks to teach by example and supply the information to complete a certain task.

The information is carefully selected and delivered in an organized and structured manner. It also evaluates the user's knowledge through different kind of questions which gives an immediate feedback of the performance. Thus, it acts as an efficient guide for students and experts linked with the particular field.

The present tutorial aims at providing intense information about the usefulness of Auditory Brainstem Responses to identify retrocochlear Pathology. The Tutorial establish theoretical framework and provide rich, meaningful data and insight into a particular aspect.

Present tutorial mainly focus on identification of reterocochlear pathology using various ABR parameters like Interpeak Latencies, Absolute Latency of Wave V, Interaural Wave Latency Difference, Wave V/I Amplitude Ratio, Absent Waveform Components, Wave morphology etc. The Tutorial also focused on ABR findings in clients with different neural disorders, like space occupying lesions, multiplesclerosis, lower brainstem lesion, upper brain stem lesion, auditory neuropathy, etc.

The information for this tutorial has been collected from books, journals, articles and other sources. The information gathered is organized and depicted in the tutorial. To assess the knowledge of the reader, information is followed by a set of different types of questions. These questions are of the following types:

- Fill in the blanks.
- Multiple Choice.

- True\False.
- Short answers.
- Complete the diagram.
- Match the following etc.

The questions are neither too simple nor too complex. These would provide the user with an opportunity to test the knowledge that he\she has gained through this tutorial. In order to crosscheck the results, answers have been provided to all the questions at the end of each section. This would give an immediate feedback to one's performance.

Thus, this Particular Project is aimed to serve the following purposes:

- To give intensive information about ABR and its application in detecting different retrocochlear pathology.
- To test one's knowledge of the topic.
- To serve as a guide for students and other concerned professionals.
- To train and evaluate trainees during a training program.

HISTORICAL ASPECTS

In 1929, Berger reported a remarkable and controversial set of experiments in which he showed that one could measure the electrical activity of the human brain by placing an electrode on the scalp, amplifying the signal, and plotting the changes in voltage over times. This electrical activity is called the electroencephalogram, or EEG. However, embedded within the EEG are the neural responses associated with specific sensory, cognitive, and motor events. These specific responses are called event-related potentials to denote the fact that they are electrical potentials associated with specific events.

The first unambiguous sensory ERP (Event Related Potentials) recordings from awake humans were performed in 1935–1936 by Davis and Davis, and work on the similar line were published a few years later by Davis in 1939. This was long before computers were available for recording the EEG, but the researchers were able to see clear ERPs on single trials during periods in which the EEG was quiescent. However, the first published computer-averaged ERP waveforms were apparently published by Galambos and Sheatz in 1962. These responses initially recorded without the advantage of computer averaging which were generated at the cortex at a time interval of 100 to 200 ms after presentation of an auditory stimulus. They were visible because of their relatively high amplitude in comparison to unrelated background physiological noise.

It was not until the late 1960s that electrical potentials generated by the brainstem were identified in the laboratories of Jewett and his colleagues in the United States and Sohmer and Feinmesser in Israel. Sohmer and Feinmesser (1967), while recording eighth nerve Auditory Potentials via ECochG, observed a series of peaks with

amplitude less than 1 μv occurring within 6 ms after presentation of an auditory stimulus as shown in Figure 1. They suggested that the peaks following the AP represented either repeated firings of the eighth nerve or activity in auditory pathways of the brainstem.

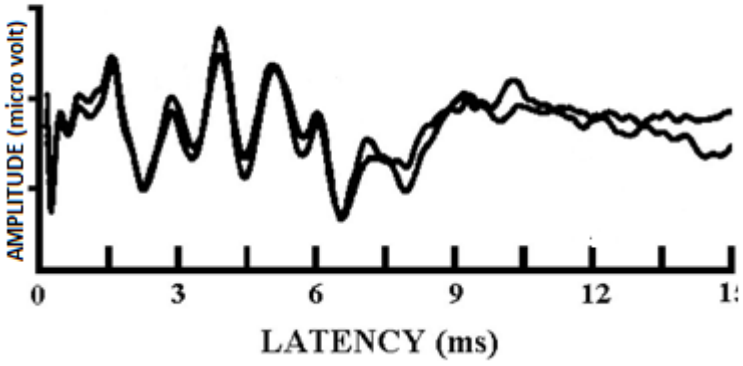


Figure 1. Depicts the waveform generated by auditory pathway.

Jewett (1969, 1970) demonstrated that neural responses to auditory stimuli could be recorded from the brainstem pathways of cats. These reports were followed by recordings in humans of a response composed of a series of 5 to 7 peaks occurring within 7 ms after acoustic stimulation (Jewett, Romano, & Williston, 1970;). Jewett and colleagues (1971) suggested that this activity represent the activity of auditory nuclei and tracts of the brainstem. They further assigned a series of Roman Numerals from (I-VII) to the peaks as shown in Figure 2. These waveforms normally occur within a 10-millisecond time period after a brief duration acoustic stimulus is presented at high intensities of 70-90 dB normal hearing level (nHL) in normal hearing individual.

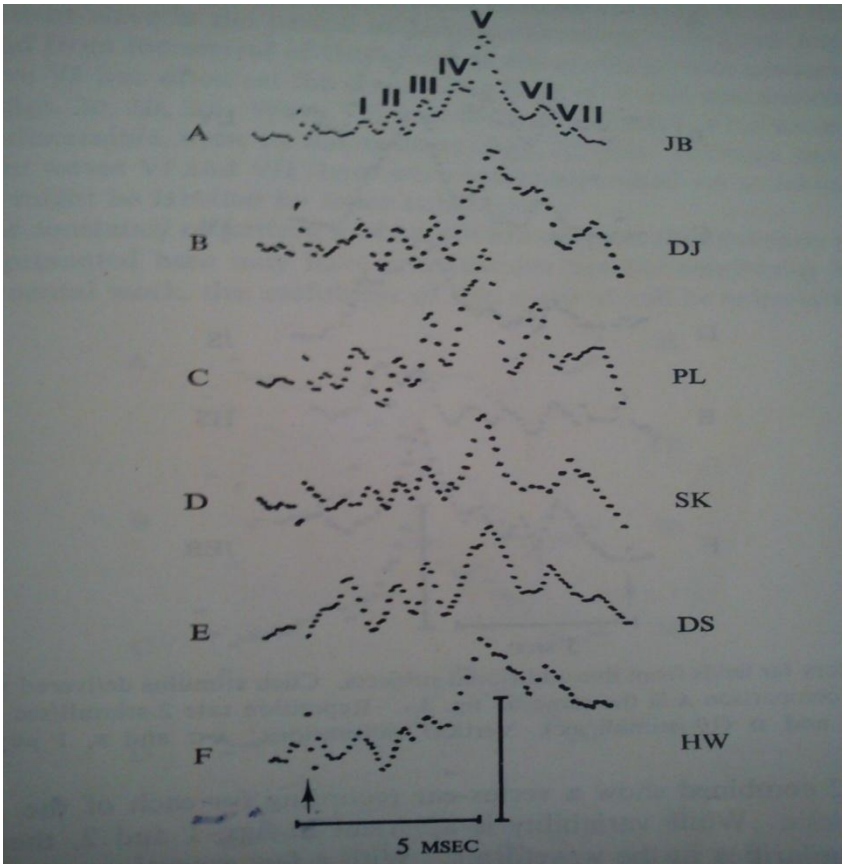


Figure 2. Auditory evoked potentials recorded by Jewett and Williston, 1971.

One reason for the relatively late discovery of the auditory brainstem potentials is their low amplitude in relation to ongoing EEG activity and the other auditory evoked potentials. It was not until sophisticated computer averaging, filtering and differential amplification of these responses, while minimizing the background noise, could be achieved, that it was possible to view the brainstem potentials. Filtering is used to remove some low frequency noises from electronic equipment and background EEG activity (Gelfand, 2001). Differential amplification is used to boost the level of the evoked response while at the same time removing noise (Gelfand, 2001). It picks the signals from two separate electrodes placed at different locations and cancels noises that are similar at the two electrodes. This process is called as common mode rejection (Gelfand, 2001). Averaging also allows the responses to be extracted from the noise.

Although discovery of the ABR occurred late, than discovery of many other evoked potentials, a vast literature has accumulated describing clinical neurological and audiological applications of the ABR (Hood, 1998). Even though the ABR varies in its sensitivity to these type of disorders (space occupying lesions, diffuse lesions, demyelinating disorders and functional abnormalities), it is nonetheless a test of choice in patients in whom the clinician suspects a neural abnormality involving the eighth nerve and/or brainstem pathway (Hood, 1998).

QUESTIONS

Fill in the Blanks

1. The electrical activity of the human brain measured by placing an electrode on the scalp is called _____.
2. Embedded within the EEG are the neural responses associated with specific _____, _____, and _____ events.
3. The electrical potentials associated with specific events are called as_____.
4. The first sensory ERP (Event Related Potentials) recordings from awake humans were performed in _____by_____ and _____.
5. The waveforms normally occur within _____time period after a brief duration acoustic stimulus presented at high intensities of 70 to 90 dBnHL.

Short Answers

6. What is the amplitude of the series of peaks recorded after presentation of an auditory stimulus by Sohmer and Feinmesser (1967)?
7. What is the process in which differential amplifier picks the signals from two separate electrodes and cancels noises that are similar at the two electrodes?
8. What are the three processes used to minimize the background noise and enhance the evoked responses?
9. What does the seven waveform peaks represents?
10. What is the purpose of using differential amplification?

Multiple Choice

11. Who was the first to measure electrical activity (EEG) measured for the first time by placing an electrode on the scalp was reported by:

a) Davis in 1939.
c) Berger in 1929.
b) Sohmer and Feinmesser in 1967.
d) Stockard et al. in 1980.

12. Galambos and Sheatz in 1962 apparently published the first:

a) Computer-averaged ERP waveform.
c) Event Related Potentials.
b) Electroencephalogram.
d) Electrical potentials.

13. The Event Related Potentials recorded initially without the advantage of computer averaging were generated by the cortex at time intervals of :

a) 20 to 30 ms.
c) 40 to 60 ms.
b) 100 to 200 ms.
d) 10 to 20 ms.

14. In relation to ongoing EEG activity and other auditory evoked potentials, Auditory brainstem potentials are discovered late due to _____.

a) Low amplitude.
c) Morphology.
b) Central conduction time.
d) Brainstem transmission time.

ANSWERS

Fill in the Blanks

1. Electroencephalogram.
2. Sensory, cognitive, and motor.
3. Event Related Potentials.
4. 1935–1936, Davis and Davis.
5. 10millisecond.

Short Answers

6. Less than 1 μv.
7. Common mode rejection.
8. Computer averaging, filtering and differential amplification.
9. It represents the activity of auditory nuclei and tracts of the brainstem.
10. Differential amplification is used to boost the level of the evoked response while at the same time removing noise.

Multiple Choice:

11. c
12. a
13. b
14. a

ABR PARAMETERS USED TO IDENTIFY RETROCOCHLEAR PATHOLOGIES

The ABR is useful in assessing the status of the auditory nerve and brainstem pathways because damage to these areas can alter the ABR in characteristic ways. The location of the lesion will affect the ear in which ABR abnormalities are seen. The various ABR parameters like Interpeak Latencies, Absolute Latency of Wave V, Interaural Wave Latency Difference, Wave V/I Amplitude Ratio, Absent Waveform Components, Wave morphology etc, are commonly used to suspect presence of retrocochlear pathology also may be the location of abnormality.

Interpeak Latencies

The time between peaks in the ABR is referred to as interwave latency intervals (IWI), interwave latencies (IWL) or, interpeak latencies (IPL). The interwave latencies used in clinical interpretation of ABR waveforms are Wave I to III, Wave III to V, and Wave I to V (Figure 3) as they are the most prominent wave in ABR. The most commonly used interpeak latency is Wave I to V. The wave I-V latency is the difference between the latency of wave I and the latency of wave V in a given waveform. This IPL is often termed **central conduction time or brainstem transmission time**. Because Wave I is generated by the auditory nerve at the periphery of the auditory system, and wave V is presumably generated by lateral leminiscus fibers as they enter the inferior colliculus (Roeser, Valente & Hosford-Dunn, 2007), the difference in latency between these waves is the time required for neural impulses to be conducted through the auditory brainstem. The interwave intervals for Wave I to III and Wave III to V is approximately 2.0 ms and Wave I-V is about 4.0 ms (Hood, 1998) which can be understood clearly from Figure 3. The

standard deviation for the I-V interval is approximately ±0.4 ms (Hood, 1998). Retrocochlear lesions may slow down neural conduction velocity and therefore increase the time between the ABR peaks. The IPL is usually considered abnormal if it is greater than 2.0 or 2.5 Standard Deviations (SDs) above the mean (Stockard, Stockard & Sharbrough, 1980). Figure 4 shows prolonged wave V latency with suspected retrocochlear pathology resulting in the increase of wave I-V IPL (bottom) compared with the ABR from a normal ear (top).

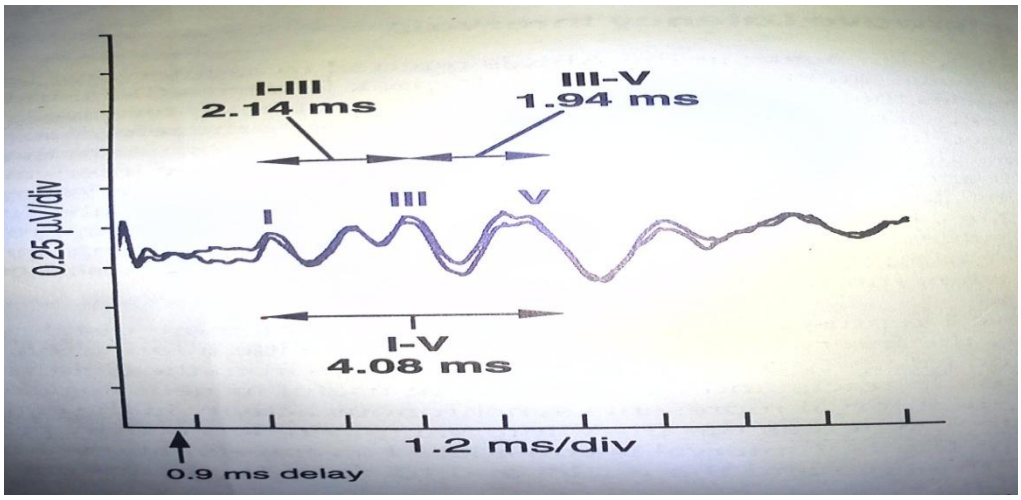


*Figure 3.*Normal ABR waveform with normal interwave latencies of Wave I-III, III-V, and I-V interpeak intervals.

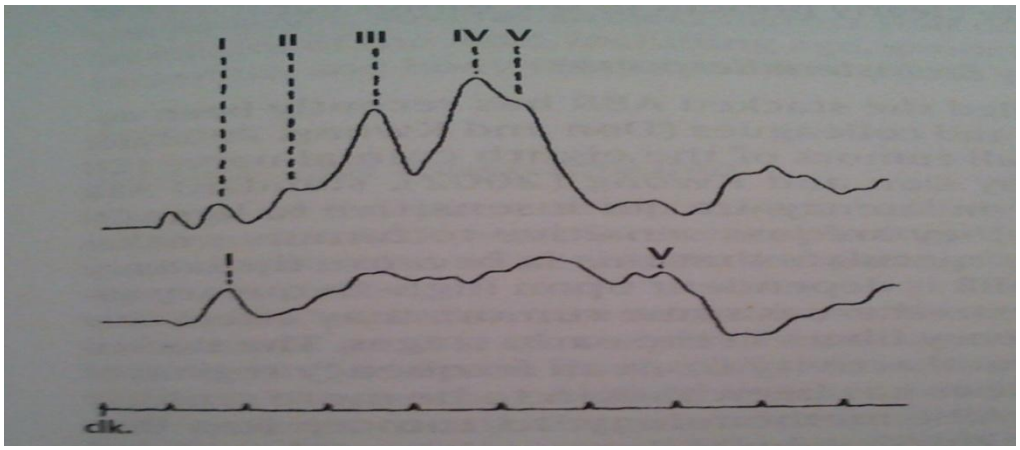


Figure 4. Prolonged wave V latency with suspected retrocochlear pathology (bottom) compared with the ABR recorded from a normal ear (top).

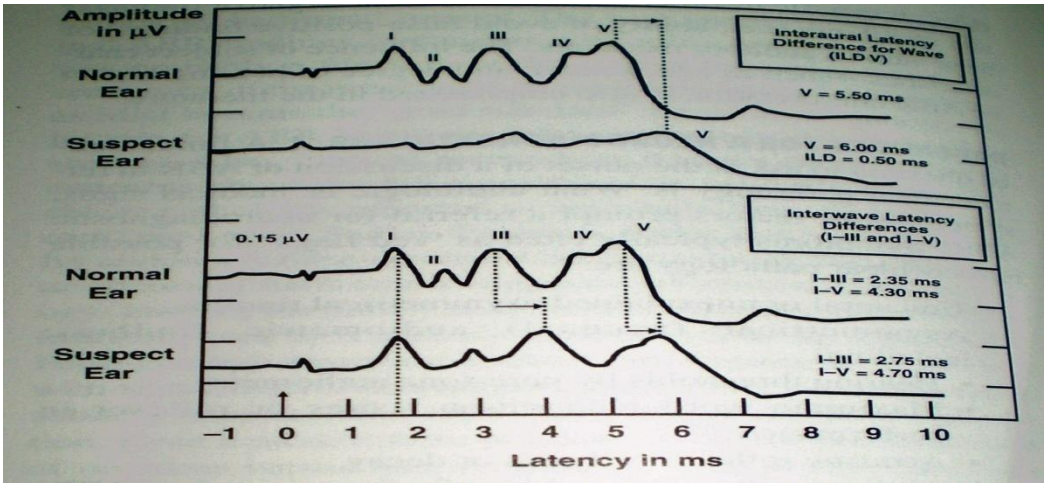


Figure 5. ABR waveforms recorded from a ear with retrocochlear pathology, compared to a normal ear ABR waveforms illustrating the interaural latency difference and interpeak latency difference.

A further refinement of the IPL measure is to obtain the wave I-III and wave III-V IPLs as well, shown in Figure 5. The wave I-III interval represents synchronous activity in the eighth nerve and lower brainstem, whereas wave III-V interval reflects activity primarily within the brainstem (Hood, 1998). These measures are made in an attempt to more precisely pinpoint the location of the abnormality within the auditory pathway (Stockard et al, 1980). The IPLs can be considered between ears in a given patient for greater sensitivity. With retrocochlear pathology, the IPL may remain within normal limits, but may be longer in the affected ear compared with the other side (Roeser et al., 2007).

Absolute Latency of Wave V

The time interval between the stimulus onset and the peak of a waveform is referred to as **absolute latency** of the response. In normal individuals, the absolute latency of wave I occur at approximately 1.6 ms after stimulus onset, wave III at about 3.7 ms, and wave V at about 5.6 ms with a standard deviation of about ±0.2 ms (Hood,

1998). Figure 6 illustrates the absolute latencies of wave I, III, V. Latency of the ABR is very consistent and repeatable in normal individuals, and peak latencies should replicate within 0.1 ms (Hood, 1998).

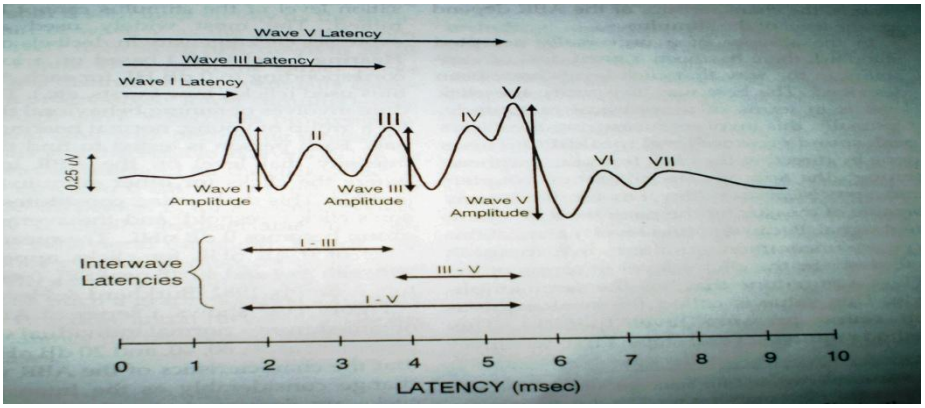


Figure 6. Normal ABR waveform showing the absolute latency of wave I, III, and V.

Measurement of interpeak latencies depends on obtaining wave I, which usually appears in the ABR waveform only at moderate to high stimulus intensity levels. With significant hearing loss as illustrated in Figure 7, it is not possible to elicit wave I at the maximum stimulus level available, making calculation of the wave I-V IPL impossible. However, because a prolongation of the wave I-V IPL will also result in a prolongation of the wave V latency itself, the wave V absolute latency can be used for evaluating patients with retrocochlear lesions (Coats & Martin, 1977). A problem with using absolute latency is that hearing loss, both conductive and high-frequency sensorineural of cochlear origin can cause some delay in the click-evoked wave V latency.

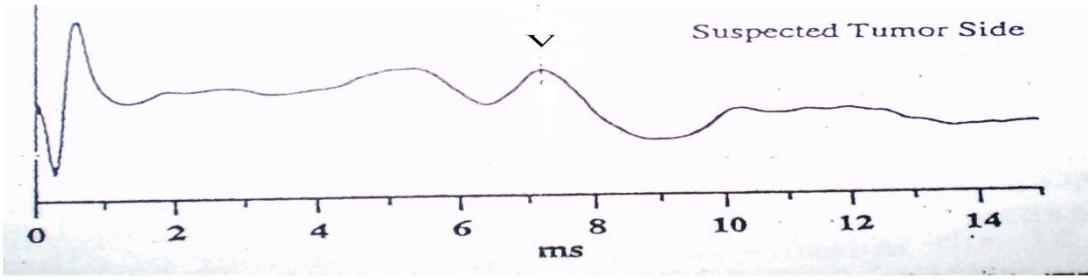


Figure 7. Absence of wave I and presence of wave V in suspected space occupying lesion.

Some clinicians recommend the use of correction factors for hearing loss, although this should be approached with caution (Hood, 1998). For example, Selters and Brackmann (1979) recommended subtracting 0.1ms from the wave V latency for every 10 dB threshold increase above 50 dB HL at 4000 Hz. Rosenhamer (1981) demonstrated a high correlation between the increase in absolute latency of wave V and the degree of hearing loss at 4000 Hz for 65 ears with high frequency hearing loss. Jerger and Mauldin (1978) advise a 0.2 ms offset for every 30 dB of threshold difference between 1000 and 4000 Hz (i.e., if the hearing threshold is 0 dB HL at 1000 Hz and 60 dB HL at 4000 Hz, one should allow a 0.4 ms increase in wave V latency beyond the 'acceptable' criterion). However, if the hearing loss is severe to profound, regardless of the configuration, a reliable ABR may not be obtained. This type of result can be associated with either a cochlear or retrocochlear lesion (Jacobson, 1985).

Interaural Wave Latency Difference

The interaural Wave Latency Difference is the difference in wave V latency, obtained at the same stimulus level, between the two ears (Roeser et al, 2007). This measure is useful when inability to elicit wave I makes the measurements of IPL

impossible as shown in Figure 8 (Roeser et al, 2007). In normal hearing individuals without neurological lesions, the interwave latency difference is typically 0 msec (± 0.2 msec). A latency difference greater than 0.2 to 0.4 msec between ears is generally considered abnormal (Bauch, Olsen, & Pool, 1996; Selters & Brackmann, 1977) as depicted in Figure 5 and Figure 8. ILD is important as most of the eighth nerve tumors, with the exceptions of those in patients with neurofibromatosis, unilateral, or asymmetrical hearing losses. Sometimes if a unilateral asymmetrical hearing loss involving the high frequencies exists, wave V latency may be significantly prolonged in one ear simply because of hearing loss, not because of retrocochlear pathology. Various correction factors have been proposed to compensate for the effects of hearing loss (Hyde, 1985; Selters & Brackmann, 1977), but none has gained universal acceptance. Clemis and McGee, (1979) relate that when hearing loss is greater than 65 dB HL, a 0.4 ms ILD criterion should be employed to indicate reterocochlear pathology. However, ILD must be cautiously interpreted since the degree of loss and auditory configuration between ears as well as the intensity presentation levels may significantly affect the results.

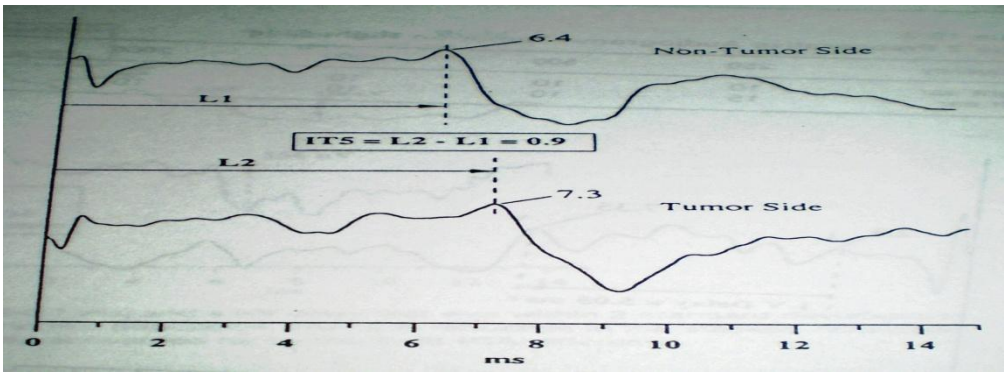


Figure 8. Abnormal interaural wave V latency with absent wave I.

These criteria involve either a comparison of ABR latency for the patient versus group normative data, or an intrasubject comparison of interwave latencies from one ear versus the other ear. Each latency criteria is clinically useful, but each has clinical limitations.

Another problem occurs when a retrocochlear lesion results in a bilateral prolongation of wave V. In this, there may be no difference in wave V latency between ears, and the retrocochlear lesion can be missed. However, such situations are very rare.

Wave V/I Amplitude Ratio

Measures of absolute amplitude of the ABR waves have not proven to be useful clinically because amplitude is highly variable both within and between subjects and varies considerably with levels of physiological noise, electrode impedance, and electrode location (Roeser et al, 2007). However, a relative amplitude measure, the wave V/I amplitude ratio, has proven to be useful in assessing brainstem integrity (Musieks et. al, 1984; Stockard et al, 1977). To obtain, this measure the peak to peak amplitudes of wave I and V are measured and are compared in the form of a ratio as demonstrated in Figure 9. In normal adults, wave V amplitude is larger than wave I, resulting in an amplitude ratio of >1.0. Retrocochlear Pathology may cause a decrease in wave V amplitude, resulting in a ratio of <1.0 (Roeser et al, 2007). Figure 10 shows the ABR waveform of right and left ear. Right ear wave V amplitude is less than wave I amplitude, resulting in an abnormal wave V/I amplitude ratio of <1.0, which suggests presence of retrocochlear pathology in right ear.

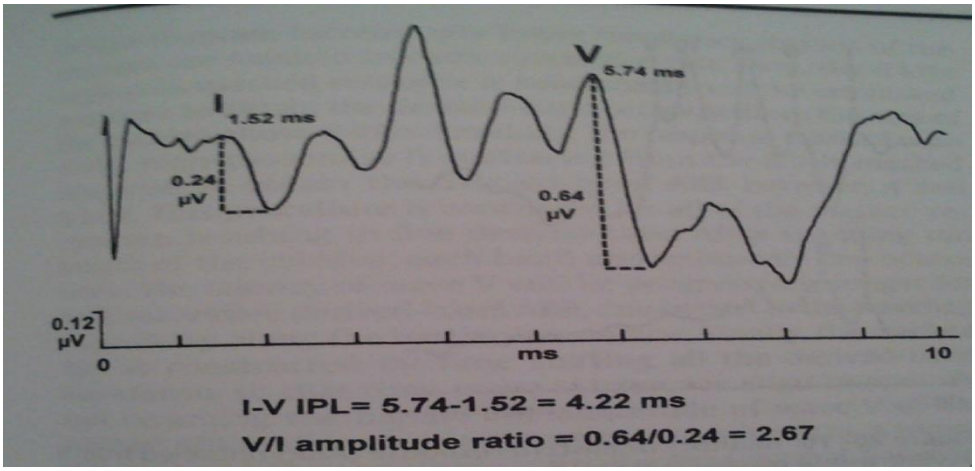


Figure 9. Normal ABR waveform with normal wave V/I amplitude ratio (2.67).

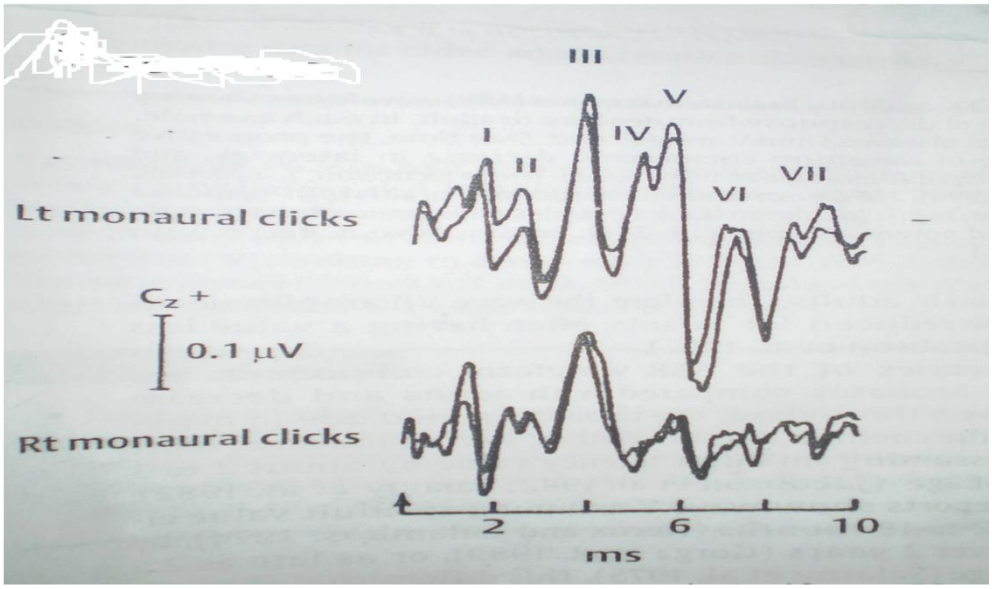


Figure 10. Shows less wave V amplitude in right ear, resulting in abnormal wave V/I amplitude ratio.

'Normal' criteria for amplitude ratios may vary according to instrumentation used, intensity level, Repetition Rate, and other variables. Hence, an amplitude ratio of 1.0 may not be universal criterion (Jacobson, 1985).

Hecox (1980) recommended that the amplitude ratio be calculated at intensity levels not exceeding 80 dBnHL, since the amplitude ratio decreases at higher intensity

levels. Hecox (1983) suggested that, if there is doubt concerning which of the early peaks is wave I, the amplitude ratio can be considered normal as long as none of the early peaks has an amplitude which exceeds that of wave V.

Repetition rate also affects amplitude. Repetition rate above 30 stimuli per second, can decrease the amplitude. However, wave V shows less of an amplitude decrease at higher repetition rates (Hood, 1998).

Waveform Morphology

The determination of abnormal waveform morphology is perhaps the most subjective index. Starr and Achor (1975) reported that distorted BAEP waveforms may be consistent with the presence of retrocochlear pathology. Eggermont, Don, & Brackmann. (1980) observed that normal BAEP waveform morphology was rarely present in ears with acoustic tumors. Peak identification is a major problem in ears with retrocochlear pathology. Abnormal wave morphology can be seen in 3 different categories.

- Totally absent waves.
- Absence of certain waves.
- Noisy wave forms.

Totally absent waves

The presence of a lesion at a given location can eliminate waves generated at the lesion site and rostral to the lesion. The absence of all waves is often noted in cases of acoustic neuroma as depicted in Figure 11(C). Total absence of ABR waves is even more likely to occur in an eighth nerve or low brainstem lesion if there is hearing loss.

Retrocochlear pathology may be severe enough to disrupt the generation of components of the ABR entirely, resulting in absent waves. The most commonly noted wave is the wave I in an eighth nerve or low brainstem lesions, especially if the hearing is good (House & Brackmann, 1979; Selters & Brackmann, 1977) as can be seen in Figure 11(B). This is because, Wave I is generated at the distal portion of the auditory nerve. Thus, wave I has a higher probability of being intact.

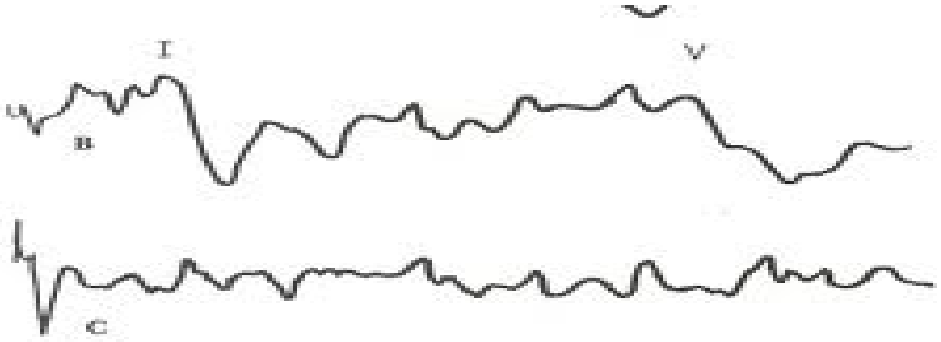


Figure 11. (B) Abnormal wave morphology with clear wave I, (C) Absence of all waves in a ear with suspected retrocochlear pathology.

However it is important to note that the absence of wave VI or VII is not diagnostically significant, because the presence of these waves is highly variable, even in normals (Roeser et al, 2007).

Absence of certain waves or Partial waves

In addition to the total wave absence or the presence of wave I only, eighth nerve or lower brainstem lesions can yield a variety of other wave form abnormalities. For example, wave I and III can be present and wave V be absent. Although these findings are more common in high brainstem lesions, it has also been reported in lesions at the cerebellopontine angle region (Harris & Almquist, 1981; Rosenhall et

al., 1981). An absent of wave III with a normal I and V has also been reported (Moller, Moller & Jannetta, 1982: Rowe, 1981). A pathological rational is difficult to ascertain for these latter findings, but it can be due to secondary effects of the lesion, individual patient differences, unusual hearing loss, and variety of other entities. An example of missing ABR waves (only waves I and II are clearly present) shown in Figure 12.

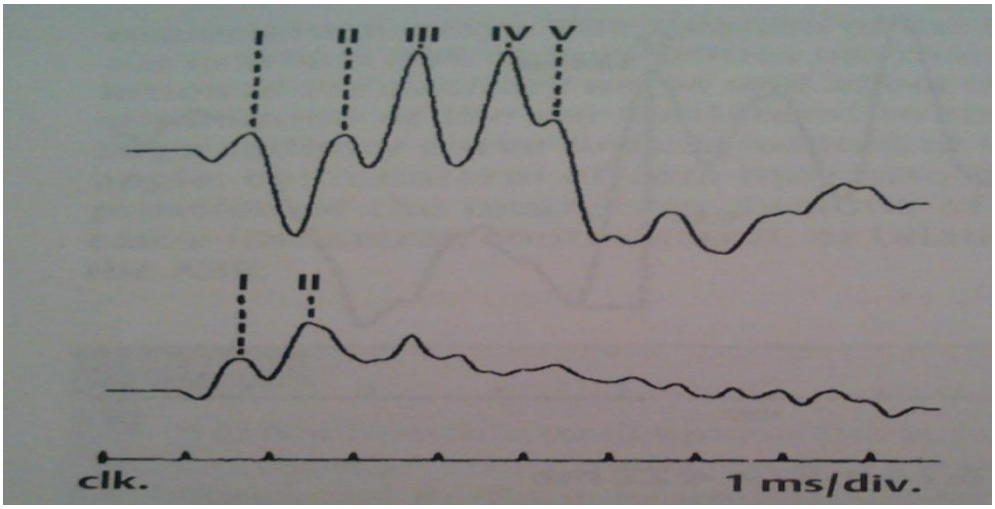


Figure 12. ABR obtained from a patient with meningioma (bottom) compared with a normal ABR (top).

Noisy wave forms

The noisy appearing waveform is a very subjective analysis, but does occur. If the patient is quiet during testing, has good hearing, and there are no technical problems, yet the waveform is noisy and poorly formed, then retrocochlear involvement should be considered (Musiek, 1982). The interpretation of the noisy waveform and totally absent wave must be based on audiometric information. These situations can occur also with cochlear involvement (Jacobson, 1985).

Repetition Rate Effects

Some investigators suggest that the use of high repetition rates of stimulation to stress the auditory system can reveal subtle abnormalities (Silman & Silverman, 1997). The physiologic basis for repetition rates is neural refractory period. The length of refractory period is dependent on the health of the cell. The absolute refractory period is the time interval in which the nerve cell cannot respond. If the nerve cells are not functioning properly a longer refractory period is required. Thus, neural delay or asynchrony resulting from a lengthened refractory period can be detected at higher repetition rates (Jacobson, 1985).

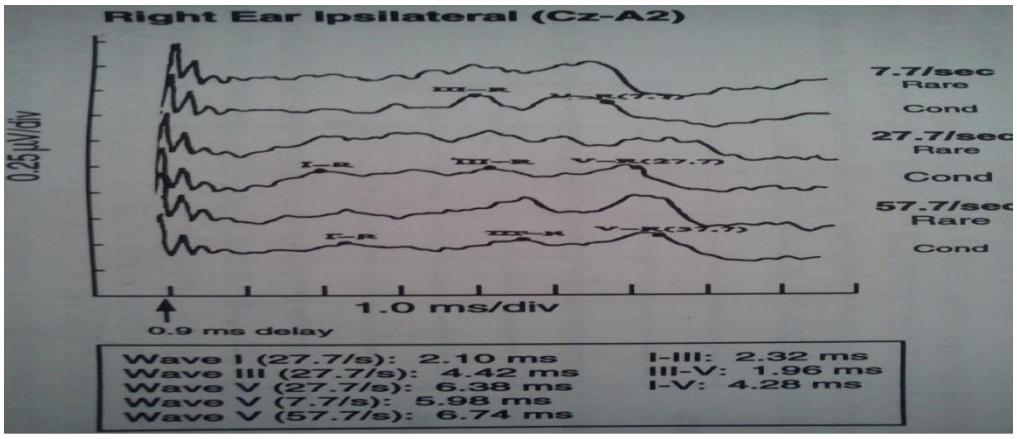


Figure 13. Increase in wave V latencies with poor wave morphology as the rate of presentation of clicks increased in a client with suspected retrocochlear pathology.

There have been several case studies of eighth nerve or brainstem lesions that have shown significant wave V shifts or degradation of wave V morphology at higher repetition rates as illustrated (Paludetti, Maurizi & Ottaviani 1983) in Figure 13. In normal subjects there is an increase in wave V latency for the high repetition condition (Don, Allen, & Starr, 1977; Paludetti et al., 1983). According to Jacobson (1985), a 0.1ms shift is allowed for every 10 clicks/s increase with variance factor of 0.2 ms.

For example, if a low repetition rate was 10/s and the high rate of 50/s, the upper limit for normal wave and latency shift would be 0.6 ms. If there is an increase in the latency more than the normal as shown in Figure 14, then it is suggestive of retrocochlear pathology (Jacobson, 1985).

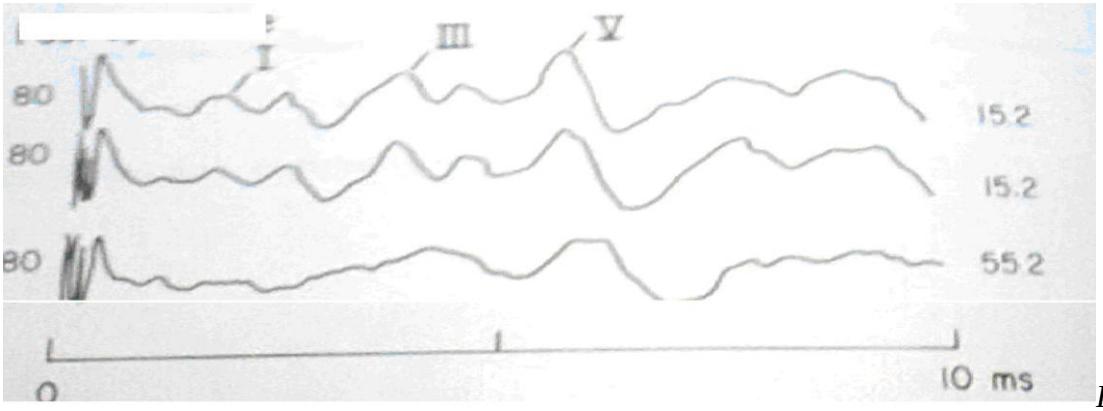


Figure 14. Normal morphology at low and at higher repetition rate with prolonged wave V latency.

Test-Retest Replicability

Some investigators have suggested that lack of test- retest reproducibility of the BAEPs is predictive of retrocochlear pathology. Musiek, Josey, & Glasscock (1986) reported that waves I, III, and V were not replicable at the same repetition rate, intensity, and polarity in 74% of their 61 retrocochlear impaired ears (depicted in Figure 15). Elidan, Sohmer, Gafni, and Kahana (1982) found that in several of their patients with multiplesclerosis, waveform morphology changed from minute to minute, possibly reflecting the presence of intermittent conduction in a demylinated fiber. Lack of replicability should be considered an indicator of retrocochlear pathology only if all technical and subject factors can be ruled out (Silman & Silverman, 1997).

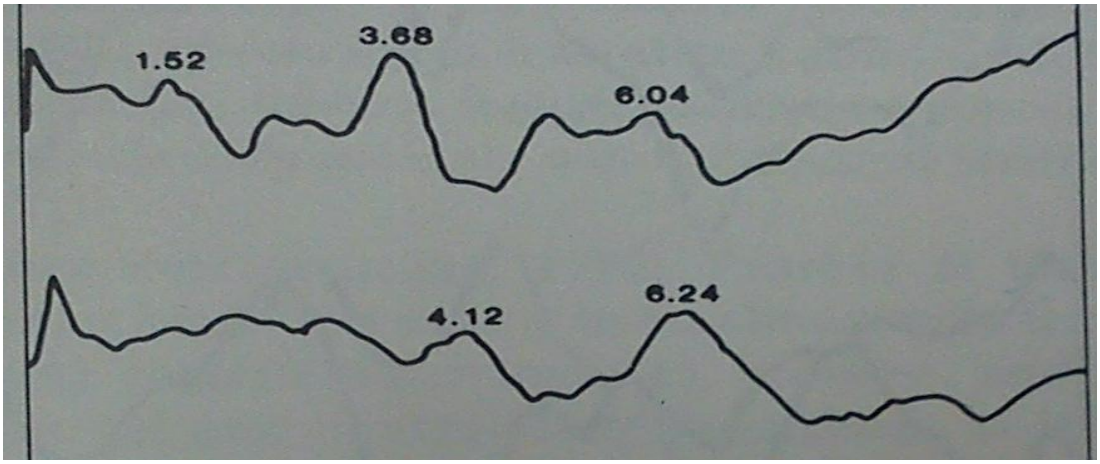


Figure 15. Abnormal wave morphology seen in a patient with suspected retrocochlear pathology recorded twice at same intensity and repetition rate.

QUESTIONS

Fill in the Blanks

1. The difference between the latency of wave I and wave V in a given waveform is called as _____.
2. The difference in wave V latency, obtained at the same stimulus level, between the two ears is called as _____.
3. The peak to peak amplitudes of wave I and V are measured and are compared in the form of a ratio called as _____.
4. The most commonly used interpeak latency is_____.
5. _____measure is useful when inability to elicit wave I makes the measurements of IPL impossible.
6. The normal wave I-V IPL is_____.
7. In normal individuals, the absolute latency of wave I occur at approximately _____ after stimulus onset, wave III at about _____, and wave V at about _____with a standard deviation of about _____.

Match the Following

8. a. Inter peak latency. >1.0

   b. Interaural Wave Latency. Central conduction time

   c. Normal amplitude ratio. Amplitude ratio of <1.0

   d. Retrocochlear Pathology. 0msec (±0.2msec)

Multiple Choice

9. Absolute latency of the ABR is very consistent and repeatable in normal individuals, and peak latencies should replicate within_____.

   a) 0.3 ms. c) 0.4 ms.

   b) 0.1 ms. d) 0.5 ms.

10. A latency difference greater than _____between ears is generally considered as abnormal.

    a) 0.2 to 0.3 msec. c) 0.2 to 0.4 msec.

    b) 0.1 to 0.3 msec. d) 0.0 to 0.1 msec.

11. The time interval in which the nerve cell cannot respond even with intense stimulation is known as

    a) Brainstem transmission time. c) Interaural time interval.

    b) Intra aural time interval. d) Absolute refractory period.

12. In retrocochlear lesions _____ neural conduction velocity and therefore increase the time between the ABR peaks.

    a) Fast. c) Degrade.

    b) Slow. d) Ease.

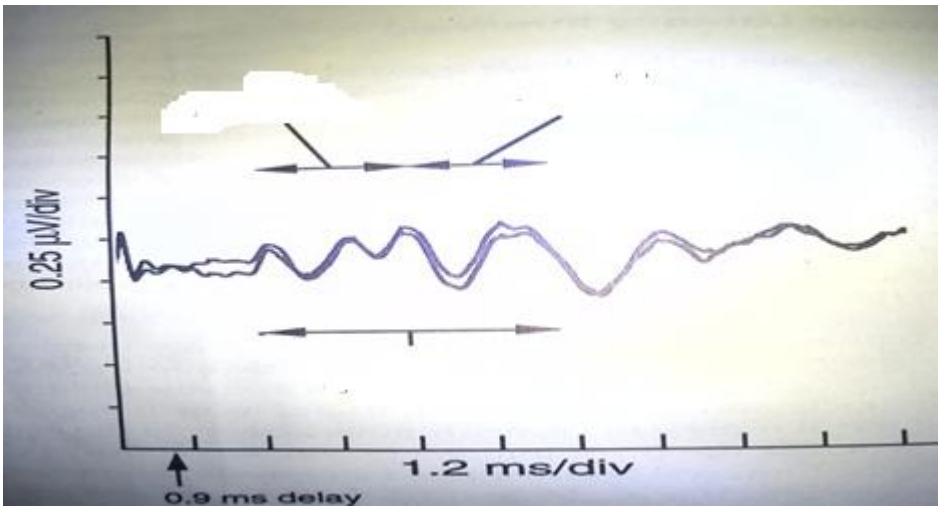
True or false

13. Wave I is generated by the auditory nerve at the periphery of the auditory system.
14. Selters and Brackmann (1979) recommended subtracting 0.3 ms from the wave V latency for every 10 dB threshold increase above 50 dB HL at 4000 Hz.
15. The length of refractory period is dependent on the health of the cell.

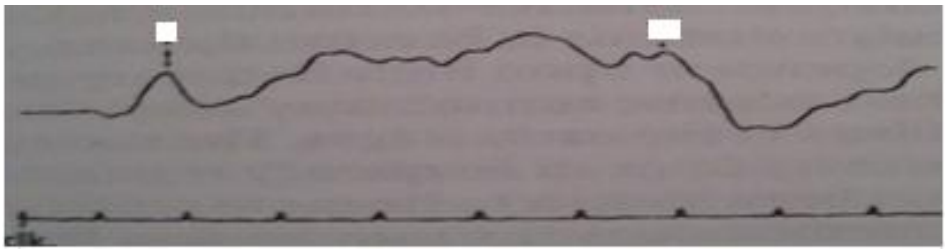
16. In normal subjects there is a decrease in wave V latency with the increase in repetition rate.

Complete the diagram

17. Normal ABR waveform.



18. Abnormal ABR Waveform.



ANSWERS

Fill in the Blanks

1. Interpeak Latencies.
2. Interaural Wave Latency Difference.
3. Wave V/I Amplitude Ratio.
4. Wave I-V.
5. Interaural Wave Latency.
6. about 4.0msec
7. 1.6ms, 3.7ms, 5.6ms and +_0.2ms.

Match the Following

8. a. Inter peak latency → Central conduction time
   b. Interaural Wave Latency → 0msec (±0.2msec)
   c. Normal amplitude ratio → 1.0
   d. Retrocochlear Pathology → Amplitude ratio of <1.0

Multiple Choice

9. b
10. c
11. d
12. b

True or false

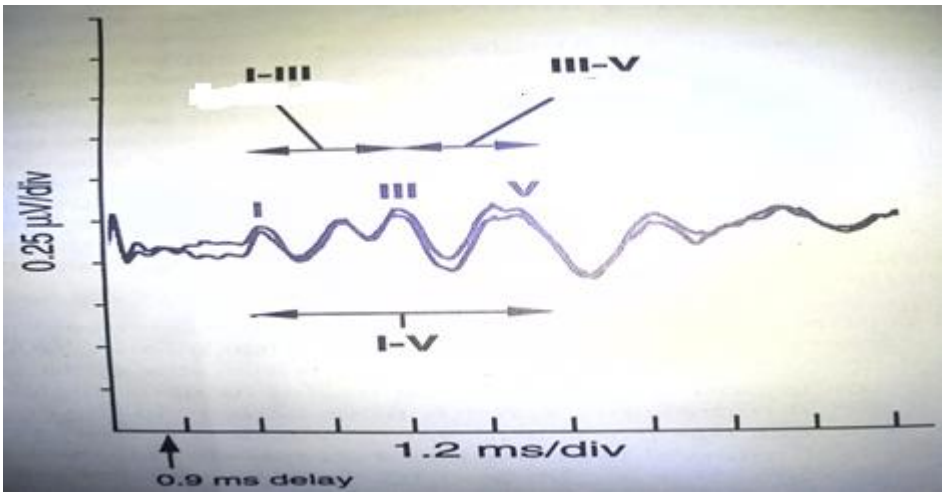
13. True.
14. False.

15. True.

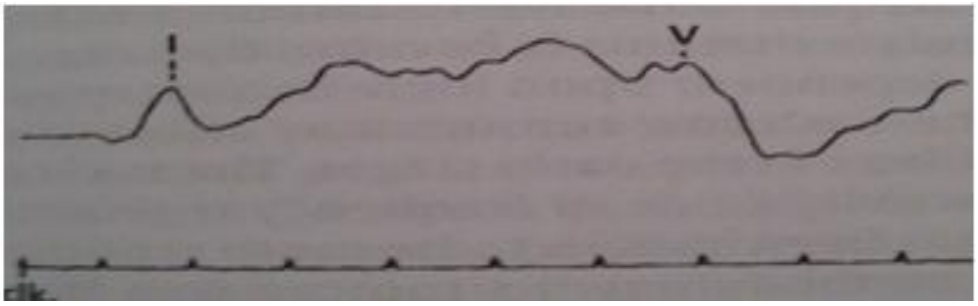
16. False.

Complete the diagram

17. Normal ABR waveform.



18. Abnormal ABR waveform.



ABR FINDINGS IN SPACE OCCUPYING LESIONS

Tumors

Neuralgia tissue covers the bundle of fibers making up the eighth nerve near the CNs, specifically the Pons in the brainstem. Distal to the pia mater, in the vicinity of the porus acusticus, schwan cells replace the neuralgia and surround the nerve cell until it reaches the cochlea. The tumors arise usually from Schwann cells of the eighth cranial nerve. It can be intra axial or extra axial. The major types of tumors are vestibular schwanomas, neurofibromas, Gliomas and meningiomas. Intrinsic or intra axial lesions originate within the substance of the brainstem and gliomas most commonly arise within the brainstem. Extrinsic or extra axial lesions originate outside the brainstem and meningiomas are second most commonly occurring extra axial posterior fossa tumor other than vestibular schwanoma being the most common one (Huertas & Haymaker, 1969). Extrinsic pressure from these mass lesions arising from the extraaxial sites can affect upper brainstem auditory functions (Jacobson, 1985).

Gliomas arise within the brainstem. Gliomas are more common in children. Although the tumors grow slowly, are highly invasive, infiltrating the brainstem, so that total surgical removal is often not possible and recurrence is often likely. ABR is useful to identify this condition when auditory pathways are primarily involved. ABRs are abnormal in 90 -100% of all brainstem gliomas, although no studies had a large number of patients (Brown et al., 1981; Stockard, Stockard, & Sharbrough, 1980). Weston, Manson, and Abbott (1986) recorded ABRs from fourteen childrens with clinically diagnosed brainstem gliomas and found that all with pontine involvement (thirteen out of fourteen) had abnormalities of ABR wave V (delayed latency, absent or reduced amplitude).

Meningiomas are found in various intracranial regions. They are more common in females than males. The tumors originate from the meningiothelial arachnoid cells and are slow growing. Meningiomas can originate and grow exclusively within the CP angle. They are very vascular, and CNS dysfunction can result from compression and displacement of brain tissue, which varies depending on location and can involve auditory system, however, ABR findings in clients with meningiomas are unequivocally abnormal (Hall, 2007).

Neurofibromas (NF) are otherwise called as von Recklinghausen's disease. The disease is now referred to as either NF1 (peripheral form), or NF2 (a central form). Both are genetically transferred and autosomal dominant. However, the gene for NF1 is on chromosome 17 and the gene for NF2 is on chromosome 22 (Lanser, Sussman, & Frazer, 1992). However NF1 is more common than NF2. Both types arise from Schwann cells. NF2 is characterized by bilateral Vestibular schwanomas and is sometimes associated with multiple intracranial and spinal tumors. Auditory system involvement can be characterized by bilateral ABR abnormalities.

Vestibular schwanomas are often found on the eighth cranial nerve, and less often associated with the fifth, seventh, or twelfth cranial nerves. The schwanoma of eighth nerve is considered benign. The tumors usually arise from Schwann cells on the vestibular portions of the eighth nerve. The tumor is an encapsulated, homogenous mass projecting from the side of the nerve. The Vestibular schwanoma typically grows to displace, deform and stretch the normal auditory nerve fibers. Clinical symptoms first occur after progressive growth of the tumor, when the tumor is 1 to 4 cm in size. It is almost always unilateral in nature. Tinnitus usually accompanies hearing loss, but it may initially be the only symptom (Hall, 2007).

The actual mechanism resulting in an abnormal ABR is not clear. Certainly it can be due to a stretch or compress of nerve fibers which slows the conduction velocity of the nerve impulse. However, desynchronisation of the firing rate of neurons as a result of theses pathologies can be a more possible explanation (Eggermont, Don, & Brackmann, 1980).

Because of the above mentioned effects of the lesions described above, the various ABR findings like (a) prolonged wave V, (b) long interaural wave V difference, (c) prolonged I-V interpeak latency, (d) absence of later waves, (e) absence of BAEP waveform, (f) absence of waveform reproducibility, (g) abnormal wave I/V amplitude ratio, (h) abnormalities at high rates, (i) contralateral effects, and (j) abnormal wave morphology can be observed (Silman & Silverman, 1997).

The wave I-V interval is generally considered the most robost characteristic of the ABR. A prolonged wave I-V interval is most commonly observed in ear with acoustic neuroma as illustrated in Figure 4. Absence of components beyond wave I or II can also be seen. Figure 16 illustrate one of such condition. Because the latency of the wave I-V interval appears most effective in identifying cerebellopontine angle tumors, it is important to obtain a clear wave I.

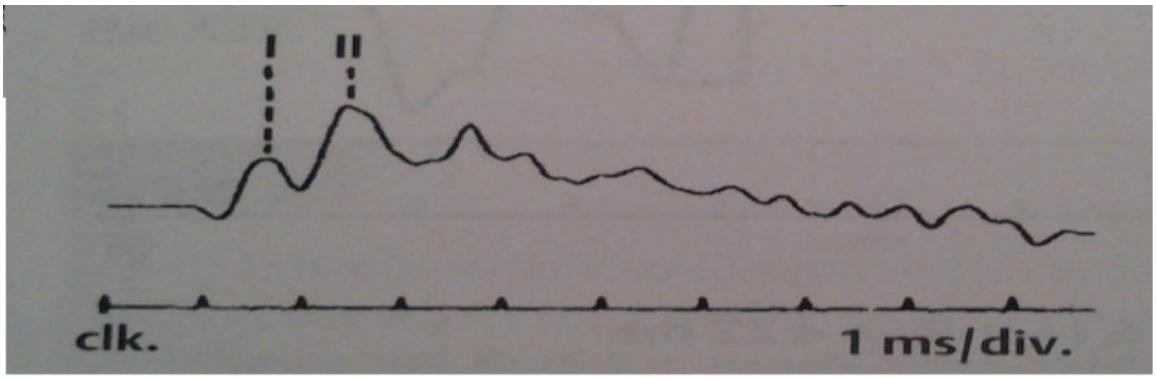


Figure 16. Absence of components beyond wave I or II in eighth nerve tumor.

Increasing stimulus rate can result in prolongations in the waves I-V interval in patients with acoustic tumors beyond that observed in normal individuals (Tanaka, Komatsuzaki, & Hentona, 1996) as depicted in Figure 12. This can be due to neural delay or asynchrony which can result from a lengthened refractory period at a higher repetition rates.

Tumors of the eighth nerve and CPA can also result in an increased III-V and normal I-III latency (Harris & Almquist, 1981). A patient with a cerebellar astrocytoma might show normal waves I-V intervals with the only abnormality of prolonged waves I-III interval in affected ear as compared to the other ear (Sostarich, Ferraro, & Karlsen, 1993). Thus, each parameter of the response should be considered and entered into the overall clinical interpretation.

Even though there are lack of agreement regarding the generators of ABR components IV, V and VI. Alterations of these ABR components are associated with upper brainstem lesions. Wave V and VI are affected by abnormalities involving in the lateral leminiscus (mid and upper Pons) and inferior colliculus (caudal midbrain). Alterations in wave VI reflect abnormalities in the inferior colliculus and at the level of medial geniculate body. Earlier waves can be present, but later waves may be absent (Figure 16) and interwave latency prolongation is between III-V are most commonly seen in these extra axial regions (Jacobson, 1985).

Prolonged absolute wave V latency is seen in cases with acoustic tumors. A problem with absolute wave V latency can be seen with hearing loss cases also. Selective action of a tumor on high and low frequency fibers of the auditory nerve is responsible for ABR wave V delays (Eggermont et al., 1980). This can be due to compressive effects of the eighth nerve tumor, which can result in compromised blood

supply to the nerve or to inner ear which can result in hearing loss and other associated symptoms. For, example, as the high frequency fibers (HF) are present on the periphery and if the tumors compresses the HF fibers then the HF fibers will get affected resulting in abnormal ABR.

Assessment of the I-V inter-wave latency measurement is complicated when, as is often seen in the cases with high frequency hearing loss, wave I is absent as shown in (Figure 7). In this situation, wave V is compared between the ears. Since wave V can be delayed in the presence of cochlear hearing loss, a correction factor is generally applied to account for this discrepancy between the ears due to the hearing loss which has been already explained in chapter 2.

Long interaural wave V differences are seen in individuals with unilateral acoustic tumor. As the tumors of the eighth nerve are generally unilateral, comparisons between the two ears can be helpful on a number of different parameters (Hood, 1998). In cases where wave I is not discernible (i.e. if the lesion is at the distal part of auditory nerve), a combination of measures may prove useful as discussed in Figure 7. Stanton and Cashman (1996) found that, although the waves I-V interval was the best measure, in instances where that was not available, a combination of wave V latency and the wave V interaural latency difference, was useful in identifying tumor patients as shown in Figure 5. This prolonged latency in acoustic neuroma patients can be due to compression of the eighth nerve by the tumor mass resulting in disruption of synchronous neural firing, in response to the auditory stimulus in the affected ear (Selters & Brackmann, 1977).

ABR amplitude criteria are relied less often than latency criteria for identification of eighth nerve tumor, mainly because, amplitude is considerably more

variable (Hall, 2007). Eighth nerve tumors have been observed in patients when the wave V/I amplitude ratio is less than 0.5 (Starr & Hamilton, 1976).

Contaralateral ear effect

At the extreme the tumor may compress and distort other cranial nerves (7^{th} and 5th), may produce a contralateral shift of the brainstem and may even compress 4^{th} ventricle. Compression of the 4^{th} ventricle results in elevation of intracranial pressure and may produce hydrocephalous. Several studies have reported that only ABR waves IV and V are affected, for the ear opposite to the tumour, though this is not the only variation.

To identify the side of the brainstem involved, evidence suggests that unilateral brainstem lesions might manifested in the altered ABR when recorded with contralateral ear stimulation as illustrated in Figure 17. Selters and Brackmann (1977) observed that, when large tumors were present, the peak latency of wave V was prolonged and the wave V peak amplitude was reduced for the ear contralateral to the side of the lesion. The delay in wave V was reflected by the prolonged wave III-V IPL in the ear contralateral to the side of the tumor. These changes can be due to the compressive effects of the large tumor resulting in slowing of conduction velocity. Selters and Brackmann (1977) hypothesized that a prolonged III-V IPL in the ear contralateral to the side of the tumor can result when the tumor is large enough to displace the brainstem and compress the contralateral auditory neurons. This hypothesis was confirmed later by the results of computerized cranial tomograms. Figure 17 depicts prolongation of wave V latency in left ear as a result of a tumor in the right ear resulting in prolongation of wave I-V latency in left ear.

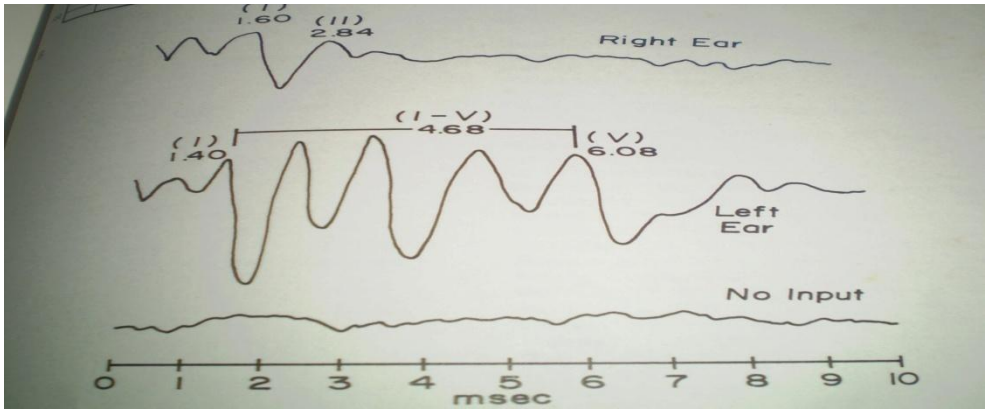


Figure 17. Prolonged wave V latency in left ear as a result of tumor in the right ear.

Effects of tumor size and location

Clemis and McGee (1979) also reported the presence of a significant correlation between tumor size and the ILD for wave V. In case when no response is observed, one can suspect a wide range in tumor size. Thus, it is not only the size of the tumor but also the site of the tumor that determines the strength of the effect on the BAEP. However, the larger the tumor, the greater its effect in the ABR latency.

Selters and Brackmann (1977) found that tumor size was highly correlated with the ILD. The BAEPs were found absent in 30% of the ears with acoustic tumors less than 2.5 cm in size and were absent in 80% of ears with acoustic tumors greater than 2.5cm in size. They also reported that the contralateral mean III-V IPL in the nontumor ear in cases the tumor size was < 3.0 cm was 1.87 ms as opposed to 2.14ms in the nontumor ear in cases the tumor size was at least 3.0 cm.

QUESTIONS

Fill in the Blanks

1. NF2 is characterized by _____vestibular schwanomas.
2. The latency of the _____appears most effective in identifying cerebellopontine angle tumors.
3. Extrinsic or extra axial lesions originate _____ the brainstem.
4. Meningiomas are _____ and usually termed as extra axial tumor.

True or False.

5. NF1 and NF2 are genetically transferred and autosomal recessive.
6. The tumor may compress and distort other cranial nerves, and may produce a contralateral shift of the brainstem and brainstem responses.
7. Increasing stimulus rate can result in prolongations in the waves I-V interval in patients with acoustic tumors beyond that observed in normal individuals.

Multiple Choice

8. Compressive effects of the eighth nerve tumor can result in compromised_____ to the cochlea:

   a) Blood Supply.
   c) Sensation.
   b) Impulses.
   d) None of the above.

9. Absence of wave I is indicative of lesion in the____ part of eighth nerve:

a) Proximal. c) Cochlear Nucleus.

b) Distal. d) None of the above.

10. Neural delay or asynchrony can result from a_____ refractory period at a higher repetition rates. .

a) Shortened. c) Unchanged.

b) Lengthened. d) None of the above.

11. If the tumor is present on the periphery_____ fibers will get affected resulting in abnormal ABR.

a) High frequency. c) Mid Frequency.

b) Low frequency. d) All the Above.

ANSWER

Fill in the Blanks.

1. Bilateral
2. Wave I-V interval.
3. Outside.
4. Posetrior fossa tumor.

True or False.

5. False.
6. True.
7. True.

Multiple Choice.

8. a
9. b
10. b
11. a

ABR FINDINGS IN VASCULAR DISORDES

Pathologies that are found in the region of the cerebellopontine angle (CPA), includes tumors, arteriorvenous malformations, vascular loops, and others (Hirsch et al. 1980, Schwaber & Hall. 1992). As the vertebrobasilar system is the origin for the anterior inferior cerebellar arterial (AICA) loop and its collaterals, including internal auditory artery, deficiencies in this network can subsequently be noted in eighth nerve and other cranial nerve lesions. The arteries can become restricted in diameter secondary to arteriosclerotic changes and compromise oxygenation in this area. These vessels can compress the adjoining nerves, causing damage to the central myelin. The AICA loop in the CPA can compress with ensuing pressure on the cochlear and vestibular portions of eighth nerve, which it may encircle. The pulsatile pressure of the artery on the nerve may create hyperfunction or loss of function. These nerve then can be disrupted from their normal activity, resulting in hearing loss, tinnitus and vestibular disorders (Moller & Moller, 1985). Increase IWLs have been observed in subjects with the compression of the arterial loop in the CPA (Moller et al., 1982). Increased I-III and III-V wave intervals have been reported with hemifacial spasm secondary to vascular compression (Moller & Moller, 1985). Patients with vascular compression in the brainstem resulting in trigeminal neuralgia have also shown an increased III-V interwave latency (Moller & Moller, 1985).

Aneurysm of the brainstem, a rare and serious condition, cannot only result in vascular disturbances of the other vessels of brainstem but may also mimic a mass occupying lesion (Musiek, Guerkink, & Spiegel, 1987). A basilar artery aneurysm in the low pons often is initially diagnosed as a CP angle tumor, though in one well documented case the ABR was slightly different from the classic ABR findings in

tumor cases (Musiek et al., 1987) as shown in Figure 18. The right ear ABR indicates the auditory nerve to be functioning but with dysfunction commencing at the level of cochlear nucleus. The ABR in left ear indicates compression and/or displacement of brainstem, affecting the later waves.

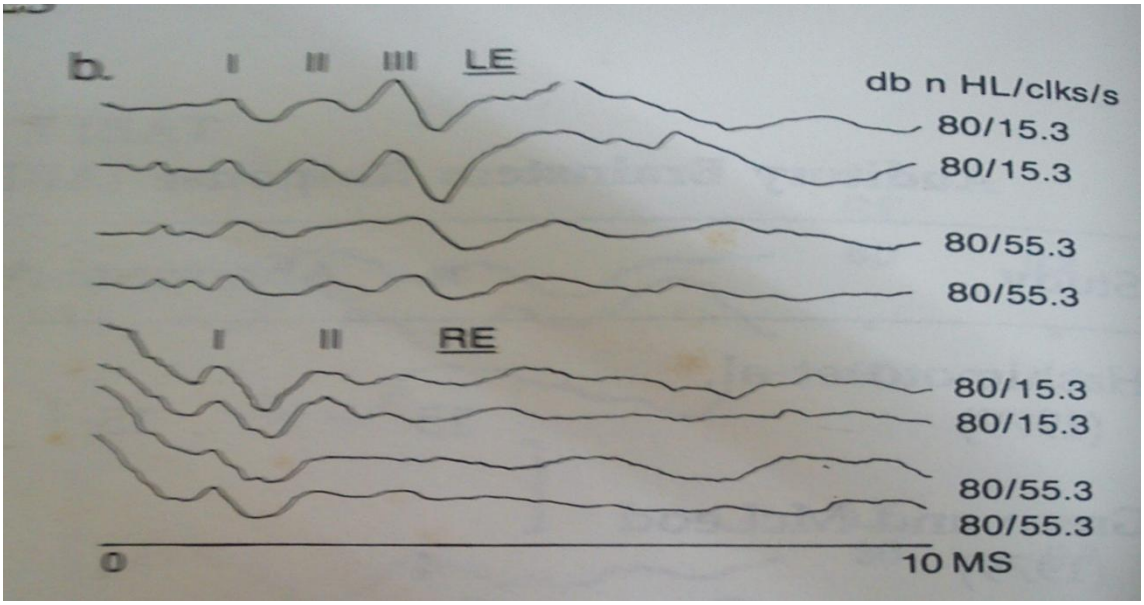


Figure 18. ABR shows only wave I and II which are of normal latencies on the involved side (right ear) and the ABR from non affected ear revealed normal early waves I,II, & III but absence /distorted IV and V complex (left side).

It must be kept in mind that the main blood supply for the brainstem is the basilar artery, which is located on the ventral surface of the brainstem, whereas most of the auditory tracts are on the dorsal- lateral suface (Musiek & Baran, 1986). The branches of the basilar artery leading to the dorsal-lateral areas of the pons would have to be compromised in order to adversely affect the ABR from the effect of right side lesion similar to what is often observed in large acoustic tumor (Musiek et al., 1987) as illustrated in Figure18.

QUESTIONS

Fill in the blanks

1. The pulsatile pressure of the artery on the nerve may create_____ which can result in disruption from the normal activity, resulting in hearing loss, tinnitus and vestibular disorders.

2. Increase _____ have been observed in subjects with the compression of the arterial loop in the CPA.

3. The main blood supply for the brainstem comes from _____.

True or False

4. A basilar artery aneurysm in the low pons can mimic a mass occupying lesion.

5. Increased I-III can result from vascular compression.

Multiple Choice

6. The AICA loop in the CPA can compress with ensuing pressure on the_____ of eighth nerve.

   a) Cochlear portion.
   b) Vestibular portion.
   c) Cochlear and vestibular portions.
   d) None of the above.

ANSWERS

Fill in the blanks

1. Hyperfunction or Loss of function.

2. IWLs.

3. Bassilar Artery.

True or False

4. True.

5. True.

Multiple Choice.

6. c

ABR FINDINGS IN OTHER NEUROLOGICAL DISORDERS

Auditory Neuropathy (AN) or Auditory Dysynchrony (AD)

The term auditory neuropathy was first used by Starr, Picton, Sininger, Hood, and Berlin (1996) to discuss the patients who showed desynchronous ABRs despite evidence of intact OHC function. In Auditory neuropathy OHCs appear functional, neural processing is desynchronized and severely compromised. Neuropathy may be caused by a primary demyelination or by an axonal disease. A myelinated nerve fiber has a much greater membrane resistance than an unmyelinated fiber. Demyelinated fibers are sensitive to increase in temperature and may develop conduction block.

In cases of demyelinating neuropathy conduction, of nerve impulse slows due to demyelination. Such altered neural conduction affects the input to brainstem pathways. Changes in ABR reflect the site of demyelination so that ABR components generated distal to the zone of demyelination are of normal latency and amplitude, whereas components generated central to the zone of demyelination are delayed in latency and their amplitudes are typically reduced, compatible with variable slowing. Neural timing patterns are not synchronous with auditory stimuli is subjects with AN (Sininger & Starr, 2001).

Cochlear and neural responses can be distinguished by reversing the polarity of the stimulus in clients with Auditory Dysynchrony. A cochlear microphonic will invert with polarity reversal whereas a neural response will not, possibly showing only a slightly latency shift. Cochlear microphonics are often present in individual with Auditory Dysynchrony as illustrated in Figure 19.

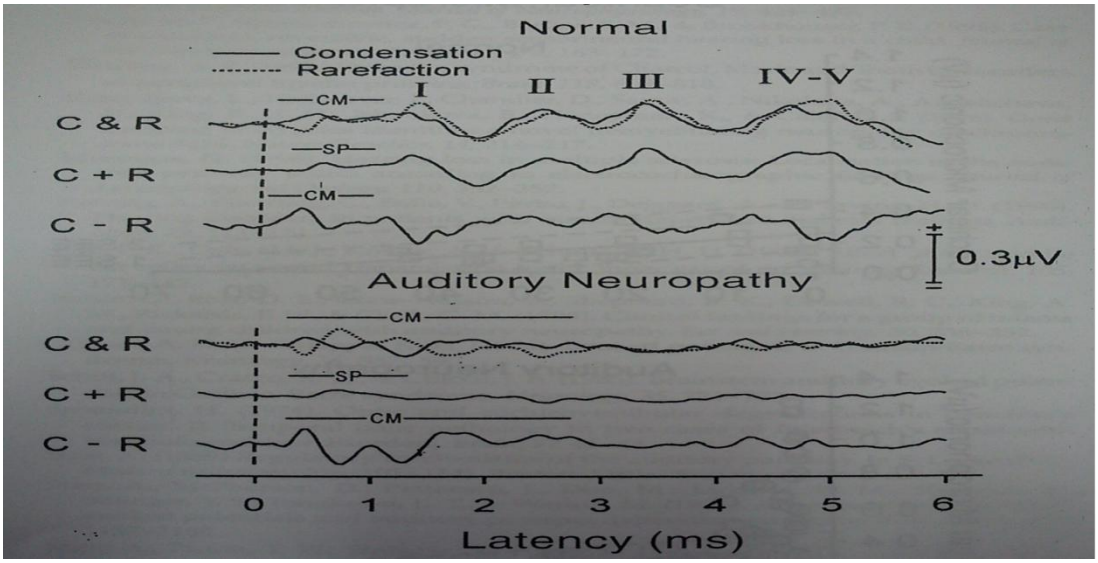


Figure 19. ABR showing the presence of cochlear microphonics recorded from a normal subject and a subject with Auditory Neuropathy using Rarefaction and Condensation polarity.

In ears with Auditory Neuropathy/Dysynchrony, auditory brainstem responses are absent (or grossly abnormal) at maximum stimulus presentation levels regardless of behavioral hearing level (Starr et al., 1996; Rance et al., 1999). In such cases, disruption of the auditory brainstem response is thought to be the result of either a reduction in the number of neural elements available to contribute to the response, or a disruption in the temporal integrity of the neural signal.

The absence or abnormality of all components of the ABR including wave I also suggests that the most distal portion of the eighth nerve is also affected, either directly or indirectly, in AD. The characteristic distinguishes between AD and space occupying lesions (SOL) affecting eighth nerve is that the wave I likely to be present in clients with SOL.

Sininger (2002) reported, out of 59 patients with AD, 70% had complete absence of ABR. 19% showed wave V only, which was poorly defined with abnormal latency. 6% had abnormal ABR but Wave III and V present. The patients with absent ABR showed the poorest pure tone average thresholds and those with several peaks in the waveform (called abnormal ABR) had the best thresholds. In all cases of AN, the threshold of the ABR was unrelated to the hearing threshold. Thus, ABR cannot be used to estimate hearing thresholds in a patient with AN.

ABRs are typically absent in patients with Auditory Neuropathy, although some patients demonstrate small responses at high stimuli level. At low repetition rates, the ABR waveforms may be seen in some cases (Sininger & Starr, 2001).

Multiple Sclerosis (MS)

Multiple Sclerosis is the most common type of demylinating disorder. The disease has a slow progressive course and characteristically is irregular with fluctuating periods of exacerbating and remission of specific symptoms. In demyelination, plaque formation usually begins with perivenular infiltration of lymphocytes and monocytes, most often in optic tract, the lateral and posterior columns of the spinal cord, the brainstem, and cerebellum. The loss of mylin is characterized by glial cell proliferation, perivascular edema, inflammation, and gliosis (scarring). As the disease progresses, plaques increase in number and size, dependent on the manifestation of pathological interstitial space. Thus, normal function in the fiber tract is rare and conduction is slower (Jacobson 1985). Hearing impairment is typically not an initial symptom or a prominent complain in Multiple Sclerosis.

Auditory brainstem Response abnormalities in Multiple Sclerosis include prolonged interwave (I – III, III – V, I- V) latencies, decreased amplitude especially of wave V, poor morphology (dysynchronisation) for later wave components, poor test repeateblity, total absence of one or more recognizable wave components after wave I or II (most often wave V), and occasional absence or prolongation of wave I, abnormal responses to changes in rate (Hall, 2007). Abnormally increased ABR latency, especially for wave V, is the most characteristic finding in Multiple Sclerosis. This clinical interpretation is compromised in some cases by difficulty in accurately identifying specific wave components, as noted by Parving, Elberling, and Smith (1981).

A frequently noted ABR phenomenon in Multiple Sclerosis is the **bimodal distribution** for latency values. In some Multiple Sclerosis patients, ABR latencies are in distinguishable statistically from those of normal subjects. When Multiple Sclerosis affects the ABR, however, latency values are markedly abnormal (Usually 4 or more standard deviations above the mean normal value). The pathophysiologic implication is that the ABR will be normal if Multiple Sclerosis for a given patient does not involve auditory brainstem pathways, but a small plaque in the auditory brainstem is enough to radically alter neural conduction along the pathways (Hall, 2007).

The most common interwave interval latency abnormality appears to occur in the III-V separation (Chiappa, Harrison, Brooks & Young, 1980; Lynn et al., 1980), although Shanon et al. (1981) found that the I-III interval to be prolonged more than III-V interval. The III-V interval is likely to be prolonged since the area between the superior olivary complex and the inferior colliculus is the longest tract of white matter in the CNS tract, and therefore is more susceptible to the effects of demyelinating

disease (Shanon et al., 1981). Demylination results in increased refraction period of transmission of the axons with reduced conduction velocity along the central auditory pathways, yielding delays in latency of progressive waves of the auditory evoked potential (Lacquaniti et al., 1979). Decreased amplitude especially of wave V can be seen in Multiple Sclerosis (Chiappa et al., 1980)

Monaural as opposed to binaural, stimulation is recommended because abnormal ABR findings may be unilateral in approximately 45 percent of patients (Hall, 2007). These lateralized lesions would go undetected with stimulation of both ears simultaneously, since a normal response could be recorded from stimulus to the unaffected ear. Comparison of ABR amplitude recorded with binaural versus monaural stimulation may have diagnostic value in MS.

Generally, an increase in repetition rate differentially prolongs wave latency while decreasing wave amplitude is common in MS. The more rostral the response, the greater the latency shift. Some investigators suggest that sensitivity of the ABR to MS is enhanced by increased stimulus rates (Elidan, Sohmer, Gafni, & Kahana, 1982); Jacobson, Murray, & Deppe, 1987; Musiek et al., 1989; Robinson & Rudge, 1977). Some investigators also suggest that alteration in the wave morphology with increase in rate can also be seen in Multiple Sclerosis as shown in Figure 20.

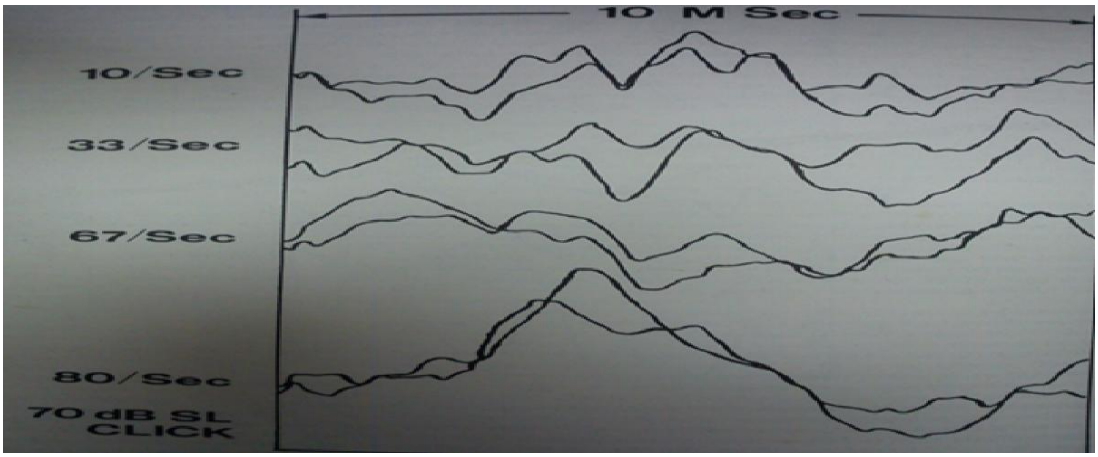


Figure 20. Abnormal change in response morphology as a result from an increase in click rate.

Several investigators reported poor test- retest repeatability (Garza, Keith & Barajas, 1982; Nodar, 1978). There are a wide variety of ABR results possible in Multiple sclerosis, with disseminated lesions possible at all levels of the brainstem. Clinicians should not expect a homogenous pattern of results in a patient population with so many possibilities of distribution of lesions (Jacobson, 1985).

Leukodystrophies

These are rare familial abnormalities of myelination formation and affect white matter that are found in infants and children. There is widespread and often symmetrical bilateral failure or degeneration in the formation of myelination in the CNS with some degree of axonal degeneration (Hall, 2007).

ABR abnormalities are typically found in this white matter disease and are useful in distinguishing white versus gray matter involvement. Prolonged ABR interwave (I-V) latencies characterize adrenoleukodystrophy (Garg, Markand & Bustion, 1982; Grimes et al., 1983). These ABR findings are associated with increased

central conduction times. Absence of ABR waves III or V, or all components after wave I and II, are not uncommon (Markand, Garg, & Brandt, 1982; Yagi, Kaga & Baba, 1980). Wave I is usually present, but the ABR is rarely normal, in patients with a mild form of the disease.

Alzheimer's disease

Alzheimer's disease can be found in persons of any age, but generally in the elderly population. It includes senile plaques, nonspecific neural loss, granulovacuolar degeneration, atrophic CNS changes. The senile plaques are found exclusively in the cortex, especially in the frontal and temporal grey matter. The brainstem is not involved typically, although midbrain nuclei can be abnormal. There are also reports of involvement of the inferior colliculus, medial geniculate body, and both primary and secondary auditory cortex (O'Mahoney et al., 1994).

Harkins (1981) observed increased wave I-V latency values in a client with Alzheimer's disease. O'Mahoney et al. (1994) also observed significant prolongations in the ABR wave I to V latency in patients with mild to moderate Alzheimer's disease.

Some case studies report that there were normal ABR findings. The supportive explanation can be that the responses reflect mostly white matter integrity where as the disease involves mostly cortical grey matter (Jacobson, 1985).

Amyotrophic Lateral Sclerosis (ALS)

It is often referred to as "Lou Gehrig's disease". There is degeneration and loss of large motor neurons and motor nuclei in the brainstem. With ALS there is degeneration and loss of large motor neurons, which is most apparent in the anterior horns of the cervical and lumbar regions and motor nuclei in the brainstem. Neuronal

degeneration in midbrain structures and the pontine tegmentum has also been reported (Hall, 2007).

Matheson, Harrington, and Hallet (1983) observed variety of ABR abnormalities in patients with ALS. It can be prolonged wave I-III latency interval, slight overall I-V latency delay, no wave III or V and no ABR bilaterally. Ratke, Erwin and Erwin (1986) also observed similar findings in their clients with ALS. Chiappa et al. (1980) and Tsuji et al. (1981) reported normal ABR findings in patients with ALS.

Huntington's disease (Chorea)

Huntington's disease is hereditary disorder and autosomal dominant and is a type of degenerative disorder. It is characterized by diffuse loss of cells in the caudate nucleus and putamen and atrophy of remaining cells. There will be progressive loss of intellectual function (dementia). Frontal horns of the lateral ventricles are dilated. These neuronal changes can also be found elsewhere in the brain, especially the substantia nigra and thalamus.

Ehle, Stewart, Lellelid, and Leventhal (1984) obtained normal ABR from clients with chorea. ABR wave I-V latency interval were equivalent to normative data for all subjects.

Parkinson's disease

In the past the main site of lesion was thought to be at the Basal Ganglion but the neuronal changes are now localized primarily to the substantia nigra and other nuclei. The etiology is however unknown. The signs and symptoms include reduction of spontaneous movements, rigidity, tremor, hypokinesia and gait disturbance. ABR

findings show increased latency and poor morphology, with normal amplitude (Gawel, Das, Vincent, & Rose, 1981).

Spastic Paraplegia

This is one of the spinocerebellar degenerative disease affecting cortico spinal tract and posterior columns. Campnella et al. (1984) and Cassandro et al. (1986), reported normal ABR.

Picks Disease

This is a rare disease consisting of severe but localized atrophy, usually in frontal and temporal lobes of the cerebral cortex and less often other CNS structures. It is often clinically very similar to Alzheimer's disease. There were significant prolongations in the ABR wave I to V latency interval observed (Hall, 2007).

Wilson's disease

This is a genetic disorder of copper metabolism. It is autosomal recessive and can appear at any time in life. Liver and CNS pathology cause the clinical manifestations. The regions of the CNS involvement include basal ganglia, caudate, putamen, and thalamus and substantia nigra. Excessive copper deposition and demyelination are suggested as mechanism (Hall, 2007).

Fujita, Hosoki, and Miyazai (1981) is apparently the first to report of ABR in Wilson's disease described increased wave (III-V and I-V) latencies in the three patients with neurologic symptoms and normal ABR latencies in three with no neurological symptoms. Chu and Yang (1987) found significant increase in the I-V latency interval in clients with Wilson's disease.

Diabetes Mellitus

Diabetes Mellitus is a chronic systemic disease related to a relative or absolute deficiency of insulin. Systemic abnormalities in diabetes can involve metabolic and vascular alterations. Metabolic disorders characteristically consist of abnormally elevated blood glucose levels with associated lipid and protein changes. Vascular disorders typically consist of defects in the structure or function of small blood vessels (micro angiopathy) and artherssclerosis. Blood hyperglysemia and glycosuria develops because of inadequate production or utilization of insulin. Abnormalities of the auditory system can include atrophy of the spiral ganglion, degeneration of the myelin sheath of the eighth nerve, decrease in the number of nerve fibers in the spiral lamina, and thickening or narrowing of the capillary walls of the stria vascularis and of the small arteries within the internal auditory canal. Pathologic studies show diffuse degeneration of ganglionic cells and nerve fibres in the cerebellum, brainstem, and cerebrum (Jerger & Jerger, 1981).

Prolonged ABR latencies have been reported in patients with type I (insulin dependent) diabetes (Virtaniemi, Laasko, Karja, Nuutinen, & Karjarainen, 1993). Wave V latencies and wave V-I intervals were prolonged, which were most likely related to the long duration of diabetes and microvascular complications associated with the disease (Hood, 1998).

Donald et al. (1981) observed ABR wave I and II latencies were within normal limits but interwave latencies (I-V) were significantly greater, however ABR morphology was consistently good. Fedele et al. (1984) found significant delays in both absolute latency for wave I and interwave (I-V) latency.

QUESTION

Fill in the Blanks

1. The characteristic difference between Auditory Neuropathy and space occupying lesions affecting eighth nerve is presence of _____.
2. Wilson's disease is a genetic disorder of _____.
3. Diabetes can involve both _____and _____alterations.
4. Leukodystrophies are familial abnormalities of myelination formation and affect_____ that are found in infants and children.

True or False

5. Presence of cochlear microphonics is seen in Auditory neuropathy.
6. Huntington's disease is hereditary disorder and autosomal dominant.
7. Wilson's disease is autosomal dominant and can appear at any time in life.

Multiple Choice

8. In some cases with auditory neuropathy at_____ repetition rates, the ABR waveforms can be seen.

   a) High. c) Both.

   b) Low. d) None.

9. The other name of Amyotropic Lateral Sclerosis is

   a) Lou Gehrig's disease. b) Picks disease.

   b) Moebius Syndrome. d) Schilder's Disease.

10. In Multiple Sclerosis, _____in repetition rate differentially prolongs wave V latency

    a) Decrease
    b) Increase
    c) Both a & b.
    d) None of these.

11. Demylination results in _____refraction period of transmission of the axons with reduced conduction velocity along the central auditory pathways.

    a) Decreased.
    b) Conduction block
    c) Increased.
    d) None of the above.

ANSWERS

Fill in the Blanks

1. Wave I.
2. Copper metabolism.
3. Metabolic, Vascular.
4. White matter.

True or False

5. True.
6. True.
7. False.

Multiple Choice

8. b
9. a
10. b
11. c.

SPECIAL TEST IN ABR TO IDENTIFY RETROCOCHLEAR PATHOLOGY

Stacked Auditory Brainstem Response

Stacked ABR has recently been developed by Don and Kwong, (2002) to detect of small tumors of the eighth cranial nerve. According to them, standard ABR measures based on latency are less sensitive to tumors smaller than 1.0 cm. They speculated that this is because the latency of the standard ABR is dependent upon high frequency auditory nerve fibers, whereas some tumors may affect only low or mid fibers in the early stages. The stacked ABR measures neural activity from all frequency regions of the cochlea, and thus, has shown to be more sensitive than traditional ABR to detect to tumors less than 1.0 cm (Don, Kwong, Tanaka, Brackmann & Nelson, 2005).

Primarily two methods have been used to record stacked ABR. They are derived band technique and tone burst method. The procedure used in these methods is described briefly in this section.

a) Derived band technique

The ABR is obtained using click stimulation, first without masking, and then in the presence of high-pass noise masking at progressively lower cut-off frequency (8, 4, 2, 1, and 0.5 kHz) as illustrated in Figure 21. In this manner, increasingly lower frequency regions of the cochlea are masked in each successive run. Next, the 8 kHz high-pass masked waveform in subtracted from the unmasked response to obtain the derived- band response from the area of the cochlea above 8 kHz. Similarly, the response masked with 4 kHz high pass noise is subtracted from the 8 kHz masked

response to obtain the derived – band ABR between 4 and 8 kHz. This procedure is continued for all of the masked responses, resulting in five derived-band ABRs spanning the length of the cochlea. Each band approximately one octave wide as illustrated in Figure 22. The latency of wave V will be progressively longer for each successive derived-band ABR, due to the traveling wave delay along the basilar membrane. Finally, the stacked ABR is constructed by time shifting all the derived-band waveforms so that their wave V latencies align temporally and summing the bands. The amplitude of wave V of the stacked ABR is then compared with normative data. A tumor is suspected if the amplitude is smaller than normal, based on an established criterion.

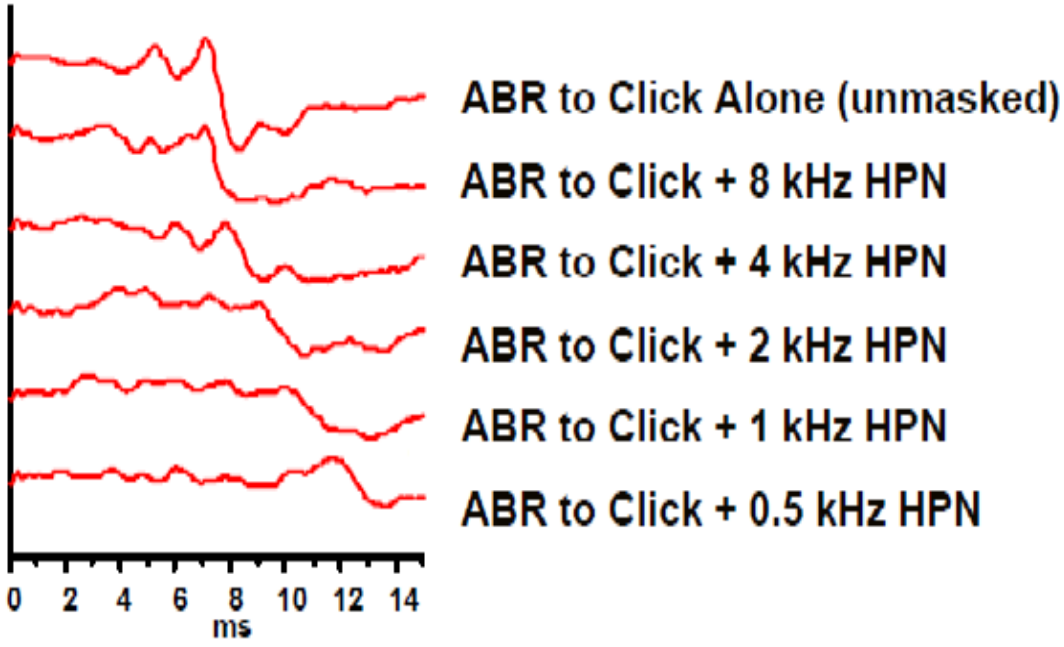


Figure 21. Illustrates the ABR obtained using click stimulation, first without masking, & then in the presence of high-pass noise masking of different lower cut-off frequencies.

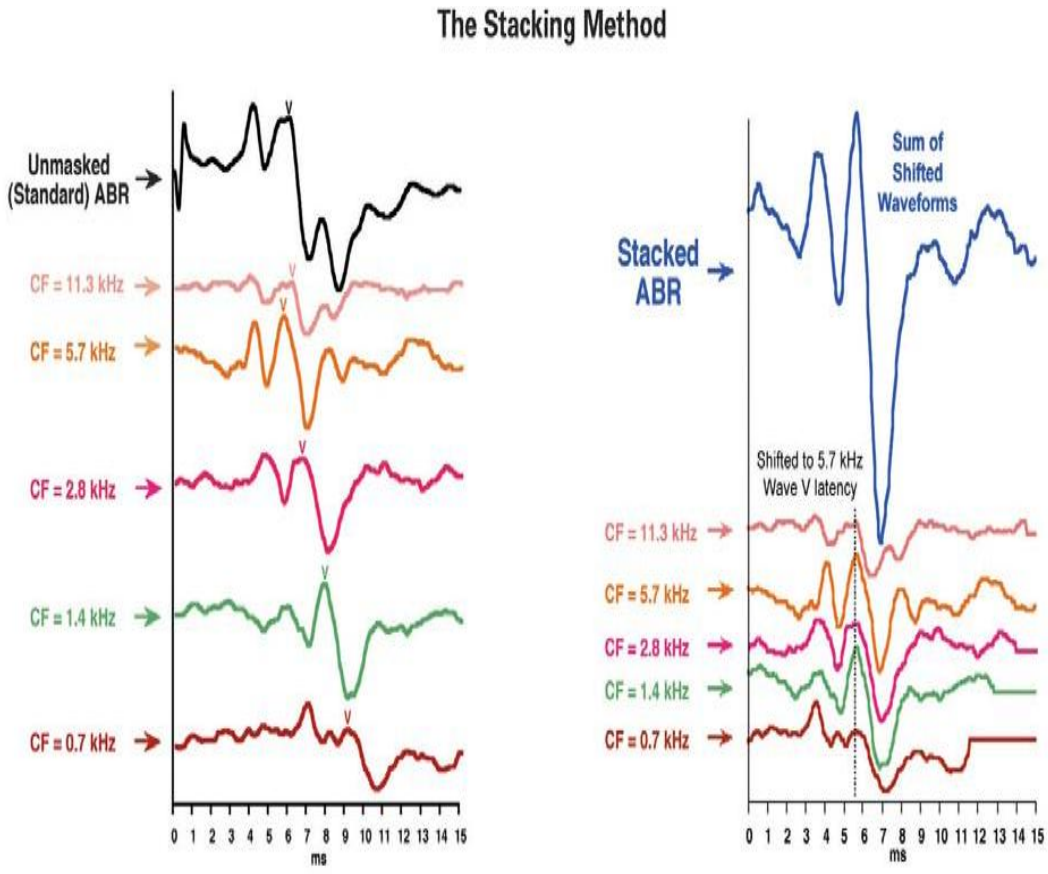


Figure 22.The standard ABR to clicks presented alone (top trace) and the five derived-band ABRs from a normal hearing subject. The derived-band ABRs represent activation of octave-wide regions in the cochlea. Construction of the stacked ABR from the derived-band ABRs is shown in the figure (right side). The stacked ABR (top trace) is obtained by (1) temporally aligning the derived-band ABR waveforms so that the peak latencies of wave V in each derived band coincide, and (2) adding together these aligned derived-band ABR waveforms.

b) Tone burst method

Philibert et al, (2003) developed an alternative method called stacked tone burst ABR to overcome the disadvantages of the derived band stacked ABR. It is assumed that, using brief tone stimuli such as tone bursts for recording ABR the responses are elicited from narrow region along the basilar membrane corresponding to the stimulus

frequency. Bekesy (1960) demonstrated that the high frequencies in the sound will vibrate only the basal region of the basilar membrane and lower frequencies in the sound will vibrate apical regions. However several investigators have reported that when using low frequency stimuli at suprathreshold levels, the responses are mediated by high frequency regions of the cochlea also (Oates & Stapells, 1997; Gorga & Thronton, 1989). But when stimulus intensity is decreased and tone evokes a response through the region of cochlea specific to its frequency (Stapells, Picton & Durieux-Smith, 1994).

Philibert et al (2003) compared tone burst stacked ABR with derived band method in 10 young normal individuals. Subsequently stacked tone burst method was used in six cases of unilateral vestibular schwanomas confirmed by MRI. The tone bursts were synthesized at same centre frequencies as derived noise bands used by Don, Masuda, Nelson and Brackmann (1997). The stimulus were presented at 40 dB SL (mean = 60 dB HL) to record tone burst ABR at different frequencies. Stacked ABR was conducted by temporally aligning the ABR wave forms recorded from different frequencies and subsequently adding them. Wave V marked in the final summed waveform and its peak to peak amplitude was measured. It was concluded that tone burst method shows good approximation of the derived band method in achieving stacked wave V amplitude enhancement**.**

In 2007, Mahajan studied the effects of cochlear hearing loss on tone burst evoked stacked ABR and amplitude of tone burst ABR. According to the study, the normative developed for stacked tone burst ABR are as follows:

Stacked ABR	N	Mean	Std. Deviation
SA	35	0.54	0.09
SA_3	35	0.53	0.11
SA_2	35	0.50	0.14

Table 1. Amplitude of Stacked ABR for individuals with normal hearing for different stacked ABRs in micro volts (µv)

Stacking ABR for 500Hz, 1000Hz, 2000Hz (SA3), Stacking ABR for 500Hz & 1000Hz (SA2), and Stacking ABR for all frequencies (SA) were done. The mean amplitude of stacked wave V was largest for SA followed by SA2 and SA3. There was no significant difference of wave V in SA and SA3, between SA3 and SA2. However there was significant between SA and SA2 ($P< 0.05$).

The main advantage of the stacked ABR is successful detection of small intracanalicular acoustic tumors that are missed by standard ABR method (Don et al, 1997). Don et al, (1997) demonstrated in a series of 25 tumor cases, five small (≤ 1 cm) intracanalicular tumors which were missed by standard ABR latency measures, were detected by stacked ABR method. The stacked wave V ABR amplitudes in all the five subjects were significantly lower than those obtained from normal hearing individuals without tumors. A small tumor was suspected if the amplitude of stacked wave V was lesser than 2 standard deviations (SD) away from mean.

A major limitation of the stacked ABR is that it must be obtained with click levels no greater than 60 to 65 dBnHL. Thus, Patients with average hearing losses greater than 60 dB across standard audiometric frequencies cannot be meaningfully screened with the stacked ABR. The reason for this limitation is that higher click

levels require higher masking noise levels to obtain the derived band responses for the stacked ABR. These higher masking noise levels would be uncomfortable and unsafe for the normal hearing subjects whose stacked ABRs provide the diagnostic reference data. Therefore we cannot obtain reference data for the stacked ABR at click levels that are significantly higher than 60 to 65 dBnHL.

QUESTIONS

Fill in the blanks

1. The stacked ABR was first developed by_____ and_____.
2. Stacked tone burst ABR was developed by_____ in _____.
3. The latency of wave V will become progressively _____for each successive derived-band ABR.

True or False

4. The stacked ABR is constructed by time shifting all the derived-band waveforms so that their wave V latencies align temporally and summing the bands.
5. The main advantage of the stacked ABR is successful detection of small intracanalicular acoustic tumors that are missed by standard ABR method.

Multiple Choice

6. An alternative method called _____ is developed to overcome the disadvantages of the derived band stacked ABR.

   a) Stacked tone burst ABR. c) Tone burst ABR.

   b) Stacked click ABR. d) None of the Above.

7. A tumor is suspected if the amplitude is_____ than normal.

   a) Larger. c) Prolonged.

   b) Smaller. d) Wider.

8. The stacked ABR measures neural activity from _____of the cochlea.

   a) All frequency regions. c) Mid frequency region.

   b) Low frequency. d) High frequency region.

ANSWER

Fill in the blanks

1. Don and Kwong.
2. Philibert et al. in 2003.
3. Longer.

True or False

4. True.
5. True.

Multiple Choice

6. a
7. b
8. a

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