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### Authors

Nuwer, MR  
Aminoff, M  
Goodin, D  
[et al.](#)

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# IFCN recommended standards for brain-stem auditory evoked potentials. Report of an IFCN committee

Marc R. Nuwer (Chairman) (*Los Angeles, CA, USA*), Michael Aminoff (*San Francisco, CA, USA*), Douglas Goodin (*San Francisco, CA, USA*), Shigeaki Matsuoka (*Kitakyushu, Japan*), François Mauguière (*Lyon, France*), Arnold Starr (*Irvine, CA, USA*) and Jean-François Vibert (*Paris, France*)

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## Introduction

Brain-stem auditory and evoked potentials (BAEPs) have come into widespread use for assessment of the clinical state of the middle portion of the brain-stem and for assessment for hearing, particularly in the screening of infants at risk for hearing loss. They have found their way into routine hearing screening for infants. They have proven themselves as objective, reproducible, sensitive indicators of many types of brain-stem disturbances.

The pathway tested by BAEPs include the acoustic conduction through the ear and the electrical transmission from cochlea along the eighth nerve into lower pons, continuing rostrally through pons and up each lateral lemniscus into the midbrain. A series of 5 or more peaks are usually recorded from the ears and scalp vertex.

The BAEP test can be easily recorded in most patients, including comatose or sedated patients in whom routine audiometry cannot be done. In fact, the best quality BAEP is often obtained with sleep or sedation. BAEP can be obtained in the presence of mild or moderate hearing impairment, but the main 5 peaks usually cannot be obtained in the presence of severe hearing impairment.

## Stimulation

BAEPs are produced by a brief "click" stimulus. This is usually a square-wave electrical pulse 100  $\mu$ sec

long. This brief pulse can move the earphone diaphragm either toward or away from the patient's ear. Earphone movement toward the ear is called an acoustic "condensation" phase stimulus, whereas earphone movement away from the patient's ear is a "rarefaction" stimulus. Occasionally the two types of phase are concatenated, which is referred to as an "alternating" phase stimulus. The latter can be useful in reducing stimulus artifact seen with very loud stimulus intensities. In clinical neurophysiology the rarefaction phase is usually chosen.

Clicks are usually presented 10–70 times/sec. At fast rates, data can be collected more quickly, but the peaks are more poorly defined. As a result, slower or intermediate rates are often chosen. The rates 11 and 31/sec are most commonly chosen. Rates are usually not exact factors divisible into 50 or 60 Hz, because such rates would predispose to line noise.

Stimuli are often delivered at about 70 dB intensity. There are several different decibel scales in common clinical use. It is important to understand the difference between these intensity scales.

(1) *Hearing level* (dB NHL, dB HL, dB nHL): this scale refers to the number of decibels of intensity compared to the threshold of hearing in a group of average normal subjects. Zero on this scale is defined as the threshold at which an average normal subject can just perceive the stimulus 50% of the time.

(2) *Sensory level* (dB SL): this is the scale on which zero is defined as the point at which the individual patient can barely appreciate the stimulus. This may be very different from 0 dB HL. Patients with hearing loss may have their personal 0 dB SL found at very high intensities such as 70 dB NHL.

(3) *The physical definition* (dB peSPL, peak equivalent sound pressure level): physical measurement of sound pressure levels use as the 0 dB reference level a

Correspondence to: Marc R. Nuwer, M.D., Ph.D., Department of Clinical Neurophysiology, Reed Neurological Research Center, University of California Los Angeles, 710 Westwood Plaza, Room 1194, Los Angeles, CA 90024 (USA).  
Fax: (310) 206-8461.

pressure of 20 micropascals ( $\mu\text{Pa}$ ), which equals  $0.002$  dyne/cm<sup>2</sup>. The 0 dB peSPL turns out to be approximately equal to  $-32$  dB HL.

(4) *Individual equipment scales*: each particular piece of equipment has dial settings in terms of dB. Although the original intention of the manufacturers is to make these equivalent to dB NHL, many individual pieces of equipment actually differ from that standard. An individual user should know the relationship between his/her equipment and the HL scale. The conversion factor is likely to be between  $-10$  and  $+10$  dB.

For testing of hearing, a latency-intensity test can be performed. In this test, the stimulus is reduced to specific lower intensities, such as 65, 50, 40 and 30 dB NHL. At each intensity, a BAEP trace is run. Wave V can be detected on each of these and changes in the wave V latency can be interpreted, as described below. Some users prefer to use just 2 stimulus-intensity steps, e.g., 70 dB and 30 dB NHL. In the latter case, the 30 dB recordings should be run at least twice to assure the reproducibility of the results.

Contralateral white noise masking is often employed. It is most often useful when there is an asymmetry of hearing between the ears. Masking blocks the effects of bone conduction of the stimulus from the side with impaired hearing to the side with better hearing. The contralateral white noise masking is usually set at 40 dB below the intensity of the click presented to the ear being tested.

## Recordings

Recording electrodes should be placed at both ear lobes and at site Cz at the scalp vertex. In each case, a 1 cm disk electrode should be securely fastened to the recording site and the electrical contact impedance should be kept below  $5000 \Omega$ . The recording electrode on the ipsilateral ear may be designated Ai, and on the contralateral ear Ac.

The recording montage suggested is:

Channel 1: Ai-Cz, the ipsilateral channel.

Channel 2: Ac-Cz, the contralateral channel.

In each case negative electrical potentials at the first electrode designated above should be displayed as upgoing deflections or peaks.

Some users prefer 1 or 2 additional recording channels. Recording Ai-Ac can sometimes help clarify wave I. Recording from Cz to an occipital or neck reference can sometimes help to better define waves III-V.

The low filter is often set at 100 Hz and the high filter at 3000 Hz. Some users prefer to set the low filter as low as 10-30 Hz, which can help increase the amplitude of waves IV-VI. Use of the 60 Hz filter does not usually interfere with BAEP recordings. Recordings are made during the 10 msec after the

stimulus in most settings. For neonates, premature infants and for latency-intensity testing, 12-20 msec analysis time is usually chosen in place of 10 msec. Usually at least 2000 trials are required to get a good quality BAEP recording. Sometimes substantially larger number of trials are required for each tracing. Two or 3 separate repetitions are run and superimposed. This is helpful to ascertain that good quality records are being obtained and to more precisely identify the latencies and amplitudes needed for scoring the test. In general, the several traces from the separate BAEP repetitions should superimpose almost exactly. Latency values measured on the separate repetitions should agree with each other within 0.10 msec or less. Amplitude values should agree with each to within 10%, and much better reproducibility should be expected in most settings.

## Principal peaks and their identification

The classical BAEP consists of between 5 and 8 vertex positive peaks, generally labeled with Roman numerals. The principal peaks I-V are the main peaks of clinical interest. These are shown in Fig. 1. The several succeeding peaks VI-VIII are quite variable and not used clinically.

The troughs immediately following each peak are designated by the same numeral followed by a prime-mark. For example, the trough after V is labeled V'. Identification of components is helped by the rules listed below, although they do not apply to every case. For example, when other abnormalities exist, the classical shapes of a particular component may be altered.

### Wave I

This wave is generated from the auditory portion of the eighth cranial nerve, probably from the proximal portion of that nerve just lateral to the brain-stem. It is a prominent initial upgoing peak in the ipsilateral ear recording channel which is markedly attenuated or absent from the contralateral ear recording channel. Patients who have only central nervous system problems should have a preserved wave I, since it is a peripheral peak. Conversely, patients who have a significant peripheral hearing impairment may have a very poorly formed or absent wave I but may have relatively normal waves II-V.

Wave I can sometimes be seen to have two separate components. The first, earlier component is present and higher in amplitude especially during high intensity, high pitched stimulation. This component should be used for scoring whenever it is present. The second, slightly later lower amplitude component of wave I, is present at a more wide range of stimulus intensities and pitch.

### Wave II

This wave may be generated near or at the cochlear nucleus. A portion of it can come from the eighth nerve fibers around the cochlear nucleus, and this part of II can be preserved despite brain-stem death. Wave II is poorly defined in some adults and most neonates. It sometimes appears as a small peak along the downgoing slope of the wave I. At other times, it merges into the upgoing slope of wave III. It is often more prominent on the contralateral channel recording, where it has a slightly prolonged latency compared to the ipsilateral channel, sometimes fusing with wave III into an M-shaped II-III complex.

### Wave III

This wave is probably generated from the lower pons as the pathway travels through the superior olive and trapezoidal body. The nuclei or fiber tracts that are most responsible for generating this potential are unknown and may be multiple.

Wave III is usually a prominent peak and is followed by a prominent III' trough. In the contralateral channel wave III often appears smaller and earlier than on the ipsilateral channel, because its amplitude is similar at the vertex and contralateral ear.

### Waves IV and V

Contribution to these two potentials probably include generators in the upper pons or lower midbrain, in the lateral lemniscus and the inferior colliculus. There are conflicting reports about whether these peaks are generated in the ipsilateral or contralateral brain-

stem, but the preponderance of evidence favors a contralateral brain-stem generator site for wave V.

These peaks may fuse together into a IV-V complex on the ipsilateral recording channel. This complex can vary between: (a) two peaks which are close but still visibly separate, and (b) a single peak which is completely fused as a tall, wide pyramid. There are also various intermediate stages of trapezoid-shaped figures which represent the partial fusion of the two peaks. On the contralateral recording channel the IV and V peaks tend to be separated more from each other with wave IV being slightly earlier and wave V being slightly later. Comparison of ipsilateral and contralateral peaks can be helpful for distinguishing which peak or shoulder to score as wave V. The wave V is generally followed by a large V' trough. Sometimes wave VI (six) appears before the bottom of this trough, and then wave VI can be confused with wave V if the reader is not careful. The fusion of wave VI into a IV-V-VI complex occurs more often when a 10-30 Hz low filter is used for recording.

The typical IV-V complex has the shape of a somewhat inflated pyramid or trapezoid. The base of this complex should be *more than* 1.5 msec across. A peak narrower than this is usually a wave IV alone. When doubt as to the identity of wave V exists, the technician should change some of the test parameters in order to help the identification process. Wave V is usually most prominent at an intermediate intensity of stimulation. As this stimulus intensity increases further beyond that point, the identification of wave V can actually become more difficult. It is often helpful to have the technician

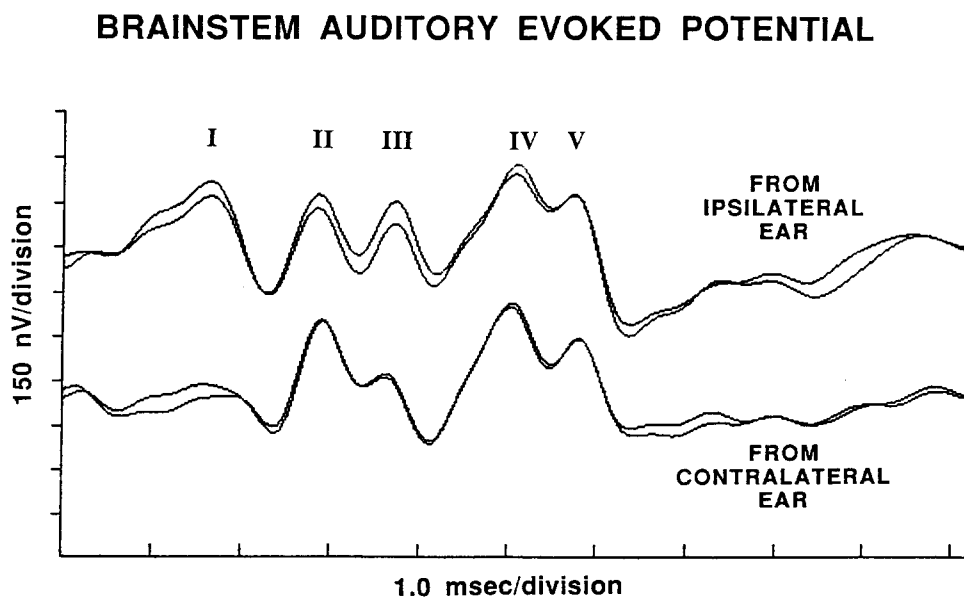


Fig. 1. The principal 5 BAEP peaks are identified by numerals I-V. Both ipsilateral and contralateral ear channels are shown, both recorded with a vertex reference. The peaks seen here are typical for an adult patient.

reduce the intensity of stimulation to identify wave V. Wave V is a robust peak that is present despite moderately low intensities of stimulation (and often even despite high frequency hearing impairment, or other types of peripheral auditory changes). Wave V and especially the V' trough are often the last deflections to disappear when the stimulus intensity is gradually decreased to threshold. Wave V can sometimes be made more clear by changing the stimulus' acoustic phase.

Overall there are several traditional ways to help identify wave V when its identity is unclear: the typical contralateral splitting of the IV-V complex; the wide base of a IV-V complex; and the preservation of wave V at lower stimulus intensities.

### Normal limits and the clinical correlation of changes

There are 5 principle features used to assess routine BAEPs. In addition to these, there are several other features which can be looked at in special circumstances; the latter include the changes seen on latency-intensity testing.

#### *I-V interpeak interval*

This is the primary feature for most BAEP interpretations. It is felt to represent conduction from proximal eighth nerve through pons and into the midbrain. It can be slowed in a variety of disorders, including focal damage (demyelination, ischemia, tumors), or diffuse problems (degenerative disorders, post-hypoxic damage, etc.).

A typical upper limit of normal for the I-V interpeak interval is 4.5 msec. That limit is slightly lower for young women and slightly higher for older men. Normal right-left asymmetries for the I-V interpeak intervals should be at most 0.5 msec. For full-term infants, the I-V interpeak interval should be less than 5.4 msec.

#### *I-III interpeak interval*

This interpeak interval represents conduction from the eighth nerve across the subarachnoid space, into the core of the lower pons. The I-III interpeak interval can be increased in any diffuse process that affects the whole I-V interval. This I-III portion of the pathway is susceptible to a tumor, inflammation or other disorder specifically affecting the proximal portion of the eighth nerve, or the ponto-medullary junction where the eighth nerve enters the brain-stem, or impairments in the lower pons around the superior olive or trapezoidal body. Acoustic neuromas or other cerebello-pontine angle tumors can cause a delay at the juncture. Infarction can cause an interruption or a delay here too, although the classical Wallenberg syndrome is

usually too caudal to affect this segment. Inflammation in the subarachnoid space can also increase this I-III interpeak interval (subarachnoid hemorrhage, meningitis, and Guillain-Barré syndrome).

The upper limit of normal for the I-III interpeak interval is about 2.5 msec. The acceptable right-left asymmetry of this interval is less than 0.5 msec. An excessively long interpeak interval I-III cannot be considered unless there is an accompanying prolongation of the I-V interpeak interval.

#### *III-V interval*

This interval reflects conduction from the lower to the upper pons, and possibly into the midbrain. There is not yet complete agreement about whether this III-V interpeak interval represents conduction along the ipsilateral or contralateral brain-stem, compared to which ear was stimulated. The preponderance of evidence favors a contralateral brain-stem site.

The typical upper limit of normal for a III-V interpeak interval is about 2.4 msec. A right-left asymmetry for these intervals should be less than 0.5 msec. An excessively long III-V interpeak interval is not considered abnormal unless either the I-V interval or the V/I amplitude ratio is also abnormal.

#### *V/I amplitude ratio*

Absolute amplitudes of BAEP peaks vary widely among normal subjects. In addition, several technical factors influence the absolute amplitudes of the BAEP peaks. To reduce this normal intersubject variability, a ratio of amplitudes is usually calculated. For this ratio, the amplitude of the IV-V complex is divided by the amplitude of the wave I. The IV-V complex is measured from the highest point of the complex to the trough of the V' peak. When V is completely separated from IV, the V amplitude is used in place of the IV-V amplitude. When wave VI is found lying part way down the descending slope of wave V, then the amplitude is measured to the trough following wave VI (the VI'). The wave I amplitude is measured from the top of the highest part of wave I to the bottom of the trough of I'. If wave II is riding on the descending slope of wave I, then wave I amplitude is measured to the succeeding trough of the wave II'.

The amplitude ratio should be between 50% and 300%. These numbers vary between laboratories, and they are especially affected by filter setting changes. When the V/I is less than 50%, then the IV-V peaks are too small. In that case, suspicion is raised of some central impairment which has diminished the amplitude of the IV-V even if it may have not increased the I-V interpeak interval. This is a useful criterion for abnormality, especially when the IV-V peaks are so low that they are difficult to distinguish from background noise. Then the record may be interpreted as

abnormal because of such low amplitude central peaks, even if the latencies cannot be precisely defined. For full-term infants, the lower limit for V/I is 30%.

When the V/I amplitude ratio is greater than 300%, wave I is usually considered to be too small. This raises the suspicion of some peripheral hearing impairment, especially of a high frequency or a sensorineural hearing loss.

#### *Presence of waves I-V*

The waves I-V all are seen in most normal individuals. Occasional normal subjects have a wave IV that is so merged into a IV-V complex that it cannot be clearly distinguished as a separate peak, unless extra traces are run at different stimulus rates and intensities. Such a merging of wave IV into a IV-V complex is considered to be a normal variant. Wave II can also be difficult to distinguish when testing some normal subjects. Upon changing stimulus intensities, rates and phase, wave II can be distinguished in essentially all normal subjects. However, wave II can appear to be missing at the specific rates and intensities used for simple clinical BAEPs, and this would be considered a normal variation.

When all of the waves I-V are absent the BAEP is abnormal, although the cause is usually peripheral. (Technical problems must also be considered.) It is also abnormal to record a wave I, but not succeeding waves. Finally, it is abnormal if waves I and III are present but the IV-V is absent. These rules for the absence of peaks are predicated upon the assumption that technically good quality records have been obtained. The records should be considered technically unsatisfactory if moderate or large amounts of background noise are present in the tracing, rather than being interpreted as showing an absence of important peaks.

Waves VI, VII and VIII can normally be present or absent or asymmetrical in latency or amplitude, without any apparent clinically correlation. The main reason for knowing of their existence is to prevent confusion with the earlier, important waves.

#### *Absolute latency measurements*

The absolute latency measurement of waves I, III and V can be occasionally of clinical value. This is particularly so when some peaks are absent. For example, the absolute latency of wave V can be compared against normal limits when there are no waves I-IV. The absolute latency of wave V is normally less than 6.4 msec. The right-left asymmetry of the wave V absolute latency is normally 0.5 msec or less. Absence of waves I-IV with delayed wave V may be due to a hearing loss. When waves I, III and V are all present, the standard means of interpretation is by the interpeak intervals.

The absolute latency of wave I can be used as part of the assessment of hearing. The wave I is often seen around 1.75 msec, but may be seen up to 2.2 msec in some normal subjects. The right-left asymmetry of wave I absolute latencies is normally 0.4 msec or less. Wave I latency delays or asymmetry suggest a hearing impairment, rather than brain-stem dysfunction.

#### *BAEP threshold*

When screening for hearing impairment, latency-intensity curves and threshold evaluations can be useful. Stimulus intensity is gradually reduced to determine the threshold of peaks. The waves gradually decrease in amplitude and increase in latency as intensity decreases. Eventually only wave V persists, and usually the V' trough is the very last deflection eventually to disappear. The threshold is considered to be the intensity at which the last peak or trough is barely seen. It is important in threshold evaluations that the background noise be kept to a minimum, usually by having the patient asleep at the time of testing.

#### *Latency-intensity slope*

A latency-intensity curve can be established by graphing the V latency across several stimulus intensities. The slope of the change in wave V latency can be calculated in microseconds per decibel ( $\mu\text{sec}/\text{dB}$ ). The slope of the wave V latencies can be compared graphically to a standard set of normal points. Alternatively, the overall slope can be compared numerically to standard normal limits for the slope. For the latter calculation, a normal slope is usually considered to be less than 50-55  $\mu\text{sec}/\text{dB}$  between intensities 30 dB and 70 dB NHL intensities.

Conductive hearing impairment usually shows an elevated threshold but a relatively normal slope. Sensorineural hearing impairment usually shows an elevated threshold along with a steep slope and a low amplitude or absent wave I. Sometimes a sensorineural impairment will have relative normal waves III-V at high and intermediate stimulus intensities, but an abrupt loss of all waves below a critical intermediate stimulus intensity value.

#### **Patient-related factors**

BAEP is relatively insensitive to many of the patient-related factors that affect other kinds of evoked potentials. Medications have very little effect on these potentials, and so subjects are often sedated in order to improve the quality of the tracings. Anesthetic agents and high doses of barbiturate drugs can produce slight increases in the wave V latency. Decreases in tempera-

ture can also produce small increases in the latencies, including the I–V interpeak interval. Sleep itself does not alter the potentials.

Age does have a distinct effect on the expected latencies. Under 1.5 years of age, BAEP normals values are age dependent. For premature infants and neonates, the expected BAEP latency values change almost weekly. Gender also influences the expected BAEP latencies for adult testing, with female I–V interpeak interval values approximately 0.1 msec shorter than for males. Older adults also have slightly longer expected I–V interpeak intervals, averaging 0.10–0.15 msec longer than for young adults.

Hearing impairment can alter the BAEP, and this is why the test is sometimes used for assessing hearing function. Prior to beginning testing, the technologist

should check the external ear canal with an otoscope to assure that the canal is not blocked by cerumen. For all patients, the interpreter should have available some information about the patient's hearing. This may be the results of routine audiometric subjective tone threshold testing. If that is not available, the technologist should test the patient's subjective hearing at least briefly before beginning the BAEP recordings. A minimum amount of testing would be the subjective thresholds for clicks and for 1000 and 4000 Hz tones, for each ear separately. A BAEP latency-intensity assessment is appropriate when the subjective testing cannot be done, e.g., for children or for comatose or uncooperative patients. This hearing assessment information should be taken into account when interpreting alterations or abnormalities in the high-intensity BAEP results.