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Update on Frequency Specificity of AEP Measurements

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Abstract

Auditory evoked potentials acquired with frequency-specific stimuli are useful in estimating hearing sensitivity in difficult-to-test patients. Stimulus characteristics, test methods, strengths, and limitations of the auditory brainstem response, SN_{10} response, middle latency response, and 40-Hz response are reviewed. Clinical strategies using frequency-specific stimuli are suggested for the evaluation of children and adults.

Key Words: Auditory evoked potentials (AEP), auditory brainstem response (ABR), middle latency response (MLR), hearing tests, hearing disorders, frequency specificity, 40-Hz response, SN_{10} response

Assessment of peripheral auditory sensitivity using auditory evoked potentials provides a powerful tool to evaluate patients who either cannot or, for some reason, will not reliably participate in behavioral measurement of hearing sensitivity. In our efforts to achieve an "objective audiogram," however, two important principles must be considered. First, auditory evoked potentials do not directly measure hearing. They measure neural synchrony in the auditory system and cannot tell us directly about "hearing" or "perception." Second, the stimuli necessary to obtain sufficient synchronous neural discharge must be very brief in duration which negates the use of pure tone stimuli and requires some compromise in the analysis of frequency specific regions.

In this brief review, some stimulus characteristics and methods used most frequently are compared. While discussion focuses primarily on low-frequency stimuli, it should be kept in mind that situations also arise when higher frequency tonebursts can be useful in auditory evoked potential testing. The reader also is referred to Stapells et al (1985), Hood and Berlin (1986), and Weber (1987) for additional discussions of various frequency specific stimuli, test parameters, and resulting responses.

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STIMULUS CONSIDERATIONS

Suggested stimuli have included filtered clicks, clicks with high-pass masking, tonebursts, and tonebursts in notched-noise maskers. Since the response to click stimuli arises primarily from the higher frequency regions of the cochlea, i.e., between 2 and 4 kHz (Jerger et al, 1980, Bauch et al, 1980; Gorga et al, 1985), it is also desirable to use some type of low-frequency stimulus to assess more apical portions of the cochlear partition. Tonebursts have been used most widely, probably since these stimuli can be generated on much of the currently available equipment.

Stimulus duration effects detailed by Davis et al (1984) are important in our effort to find stimuli that provide sufficient neural synchrony to yield evoked potentials, yet preserve as much frequency specificity as possible. Based upon duration comparisons, Davis et al (1984) recommended the use of an envelope with 2 cycles, or periods, of rise and fall time and a 1 cycle plateau as a reasonable compromise. Table 1 shows the changes in duration as a function of frequency for this "2-1-2" envelope. By keeping the number of cycles the same, a constant acoustic power spectrum is maintained across frequency even though the duration of the stimulus changes.

Use of tonebursts involves a compromise between neural synchrony and frequency specificity. The rapid stimulus onset required to achieve sufficient synchronous neural firing for an ob-

Table 1 Durations of Tonebursts with 2-1-2 Envelopes at Frequencies from 250 to 4000 Hz

Frequency	*Duration of Single Cycle*	*Duration of 2-1-2 Envelope*	*Total Duration*
250 Hz	4 msec	8-4-8 msec	20 msec
500 Hz	2 msec	4-2-4 msec	10 msec
1000 Hz	1 msec	2-1-2 msec	5 msec
2000 Hz	.5 msec	1-.5-1 msec	2.5 msec
4000 Hz	.25 msec	.5-.25-.5 msec	1.25 msec

servable early or middle latency auditory evoked potential results in considerable spread of excitation along the basilar membrane. Thus, the response obtained with a brief toneburst reflects stimulation of a broader region of the cochlear partition than observed when using longer duration stimuli such as pure tones. At higher intensities, in particular, tonebursts have greater spectral spread and excite more basal portions of the cochlear partition. However, as stimulus intensity decreases below 40 dB nHL, greater latency shifts suggest narrower spectra and more focused stimulation of the cochlear partition (Gorga et al, 1988).

METHODS OF MEASURING FREQUENCY-SPECIFIC THRESHOLDS

Application of evoked potentials (EPs) in latency periods from the ABR (early) to the late cortical potentials has been suggested to assess frequency specific thresholds to auditory stimuli. Some of the advantages and disadvantages of various EPs are discussed in the following sections and summarized in Table 2.

Auditory Brainstem Response

ABRs obtained using tonebursts, particularly lower frequency tonebursts, yield responses that differ from click ABRs in latency and morphology. Latency is prolonged due both to increased rise time of the stimulus and to longer travel time along the cochlear partition (Davis and Hirsh, 1979). Tonebursts with a center frequency of 500 Hz, for example, yield ABRs that are characterized by a single peak with a peak latency at approximately 7 to 10 msec at higher intensities. Latency also increases with decreasing intensity so that a response near threshold may have a latency of about 15 msec. Intensity series for auditory brainstem responses obtained using clicks and 500 Hz tonebursts are compared in Figures 1 and 2, respectively.

Low-frequency toneburst ABRs are characterized by a single peak and reflect greater energy from the lower frequency components of the ABR. Takagi et al (1985) separated lower (50 to 300 Hz) and higher (400 to 1500 Hz) frequency components of the ABR via digital filtering and, for stimuli below 1000 Hz, found less contribution from higher frequency components and greater amplitude of the slow component. Therefore, it is helpful to use a response filter with a low frequency cut-off of between 30 and 50 Hz when using low-frequency tonebursts. Since high frequencies contribute little to identification, the high-frequency cut-off can be set at or near 1500 Hz.

ABR responses to 500 Hz tonebursts can be identified from about 15 to 30 dB above behavioral threshold depending on such factors as stimulus envelope, filter settings, and number of sweeps averaged (Kavanaugh et al, 1984; Maurizi et al, 1984; Gorga et al, 1988).

Since the maximum intensity output of most stimulus generators is limited to about 90 nHL and average thresholds for lower frequency stimuli occur around 25 dB nHL, the dynamic range of the stimulus is limited to about 65 dB. Thus some limitation exists in distinguishing moderately severe low-frequency losses from severe or profound low-frequency hearing losses.

Table 2 Comparison of Short-Latency and Long-Latency Methods of Obtaining Frequency-Specific Thresholds

Variables	*Short Latency (ECochG, ABR, SN_{10})*	*Long Latency (MLR, 40Hz, N1-P2)*
Stimulus duration	Brief	Can be longer
Stimulus spectrum	Broader	Narrower
Replicability	Good	Less repeatable
Amplitude	Lower	Higher
Relation to	15-25 dB	5-10 dB
Age	- Present at birth	- May not be present in infants or young children
	- Matures at 12-18 months	- Longer maturational time course
Sleep/Sedation	Unaffected	Affected

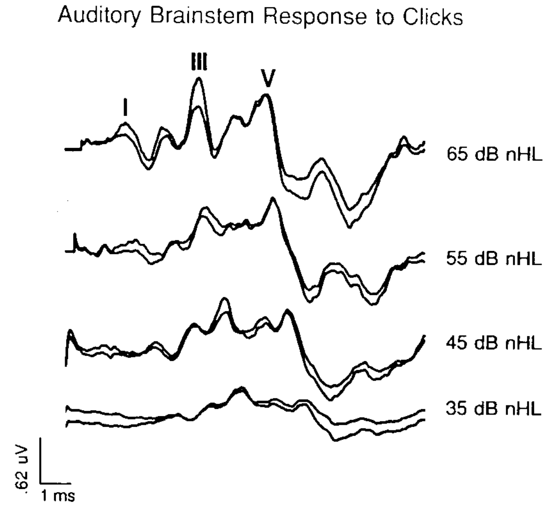

Figure 1 Auditory brainstem responses obtained from a normal-hearing adult using 100-μsec condensation clicks at intensity levels of 65, 55, 45, and 35 dB nHL. Two repetitions are shown at each intensity. Waves I through V are present in all responses and Wave V latencies are 5.8, 6.0, 6.4, and 6.9 msec from presentation levels of 65 to 35 dB nHL, respectively.

SN_{10} Response

Another method of recording responses to frequency specific stimuli is the SN_{10} response (Davis and Hirsh, 1979). The SN_{10} is the negative peak following Wave V of the ABR and is present at approximately 10 to 18 dB above behavioral threshold. Identification of the response is enhanced when using instrumentation that allows use of steep (24 dB per octave or greater) filter slopes (Davis et al, 1985).

Middle Latency Response

The middle latency response is advantageous since the amplitude of the response is generally greater than that of the ABR. A middle latency response obtained from a normal-hearing adult is shown in Figure 3. When recording middle latency responses, one can use longer duration stimuli (10 to 15 msec) that yield greater frequency specificity. In older children and adults, MLR and behavioral thresholds for low-frequency tonebursts agree within approximately 10 to 15 dB (Kavanaugh et al, 1984; Barajas et al, 1988). Application of MLRs in infants and young children for threshold seeking purposes is limited due to amplitude decreases during sleep and when using sedation. The longer neuromaturational time course of the MLR results in higher intersubject variability in young children, which diminishes its utility in this regard (Kileny, 1983).

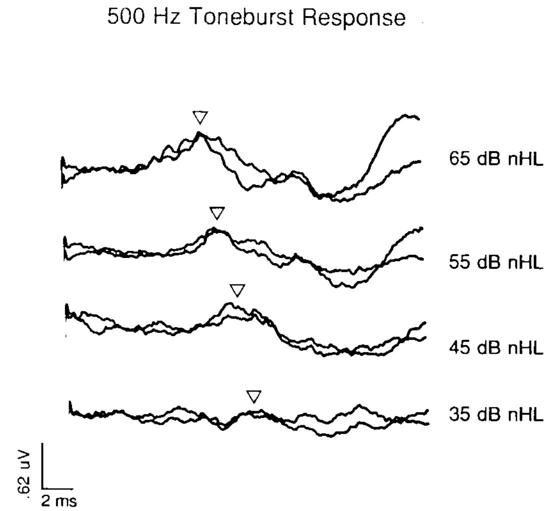

Figure 2 Auditory brainstem responses obtained from a normal-hearing adult using 500 Hz alternating polarity tonebursts at intensity levels of 65, 55, 45, and 35 dB nHL. Two repetitions are shown at each intensity. Responses are characterized by a single broad peak that increases in latency as intensity decreases. Latencies of the responses shown are 8.0, 8.8, 10.0, and 10.7 msec from presentation levels of 65 to 35 dB nHL, respectively.

ABR-MLR Combination

An ABR-MLR combination, which can be recorded simultaneously with open filters, has also been suggested to take advantage of the repeatability of the ABR and the higher amplitude of the MLR. Evaluation of tonebursts in

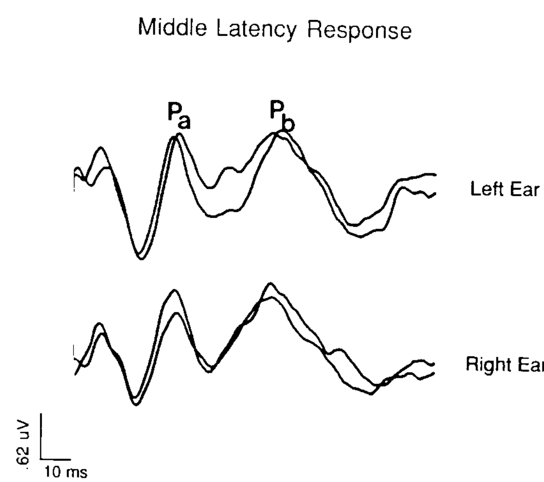

Figure 3 Middle latency responses obtained from a normal-hearing adult by presenting 100-μsec clicks at a rate of 3.3 stimuli per second. Two repetitions are shown for stimulation of the left (*upper tracings*) and right (*lower tracings*) ears. Latencies of the primary positive peaks are 29.0 msec for Wave P_a and 55 msec for Wave P_b. The first wave at 8.0 msec reflects low-pass filtering of the ABR.

normal and hearing-impaired subjects has shown that MLR Waves N_a and P_a are most detectable for 500 and 1000 Hz stimuli 10 dB above behavioral threshold and that Wave V of the ABR is most repeatable and detectable for 2000 and 4000 Hz stimuli 10 dB above behavioral threshold (Suzuki et al, 1981).

40-Hz Response

The 40-Hz response (Galambos et al, 1981) can be acquired quickly due to the relatively fast presentation rate (40 clicks or tonebursts per second) and the low number of sweeps required. The high amplitude of the response owing to the summation of ABR and MLR component waves makes it easily detectable as well, usually within 5 to 10 dB of behavioral threshold in adults (Galambos et al, 1981; Stapells et al, 1984; Sturzbecher et al, 1985). An example of a 40-Hz response obtained from a normal hearing adult is shown in Figure 4. Although the 40-Hz response is useful in testing older children and adults, it is of limited value in assessing infants and young children since, like the MLR, it is affected by sleep and/or sedation, and follows a longer maturational time course than shorter latency responses (Suzuki and Kobayashi, 1984; Kankkunen and Rosenhall, 1985).

Late Cortical EPs

Long latency AEPs are typically not used to assess hearing sensitivity due to the dependence of the responses on subject state.

A CLINICAL STRATEGY

In our clinical application of frequency specific stimuli, we use a combination of the ABR evoked with click stimuli to assess higher frequency portions of the audiometric range, and ABR or 40-Hz responses to 500-Hz tonebursts to assess the lower frequency range. For toneburst testing, we use the ABR to assess infants and young children and the 40-Hz response to test adolescents and adults. We are thus better able to assess both high and low frequency regions of the audiometric range and to differentiate flat, falling, and rising audiometric configurations, critical in hearing aid fitting. Further discussion and suggested test parameters are outlined in Hood and Berlin (1986).

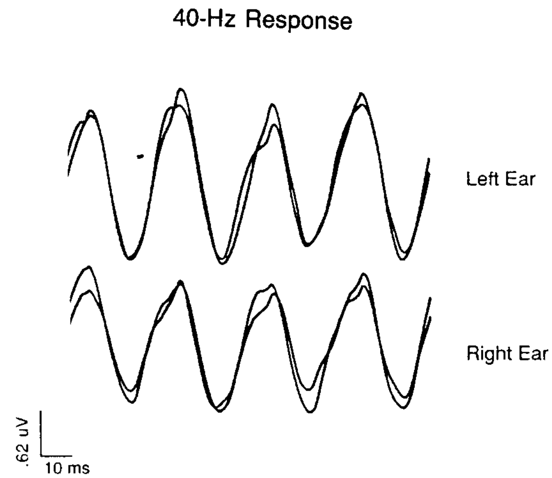

Figure 4 40-Hz responses obtained from a normal-hearing adult by presenting 100-μsec clicks at a rate of 39.1 stimuli per second. Two repetitions are shown for stimulation of the left (*upper tracings*) and right (*lower tracings*) ears. Latencies of the primary positive peaks are approximately 25 msec apart that is characteristic of the 40-Hz response.

NEW TECHNIQUES

Some recently reported techniques may have utility in testing with frequency specific stimuli. For example, Elberling and Don (1987) have shown that under ideal circumstances click ABRs comprised of 10,000 sweeps approach perceptual click threshold. In another series of studies, Don et al (1984) use a technique called Fsp in which the signal-to-noise ratio of a single point is calculated and used to determine the optimum number of sweeps that minimizes interference of background noise. Increasing the number of stimuli or assessing the inherent noise levels may be useful in enhancing the ability to approach behavioral thresholds for toneburst stimuli.

Various stimulus envelopes, such as cosine square gating functions, have less abrupt onset slopes and are somewhat narrower in spectra than tonebursts with linear envelopes. These stimuli may reduce some of the spectral spread in stimuli with fast rise times.

We have recently reported a tone-toneburst technique in which a continuous pure tone is used in conjunction with a toneburst with the same center frequency (Berlin and Hood, 1987). This technique has been shown to be 5 to 10 dB more sensitive than a toneburst alone in animal studies (Hood et al, 1988).

CONCLUSION

Tonebursts can be used to obtain auditory evoked potentials in early and middle time epochs. Early latency potentials require use of brief stimuli that result in responses reflecting stimulation of relatively broad regions of the cochlear partition. Longer duration stimuli yielding better frequency specificity can be used with later potentials, but these responses are significantly affected by sleep, age, sedation, and other factors.

Assessment of hearing sensitivity with auditory evoked potentials involves careful interpretation and consideration of the fact that we are only inferring hearing sensitivity while assuming that the neural system is intact. Cases in many clinicians' experience and the literature have shown us that hydrocephalus and/or even subtle neurologic disorders can obliterate the ABR in patients with intact cochlear function (Worthington and Peters, 1980; Kraus et al, 1984). In contrast, a normal ABR cannot foretell central auditory processing disorders. We have powerful methods with which to assess peripheral auditory sensitivity and these methods, when used knowledgeably, can facilitate early identification, intervention with hearing aids and habilitative planning not previously possible.

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