# THE RELATIONSHIP BETWEEN LOW FREQUENCY AUDITORY BRAINSTEM FAST WAVE AND SLOW WAVE RESPONSES AND BEHAVIORAL THRESHOLDS IN NORMAL HEARING ADULTS

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## INTRODUCTION

The auditory brainstem response (ABR), as first described in 1970 by Jewett, Romano, and Williston, is a scalp recording of electrical activity arising from various generator sites in the brainstem. The ABR consists of two spectral components – a high-frequency (fast) component with two energy peaks in the region of 500 to 1000 Hz and a low-frequency *(*slow*)* component with energy at 100 Hz and below (Davis and Hirsh, 1976; Suzuki et al, 1977). The high-frequency component contains a series of peaks occurring within 10 msec of stimulus onset. These peaks have been labeled Waves I-VII, with Wave V being the most prominent and occurring at approximately 5 to 6 msec following onset of a high-intensity acoustic stimulus (70 dBHL and above). The low-frequency component consists of a slow wave that peaks at approximately 10 msec. The ABR can be viewed as a broad, slow wave upon which the faster components are superimposed.

The use of a click (brief transient) stimulus has been employed traditionally as a means of attempting to obtain an auditory threshold using the ABR because of its fast rise time and short duration which produces energy over a wide frequency range. The advantage of using click stimuli is that it simultaneously stimulates a larger portion of the basilar membrane, generating synchronous firing of many auditory neurons (Davis, 1976), and consequently a stronger brainstem response. The disadvantage in using click stimuli is the lack of frequency specificity, especially with regard to lower frequencies. Low frequency regions of the cochlea are activated by the click but contribute little to the ABR due to increased travel time on the basilar membrane; i.e., the response in the higher frequency regions has already occurred by the time the traveling wave can activate hair cells in more apical regions.

Click stimuli are generally believed to activate cochlear function in the 2000 to 4000 Hz range. Utilizing a click stimulus, Gorga et al (1985) found that ABR thresholds closely correlated with behavioral auditory thresholds at 2000 and 4000 Hz, but showed large variability at 1000 Hz. Gorga et al indicated little agreement between click-evoked ABR and behavioral thresholds at frequencies below 1000 Hz. This may be related to the ABR requirement of synchronous neural discharge. Lower frequency neurons may be dispersed over a larger portion of the cochlear partition, and would exhibit less discharge synchrony at a given point in time. Thus, the ABR response to click stimuli in lower frequency regions of the cochlea less closely approximates behavioral threshold.

In order to produce more frequency-specific threshold estimations utilizing the ABR, the use of brief tone stimuli has been advocated. It has been demonstrated, however, that linearly gated tone bursts are not a reliable way of assessing auditory sensitivity in specific frequency regions, especially in regions below 1000 Hz. Investigators have indicated that in the absence of high-pass masking, tone-burst-evoked responses do not originate from low-frequency regions of the basilar membrane (Davis and Hirsh, 1976; Kileny, 1981). When using low frequency brief tone stimuli to elicit brain stem responses, the spread of acoustic energy to higher frequency regions can result in a misrepresentation of low frequency hearing thresholds.

Stimulus-shaping envelopes can be valuable tools in an attempting to predict auditory threshold via ABR measurement, however, low frequency threshold estimation continues to pose difficulty. Utilizing tone burst stimuli gated with the Hanning (cosine-squared) windowing function, Gorga et al (1988) recorded auditory brainstem responses over a wide range of frequencies. At frequencies below 1000 Hz, greater differences between ABR and behavioral thresholds were observed, and intersubject variability was also greater for lower frequencies. These researchers suggest that the greater variability in the differences between ABR and behavioral thresholds for lower frequencies may be the limiting factor in using tone-burst ABR to predict auditory threshold. If the ABR were consistently less sensitive, it would be possible to develop corrections that could be applied to low frequency tone-burst data to predict the pure-tone audiogram.

In 1995, Frattali et al assessed a technique to obtain frequency-specific ABR thresholds suitable for predicting pure-tone thresholds in the ‘speech frequencies, including 500 Hz. Frattali et al concluded that behavioral thresholds at 500 Hz could be predicted utilizing gated tone-burst stimuli by subtracting 45 dB from ABR thresholds. Based on their findings of a consistent relationship between behavioral and ABR thresholds, they believed that a pure-tone average could be predicted within 10 dB. Frattali et al caution, however, that additional experience will be needed to confirm these findings.

It appears that despite the use of brief tone stimuli and windowing functions, consistent determination of accurate low frequency thresholds utilizing traditional ABR recording techniques continues to pose difficulty. As indicated previously, the ABR has been shown to consist of fast and slow components. Takagi et al (1985) has suggested that difficulties with ABR threshold determination for lower frequency stimuli is related to the fast component having a low amplitude for frequencies below 1000 Hz. The slow wave ABR component, however, has been shown to have a relatively large amplitude, even for low-frequency stimuli. Kileny (1986) reports that for some individuals, the ABR slow wave at 500 Hz can achieve an amplitude several times that of the faster ABR component. Slow wave amplitude has also been shown to be resistant to changes in stimulus rate. Slow wave amplitude remains relatively constant across a range of stimulus rates (8/sec to 90.9/sec), whereas amplitude of Waves I through V of the fast component decreased with increasing stimulus rate (Suzuki et al, 1986). Amplitude of the slow wave to 500 Hz tone bursts has been shown to be unaffected by an increase in signal duration (Barry and Barry, 1996). As stimulus duration increases from 10 to 20 to 34 to 44 msec, no statistically significant change in slow wave amplitude was noted. Takagi et al have suggested that the use of slow wave response recordings of the ABR can be regarded as the most useful index for ABR threshold estimation of hearing.

With the exception of the study conducted by Frattali et al (1995), traditional recording of the ABR fast wave component does not appear to provide consistent data in determining low frequency auditory threshold. ABR fast wave recordings to 500 Hz stimuli have been shown to have lower amplitude in a variety of testing situations, and show greater intersubject variability in most studies. The amplitude of the slow wave component of the auditory brainstem response to 500 Hz tone burst stimuli appears to be stable across testing variables, and may show less intersubject variability than fast wave recordings, perhaps making it more accurate in determination of low frequency threshold.

The purpose of this study was to investigate the relationship between slow wave and fast wave recordings of the ABR in determining low frequency auditory threshold. Comparisons of ABR (fast and slow wave) thresholds using 500 Hz tone burst stimuli were made with behavioral threshold for the same stimulus. Intersubject variability of slow and fast wave ABR recordings was also assessed to determine whether consistencies could be identified. Dual channel recordings were employed in order to collect simultaneous tracings of fast and slow ABR components, and filter settings were chosen to isolate low frequency (slow wave) energy and mid-high frequency (fast wave) energy. A Blackman windowing function was chosen to provide a frequency-specific stimuli with minimal spread of acoustic energy to other frequencies.

## METHODS

### Subjects

Eleven females aged 20 to 23 served as subjects for this study. All subjects had audiometric thresholds of 10 dBHL or less for frequencies from 250 to 8000 Hz bilaterally, and between ear differences at 500 Hz did not exceed 5 dB HL.

### Stimuli

ABR acoustic stimuli consisted of 500 Hz tone bursts originating from sine waves generated by an MI$^2$, M308 Programmable Stimulus Generator, and gated with a Blackman window. Tone bursts were 20 msec in duration and consisted of a 2 cycle rise time, 6 cycle plateau, and 2 cycle fall time (2-6-2). The tone bursts were delivered binaurally to ER-3A insert earphones with alternating polarity at a rate of 2l/sec.

Recording System

Responses were recorded from subjects sleeping or lying passively in a reclining chair using Grass gold-cup electrodes in a vertex (noninverting) to linked mastoid (inverting) surface electrode configuration. The forehead served as ground. The impedance between any two electrodes was below 5k ohms, The EEG was amplified 100,000 times utilizing a two-stage amplification system (Grass P15 and Grass P511) and was bandpass filtered from 10 Hz to 300 Hz for slow wave responses, and 30 Hz to 3,000 Hz for fast wave responses. Filter roll-off rate was 6 dB per octave. The averaged time window was 20 msec. 2048 stimulus presentations were incorporated into each averaged response for both fast and slow wave responses. Each trace was replicated. The final waveform was the result of the addition of the responses for a total of 4096 samples per trace,

Procedure

Behavioral threshold testing was performed with the 500 Hz tone burst stimulus for comparison with the ABR threshold data. The same stimulus was used for both the behavioral and ABR threshold and intensity for ABR recordings and behavioral thresholds is reported in sound pressure level (SPL). ABR slow wave and fast wave responses were initially recorded at a level sufficient to produce good identifiable waveforms. Normally this was approximately 40 dBSL relative to the 500 Hz tone burst behavioral threshold, and recorded in decreasing 10 dB steps until no response was evident. A control run with no stimulus present was also made.

Data Analysis

ABR threshold was defined as the average between the last visually detected response and the level at which no response was evident. Mean thresholds for all subjects' slow wave and fast wave responses were computed from the individual means. Standard deviation measures were computed for differences between individual behavioral and slow vs. fast wave thresholds to determine whether either approach to threshold determination was more consistent.

RESULTS

Figures 1a and 1b illustrate waveforms for both Slow and Fast Waves for one subject.

**Figure 1a (Fast Waves)**

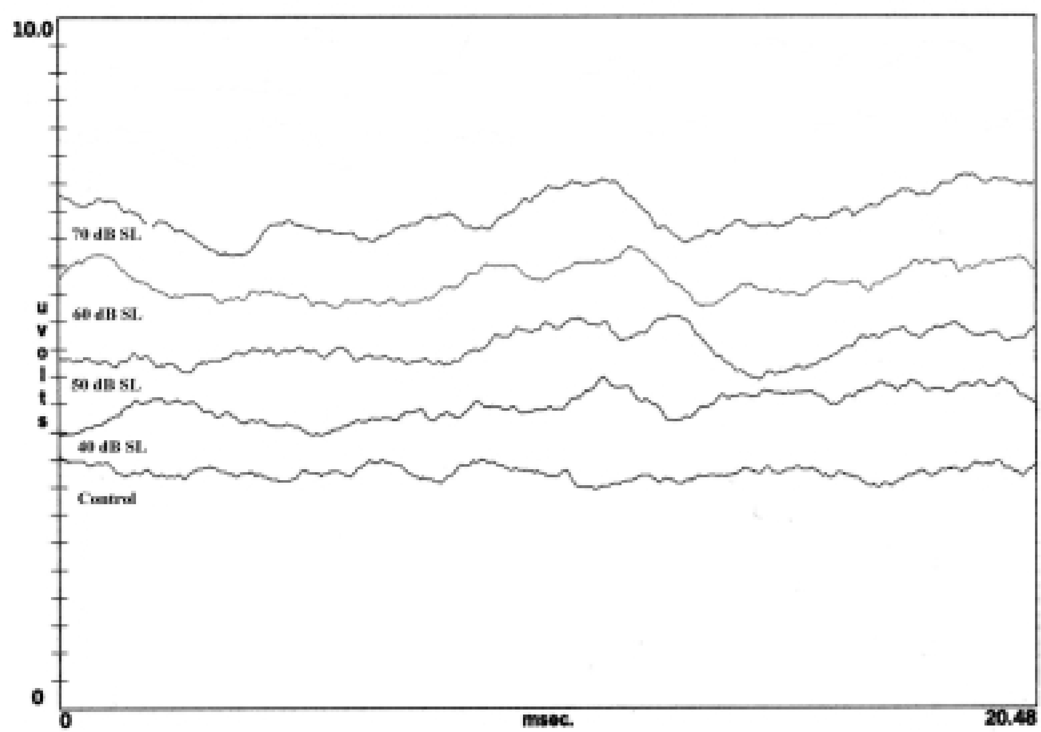


**Figure 1b (Slow Waves)**

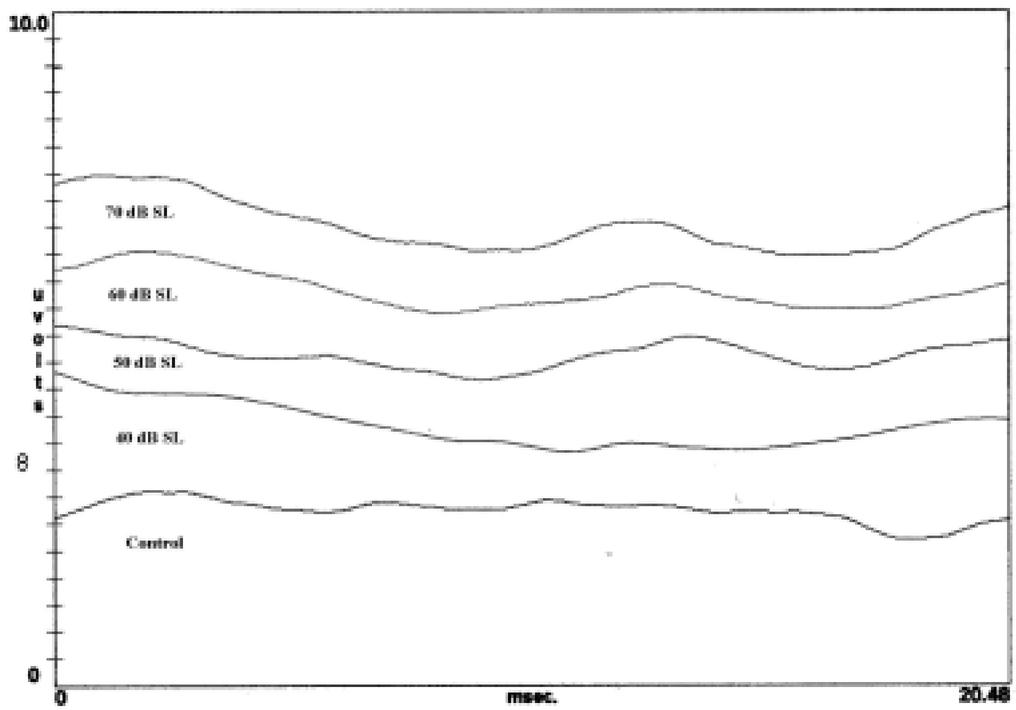
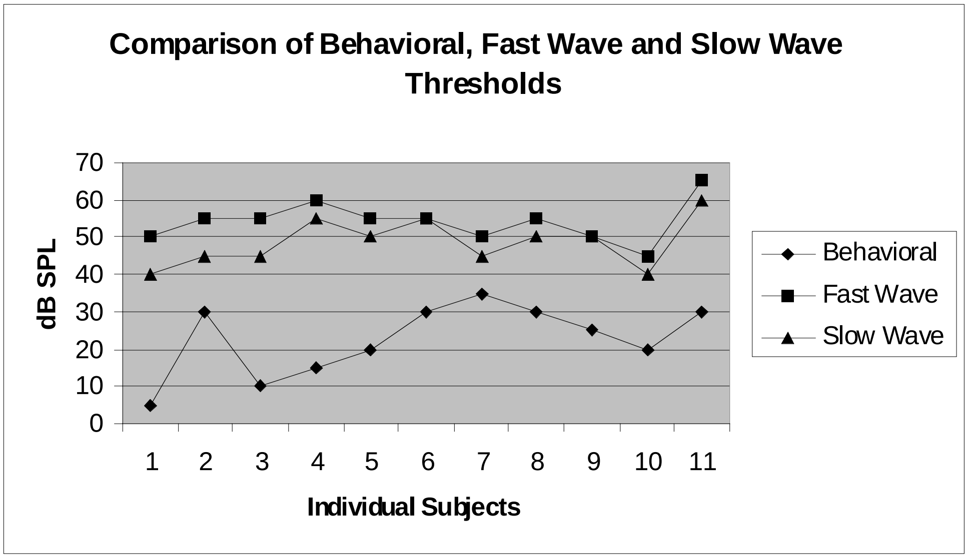



Table I and Figure 2 illustrate the findings of this study.

## Table I

| Subject | Behavioral | Fast Wave | Slow Wave |
|---|---|---|---|
| 1 | 5 | 50 | 40 |
| 2 | 30 | 55 | 45 |
| 3 | 10 | 55 | 45 |
| 4 | 15 | 60 | 55 |
| 5 | 20 | 55 | 50 |
| 6 | 30 | 55 | 55 |
| 7 | 35 | 50 | 45 |
| 8 | 30 | 55 | 50 |
| 9 | 25 | 50 | 50 |
| 10 | 20 | 45 | 40 |
| 11 | 30 | 65 | 60 |
| Mean | 22.73 | 54.09 | 48.64 |
| Standard Dev | 9.14 | 5.14 | 6.06 |

**Figure 2**




In general it can be seen that ABR Slow and Fast Wave thresholds are approximately 25-30 dBSPL poorer than the 500 Hz behavioral threhold for the stimulus used. Average ABR Slow Wave threshold is approximately 5.5 dBSPL better than ABR Slow Wave threshold. There appears to be no real difference in variability for either measure.

## DISCUSSION

Despite disagreement concerning the exact technical specifications for slow wave recordings, the slow wave has been shown to be a promising measurement technique for hearing, even near threshold. Many people have suggested that there might be a possible clinical utility for this response. Davis and Hirsh (1979) stated that the slow wave response is more reliable than Wave V for threshold measurement, especially at 500 and 1000 Hz, and Hawes and Greenberg (1981) showed that the SN10 response is a good indicator of peripheral hearing loss in adults and newborns at 1000 and 2000 Hz.

Klein (1983) investigated the correlation for the threshold sensitivity of the slow wave compared to pure tone thresholds and psychophysical thresholds for tone-pips. He found that, on average, the slow wave response threshold was 14-19 dB above the psychophysical tone-pip threshold and 18-25 dB above the pure-tone threshold in the 500-4000 Hz range.

While our results do not differ much from those of Klein we do not find that our study demonstrates much of an advantage over the use of a 500 Hz stimulated ABR fast wave.

For the most part the actual differences between the slow wave and fast wave are only about 5 dB.

While we have purposely picked a frequency (500 Hz) for our study that has been shown in the past to yield poorer slow wave results, it is this low frequency side of the audiogram that has always presented problems for electrophysical auditory threshold. Any demonstrated significant difference between fast wave and slow wave thresholds at this frequency would have been a great dividend.

It is, of course, possible that in different experimenter hands and with different instrumentation settings closer, agreement between slow wave and behavioral thresholds would have been found. This possibity makes further investigation of this relationship of some value.