EARLY AVERAGED AUDITORY RESPONSES TO 500 Hz TONE PIPS

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ABSTRACT

Early electric averaged responses were elicited by 500 Hz tone-pips from normal hearing subjects in the presence of a high pass masker with a 1500 Hz cutoff in the test ear, and from patients with high frequency hearing loss beyond 1000 Hz. The responses consisted of a series of vertex-positive waves and were obtained at levels near behavioral thresholds. A low-frequency band-pass masker (50-1500 Hz), presented to the test ear simultaneously with the 500 Hz tone-pips, abolished or depressed the response. The results suggest that the responses obtained originated predominantly from lower frequency apical regions in the cochlea.

Brain stem audiometry has become a valuable tool for the assessment of auditory function in patients whose age or handicaps do not allow a reliable utilization of conventional behavioral audiometric techniques. This electrophysiological procedure has been successfully used with neonates, infants and children of various ages (Schulman-Galambos and Galambos, 1975, Mokotoff et al., 1977). When employing unfiltered clicks (with a rather uneven but major concentration of acoustic energy between 2,000 - 6,000 Hz) as stimuli, the responses obtained are derived mostly from the high frequency basal region of the basilar membrane. These unfiltered clicks are obtained by delivering brief (50 - 100 usec) rectangular pulses to an earphone which lends its response characteristics and shapes the pulse. Further shaping is performed by the resonant characteristics of external and middle ear. The travelling wave pattern generated by clicks does not reach the apical end of the basilar membrane.* The advantage of a click as a stimulus for brainstem audiometry or electrocochleography is its fast rise time and the fact that it stimulates almost simultaneously a large portion of the basilar membrane (Davis, 1976). Thus it generates a synchronous discharge of a large number of auditory neurons. The disadvantage, as mentioned is a lack of frequency specificity of the responses it generates.

The importance of early and accurate diagnosis of hearing impairment has been stressed by many members of the health care team (Gerber and Mencher, 1978). The necessity to acquire information about hearing sensitivity in the lower frequency range increases in importance when there is an indication of hearing impairment in the higher frequency range (Picton, 1978). Rehabilitation of the young hearing impaired depends to a great extent on suitable and early amplification, which in turn depends upon accurate audiometric information.

Various methods designed to obtain frequency specific early electrophysiologic responses have been described in the literature. Frequency following responses can be

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* At threshold levels (low click intensities) a click will activate the 1-2 KHZ area on the basilar membrane. This fact and an increased latency in synaptic transmission at low stimulus intensities account for the inverse relationship between wave V (or wave I) latency and stimulus intensity (Picton 1977, 1978).

elicited by relatively slow rise-time and long duration tone-bursts (Worden and Marsh, 1968). However, these responses can be obtained only at relatively high supra-threshold levels and probably reflect the activity of units from the basal and middle turns of the cochlea responding to supra-threshold low frequency stimuli (Davis and Hirsch, 1976). Other methods for obtaining short latency frequency-specific electrophysiologic auditory responses consisted of one of the following: utilizing brief frequency - specific stimuli such as narrow bandpass filtered clicks or tone-pips (Osterhammel, 1976; Davis and Hirsh, 1976; Brama and Sohmer, 1977; Klein and Teas, 1978), selective ipsilateral masking (Teas et al., 1962; Terkildsen et al., 1975; Picton, 1978; Taylor and Dalzell, 1977).

The purpose of this study was to generate short-latency low-frequency - specific auditory responses from normal hearing subjects, and to validate the method by examining patients with high-frequency hearing loss. The low-frequency stimuli consisted of 500 Hz tone-pips presented to the test ear of the normal-hearing subjects simultaneously with high-pass filtered white noise in order to rule out responses derived from the basal end of the cochlea (Davis & Hirsh, 1976).

MATERIAL & METHODS

Stimuli and Instrumentation

The stimuli utilized consisted of unfiltered clicks and 500 Hz tone-pips. The clicks consisted of 100 usec (microsecond) pulses alternated in polarity generated by a NIC-1007 Noise Masking module, and delivered to a TDH-39 earphone. The tone-pips originated from a 500 Hz sine wave generated and gated by a NIC-1002 tone generator. The tone generator was triggered by a Nicolet CA-1000 averaging computer through a NIC-1007 Noise Masking module. Signal rise and fall time was set to 4 msec (2 cycles) and plateau to "0". The gated sine waves were delivered in phase to a Telephonics TDH-39 earphone encased in an MX/41AR cushion. The result shown in figure 1 was a 500 HZ tone-pip with an actual rise-time of approximately 4 msec and a duration of 3 msec (between 50% points on the signal envelope). A major rarefaction peak occurred at 1.6 msec following signal onset. Frequency spectrum of the signal was measured in 6 cm^3 coupler with a B & K sound level meter equipped with a B & K model 1616 third octave filter, and is also shown in figure 1.

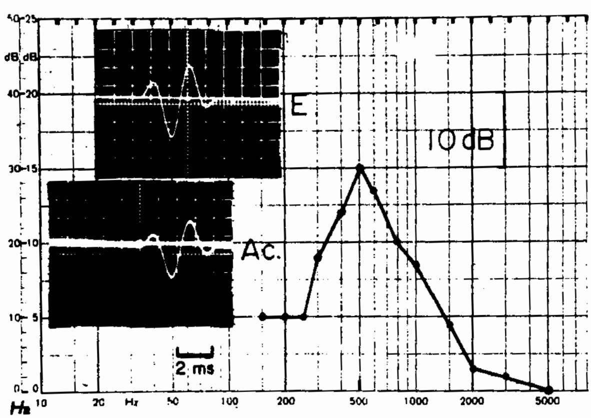

Figure 1.

Electric waveform (E) acoustic waveform (AC) and frequency spectrum measured in a 6 cm^3 coupler.

Assuming that high-pass-filtered noise eliminates synchronous neural activity from frequency regions above the cutoff frequency, continuous 1500 Hz high-pass noise was mixed with the 500 Hz tone-pips and delivered through the same earphone to the test ear in the normal hearing subjects. Similarly, to further establish the apical origin of the responses elicited by the 500 Hz tone-pips, in several normal hearing subjects, low-frequency band-pass noise (50-1500 Hz) was presented to the test ear simultaneously with the 500 Hz tone-pips. If responses elicited by the 500 Hz tone-pips indeed originated from the lower frequency apical region, they should have been unaffected by a high-pass masker, On the other hand, a lower-frequency masking noise should eliminate or depress those responses. The selective maskers were obtained as follows: white noise generated by the NIC-1007 Noise Masking module was high-pass filtered with a 1500 Hz cutoff by a Kron-Hite 3202 variable filter (two sections cascaded,) or band-pass filtered 50-1500 Hz. The filtered noise (high-pass or band-pass) was then mixed with the 500 Hz signals and introduced simultaneously to the test earphone.

Stimulus intensity in this study is reported in S.L. re: normal threshold. The behavioral thresholds of nine normal hearing subjects obtained by the method of adjustment were averaged to obtain normative threshold values. The maskers (high-pass or band-pass) presented simultaneously with the 500 Hz tone-pips to the test ear were always at an overall SPL which was equivalent to peak SPL of the 500 Hz signal as measured with a B & K model 2209 sound-level meter set to "sample and hold" (Berlin, 1978). Thus, masker intensity, when utilized was covaried with signal intensity. The tone-pips were presented at levels ranging from 75 dB SL (117 dB peak SPL) to 5 dB SL (42 dB peak SPL). Interstimulus interval was 96 msec.

The responses were recorded by a vertex to ipsilateral mastoid surface electrode configuration (with the contralateral mastoid serving as ground), and averaged after 2048 presentations by a Nicolet CA-1000 averager with a bandpass of 150 Hz-3000 Hz and a dwell time of 80 usec. The averaged responses were recorded with an X-Y recorder.

Subjects and experimental procedures

Three categories of subjects participated in this study. The first group consisted of nine normal hearing subjects (14 ears tested) with ages ranging from 26 to 30, with puretone thresholds not exceeding 10 dB HTL at any one audiometric frequency. These same subjects also served for the psychophysical calibration of stimulus intensity in the testing environment. The second group consisted of four patients with abrupt unilateral or bilateral high frequency hearing loss beyond 1000 Hz. Testing was performed in a quiet but not sound treated room. The subjects were reclining comfortably in a dental chair and were instructed to close their eyes and relax. Ongoing EEG was monitored on an oscilloscope. First, brainstem responses were elicited by unfiltered clicks and a wave V latency-intensity function was generated. The latency-intensity function for the click-evoked wave V recorded from the normal-hearing subjects was in agreement with published norms. Responses to the 500 Hz tone-pips were recorded in the presence of a steady high-pass masker in the test ear (1500 Hz cutoff) from the normal hearing subjects and in quiet from the hearing impaired subjects. To further examine the frequency-specificity of responses to the 500 Hz tone-pips they were also delivered to the normal hearing subjects simultaneously with a steady band-pass (50-1500 Hz) masker in the test ear.

The third group consisted of ten youngsters (ages 6 months to 42 months) referred to the clinic for audiological examination. These subjects were tested in the same facility as the adults. In this group, following the utilization of unfiltered clicks as stimuli, the 500 Hz tone-pips were presented in the presence of the high-pass masker in the test ear.

Click-evoked response latencies were measured from the onset of the averaging period (Jewett & Williston, 1971). The latencies of the responses generated by the 500 Hz tone-pips were measured from the first rarefaction peak of the signal waveform (Davis, 1976; Klein & Teas, 1978).

RESULTS

Figure 2 illustrates click-evoked and 500 Hz tone-pip evoked early electrical auditory responses from a normal-hearing adult. The 500 Hz tone-pips were presented to the test ear simultaneously with the 1500 Hz cutoff high-pass masker to the test ear. The most prominent features of the recorded responses are two to three vertex-positive peaks occurring 6-9 msec following the first and largest rarefaction peak of the stimulus waveform also shown in the figure. In this and the following figures vertex positivity is upward. This sequence of vertex-positive waves resembles waves III, IV, and V of the click evoked brainstem response (Jewett and Williston, 1971) The latency of wave V elicited by the 500 Hz tone-pips was 2-3 msec longer than the latency of the click-evoked wave V. Another evident difference between the click-evoked and tone-pip evoked responses in this case, is a failure of the 500 Hz response to manifest the inverse relationship between stimulus intensity and response latency.

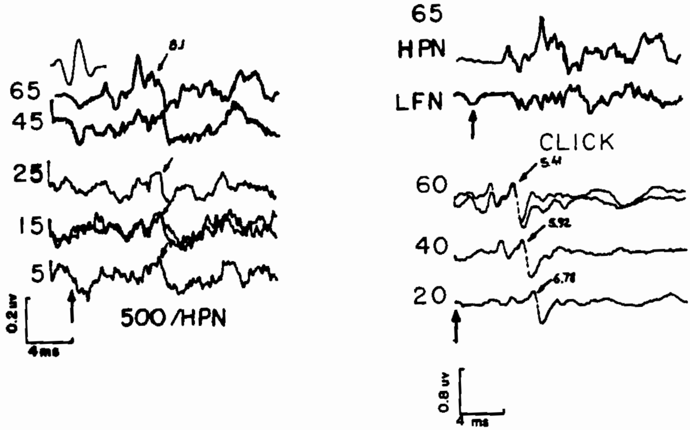

Figure 2.

Averaged electric responses elicited by 500 Hz tone-pips and unfiltered clicks from a normal hearing adult. HPN-responses obtained in the presence of a steady high-pass masker (cutoff-1500 Hz). LFN — responses obtained in the presence of a low-frequency masker (50-1500 Hz). Masker level always at stimulus peak SPL. Stimulus intensity in dB SL at the left. Latencies of waves designated in ms. (In this and the following figures showing electric response waveforms, arrows pointing up at the left of each record designate reference point for wave V latency measurement.)

As illustrated at the top of the right hand column in figure 2 and in figure 3, when 500 Hz tone-pips were delivered in the presence of a continuous ipsilateral low-frequency masker (50-1500 Hz), (recordings labelled LFN in figures 2 and 3) the responses that were evident in the presence of the high-pass masker (HPN) are abolished or depressed. The large deflections at the beginning of each recording in figure 3 are electromagnetic stimulus artifacts.

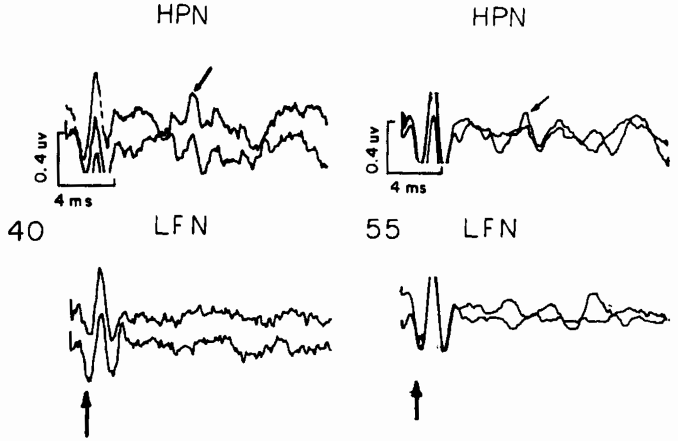

Figure 3.

The effect of low frequency bandpass noise (50-1500 Hz) on responses elicited by 500 Hz tone-pips. HPN — responses obtained in the presence of high-pass noise. LFN — responses obtained in the presence of low frequency masker. Recordings from two subjects at two different stimulus levels are presented. Stimulus levels in dB SL on the left of recordings. The large deflections at the onset of each record are electromagnetic stimulus artifacts. Peaks designated by arrows in top records are absent in bottom records.

Figure 4 illustrates click-evoked and tone-pip evoked responses recorded from a normal hearing one year old girl. Tone-evoked responses were obtained at 5 dB SL. The similarity between the click-evoked wave III - IV - V configuration and the prominent vertex positive peaks evoked by the 500 Hz tone-pips is evident. As in the case illustrated in figure 2 the latency of the tone-evoked wave V equivalent was longer, compared to the click-evoked wave V, but no shift in latency with decreasing stimulus intensities could be observed.

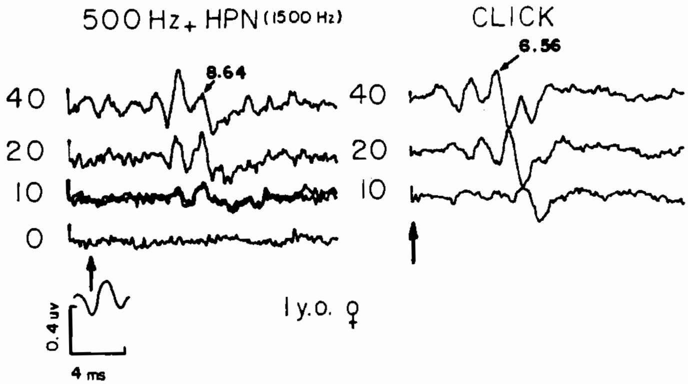

Figure 4.

Averaged electric responses elicited by 500 Hz tone-pips in the presence of high-pass noise at peak stimulus SPL (HPN) and by unfiltered clicks from a normal one-year-old. Stimulus levels in dB SL on the left of each record. Bottom trace on the left: signal waveform. Latencies in ms of waves designated by arrows also included.

Figure 5 illustrates data from one of the hearing impaired subjects. Pure-tone thresholds indicated a high frequency hearing loss beyond 1000 Hz. Click-evoked responses were poorly differentiated and the wave V latency-intensity function shown at the bottom of the figure is clearly shifted from the function generated by a normal hearing subject, also shown in the figure. Responses to 500 Hz tone-pips at three intensities are shown in the right-hand column of the figure. No attempt was made to obtain responses below 25 dB SL. The high-pass masker was not utilized in this case. The arrows point to the vertex positive peaks resembling wave V. An inverse relation between the latency of this peak and stimulus intensity may be observed in this case. Since no high-pass masking was utilized there was probably some activation of intermediate frequency areas on the basilar membrane at higher stimulus intensities.

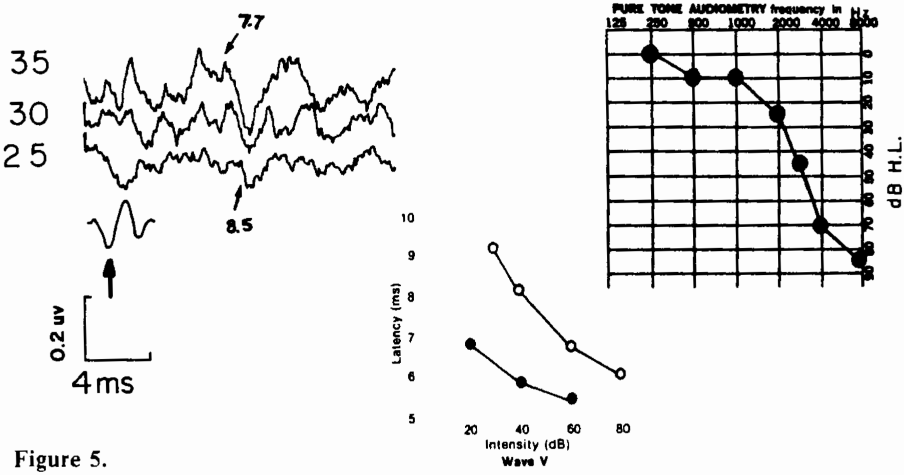

Figure 5.

Pure tone audiogram, click-evoked wave V latency-intensity function (open circles) and responses elicited by 500 Hz tone-pips from one of the hearing impaired subjects. Stimulus levels in dB SL at the left of each record. Latencies in ms of waves designated by arrows included. The wave V latency-intensity function from a normal hearing subject included for contrast (dark circles).

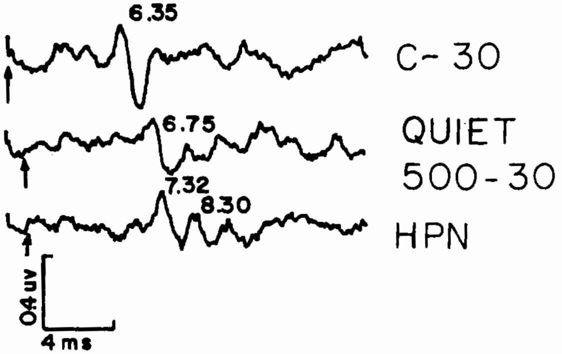

Figure 6.

Responses elicited by 30 dB SL unfiltered clicks (C-30) and 30 dB SL 500 Hz tone-pips (500-30) in quiet (QUIET) and in the presence of the 1500 Hz cutoff high-pass masker (HPN) from a normal hearing subject. Numbers designate latencies in ms of adjacent waveform peaks.

The effect of the ipsilateral high-pass masking on the response elicited by 500 Hz tone-pips is illustrated in figure 6. The responses illustrated in this figure are from a normal hearing adult subject. The upper trace (C-30) is the response to unfiltered clicks at 30 dB SL. A wave V with a latency of 6.35 ms is evident. The middle trace is the response to 500 Hz tone-pips at 30 dB SL with no masking. The vertex-positive wave resembling wave V appears with a reduced amplitude and a longer latency. The recording at the bottom of the figure (HPN) is the response to 500 Hz tone-pips at 30 dB SL in the presence of the ipsilateral high-pass masker. There is a further shift in latency of the vertex-positive wave resembling wave V. The next two positive waves are accentuated. An identical effect was observed at various stimulus intensities. While the high-pass masked response manifested a constant latency, the unmasked response to 500 Hz tone-pips manifested a latency shift with changes of stimulus intensity.

Figures 7 and 8 illustrate wave V latency intensity functions for two different subjects, for three stimulus conditions: unfiltered clicks, 500 Hz tone-pips presented in quiet, and 500 Hz tone-pips delivered to the test ear in the presence of the 1500 Hz high-pass masker. Figure 7 illustrates the data from the subject also presented in figure 6. Wave V latencies for the 500 Hz tone-pips presented in quiet are longer in general when compared to click-evoked wave V latencies. This difference diminishes at lower stimulus intensities. Ipsilateral high-pass masking (500 Hz/HPN) shifts wave V latency with respect to the unmasked condition. Again little shift occurs at the lowest stimulus intensity (i.e. 20 dB SL). In addition, in the masked condition, the inverse relation between wave V latency and stimulus intensity is lost. Figure 8 illustrates latency-intensity functions for the three stimulus conditions in a normal hearing 6-month old. The same effects occur but in general latencies are longer than in the adult subjects, as expected.

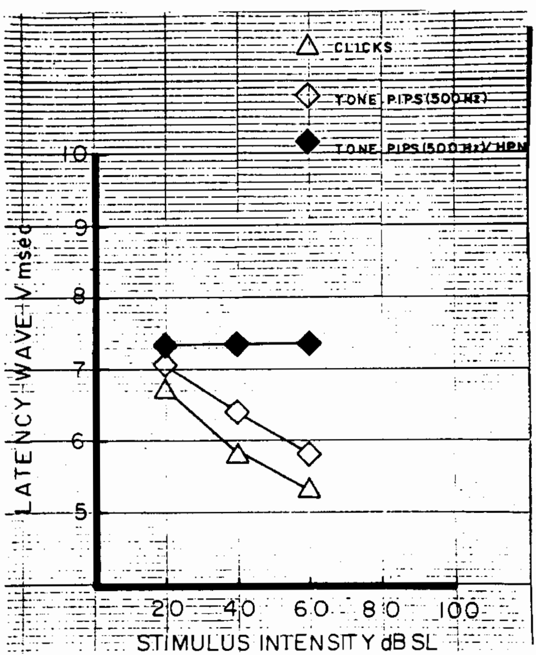

Figure 7.

Wave V latency-entensity functions for three stimulus conditins from a normal hearing adult subject.

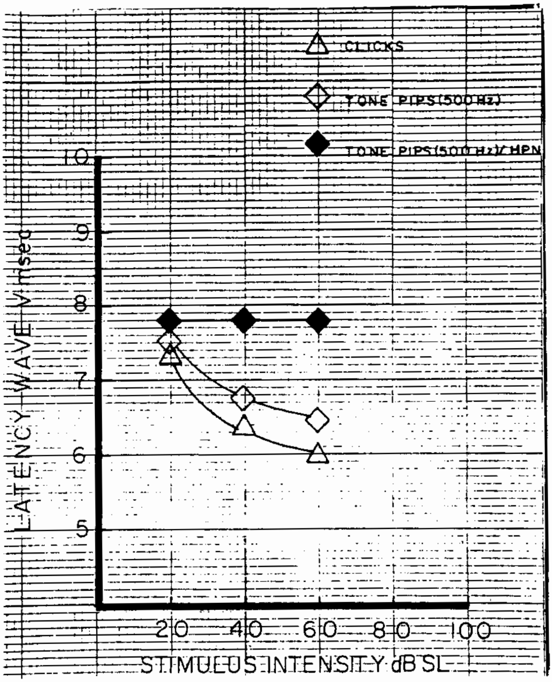

Figure 8.

Wave V latency-intensity functions for three stimulus conditions from a normal 6 month old.

DISCUSSION

When attempting to generate frequency-specific whole nerve action potentials or electric brainstem responses, certain constraints should be considered. The signal must have a short enough rise-time in order to synchronize the responses of a large enough population of auditory neurons (Davis, 1976). As a rule, maximal basilar membrane excitation is stimulus frequency related, but travelling wave characteristics are such that even low-frequency stimuli first create a displacement at the basal (high frequency) end of the basilar membrane (Davis, 1976). Consequently, one way to obtain low frequency responses is by eliminating the contribution of the basal end by introducing high-pass masking into the test ear. Another method pioneered by Teas et al., (1962) and more recently used by Tyler and Dalzell (1977) and Picton (1978), consisted of obtaining whole nerve action potential (AP) in the presence of high-pass maskers with various cutoff frequencies. AP waveforms (or brainstem responses) obtained in the presence of a high-pass masker with a certain cutoff were then subtracted from AP waveforms obtained in the presence of a different cutoff masker, and thus, the contribution of the basilar membrane included between those two cutoff frequencies was obtained.

The 500 Hz tone-pips utilized in the present study manifested a major concentration of energy at 500 Hz but their frequency spectra extended above and below this center frequency. With ipsilateral high-pass masking, these stimuli generated responses consisting of a series of vertex-positive waves. Two or three prominent waves occurred 7 - 8.5 ms following the major rarefaction peak of the stimulus waveform. In general these responses approximated those obtained by Davis and Hirsch (1976) with similar stimuli.

There is reasonable evidence supporting the lower frequency origin of these responses: they were obtained in the presence of a high-pass masker with a 1500 Hz cutoff; well defined responses to 500 Hz tone-pips were obtained from patients with high-frequency hearing loss; a low frequency masker either cancelled or depressed the response.

Latency of responses elicited by the 500 Hz tone-pips was measured from the first rarefaction peak of the stimulus waveform (Klein & Teas, 1978). This rarefaction peak also happened to be the largest of the two rarefaction peaks of the stimulus waveform. Since decreases in wave V latency with increased stimulus intensity (in the unmasked condition) were always less than one period of a 500 Hz sine wave, it may be concluded that even at higher stimulus intensities the response relates to the first rarefaction peak, of the stimulus. For instance Klein & Teas (1978) utilizing filtered clicks as stimuli demonstrated an over 2 ms decrease in wave V latency between 40-60 dB HL with their 500 Hz signal. They attributed this change to a great extent to the period of the stimulus.

Without the ipsilateral high-pass masker the latency of wave V elicited by the 500 tone-pips was not delayed considerably compared to click-evoked wave V. This was probably a result of the 500 Hz tone-pips also stimulating intermediate regions of the basilar membrane (naturally, had response latencies for the 500 Hz tone-pips been measured from the onset of the averaging period the difference would have increased).

In the high-pass masked condition, wave V latency remained constant regardless of the intensity of the 500 Hz signal. The relationship between stimulus intensity and ipsilateral high-pass masker was a constant one, therefore presumably at each stimulus intensity the responses originated from the same basilar membrane region. With decreased stimulus intensity a reduction in wave V amplitude was observed. The difference in wave V latency between the masked and the unmasked response decreased with stimulus intensity: at lower stimulus intensities, regardless of frequency content, responses tend to originate from relatively lower frequency regions.

Although in the absence of the high-pass masker the 500 Hz tone-pips appeared to excite intermediate frequency regions, they contained enough low-frequency energy to generate responses presumably originating from lower frequency areas, as demonstrated by the high-frequency hearing loss cases.

Therefore it appears that the inclusion of 500 Hz tone-pips as stimuli for brainstem audiometry with selective masking, in addition to unfiltered clicks, may supply lower frequency audiometric information.

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