TONE BURST AUDITORY BRAINSTEM RESPONSE IN SUBJECTS WITH SLOPING SENSORINEURAL HEARING LOSS

Register No. M 9910

An Independent Project submitted as part fulfillment for
the first year M.Sc. (Speech and Hearing), Mysore

ALL INDIA INSTITUTE OF SPEECH AND HEARING, MYSORE - 570006
MAY, 2000

Certificate

This is to certify that this Independent Project entitled *TONE BURST AUDITORY BRAINSTEM RESPONSE IN SUBJECTS WITH SLOPING SENSORINEURAL HEARING LOSS* is the bonafide work in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student with Register No.M 9910.

Mysore,
May, 2000

Director
All India Institute of
Speech & Hearing
Mysore - 570 006

Certificate

This is to certify that this Independent Project entitled *TONE BURST AUDITORY BRAINSTEM RESPONSE IN SUBJECTS WITH SLOPING SENSORINEURAL HEARING LOSS* has been prepared under my supervision and guidance.

Mysore,
May, 2000

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Declaration

This Independent Project entitled *TONE BURST AUDITORY BRAINSTEM RESPONSE IN SUBJECTS WITH SLOPING SENSORINEURAL HEARING LOSS* is the result of my own study under the guidance of Mrs. C.S. Vanaja Lecturer, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in any other University for any other Diploma or Degree.

Mysore,
May, 2000

Register No. M 9910

Dedicated

To

My

Family

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INTRODUCTION

The auditory evoked potentials (AEPs) are the electrical responses of the nervous system to auditory stimuli (Stapells et al., 1985). AEPs have assumed an essential role in the clinical practice of audiology and several other professions. The most widely used electrophysiologic procedure is the Auditory Brainstem Response (ABR) or the short latency AEP. ABR has gained widespread acceptance because of its abiity for objective threshold estimation without the active participation of subjects in the difficult-to-test population. Like all AEPs, these potentials can be recorded non-invasively, with no discomfort to the patient, and often without sedation or anesthesia, which further enhances their clinical applicability. Other applications include detection, localization and monitoring of auditory and neurological deficits.

Due to neurophysiological reasons, the early latency AERs, are best generated with very brief (transient) stimuli having an almost instantaneous onset and producing synchronous iiring of numerous auditory neurons (Hall, 1992). Therefore, the brief duration (0.l msec or 100 µ sec) click, which has an abrupt onset, is by far the most commonly used stimulus for ABR measurements.

An abrupt signal, lit: a click, has a very broad spectrum and when delivered to a transducer, the frequency response of the transducer modifies the signal presented. It has been reported in literature that click evoked ABR is very useful and clinically practical for estimation of auditory functioning in the 1000-4000 Hz region (Gorga et al., 1985). Unfortunately, clicks are relatively difficult to control and quantify because of this wide frequency response (Hall, 1992). Despite time honoured success with the click evoked ABR, it has been argued that its lack of frequency specificity precludes accurate assessment of auditory threshold below lOOOHz or in patients whose behavioural audiogram is characterized by a precipitous slope (Stapells, 1989). He maintains that there is a tendency to underestimate degree of sensitivity oss with a click stimuli. In other words, configuration of the audiogram cannot be predicted using click evoked ABR. Hence, click stimuli has limitations in providing a frequency specific information.

The frequency specificity of an audiological test indicates how independent a measure at one frequency is of the measures at other frequencies. When frequency specificity is poor, the threshold at one frequency may be inaccurate because of response mediated at other frequencies. Because of this limitation of unmasked click stimuli, several other techniques have been derived to improve the frequency specificity of the click evoked brain-stem potential. There has also been a trend towards the use of more place specific stimuli for threshold estimation and otoneurological investigations (Laukli. 1983b). Three general methods proposed to yield frequency specific ABRs, as reviewed by Hall (1992) are:

(i) Masking methods: This method involves masking frequency regions that are not intended to be a part of the stimulus. Three types of maskers generally used are

a) High pass noise, where *i* high frequency tone is presented with a transient stimulus, ipsilaterally. It masks some of the spectral splatter thus providing some frequency specificity.

b) Notched noise, which is a broadband noise with a portion of the frequencies removed, hence allowing only this frequency portion of the stimulus to pass through.

c) Pure tones.

(ii) Derived Response Method: In this method, the response to a stimulus at specific frequency or a defined frequency region, is derived (usually by subtracting) from two other responses. This technique may also involve masking paradigm. But his procedure is extremely time consuming, hence not very practical for routine clinical application.

(iii) Tonal Methods: This is he most straightforward method and involves the use of a tonal stimulus a spectrally constrained stimulus) with carefully selected onset characteristics.

A tone burst is a signal with specifiable carrier frequency with a specified envelope function, by which the carrier is modified (Hall, 1992). Although there is an inevitable trade off between the abruptness of the stimulus needed to produce a clear waveform, especially at lowel intensity levels, and the spectral constraint of the stimulus, the possible use of tone burst stimuli in ABR measurement continues to be the subject of considerable interest. This may be perhaps for the following reasons (Hall, 1992) -

(a) Tone burst stimulation is clinically feasible. The technique is relatively straight forward and t testing time is also relatively brief. The facility is available on many commercial evoked response systems.

(b) There is a considerable long standing experimental evidence that at low to moderate intensity levels and with proper onset gating, tonebursts can produce frequency specific early latency AEPs (Abbas & Gorga, 1981; Dallos & Cheatham, 1976; Gorga, Kaminski et al., 1988). Clinical studies of tone generated ABR, have demonstrated that behavioural thresholds can be estimated to within 20 dB HL of tone evoked ABR threshold (eg. Coats & Martin, 1977; Gorga et al., 1989; Jerger, Hayes & Jordon, 1980).

(c) There is some evidence that the spectral splatter that is associated with tone burst, that have linear onset and offset characteristic ("ramps"), may be minimized with the use of other nonlinear stimulus shaping envelopes (Gorga & Thornton, 1989).

Thus the possibility exists that with appropriate envelopes, tone burst offers an optimal stimulus which will permit frequency specific ABR recording.

Tone burst envelope or gating function determines the spectral characteristics of the stimuli. Different envelopes are associated with different spectral characteristics, especially the extent and amplitude of energy on each side of the centre frequency i.e, the side lobes (Hall, 1992). Most of the studies of frequency specific ABR have been done using linear stimulus envelopes. But there is ample clinical and experimental evidence that abrupt onset tone burst with linear gating function do not always produce frequency specific ABRs (Davis & Hirsch, 1976; Gorga & Thornton, 1989; Jacobson, 1983). Linearly gated tone bursts do not offer valid means of assessing auditory sensitivity for specific frequency regions, particularly below 1000 Hz. Nonlinear tonal stimulus gating alternatives are better suited for frequency specific ABR generation (Gorga & Thornton, 1989). A stimulus with small or no side lobes is desirable for frequency specific ABR measurement. These non-linear envelopes vary in terms of side lobe reduction rate and width of the main energy lobe (test frequency). Among the many types available, Harris (1978) found that Blackman and Kaiser Bessel met the above criteria. Among the window tVpes evaluated by Harris (1978), Cosine square and Blackman windows have been studied in ABR measurement (Gorga & Thronton, 1989).

Need for the Study:

In subjects with hearing impairment, restricted to a particular frequency region, ABRs to non-masked clicks, substantially underestimate or overestimate the degree of the loss (Oates & Stapells, 1998). This situation can occur with high frequency losses, low frequency losses or impairments that are confined to the mid frequency regions. The normal or low click ABR thresholds reflect contributions to the response from the regions of basilar membrane with normal (or better) hearing sensitivity. Hence, due to their lack of frequency specificity, click ABR cannot be used to estimate pure tone behavioural thresholds in infants, children and other difficult-to-test cases.

Although earlier there had been some controversy with regard to clinical utility of the ABR to tonal stimuli, especially for the low frequencies (Stapells, 1994), it can be accounted to some extent to methodologically incorrect studies. Several studies have proved the clinical utility of tonal stimuli in ABR measurements, in determining frequency specific thresholds (Abbas & Gorga, 1981; Dallos & Cheatham, 1976; Gorga, Kaminiski, 1988; Stapells et al, 1997). But more studies need to be done in clinical population and results need to be properly validated.

It has been claimed that the frequency specificity of the ABR may be improved by the use of a Blackman gated tone in place of the more conventional linear-gated stimulus (Gorga et al., 1992; Gorga & Thornton, 1989). Very few studies have compared the different nonlinear gating functions, which have been developed to give more specific response than the conventional linear envelope. Also, not all the gating functions have been used in experiments to get frequency specific ABRs. So, studies using newer, more specific gating functions and also studies comparing the effect of gating functions on the ABR results, have to be carried out.

AIM OF THE STUDY:

The present study aimed at:

(i) Comparison of ABR wave form for clicks and tone bursts at 500 Hz, 1,2 and 4 kHz.

(ii) Determining the effects of two different gating functions on the wave morphologic of the ABR.

(iii) Predicting behavioural threshold using tone burst evoked ABR and click evoked ABR in subjects with sloping sensorineural hearing loss.

REVIEW OF LITERATURE

Auditory Brainstem Response (ABR) is a well established method, both for audioneurological evaluation and for threshold determination in difficult-to-test patients on those who cannot be tested reliably with conventional audiometric techniques. The accuracy with which the ABR thresholds predict the pure tone audiogram in clinical population is determined to a large extent by the stimuli used and the frequency and place specificity of the ABR to these stimuli (Oates and Stapells, 1998).

The frequency specificity of an audiometric measurement indicates how independent a measure at one frequency is of the measures at other frequencies (Stapells, Picton & Durieux-Smith, 1994). Place specificity on the other hand, refers to the position of the cochlear partition contributing to the response (Starr & Don, 1988). Another relative concept is that of frequency selectivity. It represents the ability of the auditory system to resolve the different frequencies present in a complex sound. Hence, the more frequency selective a system is the more frequency specific its response to a stimulus of a particular frequency (Stapells, Picton & Durieux-Smith, 1994).

The brief stimulus that are required for recording auditory evoked potentials are quite different from the long duration pure tones used in conventional audiometry. For neurophysiologic reasons , ABRs are best generated with very brief (transient) stimuli having an almost instantaneous onset (Jacobson, 1983). The two stimuli typically used for ABR evaluation are clicks and brief tones. Clicks, with a duration of about 100µ secs. is by far the most commonly used stimulus for ABR measurement. Clicks have a broad frequency spectrum with equal energies from around 100-8000 Hz (Stapells et al., 1982). Brief tones have a concentration of energy at the nominal freuqency of the tone and side bands of energy at higher and lower frequencies (Gorga & Thornton, 1989; Laukli, 1983a). Both clicks and brief tones contain energy over a range of frequencies and evoked potentials to these, may be evoked by any of the frequencies present the spectrum of the stimuli.

The spread of stimulus energy to frequencies other than the nominal frequency is known as spectral splatter (Durrant, 1983). The degree of spectral splatter is influenced by several parameters of the stimuli, including rise time, duration, intensity and temporal shaping, as well as type of transducer employed (Durrant, 1983; Laukli, 1983 a; Stapells & Picton, 1981). Several approaches to a reasonable compromise between the brief duration of the tone and its frequency specificity are available, but none can completely prevent ipectral splatter (Davis, Hirsh, Popelka & Formby, 1984; Gorga &Thorton, 1989, Harris, 1978;Nutall, 1981).

ABR to click stimuli:

Clicks are broadband signals whose amplitude spectra are determined by their duration (Gorga, 1999). Click evoked ABR thresholds correlate best with the pure tone audiometric thresholds over 2000Hz-4000Hz region (Jerger et al., 1978; Gorga et al., 1985). The reasons for this are probably related to defferences in neural synchrony (Kiang, 1975) and neural density (Spoendlin, 1972), depending on the cochlear place. Hence, though click evoked ABRs provide useful information in high frequency region, information about auditory sensitivity in lower frequencies is not obtained. This low frequency information is important in selection of hearing aid response characteristics, especially for patients with more severe hearing losses who may relay on prosodic (low frequency) cues (Gorga, (1999). High pass noise and notched noise have therefore been used to improve the frequency specificity of click evoked brainstem potential (Jacobson, 1983). The derived band technique has also been widely used. It incorporates the use of h gh-pass masking and waveform manipulation in efforts to define response characteristics from specific cochlear regions, using a click stimuli. This approach has been applied to elicit ABRs in a number of studies (Parker & Thornton, 1978b; Don & Eggermont, 1978; Eggermont & Don, 1980).

Conijin, Brocaar & Van Zanten (1993) studied the frequency specificity of the ABR threshold evoked by a 1000 Hz filtered click in Subjects With Sloping cochlear hearing losses, both high and low frequency hearing loss. A click stimuli passed through a band pass filter, with cut off frequencies 890 Hz and 1120 Hz, was used. Results indicated that ABR threshold evoked by a 1000 Hz filtered click can be a reliable and accurate tool to predict the pure tone hearing loss at 1000 Hz. Conijin et al., (1994) reported that in comparison with the ABR threshold evoked by a click masked with 1590 Hz high pass masking noise, the 1000 Hz filtered click-evoked ABR threshold s equally low frequency specific, equally accurate and better in terms of dynamic range, response quality, time required and suprathreshold response recognition.

Click evoked A*BR* in presence of masking noise has certain disadvantages (Stapells et al.. 1994), like:

(i) Disturbing loudness of the masking noise which causes restlessness and thus, decreases response quality, especially in subjects with cochlear hearing loss with recruitment;

(ii) Difficulty in identification of suprathreshold ABRs;

(iii) Decreased dyna nic range in which hearing loss can be measured and,

(iv) Time consuming adjustment of the proper masker level.

ABR to brief tone stimuli:

In contrast to responses at threshold to clicks, ABR threshold for brief tonal stimuli, presented in quiet or in notched-noise masking, provide more frequency specific results and enable in reasonably accurate estimate of the pure tone behavioural audiogram from 500 Hz through 4000 Hz, for all age population (Oates & Stapells, 1998).

Historically, there lad been some controversy with regard to the clinical utility of the ABR to tonal stimuli, especially for low frequencies (Stapells, 1994). As repoted by Oates and Stapells (1998), some of the commonly held misconcepions are-

(i) The ABRs to tonal stimuli are not frequency specific tones.

(ii) The ABR to 500 Hz tonal stimuli are primarily generated from the basal (i.e., high frequency) end of the cochlea, especially to higher intensity stimuli. Thus, these thresholds are poor predictors of low frequency behavioural thresholds,

(iii) Waveform identifi nation of the response to 500 Hz stimuli is problematic in quiet and even more so in the presence of masking noise (Davis & Hirsh, 1976; Laukli, 1983a; Laukli et al., 1988; Laukli&Mair, 1985).

On contrary, several researches have shown that ABR to a low frequency stimulus has a broad vertex positive wave that could be recorded within 10-20 dB of behavioural threshold (Suzuki et al., 1977). Davis & Hirsh (1979), using a high pass filter, set at 40 Hz, found the vertex-negativity following wave V to be the most prominent component of the ABR to low frequency tones.

The tone burst stimuli used in ABR measurements are gated through certain windows which determines the acoustic spectra of the stimuli. The width of energy lobes in the amplitude spectra depends on stimulus duration while the windowing function determine the relative amplitude between the main lobe and side lobes (Gorga, 1999). The commercially available instruments, provide a range of options in window functions. Most of the studies describing ABRs elicited by tone bursts in quiet (Kodera et al., 1977; Suzuki et al., 1977) used short duration tone bursts that were gated with linear (Bartlett) windows. Linear windowing function result in a 27 dB difference between the main lobe and the first side lobe and a further decrease of 12 dB/octave in tne side lobe amplitude, as one moves away from the first side lobe (Gorga, 1999). Thus, these stimuli have energy concentrated around the centre frequency, but energy exists at reduced amplitudes at adjacent and distant frequencies as well (Gorga, 1999).

To overcome the limitations of linear gating, stimulus passed through nonlinear gating functions have beea used for recording ABR. It has been claimed that the frequency specificity of the ABR may be improved by the use of a Blackman gated tone in place of the more conventional linear-gated stimulus (Gorga et al., 1992; Gorga & Thornton, 1989; Telian & Kileny, 1989). Oates & Stapells, 1997; report that the acoustic spectra of these stimuli differ in three ways: (1) the acoustic energy located in the side lobes of the exact-Blackman tone is ~58 dB below the peak energy of the main lobe, in comparison to ~27 dB for the linearly gated tone; (2) the main energy lobe is wider in frequency for the exact-Blackman gated versus linear gated tone; and (3) the rate of decay in the side lobes is less steep (6 dB/octave versus 12 dB/octave) for the exact-Blackman gated versus linear gated tone (see fig.2). The reduction of energy in the side lobes of the Blackman gated tone compared vith the linear gated tone may have advantage of removing contributions to the ABR from frequencies other than the tones nominal frequency and thus improve the frequency specificity of the response (Gorga & Thornton, 1989).

Studies have also been carried using Cosine Square (Hanning) window (Gorga et al., 1988). Oppenheim & Schaffer, (1975), report that the side lobe for Cosine Square occurs at 31 dB bel)w the amplitude in the main lobe, 58 dB for Blackmail and 91 dB for Kaiser Bessel windows. Harris (1978) described that the side lobe amplitude decreases at a rate of 12. dB/octave for stimuli gated with Cosine Square window. Other com nercially available window functions include - Cosine cube, Extended cosine, Cosime and Exact Blackman. It is also reported that for linearly gated stimuli, frequency specificity increases when either rise time or duration increases. This rule, however does not apply to the spectra of the stimuli gated with more complex window. Whereas increase in rise time still result in spectrally a more narrow stimuli, including a plateau portion results in more complex spectrum as compared to one with no plateau (Gorga & Thornton, 1989).

Tone burst ABRs in Noise:

The use of tonal stimuli in quiet has its own problems in that intense low frequency stimuli can cause high frequency, basal regions of the cochlea to respond and thus reducing the frequency *i* nd place specificity of the responses (Burkard & Hecox, 1983; Folsom, 1984; Picton et al., 1979; Stapells, 1984; Stapells & Picton, 1981; Stapells et al., 1994, 1995) This occurs due to spread of energy away from the tone frequency to lower or higher frequency regions of the cochlea, as well as due to an upward spread of cochlear excitation that occurs with an increase in intensity of any stimulus (Rose et al., 1971). Noise masking paradigms (eg. High pass noise, notched noise & white noise) may be used to restrict the regions of the basilar membrane that are capable of contributing to the ABR and thus improve the frequency and place specificity of the ABR to a high intensity tonal stimuli (Oates & Stapells, 1998).

Kileny (1981), elicited ABRs by unfiltered clicks as well as 500 Hz and 1000 Hz tone pips with and without high pass noise masking, in normal hearing subjects and subjects with high frequency hearing losses. When presented in quiet, the latencies (Wave V) of responses elicited by tone pips were close to those evoked by clicks, suggesting common origins on the basilar membrane. With addition of high pass filtered white noise mixed with tone pips, wave V latency shifted, suggesting responses originating from apical low frequency regions. This procedure yielded a good approximation of behavioural thresholds of the same subjects. The unfiltered clicks inferred hearing sensitivity in the 2000 to 4000 Hz range, and the masked tone pips closely reproduced thresholds at 500 Hz and 1000 Hz.

McDonald and Shimizu (1981) obtained ABRs from 8 young, normal hearing adults, using a click and a 300 Hz tone pip with different rise times. Each stimulus was presented in quiet and in presence of noise, both low and high pass. No significant difference was observed in latency-intensity function for click in quiet and in low pass noise condition, but prolongation of the latency was seen in the presence of high pass noise. The latency for 500 Hz tone pip was essentially unaffected by the high pass noise except for 1200 Hz high pass noise condition. The threshold of the 500 Hz tone nip was significantly higher than that of the click in quiet and in the presence of noise.

Stapells, Picton, Durieux-Smith, Edwards and Moran (1990) studied the thresholds for short-latency auditory evoked potentials (SLAEPs) to tones in notched noise to 20 normal hearing and 20 hearing-impaired subjects. On average, this technique estimated pure tone thresholds within 11.6, 6.1, 6.3 and 0.8 dB at 500, 1000, 2000 and 4000 Hz, respectively. The estimates were better in the hearing impaired patients.

Munnerly, Greville, PurdV & Keith (1991) obtained ABR thresholds to ipsilaterally masked tone pip stimuli from three groups of hearing impaired subjects using a high pass (for 500 Hz tone pips) and notched noise (for 1,2 & 4 kHz). ABR threshold in subjects with low frequency, high frequency or flat cochlear losses were compared to conventional pure tone audiogram thresholds. A strong positive relationship was found between ABR thresholds and behavioural threshold elevation. Absolute ABR threshold at 500 Hz was significantly higher than those at other frequencies.

Laukli, Fjermedal and Mair (1988) in their study concluded that a 500 Hz tone with 1 kHz high pass noise masking is not reliable for routine assessment of low frequency auditory threshold at the brainstem level.

Oates and Stapells (1997) investigated the frequency specificity of the ABR and middle latency responses (MLR) to 500- and 2000 Hz brief tones using high pass noise masking. The results suggest that the ABR and the MLR show reasonably good frequency and place specificity to 500 and 2000 Hz brief tones presented at 80 dB ppe SPL. Significant increases in the latency were observed for 500 Hz masked tones when compared to non-masked tones, whereas no significant change was found for 2000 Hz tone. Also responses recorded in high pass noise showed no significant differences in the frequency specificity of the evoked potentials to exact-Blackman versus linear-gated tones.

Oates and Stapells (1997) in another study, investigated the frequency specificity of the ABR and MLR to 500 and 2000 Hz brief tones using narrow band derived response analysis of the responses recorded in high pass masking noise (HP/DR technique). Stirmili were linear- and exact-Blackman gated tones presented at 80 dB ppe SPL. Results revealed good frequency specificity for both

ABR and MLR with no significant differences in the frequency specificity of (1) ABR versus MLR; (2) these evoked Potentials to 500 Hz versus 2000 Hz tones; and (3) responses to exact-Blackman versus linear-gated tones.

Studies by Munnerly et al., (1991), Oates & Stapells (1997) reveal that in cases of steeply sloping high frequency hearing loss, the use of noise maskers with tone stimulus gives a better estimate of the magnitude of loss than tone burst ABRs in quiet which tend to underestimate the magnitude of loss. Hence Stapells and colleagues (1998) advocate the routine use of tone burst in combination with notched noise makers. Though noise stimulus gives more accurate results, they have their disadvantages also:

(i) High pass masking noise is inappropriate for mid and high frequency tones because it does not prevenj the spread of energy to frequencies below the tone frequency. This can lead to underestimation of the degree of hearing loss at these higher frequencies (Oates and Stapells, 1998; Picton et al., 1979).

(ii) A disadvantage of the note led noise technique is the spread of masking into the notch, especially from the low frequency edge (Picton et al., 1979).

(iii) Use of white noise results in response amplitude that are 33% lower compared with amplitudes of responses recorded in notched noise (Picton et al., 1979; Stapells, 1984; Stapells et al., 1985, 1994), making waveform identification more difficult, especially close to the threshold.

Tone burst ABRs in Quiet:

Due to difficulties encountered in eliciting tone burst ABR in presence of noise, several studies have been done using tone bursts in quiet. Stapells et al, (1983) reported that tone burst ABRs in quiet were at least as accurate as any other technique for estimating hearing sensitivity for octave frequencies from 500 to 4000 Hz. The waveforms were rated by different raters in terms of morphology, latency and amplitude. They found that rater reliability and response clarity were better for responses to tone bursts in quiet and in notched noise as compared to derived responses.

The ABR to brief tone stimuli consists primarily of wave V and negativity following wave V (Stapells & Picton, 1981). The absolute latencies of the responses to low frequency tones are more than responses to higher frequency tones, presented at the same intensity, as was also reported for tones in noise. They found wave V latency at 40 dBnHL at 4000 Hz to be around 7.5 ms, while it was around 11 ms. for 500 Hz tones at the same intensity. The prolonged wave V latency for 500 Hz may be due to longer rise time of the low frequency stimulus (Jacobson, 1983; Stapells & Picton, 1981). Stapells and colleagues (1995) report detectability rates for wave V In normal hearing infants to be >92% in response to 500 Hz tones at 30 dBnHL, and 96-100% for responses to 2000 and 4000 Hz at 20 dBnHL.

Suzuki, Hirai and Honiuchi (1977) recorded the vertex-positive brainstem responses to tone pips at 500,1000, 2000 and 4000 Hz, from 20 adult subjects with normal hearing sensitivity. The ABRs were detected in 53-73% of the subjects at 10 dBSL and 89-100% at 20 dBSL. The latencies recorded had inverse relation with the frequencies, the shortest being the 4000 Hz. Results also showed no significant difference in the response detectability between the four test frequencies of 500 to 4000 Hz. These results suggested that the responses were elicited through the regions on the basilar membrane, proper to each nominal frequency.

Suzuki and Horiuchi (1977) in their study reported that the brainstem response to a low frequency stimulus was a broad vertex-positive wave, that could be recorded within 10-20 dB of threshold, provided the high pass filter setting of the EEG amplifier was lowered to 0.5 Hz from the usual 100-150 Hz. Similar results were reported by Davis & Hirsh (1979). They used a high pass filter set at 40 Hz, and found the vertex-negativity following wave V to be the most prominent component of the ABR to low f equency tones. They called this wave the "slow negative wave at 10ms" or SN10.

Suzuki and Horiuchi (1977), conducted a study to investigate the effect of high pass filters on the vertex positive brainstem response to tone pips at 500, 1000, 2000 and 4000 Hz, in normal adults. Significant difference was obtained for 500 Hz tone pip, in the response for different high pass filter (50, 100 and 200 Hz). Maximum amplitude reduction of response was seen for 200 Hz filter (10.6 dB), as compared to 3.3 and 7.1 dB for 50 and 100 Hz respectively. The results indicate that the use of a high pass filter with a cut off frequency over 50 Hz is not recommended for recording the slow positive deflection of the brainstem response to low frequency tones.

Stapells and Picton (1982) conducted a similar study to investigate the effects of varying the cut off of the EEG high pass filter from 10 to 100 Hz, on the brainstem response to 500 Hz tones. They recorded the largest brainstem response, a broad vertex positive wave, us ng a high pass filter setting of 10 Hz.

Gorga, Kaminski, Beauchaine and Jesteadt (1988) studied ABR to tone bursts ranging in frequency from 250 to 8000 Hz, in normally hearing subjects. The tone burst stimuli was gated with cosine square window. ABRs were measured across vertex and ipsilateral mastoid electrodes, both of which were referenced to a forehead or contralateral mastoid ground. Responses were filtered from 100-3000 Hz and were rec orded for 20 ms. following stimulus onset. Stimuli were alternated in polarity and were presented at a relatively high rate of 44/second. Intensity was varied from 80 dB SPL till threshold level. The responses were highly reproducible within individual subjects and ABR thresholds were higher than behavioural thresholds for all frequencies especially for lower frequencies. Inter subject variability was grea ter for low frequencies. Wave V latency decreased with increase in frequency from 250 to 8000 Hz, with latency of V peak at 500 Hz ranging from 8.5-14.5 ms and for 1 kHz it was 7-14 ms, across a range of intensities, from 100-20 dB SPL. The latency of wave V also was found to increase with decrease in level from 80 to 20 dB SPL (or threshold level). At 80 dB SPL, the latency for 1 kHz tc ne was around 7.5 ms, whereas it increased to 14.2

ms at 20 dB SPL. Both central and peripheral components as well as stimulus factors may account for all changes in wave V latencies as a function of frequency and level.

Gorga, Kaminski and Beauchaine (1987) measured ABR and behavioural thresholds and ABR latencies, from 6 normal hearing subjects, in response to tone bursts from 9000 to 16000 Hz. In general, ABR thresholds were higher than behavioural thresholds, however d fferences were typically less than those derived from lower frequencies. Wave V latency-intensity function were less dependent on frequency for those stimuli than they were for lower frequency stimuli and that these measurements may have clinical utility, especially when monitoring ototoxic effects in difficult-to-test patients.

Similar observations were leported by Fausti, Olsen, Frey, Henry, Schaffer and Phillips (1995). They studied the latency-intensity functions (LIFs) of ABRs elicited by high frequency (8, 10, 12 and 14 kHz) tone burst stimuli in 20 subjects with confirmed moderate high frequency sensorineural hearing loss. This study demonstrated that tone bursts at 8, 10 and 12 kHz evoked ABRs which decreased in latency as a function of increasing ntensity and that these LIFs were consistent and orderly. ABR at 14 kHz could not be determined. These results contribute towards establishment of change criteria used to predict change in hearing during treatment with other ototoxic medications.

Gorga, Kaminski, Beauclaine and Schulte (1992), measured ABR to 1000 Hz tone bursts from 115 patients with sensorneural (SN) hearing loss, presumably of cochlear origin. The digitally generated tone burst was gated with Blackman window, having a 2 msec. rise and fall time. The mean wave V latencies (8.05 ms) were only slightly longer than what has been observed in normal hearing subjects (7.93 ms) (Gorga et al., 1988).

Balfour, Pillion and Gaskin (1998), conducted a study, using clicks and nonmasked tone burst evoked ABR thresholds and DPOAEs for behavioural threshold estimation for children with SN hearing loss characterized by islands of normal sensitivity. Three children (aged 4 to 16 years), with audiometric configurations characterized py normal auditory sensitivity for at least one frequency from 250-8000 Hz, provided data for 5 SN ears. The tone burst stimuli with centre frequencies of 500, 1000, 2000 and 4000 Hz, were gated through Blackman window with zerd plateau. The click stimuli were presented with rarefaction polarity, while tone burst with condensation. Both were presented at a rate of 27.7/sec. Results indicated that 70% of the non-masked tone burst evoked ABR thresholds for hearing impaired subjects were within 10 dB of the respective pure tone behavioural threshold, and 95% were within 20 dB. For 3 out of 5 hearing impaired ears, significant impairments would have been missed, based only on click-evoked ABR thresholds. DPOAEs were present at 3 out of 4 frequencies from 1000-4000 Hz at whicn sensitivity was normal or near normal and absent at 10 out of 11 frequencies at which sensitivity was impaired. Hence a combination of tone burst evoked ABR and DPOAEs provided a good estimate of an individuals pure tone audiograms.

Sanyukta (1998), compared the ABR wave V latency function for clicks and tone burst (500 Hz and 1000 Hz) at a constant intensity level of 60 dBnHL, in normal hearing subjects. She also (compared auditory thresholds for ABR using 500 Hz and 1 kHz tone burst stimuli with behavioural threshold for these frequencies. Thirteen subjects were tested, with age ranged from 17-25 years. The tone burst stimuli was gated with Blackman window with a 2-1-2 cycle fall time/rise time and plateau. The time window was 20 ms with a repetition rate of 11.4/sec. Her results show an increase in latency for clicks to 1 kHz tone burst to 500 Hz tone burst. The ABR thresholds for 500 Hz and 1 kHz were found to be higher than the pure tone behavioural thresholds. Amang the two, threshold was higher for 500 Hz with respect to 1 kHz. On comparison, the difference between behavioural threshold and ABR thresholds were greater for 500 Hz (16.5 dB) than that for 1 kHz (12.5 dB). Hence, the results of this study can be used to predict the approximate behavioural threshold at 500 Hz ind 1 kHz from the ABR using 500 Hz and 1 kHz tone bursts.

Despite the limitations in use of tonal stimuli in quiet, studies using tones in quiet, gated through non-linear gating functions provide reliable estimates of the behavioural thresholds in the frequency range from 500-4000 Hz. Though the shape of the gating functions being used will have little effect on the threshold estimates in normally hearing subjects, it is probable that energy splatter to frequencies distant from the nominal frequency would have greater significance for patients with steeply sloping hearing losses (Stapells, 1983). Gorga & Thornton (1989), reported that ABR thesholds can be improved significantly by gating sinusoids with more complex windows than are often used.

Several studies have compared the effect of different gating functions, on the tone burst evoked ABR, in terms of amplitude, latencies and morphology.

Gorga et al., (1988) compared normative tone burst evoked ABR thresholds and latencies for a wide range of frequencies and levels, obtained with a Cosine square and linear gating function. They found that Cosine square functions achieve 5 dB greater amplitude reduction of the first side lobe, compared to the spectra of linear function, with equivalent rise and fall time. Thus, Cosine-square function gave more frequency specific responses.

In an attempt to inves igate the use of tonal stimuli, shaped with nonlinear windowing functions in improving frequency specificity of the ABR, Robier, Farby, Leek and Van Summers (1992), conducted a study. They investigated the effects of five windows - one linear and four nonlinear, on the ABR for 30 normal hearing adults and 30 adults with high frequency hearing loss. The windows selected were Blackman, Manning, Hanning-Cosine, Triangular and Bartlett (linear). These hearing-impaired subjects often produce an abnormal click evoked ABR because of influence of the high frequency loss. Each subject was evaluated using click and a 500 Hz tone burst stimulus gated through the five windows. No significant difference in wave V latency between the groups was reported for any of the five windowed tone burst condition. Hence, they suggest that any of the windowing functions would be effective for 500 Hz tonal ABRs with this population of hearing-impaired adults.

Oates and Stapells (1997) conducted a study to assess differences in frequency specificity of ABR for 500 Hz - 2000 Hz tones, gated through exact-Blackman and linear functions, on normal hearing subjects. They used derived response technique and report no significant differences in the frequency specificity of the ABR to the exact-Blackman gated versus linear-gated brief tones despite the acoustic spectral differences that exist between the stimuli. This study supported, findings of Purdy and Abbas (1989) who investigated the frequency specificity of the ABR to Blackman versus linearly gated brief tones, by assessing the ABR thresholds in individuals with steep high frequency SN hearing losses. The majority of threshold predictions were within 15 dB of the subjects behavioural thresholds. In few cases, where the ABR thresholds either under estimated or over estimated the beha\ioural threshold, the error in threshold prediction was equal for linearly gated and Blackman gated stimuli.

Thus recent findings of Oates and Stapells (1997), as well as data of Purdy and Abbas (1989) do not support the suggestion to use Blackman or exact-Blackman gated tones to improve the frequency specificity. However, Gorga (1999), in his review on predicting auditory sensitivity from ABR measurements has recommended the use of Blackman window to obtain more frequency specific information from ABR measurements using tone burst stimuli. It is less likely that the side lobe energy in a Blackman gated sinusoid will result in direct excitation of cochlear regions distant from the nominal frequency for all but the most steeply sloping losses (Gorga, 1999).

Commercially available auditory evoked potential recording systems have the facility for several othir nonlinear gating functions such as cosine cube, extended cosine, cosine, but there is a dearth for studies which have used these functions, for estimating ABR tnresholds with tone burst stimuli. Research needs be done to determine the effectiveness of these nonlinear functions, in obtaining more frequency specific information.

METHODOLOGY

The present study aimed at:

1) Comparison of ABR wave forms for clicks and tone bursts at 500 Hz. 1, 2 and 4 kHz.

2) Determining the effects of two different gating function on the morphology of the auditory brainstem response.

3) Predicting behavioural threshold using tone burst evoked and click evoked ABR in subjects with sloping sensorineural hearing loss.

SUBJECTS

Group I : 10 ears with normal hearing sensitivity. The subjects were in the age range of 18-21 years.

Group II: 10 ears with sloping sensori neural hearing loss. The age of subjects was within the age range oi 54-74 years.

SELECTION CRITERIA

Group I : Pure tone thresholds within 15 dB HL at all frequencies.

Group II: Subjects with sloping SN hearing loss, with difference between two successive octaves greater than 20 dB (ANSI, 1969). Air bone gap within 10 dB at all frequences.

Other subject selection criteria includec-

(i) Negative history of any middle ear pathology.

(ii) Negative history of any psychological problem.

(iii) General health at the time of testing, should have been good.

(iv) Subjects should be able to relax and sit without any extraneous movements for the duration of testing.

INSTRUMENTATION

The electrophysiological equipment used was Intelligent Hearing System with TDH-39 headphones. The software used was Smart EP, Evoked Potential System, Version 2.1X.

A calib rated GSI-61 diag lostic audiometer, with TDH-50 earphone housed in MX-41/AR ear cushion, was used for pure tone audiometry.

Radioear B-71 bone vibrator was used for bone conduction testing.

A calib rated GSI-33 version II, Middle Ear Analyzer, was used for immittance measurements.

TEST ENVIRONMENT

The experimental testings w*ere* carried out in a sound treated environment.

PROCEDURE

The pure tone thresholds were tested using modified Hughson-Westlake procedure (Carhart & Jerger, 1959) across octaves between 250 Hz to 8000 Hz, for air conduction and 250 Hz to 4000 Hz for bone conduction.

Tympanometry and reflexometry was carried out to rule out any middle ear pathology.

During ABR recording, the subjects were instructed to sit comfortably on the chair and relax. They were aske d to avoid any extraneous movements of head, neck and jaw for the duration of the test.

ELECTRODE PLACEMENT

ABRs were recorded using three silver chloride (AgCl) disposable electrodes and one disc type, AgCl electrode. The electrode placement was as shown in Fig. 1.

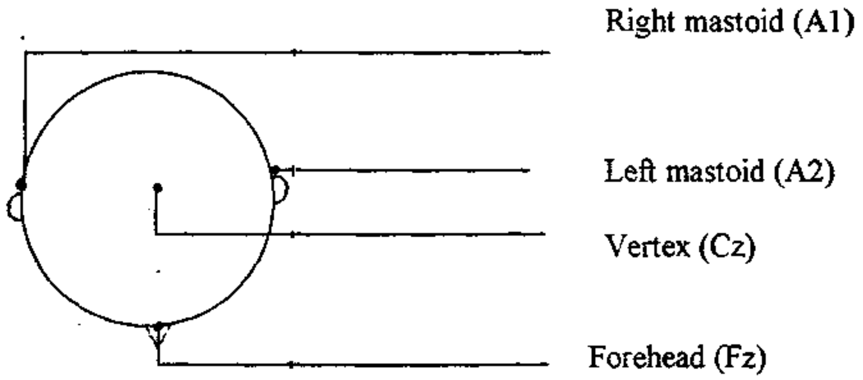


Fig. 1

As shown in Fig. 1, the electrode placed on the vertex (Cz) formed the non-inverting electrodes, the electrode on the two mastoids (Al and A2) were the inverting electrodes, while the common or ground electrode was placed on the forehead (Fz).

Before placing the electrodes, the site of electrode was cleaned by rubbing the surface with cotton wool dipped in skin preparing paste. Appropriate amount of gel was used to stick the vertex electrode and the electrode was secured firmly by a piece of plaster.

It was ensured that the impedance at all electrode was less than 7 K . Earphones were then placed, without dislodging the electrodes. Earphone diaphragm was placed directly over the ear canal so that accurate stimulus intensity levels were delivered to the ear.

STIMULUS PARAMETERS FOR RECORDING ABRS

Type **of stimulus**	**Tone burst**	**Clicks**
Transducer	Earphones	Earphones
Test frequencies	500 Hz, 1000 Hz	
	2000 Hz, 4000 Hz	
Polarity	Alternating	Rarefaction
Envelope	Blackman, Cosine Cube	

Duration of stimulus		100µs
500 Hz- 2000µs		
1 kHz, 2 kHz, 4 kHz- 1000µs		

Rise time and fall time was automatically determined by the software.

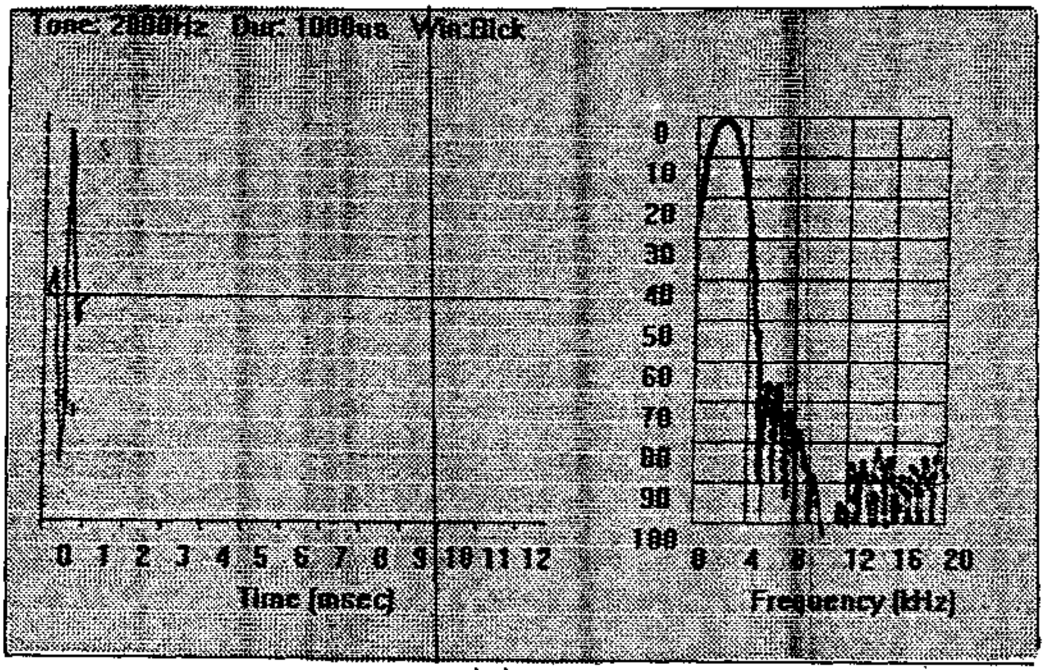
Sample number	2000	2000
Repetition rate	30.1/sec.	30.1/sec.
Band pass filtering	30 Hz-3000 Hz	100-3000 Hz
Sensitivity	50 µV	50µV
Intensity	was varied to estimate the threshold for ABR for both clicks and tone burst	
Time window	24 msec.	12 msec.

The intensity of the stimulus was calibrated in nHL (Appendix A)

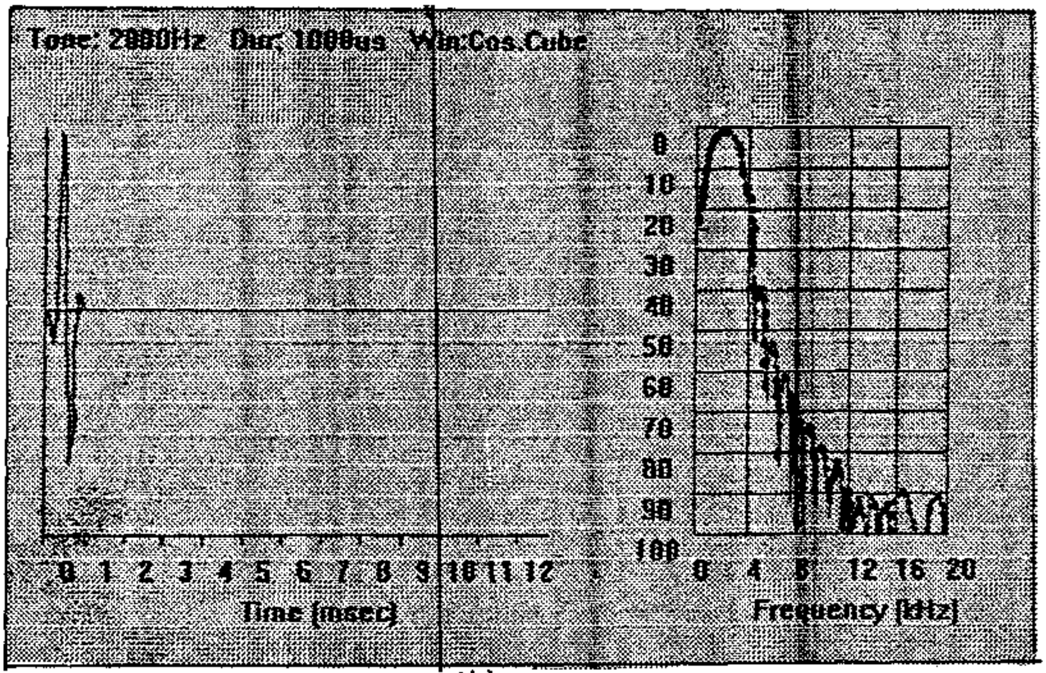
TESTING

The ABR threshold, using tone burst and click stimulus was obtained for all the subjects. For tone burst, at 60 dBnHL or higher intensities (for higher frequencies), ABR was recorded using tone burst gated through both Blackman and Cosine Cube gating functions, while at lower intensities, only Blackman envelope was used. The spectra for 2000 Hz tone burst gated through Blackman and Cosine cube envelope are shown in Fig.2.

The data was analyzed in terms of latency and morphology.



(a)



(b)

FIG 2 : SPECTRA FOR 2000Hz TONE BURST GATED THROUGH BLACKMAN (a) AND COSINE CUBE ENVELOPE (b).

RESULTS AND DISCUSSION

The present study aimed at: -

a) Comparison of ABR waveform for clicks and tone bursts at 500 Hz, 1, 2 and 4 kHz.

b) Determining the effects of two different gating functions on the wave morphology of the ABR.

c) Predicting behavioural threshold using tone burst evoked ABR and clicks evoked ABR in subjects with sipping sensorineural hearing loss.

RESULTS

The data obtained from 10 normal and 10 pathological ears were analyzed and are discussed separately for the two groups.

GROUP 1:

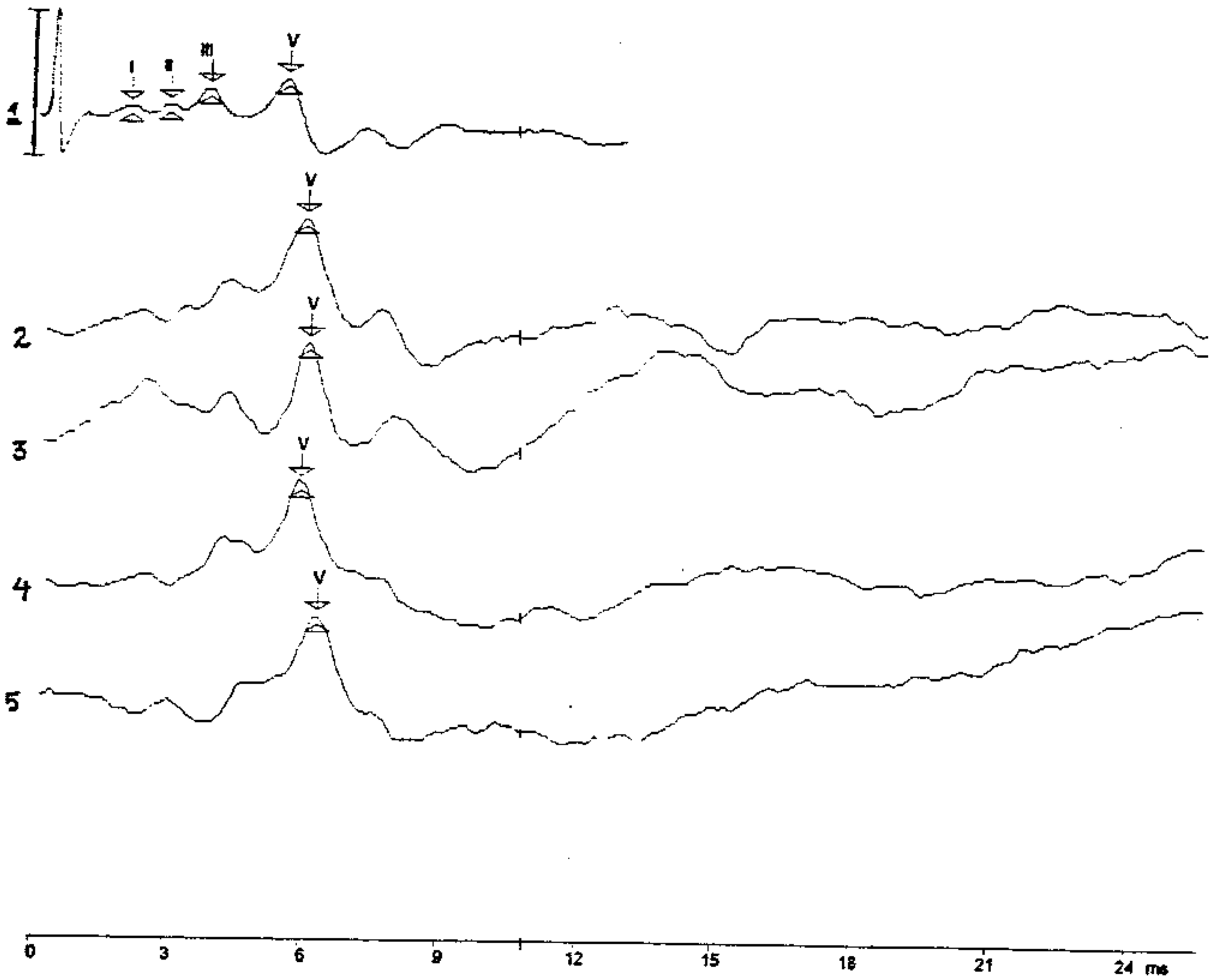
The results from normal hearing subjects were analyzed at suprathreshold level (60 dBnHL) in terms of wave morphology and wave V latency. Thresholds were estimated for tone burst and click stimuli. Mean, SD and range was calculated for the same.

ABR at suprathreshold:

a) Wave morphology: Representative waveforms of one subject, for clicks and tone bursts at 500 Hz, 1, 2 and 4 kHz, are displayed in Fig.3. The earlier peaks were observed in click evokec ABR whereas the first 4 peaks were generally absent in tone burst evoked A JR. Wave V was the prominent peak in all the waveforms and was always followed by a negative trough. There was less variability among subjects' responses and the overall morphology was quite comparable across subjects.

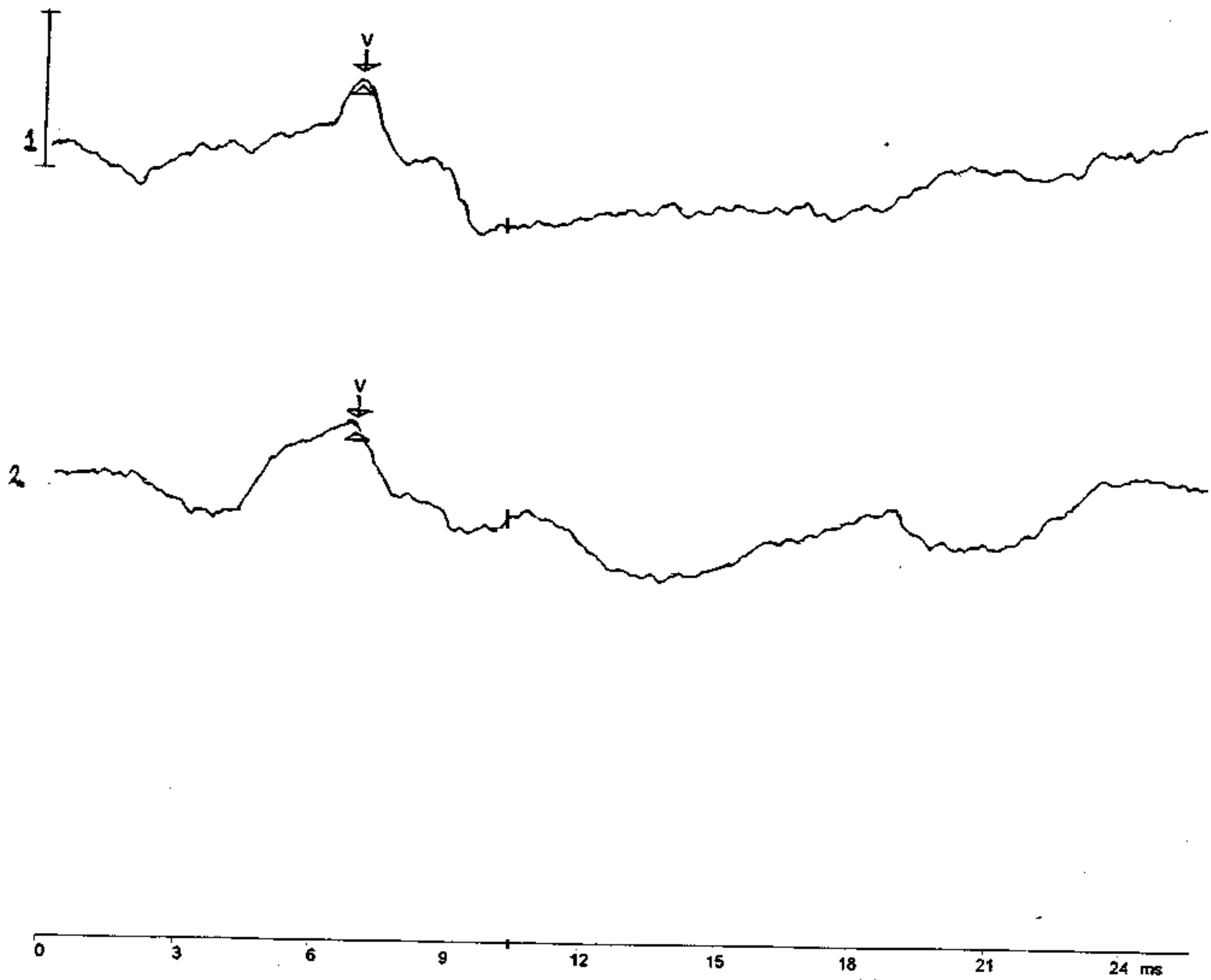
Tone burst evoked ABR was gated through two windows - Blackman and Cosine cube at 60 dBnHL. A sample of waveforms for 2000 Hz stimuli gated through the 2 windows are shown in Fig.4. Waveform morphology was better for Blackman gated when co npared Cosine cube gated stimuli. This result was based on ratings of two experienced audiologist.

There has been no publishec reports comparing these two gating function, although several studies ha\e compared Blackman with other linear and nonlinear windows (Gorga et al., 1992; Robier et al., 1992; Gorga & Thornton, 1989; Telian & Kileny, 1989; Oates & Stapells, 1997). These studies have advocated the use of Blackman over linear window, to improve the frequency specificity of the ABR. Among the various nonlinear windows (Hanning, Blackman, Hanning Cosine, Triangular) compared, Robier et al, (1992) reported no differences in response pattern obtained in normals and subjects



1 - CLICKS 2 - 500Hz TONE BURST 3 - 1000Hz TONEBURST 4 - 4000Hz TONE BURST
5 - 2000Hz TONE BURST .

FIG 3 : REPRESENTATIVE WAVEFORMS FOR CLICKS AND TONE BURST AT 60 dB nHL, OF A NORMAL HEARING SUBJECT



1 - BLACKMAN WINDOW;

2 - COSINE CUBE WINDOW;

FIG 4 : TONE BURST ABR WAVEFORMS GATED THROUGH TWO WINDOWS, AT 2000Hz.

with sloping hearing losses. The present study compared two non-linear windows and found Blackman to be superior of the two in obtaining ABR with good morphology.

b) Wave V latency: Latency of wave V was analysed for clicks and tone bursts at 500Hz, 1, 2 and 4 kHz, as the earl er peaks were absent for tone burst evoked ABR. Table 1 shows the mean, S D and range for wave V latency for clicks and tone burst stimuli.

Table 1: Mean, S.D., and range for wave V latency.

	CLICKS	500 Hz	1000 Hz	2000 Hz	4000 Hz
MEAN (ms)	5.81	6.73	6.46	6.48	6.29
S.D.	0.22	0.39	0.29	0.31	0.22
RANGE **(ms)**	5.45-6.20	6.30-7.4)	5.85-6.25	6.05-6.95	5.95-6.5

A definite trend was seen in ths wave V latency across frequencies for tone burst stimuli. There was an increase in latency as the frequency was varied from 4000 Hz (6.29 ms) to 500 Hz (6.73 ms). Wave V latency for clicks (5.85 ms) was shorter than that for tone bursts. A representative waveforms of tone burst response at 500 Hz, 1, 2 and 4 kHz a: 60 dBnHL, are given in fig.5.

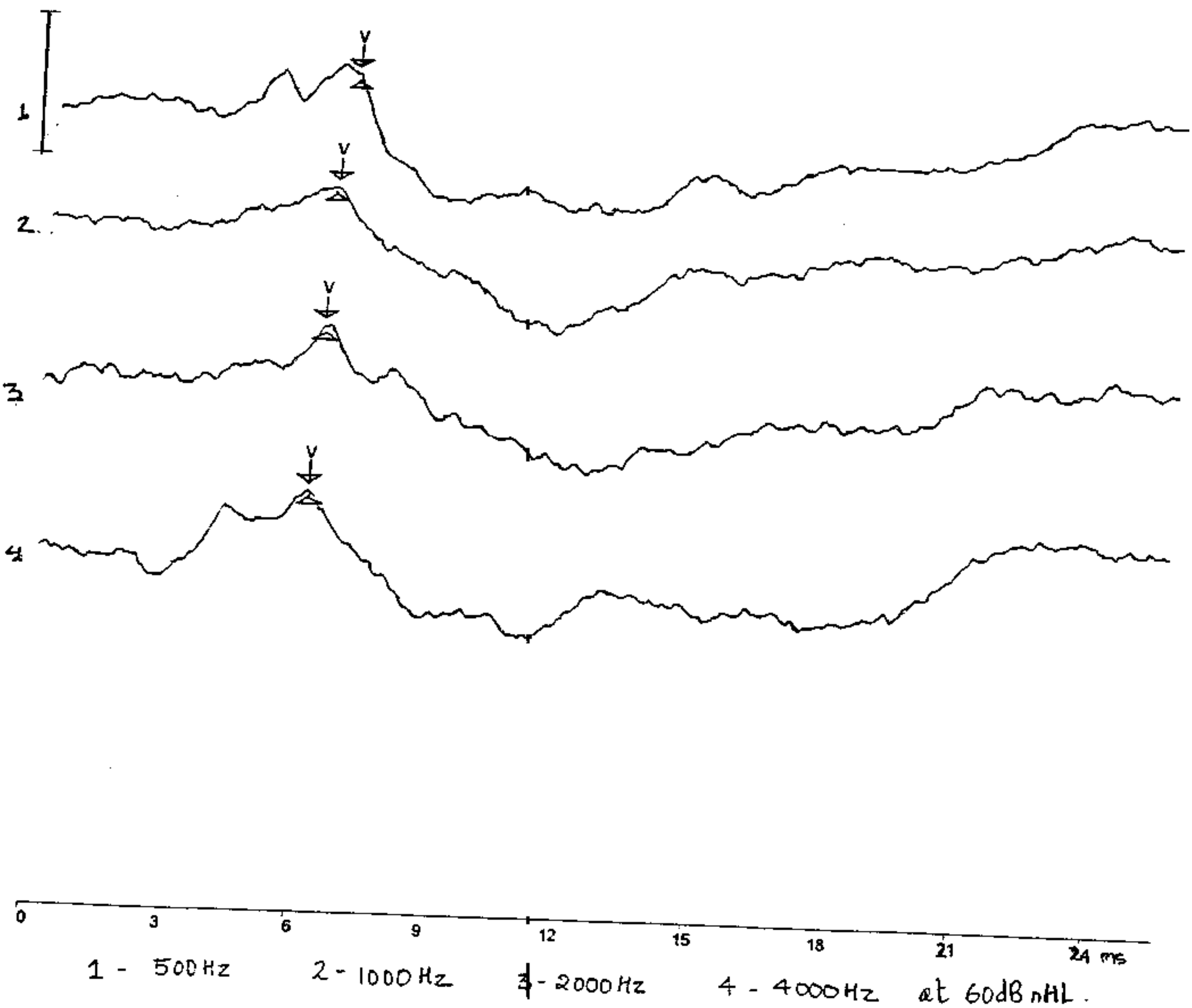


FIG:5 : TONE BURST EVOKED ABR AT 60 dB nHL, AT DIFFERENT FREQUENCIES, FOR A NORMAL HEARING INDIVIDUAL.

Results of Paired T-test snowed **that the** difference between the wave V latency of click and all the four frequencies of tone burst was significant at 0.01 level. .

This finding compares well with that in literature (Gorga et al., 1988) reported an increase in mean later cy of wave V as the frequency was decreased. Their findings were as given below:

FREQUENCY	MEAN LATENCY	LEVEL
500 Hz	9-0 ms	lOO dBSPL
1000 Hz	7-8 ms	85 dBSPL

Beattie et al., (1994) also reported similar results.

Another study with comparable results was that conducted by Sanyukta (1998). She studied wave V latency function from 13 normal hearing subjects. Stimuli used was clicks and 500 Hz and 1 kHz tone burst, at 60 dBnHL. The results were as given below:

	Clicks	1 kHz	500 Hz
Mean(ms)	5.55	7.60	9.00
S.D.	0.1	0.54	0.89
Range (ms)	5.22-5.82	6.66-8.92	7.20-9.96

Thus, the results of the present study support the consensus that there is a systematic change in latency with change in frequency. The lower latency values for clicks in comparison to 500-400C Hz tone burst could be attributed to the much shorter rise time of the click stimuli as compared to that of tone bursts. This finds support in many studies which report an increase in ABR latency with increase in stimulus rise times, beginningwith instantaneous (0 msec) onset, at least for normal hearing subjects (Kodera at al., 1977; Suzuki & Horiuchi, 1981).

Gorga et al., (1988) postulated that decrease in wave V latency with increase in frequency, while level is held constant, could be due to, in part, to differences in stimulus rise times. The longer rise time for the low frequency stimuli (500Hz) could cause an increase in response latency. The more rapid rise times at higher frequencies (1 kHz - 4 kHz) should result in greater amplitude of the response relative to the backs round noise due to greater discharge synchrony and also lower latencies. Moreover, phase effects on ABR latencies are most pronounced for stimuli containing low frequency energy (Moller, 1986). As a result presenting stimulus with alternating phase could introduce latency "jitter" into averaged response and this effect could presumably be greater for low frequencies (Gorga et al., 1988).

The latency of wave V for tone burst stimuli was shorter in the present study compared to that reported in literature (Gorga, et al., 1988; Sanyukta, 1998), probably due to the difference in he rise time of the stimuli. Sanyukta (1998) and Gorga et al, (1988) used tone burst with rise time of 2 cycles, whereas the total duration of the signal used in the present study was 2 msec at 500 Hz and 1 msec at 1, 2 and 4 kHz. The rise time, automatically calculated by the software, was probably shorter than 2 cycles.

ABR at threshold:

The result of ABR threshold, for clicks and tone burst stimuli at 500 Hz, 1, 2 and 4 kHz established for 10 normal hearing subjects are presented in Table 2.

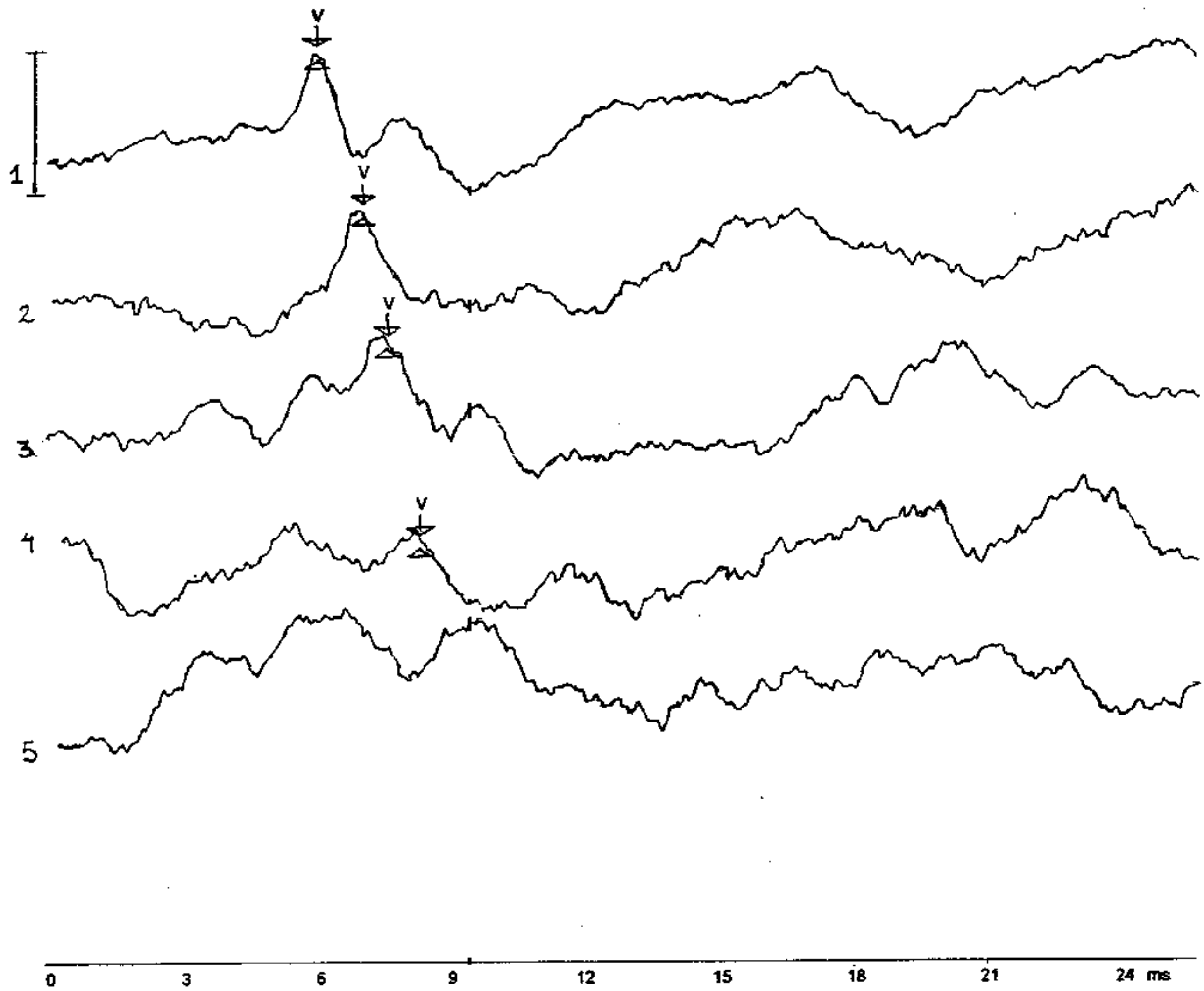
Table 2: Mean, S.D. and Range in clicks, tone bursts and behavioural thresholds.

	CLICKS	500 Hz		1000 Hz		2000 Hz		4000 Hz	
		PT	TB	PT	TB	PT	TB	PT	TB
MEAN	23 (dBnHL)	10	28.5	5	27	5	25	2	23
S.D.	8.23	3.16	10.55	4.47	10.16	5.92	5.27	5.18	9.49
RANGE	10-40 (dBnHL)	5-15	20-50	1-5 -10	10-40	-5-15	20-30	-10-15	10-40

Note: PT - Pure tone behavioural threshold in dB HL
TB - Tone burst evoked ABR threshold in dBnHL.

Representative waveforms of one subject during threshold estimation task, at 2000 Hz are given in fig.6.

The mean, S.D. and range values of ABR thresholds were compared with corresponding behavioural thresholds. As shown in Table 2, the ABR thresholds were higher than behavioural thresholds for clicks and tone bursts at all four frequencies. Among the tone burst stimuli, the mean ABR threshold was higher for 500 Hz (28.5 dBnHL) and shiwed a gradual decline to 23 dBnHL for 4000 Hz. The click threshold was similar to the threshold at 4000 Hz (i.e., 23 dBnHL), contributing to the fact that click evoked responses originate from high frequency region of the basilar membrane.



1 - 2000 Hz at 60 dBnHL
2 - 2000 Hz at 40 dBnHL
3 - 2000 Hz at 30 dBnHL
4 - 2000 Hz at 20 dBnHL
5 - 2000 Hz at 10 dBnHL

Fig: THRESHOLD ESTIMAIION USING TONE BURST ABR

These findings support many studies reported in literature. Gorga et al, (1988) reported a similar trend using tone bursts across octave frequencies from 250 Hz to 8 kHz. Similar observations were made by Suzuki, Kodera and Kaga (1982), who compared ABR and behavioural thresholds. They are report ABR threshold higher than behavioural thresholds. Comparable results were obtained by Sanyukta (1998) who found ABR threshold for 500 Hz at 33 dB with SD 8.1 and range 20-40 dBnHL and for 1 kHz at 27 dB with SD 3.3 and range 20-30 dBnHL.

In the current study, even though absolute threshold of tone burst evoked ABR at 500 Hz was higher thin succeeding frequencies, the mean difference between the ABR and behavioural threshold was better than that observed for other frequencies. This is primirily because pure tone threshold at 500 Hz was relatively higher than that of other frequencies.

Several studies in literature have reported on the trend of mean difference threshold, across frequencies. Gorga et al., (1987) reported a mean difference threshold of 28 dBSPL with SD of 7.75 at 500 Hz and a mean of 17 dBSPL with SD of 6.32 at 1000 Hz. In another study, Gorga et al., (1988) compared ABR and behavioural thresholds across 250 Hz to 8 kHz tone burst stimuli. They reported maximum difference between the two, at low frequencies, reaching 33 dB at 250 Hz and 500 Hz, 21 dB at 1000 Hz and approximately 10 dB for higher frequencies. These results also showed that the variability (SD) was as expected greater in low frequencies than at high frequencies. Similar findings were reported by Sanyukta (1998), who also found higher mean difference (16.5 dB) for 500 Hz than for 1 kHz (12.5 dB).

The findings in the present study do not follow a similar trend. The reason for this difference could be attributed to methodological differences. In this study, the total duration selected for the tcne burst stimuli at all four frequencies was shorter than that conventionally used. Generally, most of the studies recommended 2-1-2 cycle i.e., rise an I fall times of 2 cycles and a plateau duration of 1 cycle approach to classify tonal stimuli based on their duration characteristics (Davis, Hirsh, Popelka & Formby, 1984).

$$\underset{\text{(in ms)}}{1 \text{ cycle}} = \frac{1000}{\text{Frequency}}$$

Hence, for 1000 Hz tone, the 2-1-2 rule would define a total duration of 5 msec and for 500 Hz 10msec, and SO on. In the current study, the total duration selected for 500 Hz was 2 ms and 1 ms for 1, 2 & 4 kHz, with the rise and fall time controlled by the program software. Since the stimulus duration difference between the low and high frequencies was reduced, hence the difference in thresholds across the frequencies was also not very prominent. The shorter stimulus duration was selected due tc increased artifacts at longer durations.

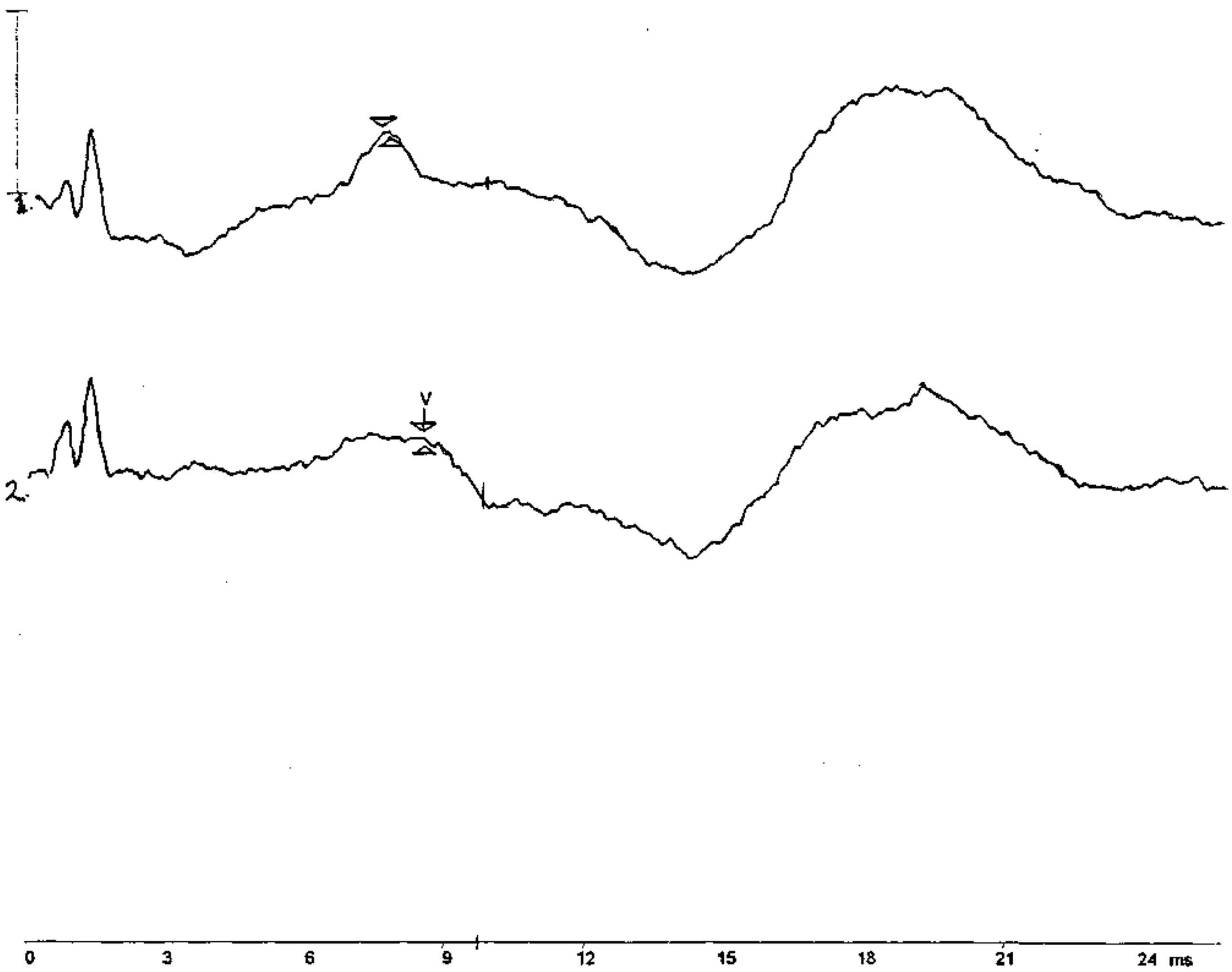
One of the aims of the present study was to predict the behavioural thresholds, using ABR evoked by clicks and tone burst stimuli. The principle clinical measurement for behavioural threshold is pure tone audiometry which measures the response to a relatively longer duration, and longer rise time stimuli. On the other hand, ABR thresholds are response to short duration stimuli. In the present study, though reliable ABR thresholds were obtained for all frequencies, the SD was high in normal subjects. Hence, prediction of behavioural thresholds from ABR will not be very accurate.

GROUP II:

The data obtained from 10 ears with sloping sensorineural hearing loss analysed at both suprathreshold and threshold levels.

ABR at suprathreshold level:

ABR waveforms for pathological group was also obtained at suprathreshold levels. The intensity varied for each subject and also across frequencies. Only at 500Hz recordable waveforms could be obtained for 8 subjects, at suprathreshold level. At 1,2 and 4 kHz, ABR could not be recorded in a majority of the subjects as their behavioural thresholds were high. Hence, ABR was gated through Blackman and Cosine cube windows, only for 500 Hz, at suprathreshold levels. The representative waveforms for one subject is shown in Fig. 7 As was seen in Group I, the waveform morphology for Blackman gated stimulus was better than that for cosine cube in Group II as well and the difference was more marked in Group II.



1 - BLACKMAN WINDOW

2 - COSINE CUBE WINDOW

FIG 7 : WAVEFORM MORPHOLOGY OF ABR FOR 500 Hz TONE BURST, GATED THROUGH TWO WINDOWS. , IN A SUBJECT WITH SLOPING HEARING LOSS.

ABR at threshold level:

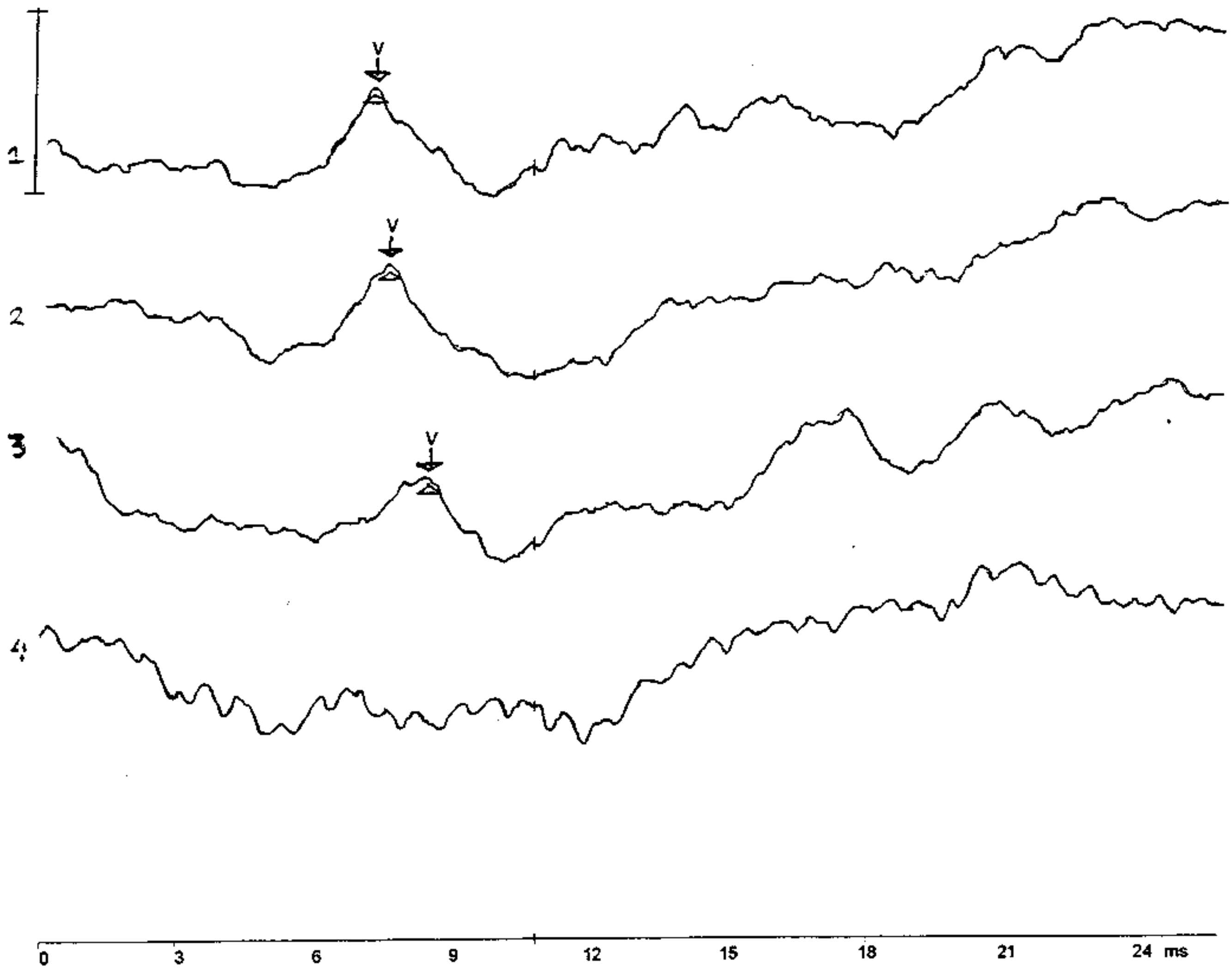
ABR thresholds were estimated using clicks and tone burst stimuli at 500Hz, 1, 2 and 4 kHz. Due to tin e constraints, thresholds for tone burst stimuli couW not be estimated at all the four frequencies, for all the subjects. Fig.8 shows waveforms at threshold for 500 Hz, for one subject.

Due to wide variation in behavioural thresholds of subjects, mean values could not be calculated, as it would not have been a true representation for the heterogenous Group II. Hence, means of difference threshold at different frequencies was calculated and the c ata was tabulated in Table 3.

Table 3: Mean of difference (Dm) between behavioural threshold and tone burst At 500, 1000,2000 & 4000 Hz, for Group I & II.

FREQUENCY (Hz)	GROUP I			GROUP II		
	Dm (d3)	S.D.	RANGE	Dm(dB HL)	S.D.	RANGE
500	18.5	10.96	5-10	28.7	14.31	5-45
1000	21	11.13	5-35	17.5	5.70	5-30
2000	20.5	6.87	5-25	27.5	3.53	25-30
4000	20.5	8.20	5-30	20	-	-

As was in Group I, no particular trend could be observed across frequencies in Group II as well, the difference threshold being 28.75 dB_A^{HL}at 500 Hz, 17.5 dB_A^{HL}at 1 kHz, 27.5 dB^{HL} at 2 kHz and 20 dB^{HL},at 4 kHz. These values cannot be compared as the number of sub ects, in which responses at these frequencies



1- 500Hz at 70 dB nHL
2- 500Hz at 60 dB nHL
3- 500Hz at 40 dB nHL
4- 500Hz at 30 dB nHL

FIG 8.: THRESHOLD ESTIMATION USING TONE BURST ABR IN A SLOPING SENSORINEURAL HEARING LOSS.

could be elicited, varied with 8 responses at 500 Hz and only 4, 2 and 1 response at 1,2 and 4 kHz respectively.

Statistical analysis, using Mann-Whitney U test, to determine significance of difference between means a; 500Hz, for the two groups, was done. No significant difference was found between the difference mean at 500Hz for the two groups, at 0.05 level. Hence, the data from the normal group can be used to predict threshold in the pathological group, but with caution as the SD is high in both the groups. Based on the results obtained, it was observed that using tone burst evoked ABR thresholds it was possible to predict the audiogram configuration reliably in 5 ears (fig.9a), it was questionable in 3 ears (fig.9b) and in the remaining 2 ears, configuration could not be predicted at all (fig.9c). On the other hand, click evoked ABR could be obtained only for 2 ears and the remaining 8 ears had no response at highest levels. Hence even when hearing was normal or near normal at lower frequencies, threshold estimation based on click evoked responses would have led to the interpretation of a severe hearing loss. This would adversely affect the hearing aid selection for the client. Tone burst evoked responses on the other hand gave a rough estimate of the pure tone thresholds and could also predict the configuration of the audiogram.Fig.l0 shows representative waveforms for 500 Hz and 1000 Hz at threshold, when response for clicks was absent at highest levels.

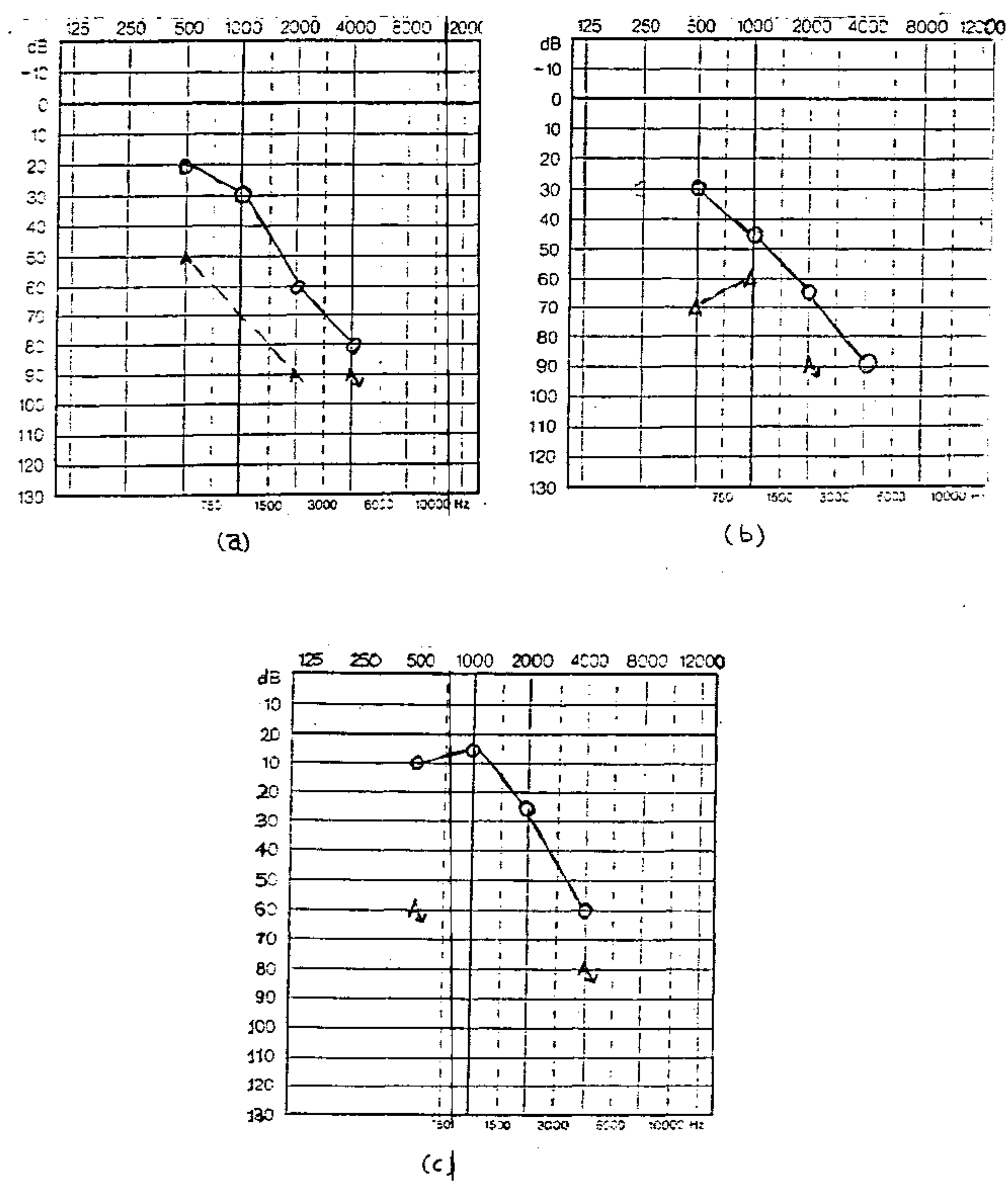
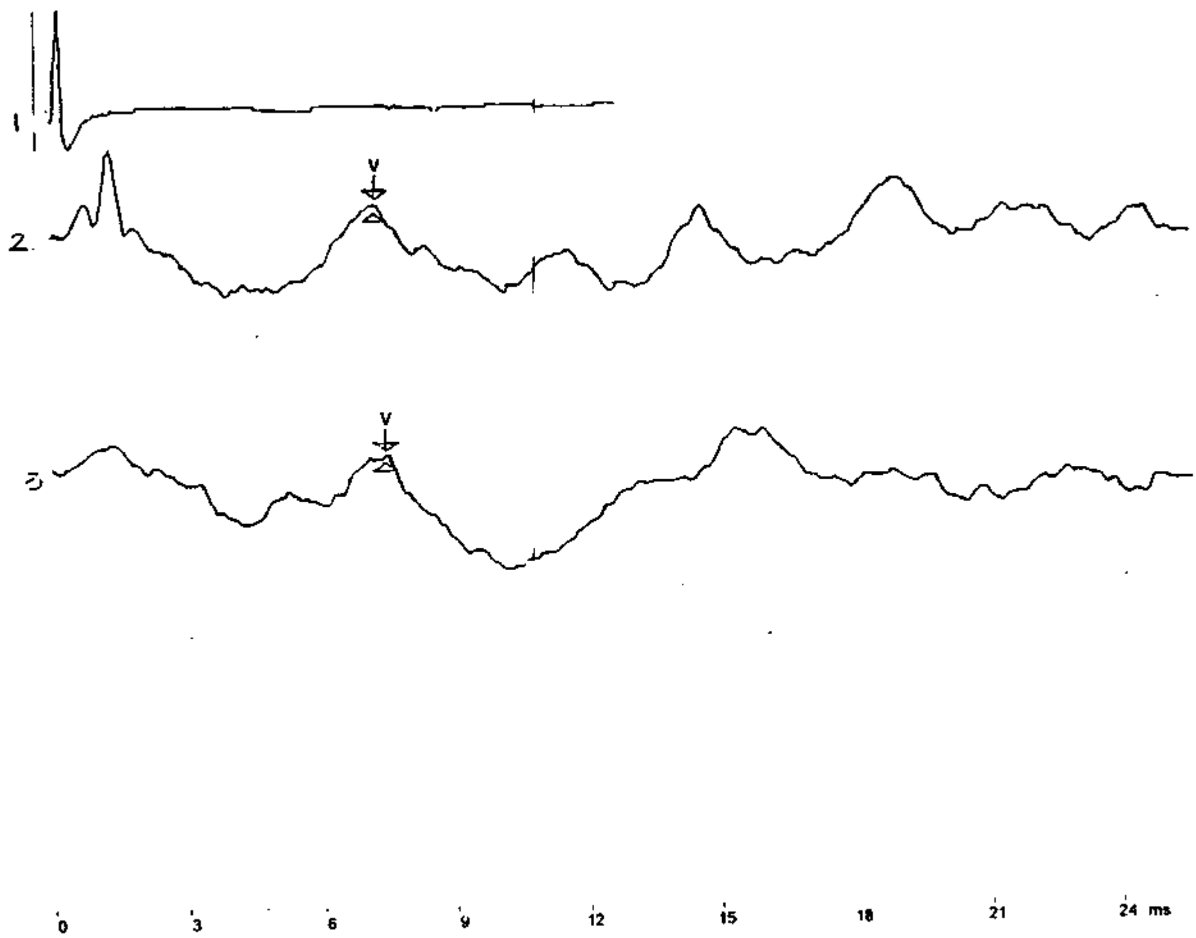


FIG 9: PREDICTION OF AUDIOGRAM CONFIGURATION USING TONE BURST ABR.

[O - PURE TONE THRESHOLD ; A - ABR THRESHOLD]



1 - CLICK EVOKED ABR AT 90 dBnHL (ABSENT)

2 - TONE BURST EVOKED ABR at 500Hz at 85 dBnHL (PRESENT)

3 - TONE BURST EVOKED ABR at 1000Hz AT 80 dB nHL (")

FIG.10 : ABR FOR CLICK AND TONE BURST, IN SLOPING SENSORINEURAL HEARING LOSS.

If the behavioural threshold is predicted based on mean difference, there are chances of under estimation cr over estimation, as the standard deviation is high. Hence, one must be cautiot s while predicting behavioural threshold based on the tone burst evoked responses

In the 2 ears where the audiogram configuration could not be predicted, one ear had click evoked responses present at 20 dB nHL [pure tone average (PTA) = 20 dB HL at 1, 2 & 4 kHz], with wave V latency of 6.85 ms. But tone burst ABR threshold was present only at 60 dB nHL for 500 Hz, even though the pure tone threshold was 0 dB HL with a wave V latency of 6.65 ms. Responses to tone burst stimuli was absent at 4 kHz, in spite of a loss of only 35 dB HL. The other ear had both clicks and tone burst evoked responses absent at highest levels for 500 Hz and 4000 Hz, when the pure tone threshold at 500 Hz and 4000 Hz was 10 dB and 60 dB respectively and PTA at 1, 2 and 4 kHz was 30 dB HL.

It was possible that the neural synchrony was affected in this subject. Neural synchrony, which is essential for recording an ABR ,is affected by the stimulus duration, especially the rise time. It has been reported in literature that neural synchrony is better for shorter rise times stimuli i.e., clicks than for longer rise time stimuli (tone bursts). With increase in rise time, synchronization reduces leading to increase in wave V latency. The affect is seen more in case of hearing loss. Hence, this may account for absent tone burst response, when click evoked response was present. Neural synchrony is also affected by the repetition rates, and reduces with higher rate repetition. In the present study, repetition rate of 30.1/sec was selected may be this could have led to absent click responses in the other ear. Maybe the ABR could have been recorded if a low repetition rate (11.1/sec) was used.

To conclude, tone burst evoked ABR correlate better than click evoked ABR, with pure tone audiogram configuration and also gives more frequency specific responses than click evoked *AB*R. Hence, the present study recommends the use of tone burst evoked responses to get frequency specific responses and to predict the audiogram configuration especially in subjects with a sloping configuration. The study also gives the option of using a shorter duration for tone burst stimuli, to get a reliable waveform.

Further studies need to be carried out on ears with different audiometric configurations like raising (low frequency loss), notched (mid frequencies affected) and other cases with islands of normal sensitivity.

SUMMARY AND CONCLUSION

Tone burst evoked auditory brainstem responses (ABR) have been studied in order to get more frequency specific responses. Tone burst evoked ABR has been studied in both noise and quiet conditions, and it has been reported that tone burst stimuli elicits more frequency specific responses than clicks. The frequency specificity of a tone burst evoked ABR can be improved by gating the stimulus through some non-linear windowing function. But very few studies have compared different non-linear gating functions, available on commercial evoked potential systems. Also, very few studies which compare behavioural thresholds with ABR threshold in subjects with different configuration of hearing loss like sloping loss, raising loss etc. have been published.

Hence, the present study was a step in this direction and it aimed at

1) Comparison of ABR waveforms for clicks and tone burst at 500 Hz, 1,2 and 4 kHz.
2) Determining the effects of two different gating functions on the wave morphology of the ABR.
3) Predicting behavioural thresl old using tone burst evoked and click evoked ABR in subjects with sloping sensorineural hearing loss.

In the present study, two groups were tested- Group I consisted of 10 ears with normal hearing sensitivity and the subjects were within the age range of 18-21 years. Group II was formed by 1© ears with sloping hearing loss the subjects were in the age range of 54-74 years.

ABR waveforms were recorded using Intelligent Hearing System with Smart EP, Evoked Potential System, version 2.1X, software. Pure tone behavioural thresholds were estimated using a calibrated GSI-61 diagnostic audiometer with TDH-50 earphone, housed in MX-41/AR ear cushions, for air conduction testing. Bone conduction testing was carried out using Radioear B-71 bone vibrator. A calibrated GSI-33, version II Middle Ear Analyser was used for immittance measurements.

Tone burst stimuli was gated with Blackman and cosine cube windows at suprathreshold levels and with only Blackman window at lower levels. The duration of the signal was 2000µs at 500 Hz and l000µs for 1, 2 and 4 kHz. The rise time and fall time was automatic ally determined by the software. Repetition rate of 30.1/sec and alternating polarity were selected. Time window was set at 24 ms for tone burst stimulus. Intensity of the stimulus was calibrated in nHL.

The results of the study were as follows:

1) ABR waveforms with a definite wave V could be obtained for clicks and tone bursts in all the subjects with normal hearing.

2) At suprathreshold levels, stimulus gated through Blackman had better wave morphology than stimuli gated through cosine cube. This difference was more marked for pathological group han normals.

3) At suprathreshold level (i.e., at 60 dBnHL), there was an increase in latency with decrease in frequency from 4 kHz to 500 Hz, for normals.

4) Stimuli frequency specific information can be obtained using ABR for tone burst.

5) It was possible to predict he audiogram configuration to a reasonable accuracy in 5 ears and also gave a rough estimate of the behavioural thresholds, of subjects in Group II., using tone burst evoked ABR .

6) The ABR thresholds for tone burst stimuli at all frequencies, were found to be higher than the pure tone behavioural thresholds. Among them, 500 Hz thresholds were higher when compared to the rest. However, the difference between ABR threshold and pure tone threshold was comparable across frequencies.

IMPLICATIONS OF THE STUDY:

- The results of the present study could be used to predict the audiogram configuration from ABR using tone burst stimuli, especially in sloping hearing losses. To overcome the time limitations while carrying out ABR using tone burst stimuli, probably ABR may be recorded for at least 500 Hz and 4 kHz to get a rough estimate of the configuration.

- It also recommends the use of Blackman over cosine cube window for gating tone burst stimuli.
- It recommends usage of tone burst stimuli over clicks to get a more frequency specific response, in ABR measurements.
- The data also shows that shorter duration of tone burst stimuli could also yield reliable results.

LIMITATIONS OF THE STUDY:

- Due to limited number of subjects extensive analysis could not be done.
- The two groups were not age matched.
- Due to time constraints, could not test all the four frequencies, for the hearing impaired population.

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APPENDIX

Calibration of Tonal Stimuli for ABR Testing

In conventional pure tone behavioural audiometry, behavioural thresholds are expressed in dB HL units whereas A3R thresholds are expressed in dB nHL units. Normal hearing level (nHL) refers to normal threshold for click or brief tone stimuli. Zero dB nHL will differ for tones of different frequency and duration-

Procedure:

A group often normal hearing subjects were taken. The behavioural threshold for clicks, and tone bursts (500 Hz, 1000 Hz, 2000 Hz and 4000 Hz) was estimated. The behavioural threshold estimation was done using the same instrument and in the same test environment as the actual ABR testing. Threshold was defined as the lowest level at which 50% of the responses were observed. Their average behavioural threshold was taken as 0 dB nHL for that stimulus. The obtained values are:

		Tone bursts			
	Click	500 Hz	1000 Hz	2000 Hz	4000 Hz
OdBnHL =	42 dB SPL	47dB SPL	37dB SPL.	28 dB SPL	29dB SPL