COMPARISON OF AUDITORY BRAINSTEM RESPONSE WAVEFORMS TO CLICKS AND TONE BURSTS

Reg. No.M97l6

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

All India Institute of Speech & Hearing
Mysore 570006
1998

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vakraṭunḍa maha:kaya suryakoṭi
samaprabha II
nirvighanam kurume: de:va
sarvakaryeshu sarvada: II

matru devo: bhava

pitru devo: bhava

acharyadevo: bhava

CERTIFICATE

This is to certify that this Independent Project entitled COMPARISON OF AUDITORY BRAINSTEM RESPONSE WAVEFORMS TO CLICKS AND TONE BURSTS is the bonafide work in part fulfilment tor the degree of Master of Science (Speech and Hearing) of the student with Register No.M9716

Mysore

May, 1998

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CERTIFICATE

This is to certify that this Independent Project entitled *COMPARISON OF AUDITORY BRAINSTEM RESPONSE WAVEFORMS TO CLICKS AND TONE BURSTS* has been prepared under my supervision and guidance.

Mysore

May, 1998

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DECLARATION

This Independent Project entitled *COMPARISON OF AUDITORY BRAINSTEM RESPONSE WAVEFORMS TO CLICKS AND TONE BURSTS* is the result of my own study under the guidance of Mrs. Vanaja C. S., Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier at any University for any other diploma or degree.

Mysore
May, 1998 ***Reg. NO.M9716***

ACKNOWLEDGEMENT

I express my sincere gratitude to Mrs. Vanaja C.S., Lecturer in Audiology, All India Institute of Speech and Hearing, Mysore for her able guidance and constant encouragement while carrying out the project. Maa'm your immense patience and dedication towards work is commendable.

I extend my gratitude to Dr. (Miss)S.Nikam, Director, All India Institute of Speech and Hearing, Mysore for granting me permission to carry out this project.

Respected Baba, I owe my presence in the field to you. You are a source of inspiration to all those around you.

My dearest "Patti" and "dadi" - you both have been epitomes of mental fortitude and resilience. You defintitely are Grand-mothers.

Ma and Papa, `A plant is only as strong as its roots' I can't thank you enough for the selfless love and careful nurturence during those formative years, "home is where my heart is".

Sharad, we have shared a unique and special bond which only a brother and sister can have. I have had in you my confidante, friend and a pest- all rolled in one. Aren't you glad to see yourname in print?

Guardian angel Nidhi, you make your presence felt wherever you go - is it [illegible] surprising you have a `big' presence in our hearts too?

Priti, I have found the perfect friend in you. I am lucky to be able to `bank' on you any time, anywhere.

Sangeetha.V., friendship crossess all barriers of distance and time.you are loved just as much as before.

Ruch and Sarmi, I have a special place for you both in my heart which time and distance cannot erase. Miss you a lot.

Hia, my `small wonder' you have shared both moments of happiness and deepest blues with me. I want our friendship to last forever.

Kutta, Gundu, Pandu, Chandan, Gokul and Suman, we are not just friends, but a family. I could always count on you.

Prarthana, Vini and the super 7. You definitely spice up my life with your "yazzy', "zany' ways.

Kavitha, Neha, Aditi, your caring ways have had that special touch.

Arushi, Anshula, Beula, Kaveri, Radhika, Ponty, Sonty and Kamna. Moments spent with you will be cherished forever.

Koolkats :miss you guys - I mean it.

Mona, Tara and the Gang. We've had a GREAT time together and its nice to know that in this world of transient relationships, our friendship is here to stay.

Aunty, uncle, Soni and Kamlesh. Your house has been a second home for us. Thanks for the affection and love.

To all my classmates who are special in their own unique way.

My subjects,but for your patience this work wouldn't have seen light of the day.

Thanks to Rajalakshmi Akka for her great work. I am amazed by your unflagging, dedication to your work.

Thanks to the sponsors of this project

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INTRODUCTION

The auditory evoked potentials are the electrical responses of the nervous system to auditory stimuli (Stapells et al. 1985). Auditory Brainstem Response (ABR), through its clinical application has provided a unique diagnostic dimension that has transcended inter-disciplinary boundaries. One reason the ABR has gained such rapid acceptance, is its ability for objective threshold estimation without the active participation of subjects in difficult-to-test population. Other applications include objective detection, localisation and monitoring of auditory and neurological deficits. In evaluations using ABR, the electrical potentials generated at various levels of the nervous system in response to acoustic stimulation, can be recorded non-invasivery with no discomfort to the patient and often without anesthesia, which further enhances their clinical applicability.

The ABR latency epoch consists of five to seven peaks measured within the first 10 msec. (Jacobson, 1985). The latency and amplitude values in newborns and infants differ from adult values (Jacobson, Morehouse, Johnson, 1982). Technical aspects also affect the latency epoch. These include factors such as electrode placement, stimulus polarity, filtering characteristics, rate of presentation and above all the stimulus itself which may influence the latency, amplitude and morphology of the brainstem response (Jacobson, 1985). Stimulus properties such as frequency, duration, intensity, rate and polarity exert profound and often inter-related effects on ABR measurements (Hall, 1992).

For neurophysiological reasons, the early latency ABRs are best generated with very brief (transient) stimuli producing synchronous firing of numerous auditory neurons (Hall, 1992).

Thus, the brief duration (eg. 0.1 msec, or 100 msec) click; which has an abrupt onset, is by far the most commonly used stimulus for ABR measurements. The click stimulus may actually be one of several somewhat different acoustic signals, including a rectangular voltage electrical pulse, diphasic square wave, pulses, triangular waves, or a single period of high frequency haversine or half sinewave, which then excite the headphones to provide the stimulus (Hall, 1992).

Unfortunately, clicks are relatively difficult stimuli to control and quantify. They have a broad acoustical energy density spectrum at the tympanic membrane and will excite a much larger region of the cochlear partition than a puretone of comparable intensity (Hall, 1992). Besides this, the stimulus evokes a travelling wavefront which progressively excites a considerable length of *the* cochlear partition and associated hair cells. The velocity of the travelling wave decreases apically and the innervation density also varies, so the number of primary neurons activated per unit time depends on cochlear position. The major contribution to the overall response in **the** ABR come from cochlear regions where excitations are most highly synchronised, especially basal regions. Another factor is the tuning characteristic of primary auditory neurons which typically have a steep high frequency segment and a more gradually sloping tail towards low frequencies (Evans, 1983). This suggests that low frequencies may excite neurons tuned to higher frequencies whereas the converse is less likely (Hall, 1992).

Click ABRs are an important part of objective audiometry as these responses can provide :

(i) an evaluation of retrocochlear pathways;
(ii) a general idea of auditory sensitivity, particularly at higher frequencies; and

(iii) some suggestion about whether a peripheral hearing loss is conductive or not, if the loss is in high frequencies or if recruitment is present.

There are several disadvantages to limiting the evaluation to unmasked clicks only. Individuals with hearing loss restricted to particular frequencies may show normal ABRs. Normal thresholds and latency intensity functions for click-evoked ABRs can be recorded from ears having significant losses between 500 and 6000 Hz (Picton, Ouellette, Hamel and Smith, 1979; Yamada, et al. 1979). Furthermore, the residual low-frequency sensitivity in a patent with a severe high-frequency loss cannot be assessed with these responses. Finally, the click-evoked ABR cannot provide the information at different frequencies that is necessary for proper fitting of hearing aids. Several techniques have therefore been devised to improve the frequency specificity of the click evoked brainstem potential. There has also been a trend towards the use of more place specific stimuli for threshold estimation and otoneurological investigations in an attempt to avoid some of these physical and physiological problems of clicks and their interaction with hearing loss (Laukli, 1983).

The *frequency specificity* of an audiometric measurement indicates how frequency 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 inaccurately measured because of responses mediated by other frequencies. Three general methods are proposed to yield frequency specific ABRs :

1 Masking frequency regions that are not intended to be a part of the stimulus. The masker may be (a) high pass (high frequency noise) (b) band reject masking (noise with a notch in the region or (c) masking with a pure tone.

2. The response to a stimulus at a specific frequency or with a derived frequency region is derived (usually by subtraction) from 2 other responses. This may also involve a masking paradigm.

3. The third method, which is the most straightforward, involves the use of a tonal stimulus (a spectrally constrained stimulus) with carefully selected onset characteristics.

A *tone burst* is a signal with specificable carrier frequency with a specified envelope function by which the carrier is modified (Hall, 1992). Although, there is an inevitable tradeoff between the abruptness of the stimulus needed to produce a clear ABR waveform, especially at lower intensity levels and the spectral constraints of the stimulus, the possible use of tone burst stimuli in ABR measurement continues to be the subject of considerable research interest. There are perhaps, three reasons for the unflagging interest in this stimulus paradigm for frequency specific ABR measurement.

1. Tone burst is clinically feasible. The technique is relatively straight forward. Test time is relatively brief and tone burst stimuli are already available on many commercial evoked response systems.

2. Second, there is considerable long standing evidence that at low to moderate intensity levels and with proper onset gating, tone bursts can produce frequency specific early latency AERs (Abbas and Gorga, 1981; Dallos and Cheatham, 1976; Gorga, Kaminski, Beavchaine and Jesteadt, 1988; Klein and Mills, 1981).

Clinical studies of tone generated ABR, while neither uniformly encouraging nor always yielding audiometrically valid findings have demonstrated that behavioural thresholds can be estimated to within 20 dB (Coats and Martin, 1977; Fjermedal and Laukli, 1989 a, b; Gorga, Kaminski, Beauchaine and Jesteadt, 1978; Moller and Blegvad, 1976; Pratt and Sohmer, 1978; Smith and Simmons, 1982).

3. Third, there is some evidence that the spectral splatter that is associated with tone bursts that have linear onset and offset characteristics ("ramps") specifically the amplitude and frequency range of side lobes of frequency of interest, may be minimised with the use of other nonlinear stimulus shaping envelopes (Gorga and Thornton, 1989).

Thus the possibility exists that, with appropriate envelopes, tone bursts offer an optimal stimulus that is one that permits frequency specific recording, simply, quickly and with relatively inexpensive instrumentation.

NEED FOR THE STUDY

Though a number of studies suggest that tone bursts in quiet with better gating functions may be as good as any of the currently available techniques for evoked potential estimates, few comprehesive sets of tone burst data have been published.

In addition, very few studies have assessed intrasubject reliability for tone burst latencies for 500 Hz and 1 kHz tone burst stimuli.

Before tone bursts can be used as a reliable ABR stimuli for estimation of thresholds and otoneurologic evaluation in hearing impaired population a comprehensive normative data needs to be established.

AIM OF THE STUDY

1) Studying the ABR wave V latency function for clicks and tone bursts (500 Hz and 1000 Hz) at a constant intensity level (60 dB nHL) in normal hearing subjects.

2) Comparison of auditory thresholds for ABR using 500 Hz and 1000 Hz tone burst stimuli with behavioural thresholds for these frequencies in normal hearing subjects.

REVIEW OF LITERATURE

Audiometric Brainstem Response (ABR) testing is often used to estimate pure tone behavioural thresholds in children and/or adults 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 (Stapells and Oates, 1997).

The '*frequency specificity*' of an audiometric measure *is* a term generally applied to the evaluation of thresholds and refers to how independent a threshold at one stimulus frequency is, of contributions from surrounding frequencies (Stapells, et al. 1985; Stapells, Picton and Durieux-Smith, 1994). *Place specificity* on the other hand, refers to the portion of cochlear partition contributing to the response (Starr and Don, 1988).

The brief stimuli that are required for recording auditory evoked potentials are quite different from the long duration pure tones used in conventional audiometry (Stapells et al. 1985). Two types of stimuli typically used in conducting ABR evaluations are clicks and brief tones (Stapells and Oates, 1997).

1) ABR RESPONSES TO CLICKS :

The most common stimulus in ABR measurements is a click (Gorga and Thornton, 1989). Clicks produced by passing a brief square wave through an earphone, have a broad frequency spectrum with a null value at the frequency equal to the reciprocal of the square wave duration (Pfeifer, 1974). While some frequency specific auditory threshold data can be gained from the click response, more information is available if the clicks are presented with various masking stimuli (Stapells, et al. 1985).

(a) **UNMASKED CLICKS** : Transient acoustic signals, i.e. clicks generated by feeding an earphone with an electric pulse were used in first ABR recordings (Jewett and Williston, 1971).

Currently, the most widely used evoked potential method for evaluating auditory thresholds is the ABR to non-masked clicks (Stapells and Oates, 1997). The rapid onset and its broad frequency spectral content result in activation of wide area of the basilar membrane. Since a broad range of frequencies are stimulated, it is not possible to obtain accurate information about hearing sensitivity at different frequencies using a nonmasked click alone (Stapells et al. 1985; Starr and Don, 1988; Hyde, 1985).

Several reports have indicated that the click ABR threshold correlates best with hearing threshold at 2000-4000 Hz region (Coats and Martin, 1977; Jerger and Mauidin, 1978; Yamada, Kodera and Yagi, 1979; van der Drift et al. 1987). This is because high frequency regions of the cochlea are located close together in an area of the basilar membrane where the travelling wave has relatively high velocity resulting in a more synchronised discharge and a higher amplitude response (Stapells et al. 1985).

On average, across a large group of patients with hearing loss this may be true. These results however, do not translate into one being able to use click ABR threshold as reliable estimate of 2000 Hz - 4000 Hz threshold for individual patients (Stapells and Oates, 1997). Stapells and Oates (1997) reported the relationship between nonmasked click ABR thresholds and the average of pure tone behavioural thresholds at 2000 Hz and 4000 Hz for 161 ears of 82 adults with sensori-neural hearing loss. They demonstrated that any particular click ABR threshold may represent a wide range of pure tone thresholds making accurate determination of the degree of hearing loss impossible. There was no one-to-one relationship between increase in high frequency hearing loss and click ABR threshold. The likely explanation for the low slope value is that significant contributions to the response derived from the more sensitive lower frequency regions of the cochlea since many of these patients had sloping hearing loss. Similar results were seen when click ABR threshold was plotted against the best of 1000, 2000 and 4000 Hz pure tone thresholds (Picton, Durieux-Smith, Moran, 1994). Studies employing the high pass noise derived response technique have shown that ABRs to moderate intensity (i.e. 50-70 dB nHL) nonmasked clicks receive contributions to the response from 500 to 8000 Hz frequency regions of the cochlea (Don and Eggermont, 1978; Picton, Stapells, Campbell, 1981; Kramer, 1992).

The lack of frequency specificity of the click ABR demonstrates that nonmasked click ABR threshold cannot be used reliably to estimate pure tone behavioural thresholds in infants, children and/ or adults (Stapells and Oates, 1997).

Because of the pressing clinical need for an electrophysiologic technique to assess auditory sensitivity at different frequencies, a tremendous research effort has been directed towards developing a method for recording frequency specific ABRs (Hall, 1992).

The general methods proposed by Hall (1992) to yield frequency specific ABRs are -

(1) One which involves masking frequency regions that are not intended to be part of the stimulus. The masker may be

(i) high pass (high frequency) noise
(ii) noise with a notch in the region of desired frequency (band reject masking), or
(iii) masking with a pure tone.

(2) "With another method, the response to a stimulus at a specific frequency or with a defined frequency region is derived (usually by subtraction) from two other responses. This may also involve a masking paradigm.

1. MASKING METHODS

i) HIGH PASS MASKING

High pass noise has been widely used to evaluate the frequency specificity of auditory responses since its initial introduction by Teas, Eldredge and Davis (1962). This involves presentation of high frequency ("high pass") masking along with a transient stimulus using ipsilateral masking (i.e. masking noise presented through the same earphone as stimulus) (Hall, 1992).

With the high frequency masking method, the stimulus may be a click or a brief tone (usually a tone burst). Use of a transient stimulus optimises the likelyhood of a clear well formed ABR even at low intensity levels. Some spectral splatter including unwanted frequencies above the stimulus frequency is masked by noise (Hall, 1992). The travelling wave in the cochlea and response pattern of single auditory nerve fibres shows a very steep high frequency edge. Noise in the high frequency region can therefore mask the responses of high frequency fibres without affecting fibres with lower characteristic frequencies (Stapells, et al. 1985).

The response to ABR with clicks when high pass masking noise is used remain relatively unchanged in the presence of masking noise that has been high pass filtered as low as 4 kHz. Lowering the cut off frequency causes the earlier waves I to IV to disappear leaving only wave V clearly recognizable (Don and Eggermont, 1978; Thiimmler, Tietze and Matkei, 1981). High pass cut offs as low as 500 Hz still result in a clear wave V with a latency of about 4 ms. later than the latency of unmasked response (Don and Eggermont, 1978; Thummler, et al. 1981).

Kinarti and Sohmer (1982) similarly evaluated the usefulness of high pass masking for ABRs generated with low frequency filtered clicks.

The H.P noise masking technique has been shown to give reliable estimates of hearing sensitivity at 500 Hz in both normal and hearing-impaired individuals (Kileny, 1981; Purdy et al. 1989; Munnerley, et al. 1991).

The disadvantage for clinical use of HP masking noise is that it is inappropriate for middle and high frequency tones because it does not prevent the spread of energy to frequencies below the tone frequency. This can lead to under-estimation of the degree ofhearing loss at these higher frequencies due to contribution of responses from more sensitive low frequency regions. HP noise masking does not improve the frequency specificity of ABRs to mid-to high frequency tones for individuals with sloping high frequency loss (Stapells and Oates, 1997).

II) NOICHED NOISE

Notched noise is broad band noise in which one band ©f frequencies has been stopped or rejected band reject (filtered noise)

(Stapells et al. 1985). It allows responses to frequencies within the notch while masking responses to frequencies outside the notch. This type of masking was initially used in human neurophysiology by Eggermont and Odenthal (1974) to assess the frequency specificity of the auditory nerve response.

Pratt and Bleich (1982) found that waves III and V of ABR remain clearly defined with notched noise masking, that the latency of wave V increased by about 0.6 mm from its latency in the unmasked condition and there was no significant effect of the frequency of the notch on the latency of wave V (instead of expected increased latency of response with decreasing frequency of the notch). Pratt, Ben-Yitzhak and Attias (1984) reported that the thresholds for the responses obtained in this manner, did not correlate very well with the results of pure tone audiometry in a group of patients with hearing loss. In contrast, van Zanten and Brocaar (1974) found that the latency of the response to clicks in notched noise increased with decreasing frequency of notch.

Stapells (1984) used notched noise with slopes of 48 dB/octave to examine the effective depth of the notch by recording the improvement in click psychophysical thresholds in notched and unfiltered noise conditions. The average improvement was only 4, 5 and 7 dB for the noise with notch width of 0.5, 1 and 2 octaves respectively. In a study of 10 normal subjects using masking SPL levels of 28 dB greater than nHL of the click and one octave notches, the average amplitude of the response was 0.18 /uV for across frequencies 500 Hz, 1 kHz, 2 kHz and 4 kHz. The small size of the response makes it very difficult to be recognised. In these ten subjects and in ten hearing-impaired patients, response thresholds significantly over estimated those obtained from pure tone audiometry and were much more variable than those obtained with other electrophysiological tests (Stapells, 1984).

Hall (1992) summarizes the following disadvantages of the notched noise masking technique -

(a) spread of the low-frequency component of the masker into the notch,
(b) broad-small amplitude and sometimes indistinct wave V morphology,
(c) extra peaks in the waveform even at high masking levels, which may be misinterpreted as wave V for the stimulus frequency of interest,
(d) over-estimation of auditory threshold levels.

iii) PURE TONE MASKING

Pure tone masking paradigms have also been applied for derivation of frequency specific ABRs (Folsom, 1984; Klein, 1983). In this an ABR is recorded with a tone burst or click stimulus in the presence of a continuous pure tone (at the frequency of interest), and another ABR is recorded for just the click or the tone burst stimulus . In theory, the continuous pure tone will mask out the frequency specific portion of the cochlea. Then, when the ABR for just the click (or tone burst) is subtracted from the ABR waveform for the stimulus plus the pure tone, only the portion of the ABR generated by the pure tone masker frequency will remain (Hall, 1992). One advantage of this technique versus other frequency specific ABR recording methods, based on data in guinea pigs, is the apparent consistency of the discrete frequency activation even at high intensity levels. As expected, latency of the ABR component decreases as frequency of the pure tone is increased. A continuous high level, low' frequency stimulus activates fibers in the basal region of the cochlea, as well as in apical region. The remote activation is not due to spectral splatter but due to basilar membrane mechanics (Gorga and Thornton, 1989).

Clinical feasibility and effectiveness of this pure tone masker derived method has yet to be documented. Pantev et al. (1982) in a follow up study offered additional evidence that the pure tone masking method was feasible and valid through the range of 500 Hz - 8000 Hz. Pure tone masking at intensity levels of 20- 25 dB were evaluated. They reported clear detectibility of responses for low frequency region stimuli.

As in derived methods, an important consideration is the electrophysiological variability and increased noise level that is caused by the subtraction process. The subtraction process has the effect of limiting the noise reduction obtained during signal averaging. Stapells et al. (1985) estimate a noise level 1.4 times. Larger than the level for unsubtracted ABRs. Sequential ABR waveforms may not have precisely the same latency values.

2. DERIVED RESPONSE METHODS

The first major study of the use of derived masking methods in generating frequency specific AERs is that of Teas, Eldredge and Davis (1962) conducted with EcochG in an animal model. With the derived response methods, an ABR is generated by a sound that includes the stimulus plus a second acoustic signal (narrow band noise, high pass noise or a pure tone masker) that has contributions from portions of cochlea other than those underlying the stimulus. Then, the ABR is generated by the non stimulus signal (i.e. the noise). The ABR waveform or the noise is subtracted from the ABR waveform for the noise plus stimulus condition. Theoretically, during the subtraction process, the contribution of the masker to the waveform (and nonstimulus frequency regions of the cochlea) is removed, leaving only the ABR for the spectrally constrained stimulus (Hall, 1992).

(i) HIGH PASS NOISE

The relative contributions of each region along the basilar membrane to click ABR can be obtained by sequential subtraction of the recorded responses using high pass noise with decreasing high pass cut off frequencies. Subtraction of the response in high pass noise at one cut off frequency from the response of higher cut off frequency leaves a 'derived response' to the frequencies between the two cut off settings (Stapells, et al. 1985). This technique was first applied to human cochleography by Elberling (1974) and has subsequently been used in analysing human ABR (Don and Eggermont, 1978, Don, Eggermont and Brackman, 1979; Parker and Thornton, 1978 a, b, c).

In normal hearers, Don, Eggermont and Brackmann (1979) recorded an ABR with the derived method at intensity levels down to 30 dB SL for cochlear regions above 8000 Hz and at 500 Hz and below. Within the 1000-4000 Hz region, the derived ABR thresholds was observed down at least 10 dB SL. The authors found very close correspondence between audiometric hearing threshold levels and derived ABR reconstructions of audiograms (usually within 5-10 dB) for patients with isolated deficits at 4000 Hz and with low frequency or flat configuration hearing-impairment (Hall, 1992).

One major problem with the technique is that the derived responses are difficult to recognise in the background EEG noise.

Primarily due to increased noise levels introduced when one waveform is subtracted from another. High levels of noise required to mask high intensity clicks can also cause temporary threshold shifts. Although high levels of noise can be prescribed for very brief periods to normal subjects without affecting. Cochlear function, it is difficult to predict what might happen in patients with pathological cochleas (Stapells et at. 1985).

(ii) *NARROWBAND NOISE*

Derived responses may also be obtained with narrow band masking. ABR responses are first recorded with a click stimulus encompassing a wide frequency region. Then ABR waveforms are recorded with a click plus a simultaneously presented narrow band of noise centred around the frequency of interest (eg. 500 or 2000 Hz). Digital subtraction of the noise-band masked ABR from the unmasked ABR yields a difference waveform with all frequency contributions removed except those in the desired frequency region (Hall, 1992).

Stapells et al. (1985) examined this technique using narrow band noise rather than pure tones. Rarefaction clicks were presented at an intensity of 70 dBnHL (106 dB SPL) and a rate of 21/sec. Broad band noise of 98 dB SPL was band pass filtered with a two third of octave width centred at either 500 or 2000 Hz. The 500 Hz derived response showed a prominent wave V at about 9 ms but it also produced earlier components similar to those in the response to unmasked clicks. These components were probably caused by the spread of masking from the 500 Hz NBN into the 1000 to 4000 Hz frequency region of cochlea. This spread of masking is not a problem when using high pass masking techniques though masking with narrow band noise can be done at higher intensities than those possible using high pass noise masking.

II ABR Responses to Brief Tone Stimuli

Brief tones have their concentration of energy at the nominal frequency of the tone and side bands of energy at low and higher frequencies (Harris, 1978; Nuttal, 1981; Durrant, 1983; Laukli, 983; Gorga and Thornton, 1989). Like clicks brief tones contain energy over a range of frequencies and evoked potentials to these may be evoked by any of the frequencies present in 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 by type of transducer used (Stapells andOates, 1997).

Several approaches to a reasonable compromise between the brief duration of the tone and its frequency specificity are available (Davis, et al. 1984; Gabor, 1947; Harris, 1978) but none can completely prevent spectral splatter (Stapells et al. 1985).

When stimulus intensity is increased to 90 dB SPL and higher, there will likely be greater contributions to the evoked potentials from frequencies away from the tones nominal frequency thus reducing frequency and place specificity of the response (Stapells et al. 1985; Stapells and Picton, 1981; Burkard and Hecox, 1983). This occurs due to spread of energy away from the tone frequency to lower or higher frequency regions of the cochlea (i.e. spectral splatter) 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). In clinical practice, there is a problem only when assessing evoked potential thresholds for ears with fairly steeply sloping hearing loss, where significant contributions may derive from the significantly better hearing at other frequencies (Stapells and Picton, 1985; Stapells et al. 1994; Picton, et al. 1979).

Noise masking paradigms may be used to restrict the regions of basilar membrane that are capable of contributing to the ABR and thus improve the frequency and place specificity of the ABR to higher intensity stimuli.

In contrast to thresholds to clicks, ABR thresholds to brief tonal stimuli presented in quiet or in notched noise masking provide more frequency specific results and enable the audiologist to obtain reasonably accurate estimates of pure tone behavioural audiograms from 500 Hz to 4000 Hz form all age populations (Stapells and Oates, 1997).

Notched noise and high pass noise are used to mask tonal stimuli.

1) TONES IN NOTCHED NOISE

Notched noise can be used to restrict the responsiveness of the cochlea to frequencies within the notch. Picton et al. (1979) recorded ABRs to tones in notched noise using rise and fall times of 1 ms. and 2-octave notch width. Although the slope of filters creating the notch was 48 dB/octave, the effective notch was reduced to about 27 by the spread of masking from the low-frequency edge of the notch. The advantage of using tones rather than clicks is the lower intensity of noise necessary to mask responses outside the notch. In the study, SPL noise levels (before filtering) of 15 dB below the peak SPL of the tone were found to provide effective masking even in patients with steep frequency hearing losses. The difference is even more striking if one considers that since the tones concentrate their energy in one frequency region, they have much lower thresholds than broad band clicks. Tones in notched noise provide a greater concentration of stimulus energy at the frequency under examination than do clicks in notched noise. This leads to larger but no less frequency specific response (Stapells et al. 1985).

Notched noise has different effects on the responses to tones of high and low frequencies (Stapells et al. 1985). Notched noise does not significantly alter the latency of wave V to tones of 2000 and 4000 Hz but it does reduce the amplitude of the response at high intensities. These effects are most easily explained by the removal of an underlying broad response to the low frequency spread of energy in the tone. The removal of this broad component does not alter the peak latency, which is measured at the sharp deflection initiated by the well synchronised high frequency region of cochlea (Stapells et al. 1985). Notched noise significantly increases the latency and decreases the amplitude of the response to high intensity tones of 1000 and 500 Hz. This is because of the removal of the early sharp wave that is evoked by the spread of energy into the high frequency regions of the cochlea and is superimposed upon the broad wave V evoked from the low frequency regions (Stapells etal. 1985).

The ABR to tone in notched noise can provide an accurate assessment of the pure tone audiogram even in patients with steep hearing loses (Picton et al, 1979). Tones in notched noise have been used to assess hearing-impairment in infants (Alberti et al. 1983; Stockard et al, 1983).

A simpler approach to masking the energy spread in brief tones is to use unfiltered white noise (Picton et al, 1979). White noise causes effects similar to those of notched noise, except that the amplitudes of the responses are reduced.

ii) TONES IN HIGH PASS NOISE

The responses to low frequency tones are more frequency specific when presented in high pass masking noise which prevents the contribution of basal cochlear regions which could be activated either by travelling wave hydrodynamics or by the spread of energy in the spectrum of the brief tone (Stapells et al. 1985). This approach has been used by Jacobson (1983), Kileny (1981) and Laukli (1983 a). Its advantage over notched noise is based on -

> lack of any spread of masking from high to low frequencies; therefore very little masking occurs at frequency of tone,
>
> the overall intensity of high pass noise is less than that of notched noise and therefore produces less stapedius reflex effect which could result in an attenuation of hearing at low frequencies.

Stapells et al. (1985), investigated the effects of high pass noise on the combined brainstem wave V and 40 Hz response to 500 Hz tones. Tones with rise and fall time 5 ms. and 5 ms plateau were presented alone or in the presence of noise. The tone intensities were 100, 80 and 60 - peak equivalent SPL. The high pass noise had a cut off 1300 Hz and a slope of 60 dB/octave. For the high intensity tones, the high pass masking noise caused a decrease in the amplitude of an overall response and an increase in latency of wave V (due to travelling wave delay). Results suggested that there is decreasing frequency specificity with increasing intensity of the tone.

Although the masking techniques are theoretically appealing. There are definite practical disadvantages to their routine use for frequency specific ABR measurement.

Currently, sophisticated ipsilateral masking paradigms cannot be incorporated into clinical ABR recording with most commercially available evoked response systems.

The actual effectiveness of masking in limiting the cochlear activation to the portion of basilar membrane underlying the desired stimulus frequency has not been conclusively defined in the normal or cochlear impaired ear [that is, even though hair cells in portion of a cochlea may be activated by a steady state (continuous) masking noise, it is conceivable that these or other hair cells in the same region may be still responsive to transient stimulus].

A second unknown, concerns the extent and effect of masking noise spread into the stimulus frequency region, as well as on interactions between masker and stimulus.

Complicating interpretations of ABR obtained with this method are the steep slope for the high frequency side tuning curve versus the more gradual slope for the low frequency side and differences in tuning curve slope for high frequency units (sharper slopes) versus low frequency units (less sharp slopes).

In combination, these factors conspire to limit the validity of the techniques especially for the low frequency region which is of greatest clinical concern (Stapells and Oates, 1997).

iii) ABB. RESPONSES TO UNMASKED TONS BURSTS

Tone burst is a stimulus having a specifiable carrier frequency with a specified envelope function by which the carrier is modified (Hall, 1992). Historically there has been some controversy with regard to the clinical utility of the ABR to tonal stimuli, especially for the low frequencies (Stapells, 1984).

Based on these early studies, many clinicians today continue to hold the incorrect belief that

1) The ABRs to tonal stimuli are not frequency specific (i.e. tone ABR thresholds do not represent the behavioural thresholds for the tone's normal frequencies (Stapells and Oates, 1997).

2) The ABR to 500 Hz tonal stimuli is primarily generated from the basal (i.e. high frequency) end of the cochlea, especially to higher intensity stimuli and thus these thresholds are poor predictors of low frequency behvioural threshold, and

3) Waveform identification of the response to 500 Hz stimuli is problematic in quiet and even more so in the presence of masking noise (Davis and Hirsh, 1976; Laukli, 1983; Sohmer and Kinarti, 1984; Laukli and Mair, 1986; Weber, 1987; Laukli, Fjermedel, and Mair, 1988) (Stapells and Oates, 1997).

The rise time of a tonal stimulus has a direct relationship with its frequency specificity. Tones with longer rise times (eg. 10 Vs. 2 cycles) had greater acoustic frequency specificity, meaning there is less splatter of stimulus energy to frequencies above and below the tone's nominal frequency (Burkard, 1984; Gorga and Thornton, 1980; Stapells and Picton, 1981; Jacobson, 1983). When rise time is increased beyond 5 ms, however, there is a significant decrease in the amplitude of ABR wave V-V (Stapells and Picton, 1981). The use of tonal stimuli with 2 cycle rise and fall times and 1 cycle plateau times referred to as '2-1-2' cycle tones have been recommended for frequency specific ABR testing as a good compromise between the acoustic frequency specificity of a tone and the resulting amplitude (Davis, et al. 1984). Subsequent studies have shown that 2-1-2 cycle tones presented in either quiet or in the presence of high pass and/or notched-noise masking, provide frequency specific ABR thresholds in infants, young children and adults with impaired hearing (Stapells, 1989; Davis and Hirsh, 1979; Kileny, 1981; Purdy, et al. 1989; Stapells et al. 1990; Stapells et al. 1995; Munnerley, et al. 1991).

Many studies have shown that reasonably accurate estimates of 500, 1000,2000 and/or 4000 Hz pure tone behvioural thresholds may be obtained by recording ABRs to air conduction brief tones presented in either quiet or notched noise masking for infants, young children and adults with normal hearing sensitivity or peripheral hearing impairments (Stapells et al. 1985; Stapells, Picton, Durieux-Smith, 1994; Davis and Hirsh, 1979; Picton et al. 1979).

Stapells (1983) and Stapells, Picton and Durieux-Smith examined the relative accuracy of a variety of approaches for estimating the pure tone audiogram, including tone bursts in quiet, tone bursts centred in notched noise and derived response technique. Chi average, tone burst ABRs in quiet were at least as accurate as any other technique for estimating hearing sensitivity for octave frequencies from 500 Hz to 4000 Hz. In cases, of steeply sloping high frequency loss, however, there was a tendency for tone burst ABR in quiet to underestimate the magnitude of loss. This effect was presumably due to excitation of more normal low frequency cochlear region, due to spectral spread of gated sinusoids (Gorga, et al. 1988). However, in their studies tone burst were gated with linear functions whose spectra are characterised by relatively large side lobe amplitude.

According to Gorga et al. (1988), this problem would be reduced if more spectrally narrow stimuli (as suggested by Davis, 1976) were used. Stapells (1983) found that rater reliability and response clarity were better for responses to tone bursts in quiet and tone bursts in notched noise as compared to derived responses. These data suggest that tone bursts in quiet with better gating functions may be as good as any of the currently available techniques for evoked potential estimates of pure tone audiogram (Gorga et al. 1988).

Gorga et al. (1988) studied auditory brainstem responses to tone bursts for frequencies from 250 Hz to 8000 Hz in normal hearing subjects ABR was recorded from 20 normal hearing young adults using tone burst stimuli gated with cosine squared (Hanning) gating. The waveforms were measured across vertex and ipsilateral mastoid electrodes both of which were referenced to a forehead or contralateral ground. Responses were recorded for 20 ms. following stimulus onset. Stimuli were alternated in polarity and were presented at a relatively high rate of 44/sec. They studied wave V latencies as a function of level for 4 subjects. Data for an individual subject was collected for stimulus frequency 500 Hz, 2000 Hz and 8000Hz.

Three general observations were made from the data -

First data are more reproducible for high frequencies than for low frequencies.
data are more reproducible at high intensity for any frequency within a given subject, wave V latencies were highly reproducible (there is little intra-subject variability at any given frequency and intensity).

The mean ABR and behvioural thresholds in dB SPL as a function of frequency were compared. ABR thresholds were always higher than behavioural thresholds. The differences between these estimates were greatest for low frequencies reaching 33 dB at 250 Hz; 21 dB at 1000 Hz; and 10 dB at higher frequencies. These differences in threshold with respect to frequency could be due to differences in rise/fall time and/or cochlear organization both of which might adversely affect the signal to noise ratio for ABR measurements.

Mean wave V latencies (±1SD) as a function of level were also presented with frequency as the parameter. There was a decrease in latency with increase in level for all frequencies (250 Hz - 8000 Hz). Furthermore there was an orderly dependence of latency on frequency at any level.Gorga et al. (1988) reported that the convergence of wave V latencies, which is most obvious at high levels may result from spread of excitation for low frequency stimuli.

Level in dB SPL	Latencies		
	500 Hz	1 kHz	2kHz
20		14.3	12.0
40	15 ms	11.8	10.o
60	12 ms	9.7	9.0
8O	10 ms	**8.O**	**7.8**
100	9 ms	7.2	7.0

It has been claimed by many authors that the frequency specificity of the ABR may be improved by the use of Blackman gated tone in place of more conventional linear gated stimulus (Gorga and Thornton, 1989). There is ample clinical and experimental evidence that abrupt onset tone bursts with these conventional gating characteristics do not produce frequency specific ABRs (Burkard and Hecox, 1983; Davis and Hirsh, 1976a; Gorga and Thornton, 1989; Jacobson, 1983; Kileny, 1981; Mair and Laukli, 1985). ABR waveforms with these tonal stimuli may be essentially in distinguishable from those of unfiltered click stimuli. Linearly gated tone bursts do not offer a valid means of assessing auditory sensitivity for specific frequency regions, particularly below 1000 Hz. The acoustic spectra of Blackman gated tone stimuli differs in 3 ways.

(1) the acoustic energy located in the sidelobes of the exact Blackman tone is approximately 68 dB below the peak energy of the main lobe, in comparison to approximately 27 dB for the linear gated tone.

(2) the main energy lobe is wider in frequency for the exact Blackman versus linear gated tone and

(3) the rate of decay of sidelobes is less steep (6 Vs. 18 dB/octave) for the exact Blackman versus linear gated tone.

These spectral differences are indepencent of stimulus frequency (Harris, 1978;Nuttal, 1981).

In a study, Gorga et al. (1987) compared behavioural threshold versus ABR latencies and thresholds in 6 normal hearing subjects with brief duration high frequency tone bursts (9000 Hz to 16000 Hz) gated with Blackman functions having rise/fall times of 500 msec -with no plateau. The authors confirmed the clinical feasibility of high frequency ABR measurements but recommended additional study in hearing impaired patients before the technique is applied clinically in appropriate populations (eg. patients treated with ototoxic drugs and therefore at risk for high frequency auditory deficits).

Thus, the possibility exists that with appropriate envelopes, tone bursts offer an optimal stimulus-that is one that permits frequency specific AB recordings simply, quickly and with relatively inexpensive instrumentation.

Grorga, Kaminski, Beauchaine and Schulte (1992) measured ABR responses to 1000 Hz tone bursts from 115 patients with sensorineural hearing loss, presumably of cochlear origin. ABRs were recorded between chlorided silver silver disc electrodes placed at the vertex and ipsilateral mastoids with the ground electrode placed at high forehead. The stimulus consisted of digitally generated 1000 Hz tone burst gated with Blackman windows having 2 ms. on both rise and fall with no plateau. A stimulus level of 88 dB peak pressure was used. Mean absolute wave V latencies elicited by the 1000 Hz tone burst were plotted as a function of the average hearing loss at 2000 Hz and 4000 Hz. There was a clear trend towards longer latencies as the magnitude of the high frequency hearing loss increases. That is, in the absence of any hearing loss, the stimuli used to elicit these responses are probably exciting higher frequency cochlear regions. As the hearing loss increases, the contributions to the response from these high frequency regions are reduced. As high frequency thresholds increase from less than 20 dB HL to over 60 dB HL the magnitude of this effect was only 0.5 msec. Furthermore, mean overall wave V latency, collapsed across hearing loss was 8.05 ms. (SD 0.3 ms). This value is only slightly longer than what has been observed in normal hearing subjects for comparable stimuli where the mean wave V latency was 7.93 msc.

(SD was 0.42) (Gorga, et al. 1988). This agreement given the differences in hearing sensitivity, suggests that spread of excitation for these stimuli does not differ between normal and impaired ears. It also suggests that stimulus spectrum for tone burst stimuli is perhaps more important determinant of response latency than is the relationship between magnitude of stimulus and hearing loss.

Fausti et al. (1993) studied high frequency tone burst evoked ABR latency intensity functions (LIF) in sensorineural hearing impaired humans. Such data would be important to the development of improved criteria for detecting ototoxiety in patients with some degree of sensori-neural hearing loss prior to treatment. The LEFs of ABRs elicited by high frequency (8 kHz, 10 kHz, 12 kHz and 14 kHz) tone burst stimuli were evaluated in 20 subjects with confirmed moderate high frequency SN hearing loss. Tone burst stimuli were gated with 0.2 msec, rise-fall times with a 1.6 msec, plateau. Comparisons of the linear regression curves were made between the current subjects and a group of normal hearing subjects reported in Fausti et al. (1991 b). At each presentation level, mean latencies were longer for sensorineural hearing impaired group (ranging from 0.38 to 0.75 msec, later). Linear regression curves between the two showed no significant difference. This study demonstrated that tone bursts at 8, 10, and 12 KHz evoked ABRs which decreased in latency as a function of increasing intensity and that these LIFs were consistent and orderly (14 Khz was not determinable). Fausti et al. (1993) speculated that these results will contribute information to facilitate the establishment of change criteria to predict change in hearing during treatment with ototoxic medications whereas click stimuli cannot provide the frequency specificity required for accurate estimation of thresholds across hearing spectrum.

Thus, the studies using tone bursts suggest that the tone bursts, if adequately gated and having appropriate rise/fall time have greater clinical application in estimation of frequency specificity threshold as well as for otoneurological purpose.

METHODOLOGY

The present study aimed at v

1) Studying the ABR wave V latency function for clicks and tone bursts (500 Hz and 1000 Hz) at a constant intensity level (60 dB nHL) in normal hearing subjects.

2) Comparison of auditory thresholds for ABR using 500 Hz and 1000 Hz tone burst stimuli with behavioural thresholds for these frequencies in normal hearing subjects.

SUBJECTS :

The study was carried on a group of 13 subjects within age range of seventeen to twenty-five years. Criteria for selection included :

(i) *Normal Hearing* : All subjects had auditory behavioural thresholds ≤ 25 dB HL (ANSI, 1989) across all octave frequencies from 250 Hz to 8000 Hz.

(ii) Negative histories of noise exposure or middle ear dysfunction.

(iii) Negative history of any psychological problem.

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

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

INSTRUMENTATION

The electrophysiological test unit used to record ABR waveforms was Nicolet Spirit, Auditory E voiced Potential System, Version 1.5. TDH 39P headphones encased in MX/ 41 -AR ear cushions were used to present the stimulus.

Pure tone audiometry

A double channel ed diagnostic audiometer GSI-16 was used for pure tone behavioural threshold estimation with TDH 50 P headphones to present the stimuli. Bone conduction testing was carried out using a Radio ear B-71 bone vibrator. All these were calibrated prior to the study.

TEST ENVIRONMENT

All the testing was carried out in a sound treated room with optimum lighting and temperature. The subjects were made comfortable in a chair during the testing session.

TEST PROCEDURE

(i) *Pure tone testing :* All the subjects were tested for auditory pure tone thresholds for air-conduction and bone-conduction made across octave frequencies between 250 Hz and 8000 Hz. Modified Hughson-Westlake procedure was applied for estimation of thresholds. Pure tone average (PTA) was calculated for threshold values at 500 Hz, 1000 Hz, and 2000 Hz.

(ii) *ABR testing*

(a) **Instructions**

The subjects were instructed to *"sit comfortably and relax"* on a chair facing away from the instrument. They were told to avoid extraneous movements of head, neck and jaw for the duration of the test. Instructions were given in a language femiliar to the subject.

(b) **Electrode Placement**

Four silver coated disc type electrodes were used which were checked for continuity before placement. The placement was as follows :

Position	Function	Connection to Electrode box
Vertex (Cz)	Non-inverting	Cz
Forehead (Fz)	Common	A
Mastoid region behind auricles of		
- Right ear	Inverting	A2
-Left ear		A1

Before placing the electrodes, the areas of electrode placement were cleaned by scrubbing with cotton wool dipped in rectified spirit and skin preparing paste.

Adequate amount of gel was used to stick the electrodes in their appropriate positions and secured by a piece of plaster.

Impedance matching for the electrode was done to ensure that the impedance at all the electrodes was less than 5 K ohms and inter-electrode impedance -was less than 2 K ohms. Earphones were then placed without dislodging the electrodes (blue for left and red for right ear). Earphone diaphragm was placed directly over the ear canal so that accurate stimulus intensity levels were delivered to the ear.

Stimulus Parameters :

The stimulus parameters for tone bursts and clicks are as follows:

Parameters	**Clicks**	**Tone burst**
Transducer	Phone	Phone
Type of stimulus	Clicks	Tone bursts
Repetition Rate	11.4/sec	11 4/sec
Sensitivity	50 uV	50 uV
Sample number	1500	1500
Time	10 ms	20 ms
Polarity	Rarefaction	Alternating
Gain	64	64
Level	6OdBnHL	60dBnHL*
Frequency of stimuli	-	500 Hz/1 kHz
Plateau	-	1 cycle
Rise time/fall time	-	2 cycles
Envelope	-	Blackman
Bandpass	100Hz-3kHz	30 Hz-3 kHz

* The level was lowered till threshold was achieved

The ABR waveforms for clicks were recorded at 60 dB nHL from only one ear.

The ABR testing for tone bursts (500 Hz and 1 kHz) was started at 60 dB nHL. The intensity level was reduced by 10 dB steps. The lowest intensity at which a clear waveform could be obtained was found out. Repetition of the waveforms was done.

The thresholds were traced for 500 Hz and 1 kHz tone burst stimuli (the lowest level till where wave V was identifiable).

The waveforms obtained from the subjects were stored and data compared and analysed.

RESULTS AND DISCUSSION

The aim of the present study was to -

(a) Study the ABR wave V latency function for clicks and tone bursts (500 Hz and 1000 Hz) at a constant 60 dB nHL intensity level in normal hearing subjects.

(b) Comparison of auditory thresholds for ABR rasing 500 Hz arid 1 kHz tone burst stimuli with behavioural thresholds for these frequencies in normal hearing subjects.

Results

(1) Wave Morphology

The representative waveforms of one subject is displayed in the figure la,b. Wave identification techniques used for choosing waveforms of standard ABR click stimulus and Jewett scheme for peak labelling using Roman numerals were applied for identification and labelling of both click and tone burstevoked waveforms. To facilitate peak identification, especially at low intensities, replication of ipsilateral waveforms and contralateral waveforms were used.

The click waveform obtained at 60 dB nHL consisted of fast vertex positive peaks labeled I, II, III and IV in addition to a V-V' slow wave (Figure la). Wave V was defined as the largest vertex positive wave followed by a rapid negative going slope (often labeled ^{i}V). The ABR to tone burst stimuli consisted primarily of this V-V slow wave. In most responses to 60 dB nHL tone burst stimuli, waves I to IV were absent and/or highly variable (Figure lb). Responses at high level conditions were used to help guide in the

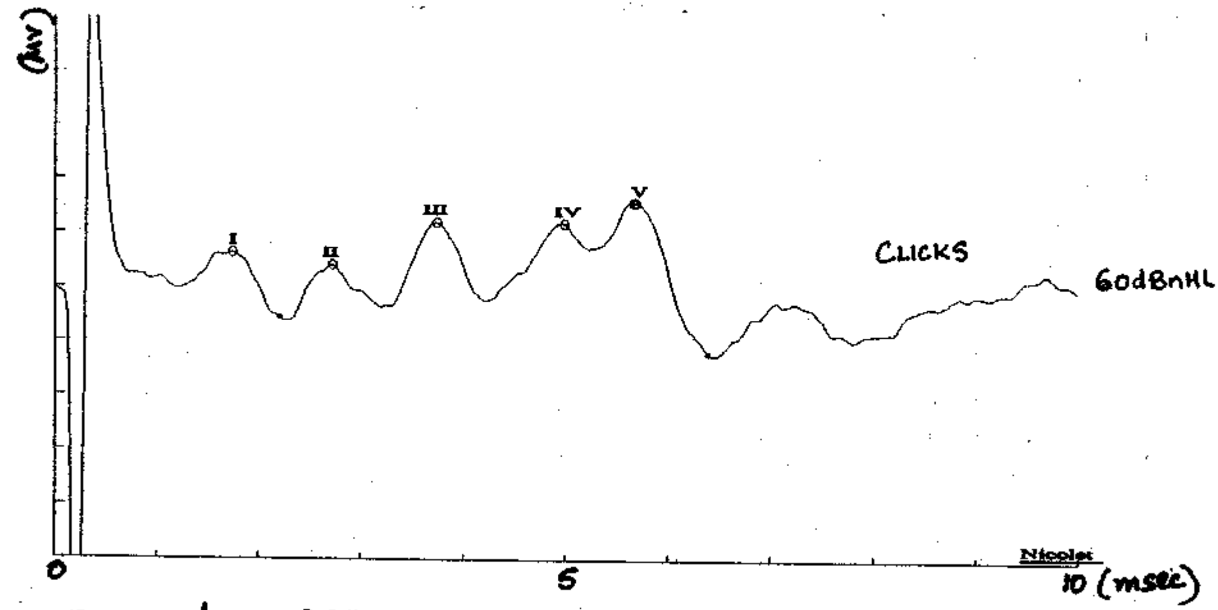


FIGURE 1a : ABR WAVEFORM TO CLICK STIMULI AT 60dBnHL

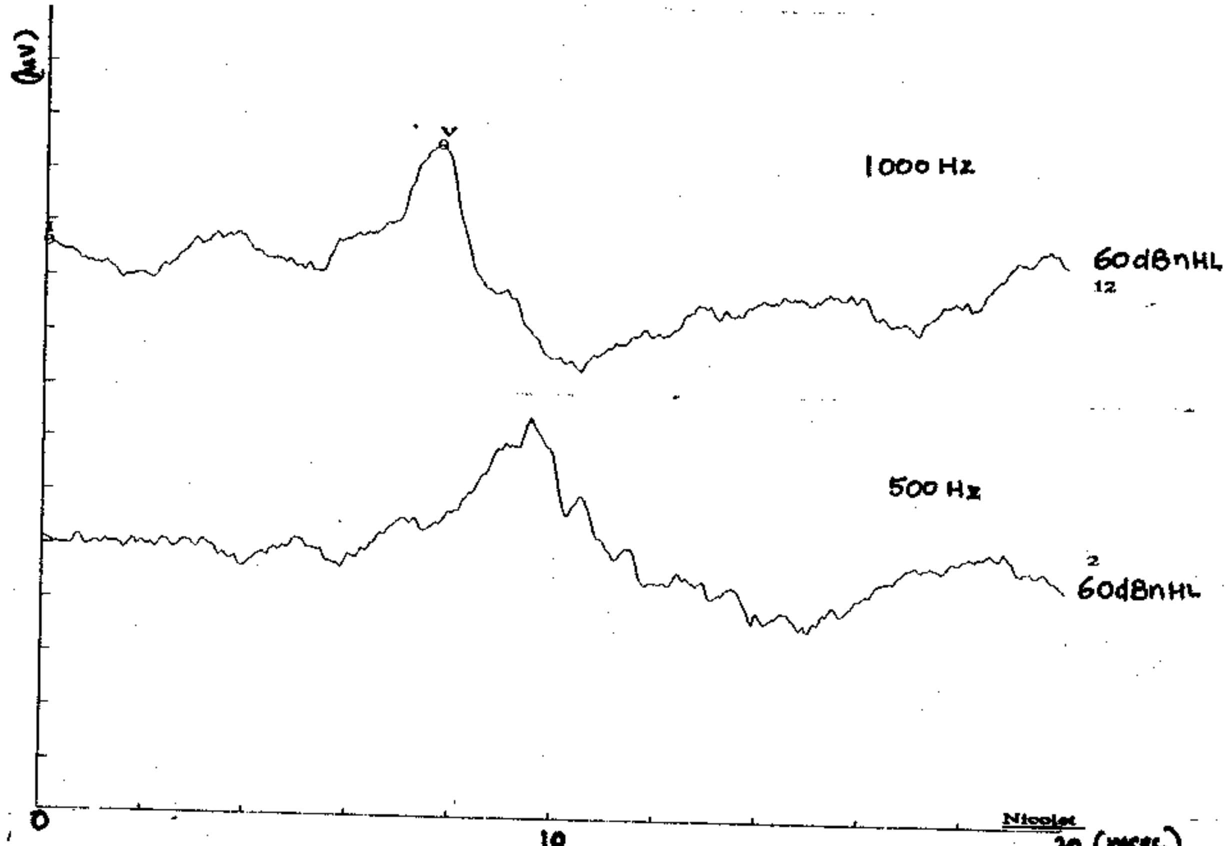


Figure 16 : ABR waveform to 1000Hz and 500 Hz tone burst at 60 dB nHL

identification of wave V for lower levels. Wave V could be identified over a wide range of levels. Although, less clear and rounded at low or near threshold levels, the response could be resolved on replication. While there was some variability in thresholds among subjects the overall morphology of these waveforms was quite comparable across subjects. The threshold was defined as the lowest intensity at which wave V could be measured. The data was found to be slightly more reproducible for 1 kHz tone burst than 500 Hz. as the artifacts were lesser for the former. At lower intensity levels the sharp definition of response peak diminished and a more gradual, rounded waveform was seen. Absolute latencies were measured for wave V on using clicks and 500 and 1000 Hz tone bursts stimuli at 60 dB nHL intensity.

These findings support those in literature. Gorga et al. (1988) had identified wave V over a wide range of levels, across octave frequencies from 250 Hz - 8 kHz. Data was found to be more reproducible at higher frequencies and at high intensity levels for any particular frequency. Gorga et al. (1988) reported little intra-subject variability for wave V latencies at any given frequency and level. The ABR wave morphology obtained in present study corresponded well with those obtained in their study. Stapells and Picton (1981) had also reported about the V-V' slow-wave seen in ABR with brief tonal stimuli.

(ii) Wave V latency function for clicks and tone bursts (500 HZ, 1 kHz)

The mean, SD and range of wave V latency function, from 13 normal hearing subjects, for clicks, 500 Hz and 1000 Hz tone burst at 60 dB nHL intensity level are represented in Table-1.

Wave V latency	**Stimulus**		
	Clicks	1000Hz	500 Hz
Mean	5.55	7.60	9.00
SD	0.1	0.54	0.89
Range	5.22 - 5.82	6.66 - 8.92	7.20 -9.96

Table-1 : Mean, S£> and Range for wave V latency for clicks and 500 Hz and 1000 Hz tone burst stimuli at 60 dB nHL.

The present data shows an increase in latency across clicks (5.55 msec) to tone bursts - 1 kHz (7.60 msec) and 500 Hz (9.00 msec) (Figure 1a,b). Statistical analysis using "difference method" to determine significance of difference between means was done on the data. The differences in mean wave V latencies between clicks, 500 Hz and 1 kHz tone bursts stimuli at 60 dB nHL were found to be statistically significant (at 0.01 level). This finding compares well with that in literature. Gorga et at. (1988) *reported* an increase in mean latency of wave V as the frequency was decreased. Their findings were as given below:

Frequency	Mean latency	Level
500 Hz	9 -10 msec	100 dB SPL
1 kHz	7-8 msec.	85 dB SPL

Since the data in their study was reported for intensity in SPL, SPL values equivalent to 60 dB nHL of present study were taken up for comparison of the results. The latencies of wave V reported for 500 Hz and 1 kHz tone burst in present findings compares well with those by Gorga et al. (1988).

Beattie et al. (1994) studied the effects of signal-to-noise ratio on the ABR response to tone burst in notch and broadband noise. They reported the following mean latencies for wave V in quiet for 1 kHz tone burst stimuli.

Intensity	Mean	SD
80dBnHL	7.02 msec	0.29
40dBnHL	10.49 msec	0.70

(0 dB nHL = 21 dB SPL)

In another study Beattie et al. (1994) reported the mean wave latencies for 500 Hz tone burst stimuli.

Frequency	Mean	SD
500Hz	7.21 msec	0.41
1 kHz	11.0 msec	0.67

(0 dB nHL = 26 dB SPL)

These studies indicate a systematic change in latency with change in frequency. This is supported by the present findings. The lower latency values for clicks in comparison to 500 Hz and 1 kHz tone burst could be attributed to the fact that response to click stimuli correlates best with responses in 2000 Hz - 4000 Hz region (Coats and Martin, 1977; Jerger and Mauldin, 1978). Since there is a decrease in wave V latency with increase in frequency of stimulus, the wave V latency for clicks (2000 Hz - 4000 Hz) would be shorter than that of 500 and 1000 Hz. tone bursts.

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 times for low frequency stimuli (500 Hz) could cause an increase in response latency. The more rapid rise times at higher frequencies (1 kHz) should result in greater amplitude of the response relative to the background noise due to greater discharge synchrony and also lower latencies. Moreover phase effects on AJBR 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).

These reasons can probably explain the present findings.

(iii) Comparison between ABR (500 and 1000 Hz tone burst) threshold and pure tone behavioural threshold.

The mean, SD and range values of auditory thresholds with 500 Hz and 1 kHz tone bursts are compared with corresponding behavioural thresholds in the Table-2. Data from 10 normal hearing subjects were considered for this study.

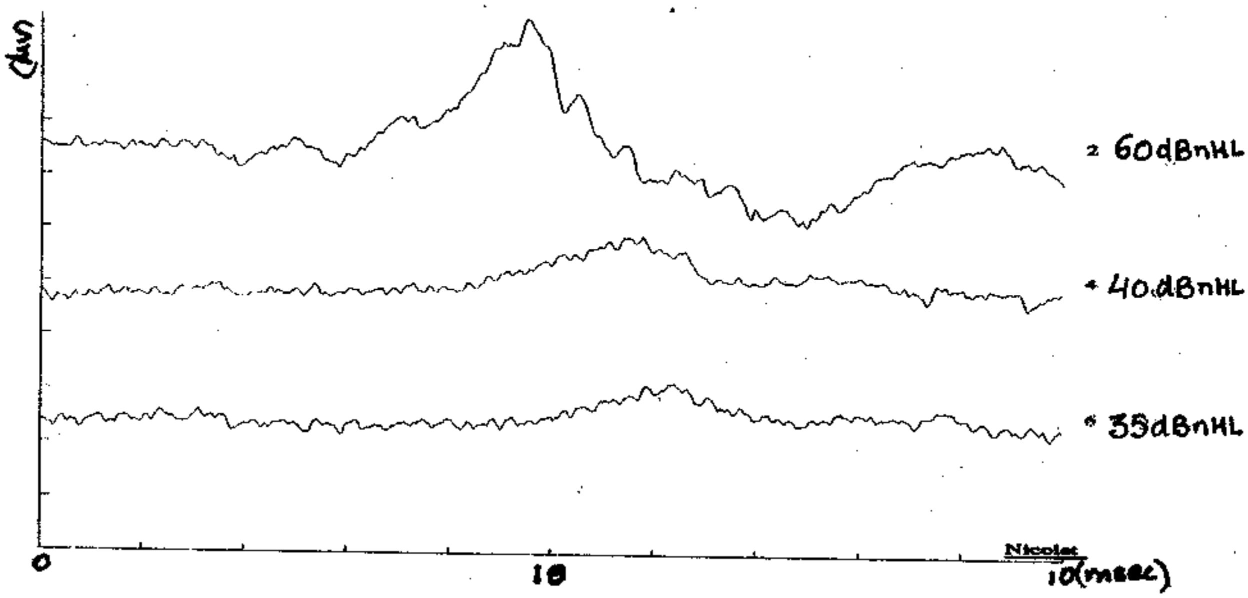


FIGURE 2a . THERSHOLD ESTIMATION FOR Hz TONEBURST STIMULI

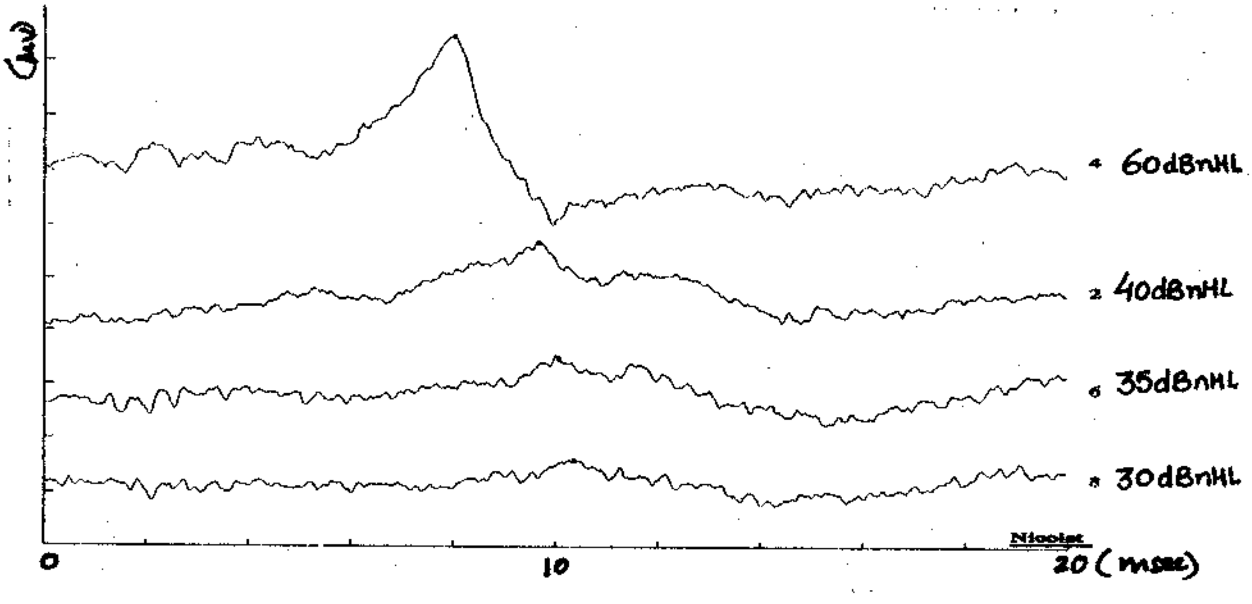


FIGURE 2.b. THERSHOLD ESTIMATION FOR 1000Hz TONEBURST STIMULI

	ABR Threshold (dBnHL)			Behavioural Threshold (dBHL)			Difference (dB)	
Frequency	Mean	SD	Range	Mean	SD	Range	Mean	SD
500 Hz	33.0	8.1	20-40	16.5	3.1	10-25	16.5	11.6
1000 Hz	27.0	3.3	20-30	15.0	6.3	5-25	12.5	6.8

Table-2: Mean and SD of ABR (in dB nHL), Behavioural thresholds (dB HL) and threshold differences between these measures for 500 Hz and 1 kHz tone burst.

From the data, it can be observed that ABR threshold were higher than behvioural thresholds for both 500 Hz and 1 kHz tone burst stimuli (Figure 2a, b). Gorga et al. (1988) had reported this trend using tone bursts across octave frequencies from 250 Hz - 8000 Hz. Suzuki, Kodera and Kaga (1982) compared ABR and behavioural thresholds for 500 Hz and 1000 Hz only and reported higher ABR thresholds for adult subjects.

In the present study, statistical analysis using difference method to determine significance of difference between two means was done. The mean difference between ABR and behvioural thresholds for 500 Hz and that for 1 kHz was found to be statistically significant at 0.01 level . The comparison between ABR thresholds and behaviour threshold were not made in dB SPL as the aim was to predict approximately at what dB nHL value, with respect to behavioural threshold, the ABR thresholds for normal hearing subjects is expected. Thresholds for 500 Hz were determined at higher dB nHL (Mean= 33.0 dB nHL) values than for 1 kHz (Mean

27.0 dB nHL). With respect to the behavioural thresholds, the ABR thresholds were higher for 500 Hz (Mean difference 16.5) than for 1 kHz (mean difference 12.5).

Gorga et al. (1987) reported a mean difference of 27.00 dB, (SD 7.75) at 500 Hz and 17.00 dB, (SD 6.32) at 1000 Hz between ABR and behavioural thresholds in dB SPL. The mean **ABR** threshold at 500 Hz was reported to be 43.3 dB SPL, (SD 7.53) and that at 1 kHz was 28.33 dB SPL,(SD 5.16). The behavioural threshold was 16.44 dB SPL (SD 5.16) for 500 Kz and 11.33 dB SPL (SD 4.08). Gorga et al. (1988) compared **ABR** and behavioural thresholds across 250 Hz - 8000 Hz tone burst stimuli. They reported that the differences between the two were greatest for low frequencies reaching 33 dB at 250 Hz and 500 Hz. At 1000 Hz the difference was 21 dB while for higher frequencies it was approximately 10 dB. These results also showed that variability (SD) was greater in low frequencies than at high values which matches with the present study findings.

There is a lot of variation in the values for mean difference between ABR and behavioural thresholds across studies. These differences could be attributed to procedural differences. Moreover, the value of nHL would differ across studies. The present study shows a similar trend in findings as reported in literature. The slight elevation in thresholds could be attributed to the ambient instrument generated noise.

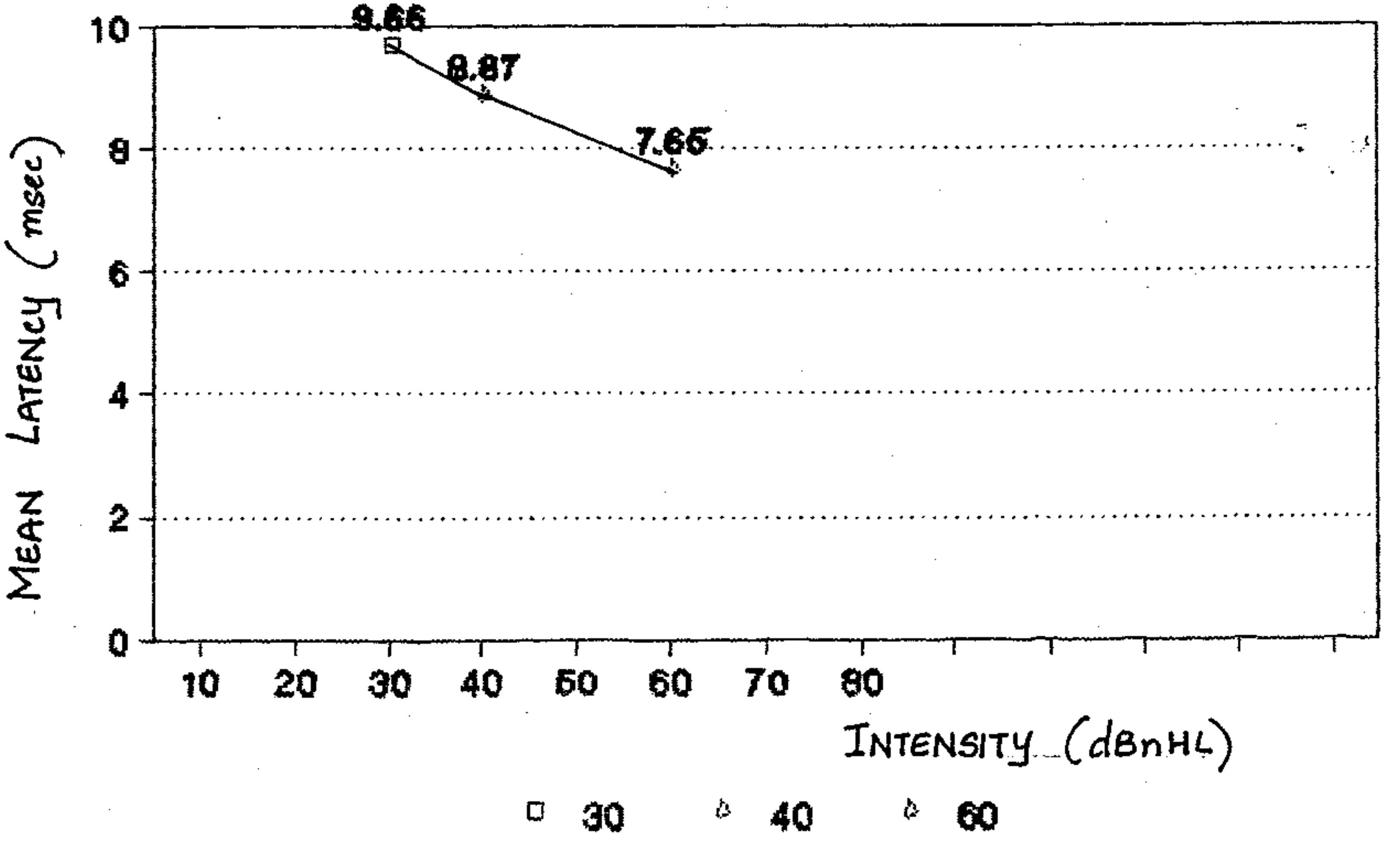
The observations made in the study could be accounted by the fact that more rapid rise times were used for high frequency (1000 Hz) tone burst without sacrificing stimulus frequency specificity. For lower frequency (500 Hz) shorter rise times were used. Gorga et al. (1988) had suggested that it is likely that more rapid rise time would result in better synchrony among individual neural responses which would result in better synchrony among individual neural responses and lead to a better signal to noise ratio for the response. Additionally it was suggested that the displacement of the basilar membrane is broader for low frequency stimuli and consequently neural discharges might be temporarily more diffuse. This could also have adverse effects on the response signal to noise ratio for low frequency threshold (Gorga, et al. 1988).

The present study compared ABR thresholds in response to short duration stimuli to behavioural thresholds in response to long duration stimuli. The principal clinical measurement of hearing sensitivity is pure tone audiogram which is measured in response to relatively long rise time long duration tones. In clinical application of ABR interest is greater for predicting the threshold that would be observed if a pure tone audiogram would have been measured. Because behvioural thresholds are not measured using short duration, stimuli for both measures do not provide the necessary data to test their relative sensitivity. Although the agreements between ABR and behvioural thresholds would be greater if short duration stimuli were used in obtaining the behavioural data, these are not the behavioural thresholds of greatest interest.

(iv) **The Latency-Intensity Function for 1000 Hz tone burst**

The trend for wave V latency-intensity function was studied at three intensity levels for 1000 Hz tone burst stimuli in nine normal hearing subjects. The mean, SD and range are given in the Table 3.

FIGURE -3 : **Latency - intensity function for 1kHz tone burst stimuli at 60, 40, 30 dB nHL**



	Intensity (in nHL)		
	60 dB	40dB	30 dB
Mean	7.65	8.87	9.66
SD	0.61	2.68	2.76
Range	6.66-8.92	7.78-10.08	7.96-10.52

This can be graphically represented as in the Figure 3.

The graphical representation of mean latency as a function of level for 9 normal hearing subjects depicts that there is a decrease in latency with increase in intensity level. The latency is seen to be greater near threshold (Figures 2a & b) levels. Though the data is not extensive and does not consider intensity in 10 dB decrement steps, it is useful in providing a picture of the trend of latencym intensity function. This data correlates with the findings in literature Gorga et al. (1988) reported the following data for 1000 Hz tone burst.

Intensity	Latency
60dB nHL	7-8 msec
40dB nHL	8-9 msec
3OdB nHL	8-9 msec

This was determined by converting the nHL value into SPL. Comparing the results between present study and that by Gorga et al. (1988) there is correlation between the results at these three intensity levels (60, 40, 30 dB nHL). Beattie et al. (1994) reported latency of 7.02 msec, (SD 0.29) at 90 dB nHL for 1000 Hz in quiet and 10.49 msec., (SD 0.78) at 40 dB nHL (nHL = 21 dB SPL).

The value at 80 dB nHL in this study would correspond with the 60 dB nHL intensity in present level the latencies of which have been found to be 7.02 m and 7.65 msec, respectively. Since the present study has corresponding value, the trend for other levels of intensity may also collaborate with that of literature.

Decrease in wave V latency with increase in level while frequency is held constant could result from a basal spread of excitation (Gorga, et al. 1988). Other factors may also contribute to the dependency of latency on level. Assuming that the neural response occurs when the stimulus envelope exceeds a certain amplitude, then this threshold amplitude will be reached earlier for higher levels of stimulation even though rise time is held constant (Gorga, etal. 1988).

The pattern of latency intensity function for 500 Hz could not be traced as the subjects thresholds were achieved at or above 30 dB nHL and corresponding comparison at the above three intensities could not be made.

There is some suggestion in the literature that the interpeak latency differences remain relatively constant as a function of frequency and level for stimuli exciting narrow frequency regions. This could not be verified in this study as components other than wave V were not observed clearly in response to tone burst.

SUMMARY AND CONCLUSION

The present study aimed at t

1. studying the ABR wave V latency function for clicks and tone bursts (500 Hz and 1000 Hz) at a constant intensity level (60 dB nHL) in normal hearing subjects.

2. comparison of auditory thresholds for ABR using 500 Hz and 1 kHz tone burst stimuli with behavioural thresholds for these frequencies in normal hearing subjects.

In the present study 13 subjects (5 males and 8 females) whose age ranged from 17-25 years, having normal hearing were tested. ABR waveforms were recorded using Nicolet Spirit Auditory evoked potential system (Software version 1.5). Pure tone behavioural thresholds were estimated using double channel $d diagnostic audiometer GSI 16 with TDH-50 headphones for air conduction testing. Bone conduction testing was carried out using a Radioear B-71 bone vibrator.

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 set at 20 ms with repetition rate of 11.4/sec. The stimulus had alternating polarity. Calibration was done using 10 subjects to convert SPL into nHL values prior to the study (Appendix).

A descriptive statistical analysis was used (mean, SD, range) along with 'difference method* for calculating significance of difference between two means. The results from the study are :

1. Tone bursts can be used to record ABR waveforms which have intra-subject reproducibility even at low intensity level.

2. On comparing the latencies of wave V for clicks and tone bursts (500 Hz and 1 kHz) at constant 60 dB nHL intensity. The data showed an increase in latency for clicks to 1 kHz tone burst to 500 Hz tone burst. This increase in latency was found to be statistically significant for the three stimuli at 0.01 significance level.

3. The **ABR** thresholds for 500 Hz and 1 kHz were found to be higher than the pure tone behavioural threshold. The **ABR** thresholds were higher for 500 Hz with respect to 1 kHz. On comparison, the difference between behavioural threshold and **ABR** thresholds were greater for 500 Hz. than the difference for 1 kHz. These results were statistically significant at 0.01 level.

4. The latency intensity function graph for 1000 Hz tone burst at intensities 60 dB nHL, 40 dB nHL and 30 dB nHL showed a pattern of increase in latency with decrease in intensity. The latency shift was longer near threshold level.

Implications of the study

The results of the present study could be used to predict the approximate behavioural threshold at 500 Hz and 1000 Hz from the **ABR** waveforms with 500 Hz and 1000 Hz tone bursts.

The results of the study could be used to develop the normative data for **ABR** recordings and threshold estimation using tone bursts.

The data obtained from normals could be used to compare with that for hearing impaired population.

Limitations

Due to limited number of subjects extensive analysis could not be done

Ambient noise due to ABR instrument could not be controlled in the test environment.

Comparison of tone burst and click waveform were done at only one intensity level

Age group undertaken was limited.

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APPENDIX

Calibration of Tonal Stimuli For ABR Testing

In conventional pure tone behavioural audiometry behavioural threholds are expressed in dB HL units whereas ABR 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 of ten normal hearing subjects (5 males, 5 females) were taken. The behavioural threshold for clicks, and tone bursts (500 Hz and 1000 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 reponses were observed. Their average behavioural threshold was taken as OdB nHL for that stimulus. The obtained values are

		Tone bursts	
	Click	500 Hz	1000 Hz
OdB nHL =	30 dB SPL	50 dB SPL	40 dB SPL.