Effect of Configuration of Audiogram on Auditory Brainstem Response

Reg. No. M9920

SURESHA B

A Dissertation Submitted in a part fulfillment of Final Year M.Sc (Speech and Hearing), University of Mysore, Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI

MYSORE-570 006

May - 2001

DEDICATION

I am humbly dedicating this "Yaga" - the great work,

Being the outcome of my efforts by concentrating my

mind, body, speech, behavior, sensitivity, energy,

hardwork, knowledge and thouqht,

To

"PUSHPA MA'AM"

who has given all the wealth, health and protection

throughout my speech and hearing career

and ro

"KAVERI PANT"

who has given me everything

expecting nothing in return.

CERTIFICATE

This is to certify that this dissertation entitled **"EFFECT OF CONFIGURATION OF AUDIOGRAM ON AUDITORY BRIANSTEM RESPONSE"** is a bonafide work in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student (Register No. M9920).

Mysore,
May, 2001

DIRECTOR
All India Institute of
Speech and Hearing.
Mysore - 570 006.

CERTIFICATE

This is to certify that this dissertation entitled **"EFFECT OF CONFIGURATION OF AUDIOGRAM ON AUDITORY BRIANSTEM RESPONSE"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any diploma or degree.

Guide

Mysore,
May, 2001

VANAJA. *C.S.*
Lecturer in Audiology,
Department of Audiology,
All India Institute of Speech & Hearing.
Mysore - 570 006.

DECLARATION

This dissertation entitled **"EFFECT OF CONFIGURATION OF AUDIOGRAM ON AUDITORY BRIANSTEM RESPONSE"** 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 not been submitted earlier in any other University for the award of any diploma or degree.

Mysore,

May, 2001 Reg. No. M9920

ACKNOWLEDGEMENTS

When I ruminate over the recent past, I find Vanaja Mam, my guide and teacher first amongst the very many whom I need to acknowledge Madam, "One looks back with appreciation to the brilliant teachers, but with gratitude to those who touched one's human feelings". To give an accurate and exhaustive account of my feelings would require for more a brilliant pen than mine. Do hands talk, on mind's behalf..... "Thank, you" is just not the word to conclude but rather a word to start and continue too........! Thank you madam.

I thank Dr. M. Jayaram, Director, AIISH, for permitting me to carry out this project at AIISH.

I thank Dr. S.R. Savithri and Mr. Jayaprakash .E. for their innumerable help and guidance through out my stay at AIISH.

I am indebted to all my teachers for the foundations they have given me and the faith they have in me.

I thank Dr. Asha Yathiraj, Dr.K.R. Rajalakshmi, Mrs.Manjula. P, Mr. Animesh Burman, Mr. Jobi and Mr. S ameer for their help rendered various junctures of this project.

I thank Dr. Lanci and Dr. Venkateshan for hefping me doing Statistics.

Arushi and Laxmi my postingmates thanks for your valuable guidance, support and encouraqement.

Naveen, Ajith, Vinag, Peru, Vijay and Beula - you had given me the real meaning of "friend" by sharing my ups and dips throughout my AIISH life.

It is my pleasure to thank Pambe for spreading fragrance of fun in my life and giving hefping hand whenever I needed.

I would like to thank Poornima, Sangeetha madam, Prachi, Jaya, Chandu and all other classmates for helping me directly or indirectly in completing this work.

My special thanks to Prakash and Savitha, my seniors who helped me a lot and gave this valuable guidance.

My thanks to library staff of AIISH, Mr. Lokesh, Mr. Mahadev, Mr. Sivaprakash and Mr. Subramanya for helpinq me in completinq the library work on time. Also I thank Mr. Shivappa and Mr. Basavaraj for gettinq me the beautiful copies of this dissertation.

My heartful thanks to my juniors Sivaprakash, Peter, Jayakumar and Rajkumar for helping in the whole process of this project and especially during data collection.

Thanks to Mr. Ramaswamy, Mr. Mahadev and Mr. Pande - our hostel cooks for providing me the healthy food, which gave all the energy to complete this project.

Last but not the (east my special thanks to Mr. Jagadeesh (Graphics Studio Works) and Mrs. Parimala for your nimble finger typing.

Investigator

TABLE OF CONTENTS

CHAPTER I

INTRODUCTION

The auditory evoked potentials are the electrical responses of the nervous system to auditory stimuli (Stapells, Picton, Abalo, Read, and Smith. 1985 cited in Jacobson.1994). AEPs are widely used for threshold estimation and neurodiagnosis. Auditor)' Brainstem Responses (ABR) to unfiltered clicks is one of the AEPs, that is used in a majority of clinics for threshold estimation. Although, a click, theoretically has energy- at all frequencies, the spectrum reaching the basilar membrane is shaped by the transducer and filter characteristics of the external and middle ears (Durrant, 1983). So, the energy concentration of the click reaching the inner ear is more between 2000 and 4000 Hz. Thus, though ABR can be used in prediction of thresholds, the click evoked ABR threshold does not give any information about the pattern of hearing loss.

Results of a majority of investigations have revealed that the ABR threshold correlates best with the average behavioral threshold of 2000 to 4000 Hz (Bauch and Olsen, 1986; Coats and Martin, 1977; Gorga and Thornton, 1989; Moller and Blegvad, 1976), but a few studies have shown that the ABR threshold also correlates with behavioral average threshold at other frequencies such as 1000 to 4000 Hz (Jerger and Mauldin, 1978), the frequency with best threshold between 1000 and 4000 Hz (Stapells., 1989).

Thus it is difficult to predict the configuration of audiogram based on click evoked ABR threshold.

A review of literature reveals that the audiometric configuration has an effect on different parameters of ABR. However, the results of various studies are equivocal. Some investigators demonstrated no change in wave latency with respect to configuration of hearing loss and also in I-V interval, in individuals with high frequency hearing loss (Rosenhamer., Lindstrom and Lundborg, 1981) whereas other investigators reported an increase in latency and I-V interval with sensory dysfunction (Abramvich and Billings, 1981 cited in Hall, 1992; Eggermont, Don and Brackman, 1980). Keith and Greville (1987) reported that the latency of wave I and wave V were affected differently by different patterns of hearing loss. The high frequency hearing loss group showed delayed wave I latency and normal wave V latency at high levels, whereas in individuals with low frequency hearing loss wave I latency was normal and wave V latency was shorter. They observed reduced I-V IWI in subjects with rising configuration and unchanged I-V IWI in subjects with sloping configuration. In subjects with flat hearing loss, latency of wave I. wave V and interpeak latency difference tended to be normal. In notched hearing loss group, wave I appeared at normal latency or earlier whereas wave V latency was delayed resulting in prolonged I-V interval.

A review of literature also shows that latency-intensity function of waves van' depending upon the audiometric configuration. A fundamental component of sloping hearing loss is the repeatedly described minimal latency increase in wave V at high stimulus intensity levels, despite moderate to severe hearing loss (Coats and Martin, 1977; Sohmer, Kinarti and Garni, 1981; Jerger and Mauldin, 1978; Brackmann and Selters, 1976 cited in Hall, 1992). This results in L-I function which is steeper than that of normals. The steepness of the L-I function increases as the magnitude of the hearing loss increases (Coats, 1978).

Keith and Greville (1987) described the L-I functions in subjects with different configurations of cochlear hearing loss. It was observed that the I-V interval was normal or reduced in subjects with high frequency loss due to delayed occurrance of wave I. On the other hand in patients with low frequency hearing loss, wave I occurred at latency similar to that of normals, but I-V interval was reduced as there was an early occurrence of wave V. They reported that interwave latency difference and L-I function for flat hearing loss group was similar to that of normals. In subjects with notched hearing loss, L-I function for wave I was similar to that of normals and wave V had steep L-I function giving rise to steep L-I function for I-V IPL difference. Thus, inter-peak latency difference and latency - intensity function will van" depending on the audiometric configuration.

Need for the study and Aim of the study:

The ABR to broad band clicks is widely used for threshold estimation. This click evoked ABR threshold does not give information about audiometric configuration. The commonly recommended electrophysiological procedure for obtaining frequency specific information from ABR is tone burst evoked ABR. But, this procedure is time consuming. If audiometric configuration could be predicted from ABR for broad band clicks, it would save a lot of time in clinical testing. A review of literature shows that it may be possible to predict audiometnc configuration based on click evoked ABR as there is a difference in contribution of basilar membrane to various waves of ABR (Keith and Greville, 1987). However, there are equivocal reports on effect of audiometric configuration on ABR. In this context, the present study was aimed to investigate the effect of audiometric configuration on the following parameters:

- Absolute latency of wave I, III and V at
- L-I function of wave I, III and V
- Inter wave interval I-V
- L-I function of IWI of I-V

CHAPTER II

REVIEW OF LITERATURE

The measurement of the scalp recorded Auditor}' Brainstem Response (ABR) to air conducted stimuli has become an integral part of audiological practice. It has been widely accepted that the basilar membrane is tuned to specific frequency along its length, with low frequencies represented more towards the apical portion, whereas high frequencies towards the basal area (Bekesy, 1960, cited in Hall., 1992). The frequency content of auditory stimulus is analyzed in the cochlea by several mechanisms. The travelling wave results in a place coding for frequency on the basilar membrane (Bekesy, 1960). The higher frequencies in the sound will lead to vibration only in the basal regions of the basilar membrane, whereas the lower frequencies will lead to vibration of all the regions of the basilar membrane, but mostly the apical regions. Thus, the audiometric configuration will vary depending on the site of damage on the basilar membrane. (Keith and Greville, 1987; Xu et al. 1998; Oates and Stapells, 1992; Rosenhamer et al., 1981).

A number of investigators have studied the ABR in patients with different audiometric configuration and the results indicate that the different configuration of the audiogram have differential effect on ABR (Keith and Greville, 1987; Xu et al. 1998; Oates and Stapells, 1992; Rosenhamer et al., 1981). A review of research on ABR in patients with different audiometric configuration is discussed here.

1. ABR findings in sloping hearing loss:

A majority of the patients with sensorineural hearing loss have sloping loss. Therefore, more number of studies have investigated the effect of sloping configuration on different parameters of ABR such as latency of different waves, interwave interval and latency-intensity' function.

i. Latency of wave V:

Oates and Stapells (1992) studied 103 patients (194 ears) with various degrees of cochlear impairment and found that the latency of wave V increased as hearing threshold at 4000 Hz increased. Bauch and Olsen (1986) studied the pure-tone hearing thresholds and ABR thresholds in sloping hearing loss cases and considered the sensitivity at 2000, 3000, and 4000 Hz; the data were collected from 458 patients of cochlear hearing loss. They reported that the pathology result in increased latency of wave V or distortion of the waveforms for many patients particularly when contribution from the region of basal portion of the cochlea was diminished. Supporting this, a good correlation between behavioural thresholds at 4000 Hz and the wave V latency has also been reported by man}' other investigators (Coats, 1978; Coats and Martin, 1977; Jerger and Mauldin, 1978; Moller and Blegvad, 1976; Rosenhamer et al., 1981). Keith and Greville (1987) reported an increase in the wave - V latency as slope of the audiogram increased.

ii. Wave V latency-intensity (L-I) function:

In subjects with sloping hearing loss of cochlear origin the L-I function was steeper than normals (Coats and Martin, 1977; Hall, 1992). A fundamental component of this pattern was the repeatedly described minimal latency increase in wave V at high stimulus intensity levels, despite moderate-to-severe sensory loss (Coats and Martin, 1977; Jerger and Mauldin, 1978; Brackman and Setters, 1977; Sohmer, Kinarti and Garni, 1981). The steepness of the L-I function increases as the magnitude of the hearing loss increases (Coats, 1978; Shepard, Webster, Bauman and Schuck, 1992; Oates and Stapells, 1992). Jerger and Johnson (1988) in their study on a large series of patients with sensor}' hearing impairment, reported that latency was stable for hearing loss upto 60 dB HL, and then it increased linearly to a maximum of about 0.4 msec, through 90 dB HL, with most pronounced latency change in patients with hearing loss more than 70 dB HL. In agreement to this, Kirsh et al. (1992) also reported a steep L-I function for wave V in subjects with sloping hearing loss. Keith and Greville (1987) studied L-I function for wave V in patients with high frequency hearing loss, and reported that wave V tended to be delayed at low intensities but was normal or near normal at high levels.

iii. Wave I:

It has been also reported in literature that the wave I is affected in subjects with sloping hearing loss (Watson, 1996; Kirsh et al., 1992; Keith and Greville, 1987), Watson (1996) studying 201 patients with sensorineural hearing loss of various degrees reported that the wave I displayed latency extension with increasing levels of high frequency hearing loss, whilst for wave V, increase in latency was dependent upon both degree and slope of hearing loss. Based on the results of a detailed study, Keith and Greville (1987) reported that the wave I latency in high frequency hearing loss group was delayed at all the intensity levels. The same results were also reported by Kirsh et al. (1992).

iv. *I-V Interwave latency:*

There is a controversy regarding the effect of high frequency hearing impairment on the interwave (I-V) latency interval of ABR. Some investigators demonstrated no change in I-V interwave interval values with high frequency hearing loss (Rosenharrmier et aL 1981; Abramovich and Billings, 1981; Eggermont et aL 1980). Rosenhammer et al. (1981) recorded the I-V and III-V interwave interval in 110 ears with cochlear hearing loss of various audiometric configuration and etiologies. In 77 subjects with high frequency hearing loss, the changes in I-V and III-V IWI were found to be insignificant. Keith and Greville (1987) observed unaltered I-V interwave interval in their subjects with high frequency loss. On the contrary a few investigators report a significant decrease in the interwave latency difference in patients with high frequency sensory impairment (Coats and Martin, 1977; Struzebecher et al., 1985). Evaluating thirty seven cochlear impaired subjects with sloping hearing loss, Struzebecher et al. (1985) reported that I-V interwave interval reduced as stimulus intensity increased. Coats and Martin (1977) in their study using simultaneous recording of ECochG and ABR also found that the interwave latency difference between wave N_1 and wave V was reduced in subjects with high frequency hearing loss. The reason attributed for this differential effects was opined that usual major components of wave I were absent because of pathology in the high frequency region and the wave I was comprised of only later components from lower frequency regions leading to reduction in amplitude. Wave V, less dependent on the basal region, was less affected except at intensities approaching threshold.

The hypothesis that the wave latencies are determined not only by neural generators but by the area of activation in the cochlea too was supported by Gorga et al. (1985). They reported I-V IPL to be just below the normal range in a subject with high frequency conductive hearing loss of mild to moderate severity. They also observed a steep L-I function for the wave V. They attributed this to be basal spread of excitation at high intensities.

Thus, there is a consonance among investigators regarding the increase in absolute latency of wave V, wave I and steeper than normal latency-intensity function of both the waves. But controversy exists about I-V interwave interval. Some researchers demonstrated reduction in I-V IPL (Coats and Martin, 1977; Gorga et al., 1985) and others opine that there was no change in interwave interval (Rosenhammer et al., 1981; Eggermont, Don, and Brackmann, 1980 cited in Hall 1992; Keith and Greville, 1987).

2. ABR finding in rising hearing loss:

Generally low frequency or rising hearing loss is seldom detected by click evoked ABR (Hall, 1992). Hence there are very few studies describing ABR in subjects with low frequency hearing loss. Rosenhamer et al. (1980) measured wave V latency and I-V and III-V IWI at 80 dB nHL (for unfiltered clicks of alternative polarity) in 11 ears with rising cochlear hearing loss. They reported an increase in wave V latency related to the hearing loss at high frequencies but there was no significant increase of interwave intervals. However, Keith and Greville (1987), studied 8 ears (7 subjects) with low frequency sensorineural hearing loss and reported that wave V latency was reduced whereas wave I latency was unaffected resulting in shortened interpeak intervals. This difference was more evident at low levels than high levels. Probably, similar results would have been observed if Rosenhamer et al., (1980) had recorded ABR at low intensities.

3. Subjects with Flat hearing loss:

If the hearing loss is flat or only mildly sloping, and mild-to-moderate in severity, then the effect of hearing loss on the ABR for high level stimuli are substantially reduced. The latency of waves are essentially equivalent to those collected at the same intensity level in normal hearing subjects (Sellers and Brackmann, 1977). Galambos and Hecox in 1978 (cited in Hall 1992), reported that in subjects with that sensory hearing loss, the ABR thresholds were elevated as in case of conductive hearing loss and the L-I function for wave V had a steep slope, that is, the latency values were prolonged at low intensities, but approached normal values at high intensities.

Coats (1978) evaluated 37 cochlear-impaired ears and found that the ABR threshold increased with increase in behavioral threshold at 4000-8000 Hz region. These results agree with the other reports in literature that ABR wave V latency increases as hearing loss at 4000 Hz increases (Coats and Martin, 1977; Jerger and Mauldin, 1978; Moller and Blegvad, 1976; Rosenhamer, Lindstrom and Lundborg, 1981). Other investigators have observed that the increase in the latency of ABR wave V in ears with sensory impairment was relatively lesser for flat losses than that for sloping audiometric configuration. (Jerger and Mauldin, 1978: Moller and Blegvad, 1976).

Keith and Greville (1987) found that both wave V and wave I were equally affected by flat hearing loss. Based on a study of 44 ears (38 subjects) with flat sensory hearing loss they reported that the wave V latency was prolonged corresponding to the amount of hearing loss. But contrary to earlier findings they reported that the L-I functions for wave V and IWI was similar to that of normals. In 22 ears with flat hearing loss, Rosenhamer et al. (1981) measured interwave interval (I-V and III-V) difference at 80 dB nHL. The increase in wave V latency was related to severity of hearing loss and there was no significant change in wave intervals.

Gorga, Reiland and Beauchaine (1985) opined that the latency of wave V at high intensity was related to the region of the cochlea which predominated in the response. In normal hearing subjects and subjects with mild-to-moderate flat hearing loss, the latency of wave V at high intensities is determined by the basal regions of the cochlea. At low intensities, the latency of wave V is dominated by slightly more apical regions of the cochlea.

To summarize, in subjects with flat hearing loss, the latency of both wave I and wave V are prolonged depending on severity of sensory loss and interwave interval remains unaffected. The findings regarding slope of L-I function of wave V are equivocal. Few investigators have reported steeper slope than normals and less steeper than sloping losses (Jerger and Mauldin, 1978; Moller and Blegvad, 1976), whereas others have reported L-I function similar to that of normals (Keith and Greville, 1987).

4. ABR findings in subjects with notched hearing loss:

It has been reported in the literature that the hearing loss restricted to only one of the high frequencies result in abnormalities of ABR (Keith and Greville, 1987; Bauch and Olsen, 1986; Saha, 1999). Bauch and Olsen (1986) studied the ABR in patients with dip at 4000 Hz. They reported that ABR was normal till the hearing loss was restricted to 4000 Hz and was not more than mild in degree. If the loss extended to 3000 Hz and hearing loss at 4000 Hz was more than 40 dB HL, the latency of wave V was prolonged. Similar results were observed by Xu et al. (1981). Keith and Greville

(1987) reported that in their subjects with notch between 3000 Hz-4000 Hz, a prolonged V wave and an earlier I wave was seen. This resulted in an increase in the I-V IWI. Saha (1999) simulated 4000 Hz dip in 30 normal subjects and found that absolute latency of wave V, III and interpeak latency difference (I-V and I-III) was increased. There was also an increase in V/I amplitude ratio. He also reported a decreased absolute latency of wave I.

Thus, the striking feature in subjects with notched hearing loss is delayed wave V and early occurrence of wave I resulting in prolonged I-V interwave interval. The results would vary if the notch is at a frequency other than 4000 Hz.

Physiological explanation for the effect of audiometric configuration on ABR:

The possible reason for this effect of audiometric configuration on ABR is the difference in cochlear contribution for various waves of ABR. It has been reported that wave V *is* influenced by a wide portion of basilar membrane, whereas wave I is dependent on activity' in the basal region of the cochlea (Klein, 1986; Goldstein and Kiang, 1958; Xu et al., 1998; Keith and Greville, 1987; Struzbecher et al, 1985; Sohmer et al., 1981; Don and Eggermont, 1978). Klein (1986) studied the location of generation of wave I and wave V using the masking paradigm, using a 4000 Hz tone pip as stimulus. It was observed that wave I was more sensitive to high frequency maskers than wave V. Latency of wave I was severely affected by

5000-8000 Hz high pass masking noise where as wave V showed a marked increase in latency with 5000 Hz low pass noise. On the other hand a low pass noise with cut-off frequency slightly above 4000 Hz had no effect on the wave I latency or amplitude. Xu et al., (1998) studied TEOAE and ABR patterns in 22 subjects (44 ears) with noise induced permanent hearing loss and reported that the wave V latency increased when the hearing loss increased from the region of 4000 Hz to 1000 Hz. Thus indicatmg wider contribution of cochlear portion for wave V generation. Don and Eggermont (1978) studied ABR responses to 60 dB SL clicks in noise, which was high passed at various cut-off frequencies. They reported that waves I, III and V to unmasked clicks are normally determined by activity in the basal 2-3 octaves of the cochlea, but with high pass noise masking, a relatively large contribution to wave V from frequencies as low as 400 Hz can be demonstrated. A study of the action potential (AP) and wave V to tone burst stimuli indicated that wave V is generated on the basilar membrane at a location closely related to stimulus frequency, in contrast to wave I which is determined by high frequency units in the basal area on basilar membrane. (Terkildsen, Osterhammel and Huis in't veld 19?5,cited in Keith and Greville, 1987).

Thus, a review of literature shows that the latency of ABR waves may be differentially affected by different configuration of audiogram. But the results of various studies are equivocal. Therefore, the present study was designed to study if there is a definite pattern of results in subject with different configuration of audiogram.

CHAPTER III

METHODOLOGY

The present study was aimed at studying the effect of audiometric configuration on the following parameters:

- Absolute latency of wave I, III and V
- L-I function of wave I, III and V
- Interwave interval I-V
- L-I function of IWI of I-V

A. Subjects:

Data was collected from eighty ears with hearing impairment. Subjects who met the following criteria were selected for the study;

- Age range: 18 - 55 years.
- Should not have any middle ear pathology.
- No signs or indications of retrocochlear pathology.
- Negative history of psychological problems.
- Genera] health should be good at the time of testing.
- Subject should be able to relax and fit without any extraneous movements at the time of testing.

Based on the configuration of audiogram, the data was grouped into four categories as shown in Table la.

Table 1a: Showing details of subjects included for the study.

Sl. No.	Type	Description	No. of ears
1.	Flat	• <5 dB Rise/fall per octave • The difference between behavioral thresholds at 4000 Hz and 500 Hz was ± 10 dB	21
2.	Sloping Hearing loss	• 5 - 12 dB increase in threshold • The difference between thresholds at 8000 Hz and 2000 Hz was least 20 dB and between 8000 Hz and 4000 Hz was atleast 10 dB.	33
3.	Rising hearing loss	• 5 - 12 dB decrease in threshold per octave • The difference between thresholds at 8000 Hz and 2000 Hz was at least 20 dB and between 8000 Hz and 4000 Hz was atleast 5dB.	16
4.	Notched hearing loss	Dip of atleast 20 dB at 4000Hz.	10

B. Instrumentation:

The following instruments were used for the study;

- A calibrated two channel audiometer with earphones and bone vibrator.
- A calibrated immittance meter.
- Auditory evoked potential system, Biologic Navigator with software EP-317.

C. Test procedure:

Pure tone audiometry was conducted using a clinical two channel audiometer in a sound treated booth. Pure tone audiometry included assessment of thresholds at octave frequencies from 250 Hz to 8000 Hz for air conduction and from 250 Hz to 4000 Hz for bone-conduction testing, using modified Hughson and Westlake method. Before initiation of the test a detailed case history was taken.

Immittance evaluation:

Immittance evaluation included tympanometry and measurement of ipsilateral and contralateral acoustic reflex threshold at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

ABR testing:

a. Instructions:

The subjects were instructed to "Sit comfortably and relax", on a chair facing away from the instrument. They were instructed to avoid extraneous movements of head, neck, and limbs for the duration of test.

b. Electrode placement:

Four silver chloride disc type electrodes were used for recording ABR. The non-inverting electrode was placed on vertex, inverting electrodes were placed on the mastoid of right and left ear with the common electrode on the forehead. The electrode sites were first cleaned by scrubbing with cotton wool dipped in skin preparing paste. Adequate amount of conduction material and a piece of plaster were used to stick the electrodes. It was ensured that the electrode impedance was ≤ 5 kΩ at each sites and the mterelectrode impedance was ≤ 2 kΩ. TDH–39P earphones were then placed without dislodging the electrodes. The data acquisition of ABR was recorded using the parameters showed in Table 1b.

Table lb: Showing parameters for ABR recording.

General set-up	Amplifier set-up	Channel -1	Channel - 2
Test: AEP	Gain	75,000	75,000
No. of channels:2	Band pass filter	100 Hz-1,500 Hz	100 Hz-1,500 Hz
	Notch	Out	Out
	Artifact	Enabled	Enabled
	Montage	Cz/Ml	Cz/Ml

1500 rarefaction clicks were presented through TDH-39P supraaural headphones. The stimuli were presented at the rate of 11.1/sec. The ipsilateral and contralateral ABR waveforms for clicks were recorded first at 90 dB nHL (0 dB nHL = 40 dB SPL), and then the intensity was reduced in 10 dB steps till ABR threshold was obtained. ABR threshold was defined as the minimum level at which wave V could be detected. The waveforms obtained from the subjects were stored and data was analyzed to investigate the aims of the study.

CHAPTER IV

RESULTS

The objective of the study was to examine the effect of audiometric configuration on ABR. ABR was recorded from subjects with different configuration of hearing loss at 90 dB nHL and ABR threshold was obtained by decreasing intensity in 10 dB steps until there was no response. The waveforms at each intensity was analyzed in terms of absolute latency of waves I, III, V and interwave intervals (I-III, III-V and I-V). The latency intensity functions were derived for absolute latency as well as interwave intervals. Following statistical analysis were carried out on the obtained data, which was divided into four groups based on the configuration of the audiogram.

a. Mean and Standard deviation was calculated for absolute latency as well as interwave interval at 80 dB nHL.
b. One-way ANOVA was carried out to find the main effect of configuration of hearing loss on each of the parameters. If there was a main effect, Duncan's post hoc test was used to study the differences among the groups.
c. Regression analysis was carried out to find out the slope of L-I functions for each group separately.

To investigate the effect of configuration when the severity of hearing loss was controlled, the data collected was divided into following sub groups depending on the ABR threshold.

Group 1: ABR threshold less than or equal to 40 dB nHL

Group 2: ABR threshold between 50 and 60 dB nHL

Group 3: ABR threshold greater than or equal to 70 dB nHL

I. A. **Absolute latency of Wave** V:

Table 2 Shows the mean absolute latency and standard deviations of wave V for four patterns of configuration. Inspection of the table shows that the latency value was maximum for subjects with notched configuration and least for those with rising configuration. Analysis of variance showed a significant main effect at 0.03 level (F = 5.197). Duncan's post-hoc test (Table 3) revealed that absolute latency for subjects with rising configuration of audiogram was sigmficantly shorter than that of the other groups. On the other hand subjects with notch at 4 kHz had slightly longer latency when compared with the other groups. There was a overlap in the absolute latency values obtained for subjects with sloping and flat hearing loss

Table 2: Showing Mean latency (M) and standard deviation (SD) for wave V at 80 dB nHL (N = No. of ears).

Configuration	N	Latency of wave - V (in msec)	
		M	SD
Sloping	33	5.779	0.134
Rising	16	5.523	0.257
Flat	21	5.737	0.299
Notched	10	5.875	0.134

Table 3: Showing the results of Duncan's post - hoc test for wave V at 80 dB nHL (N = No. of ears).

Group	N	Sub test for alpha = 0.05		
		1	2	3
Sloping	33		5.77	
Rising	16	5.52		
Flat	21		5.73	
Notched	10			5.87

2. Absolute latency of wave III:

Table 4: Showing Mean latency (M) and standard deviation (SD) for wave III at 80 dB nHL (N = No. of ears).

Configuration	**N**	**Latency of wave -III(in msec)**	
		M	SD
Sloping	33	4.043	0.344
Rising	16	3.776	0.268
Flat	21	3.781	0.188
Notched	10	3.790	0.100

Scrutinizing the Table 4 reveals that the three groups rising, flat and notched hearing loss had almost similar latency values, whereas the latency was delayed in subjects with sloping configuration (Mean latency = 4.043 msec). ANOVA showed a main effect which was significant at 0.02 level (F = 5.440), but the Duncan's post hoc test showed that only subjects with sloping hearing loss had significantly different value when compared to that of the other three groups. The results of Duncan's post hoc test are shown in Table 5.

Table 5: Duncan's post - hoc test for wave III at 80 dB nHL.

Group	N	**Sub test for alpha = 0.05**	
		1	**2**
Rising	16	3.776	
Flat	21	3.781	
Notched	10	3.790	
Sloping	31		4.04

3. Absolute Latency of wave I:

Table 6: Showing Mean latency (M) and standard deviation (SD) for wave I at 80 dB nHL (N = No. of ears).

Configuration	N	Latency of wave - I (in msec)	
		M	SD
Sloping	26	1.933	0.207
Rising	16	1.615	0.197
Flat	16	1.838	0.215
Notched	10	1.604	0.203

Table 6 shows the mean latency and standard deviation for wave I for the four groups. It is evident from the table that the latency in subjects with rising hearing loss and notched hearing loss were near normal, while the latency for subjects with flat and sloping category was delayed (1.83 and 1.93 msec respectively). ANOVA revealed a main effect at 0.000 level (F = 12.643). Duncan's post-hoc test (Table 7) showed that there was no significant difference between latency of wave I in subjects with notched and rising configuration, but the latency values obtained in these groups were significantly different from that obtained for subjects with sloping and flat configuration. There was no difference between latency obtained for subjects with sloping and flat audiometric configuration.

Table 7: Duncan's post - hoc test for wave I at 80 dB nHL.

Group	N	Sub test for alpha = 0.05	
		1	2
Notched	10	1.604	
Rising	**16**	1.615	
Flat	**16**		1.838
Sloping	26		1.933

4.I-III interwave interval (I-III IWI):

Inspection of Table 8 reveals that the IWI for I-III was delayed for subjects with rising and noted audiometric configurations. ANOVA showed significant variations among the groups at 0.016 level (F = 3.723). The Duncan's post-hoc test (Table 9) revealed that the two groups i.e., subjects with rising and notched configurations were significantly different than other two groups of subjects. But there was no significant difference between subjects with sloping and flat configuration or between subjects with rising and notched configuration.

Table 8: Showing Mean I-III IWI and SD for four configurations at 80 dB nHL (N = No. of ears).

Configuration	N	**I-III IWI (In msec)**	
		M	SD
Sloping	26	1.920	0.23
Rising	16	2.161	0.20
Flat	16	1.989	0.24
Notched	10	2.186	0.14

Table 9: Duncan's post-hoc test for I-ffl IWI at 80 dB nHL.

Group	N	Sub test for alpha = 0.05	
		1	2
Sloping	26	1.920	
Rising	16		2.161
Flat	16	1.989	
Notched	10		2.186

5. III-V interwave interval (III-V IWI):

Table 10: Showing Mean III-V IWI and SD for four configurations at 80 dB nHL (N = No. of ears).

Configuration	N	**III-V IWI (In msec)**	
		M	**SD**
Sloping	31	1.809	0.23
Rising	16	1.747	0.25
Flat	17	1.929	0.32
Notched	10	1.982	0.15

Scrutinizing the Table 10 reveals that the III-V IWI was maximum for subjects with notched audiogram configuration and lowest for subjects with rising configuration. However, results of ANOVA revealed that the difference was not statistically significant ($F = 2.601$, $p > 0.05$ level). Comparison of these values with that of absolute latency of wave III and V waves for respective configuration indicated that the prolongation of III-V IWI in subjects with notched configuration was caused by delayed response of wave V. Early occurrence of wave V in subjects with rising configuration had given rise to shortened III-V IWI.

6.I-V interwave interval (I-V IWI):

The interwave interval (IWI) between waves I and wave V at 80 dB nHL are depicted in Table 11. The IWI was maximum obtained for subjects with notched configuration. The IWI was nearly same for subjects with rising and sloping configuration. Examining these results along with the absolute latency of wave I and wave V of corresponding configuration revealed that the prolongation of I-V IWI in subjects with notched configuration was because of reduction of wave I latency and delayed occurrence of wave V. The reduced I-V IWI in subjects with rising configuration was because of early occurrence of wave V but on the other hand in subjects with sloping configuration delayed latency of wave I resulted in reduced IWI. ANOVA showed that the difference was significant at 0.013 level ($F=3.876$). The Duncan's post-hoc test revealed that only IWI in subjects with notched configuration were significantly different from the other three groups (Table 12).

Table 11: Showing Mean and SD for I-V IWI and at 80 dB nHL (N = No. of ears).

Configuration	N	I-V IWI (in msec)	
		M	SD
Sloping	26	3.868	0.279
Rising	16	3.862	0.165
Flat	16	3.908	0.321
Notched	10	4.168	0.147

Table 12: Duncan's post-hoc test for I-V IWI at 80 dB nHL.

Group	**N**	**Sub test for alpha = 0.05**	
		1	**2**
Sloping	26	3.868	
Rising	16	3.862	
Flat	16	3.908	
Notched	10		4.1678

B. Latency-Intensity functions (L-I function):

1. L-I function / slope of wave V:

The L-I functions for wave V for subjects with different audiogram configurations are shown in Figure 1. It can be observed from this figure that all the groups presented with the similar L-I functions and hence could not be separated based on the visual inspection. The slope of the L-I function (in usec/dB), derived using regression analysis indicated that the L-I function was steeper in subjects with notched configuration (37 usec/dB). The slope was 33 usec/dB, 30 usec/dB and 28 usec/dB for subjects with sloping, flat and rising configurations respectively.

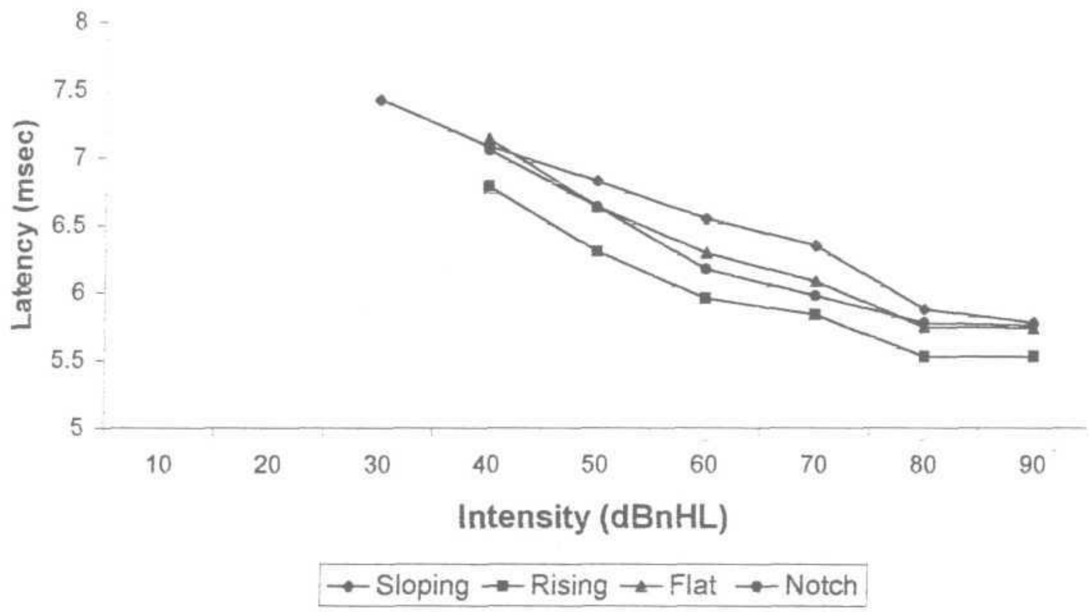


Figure 1: Showing L-I function for wave V across the configurations.

2. **L-I function / slope of waves III:**

Figure 2 depicts the L-I function for wave III for subjects with different audiometric configurations. The regression analysis carried out revealed a slope of 20 usec/dB, 23 usec/dB, 28 usec/dB, and 19 usec/dB for subjects with sloping, rising flat and notched configurations respectively. Thus, the slope was maximum for subjects with flat configuration and lowest slope was obtained for subjects with notched configuration.

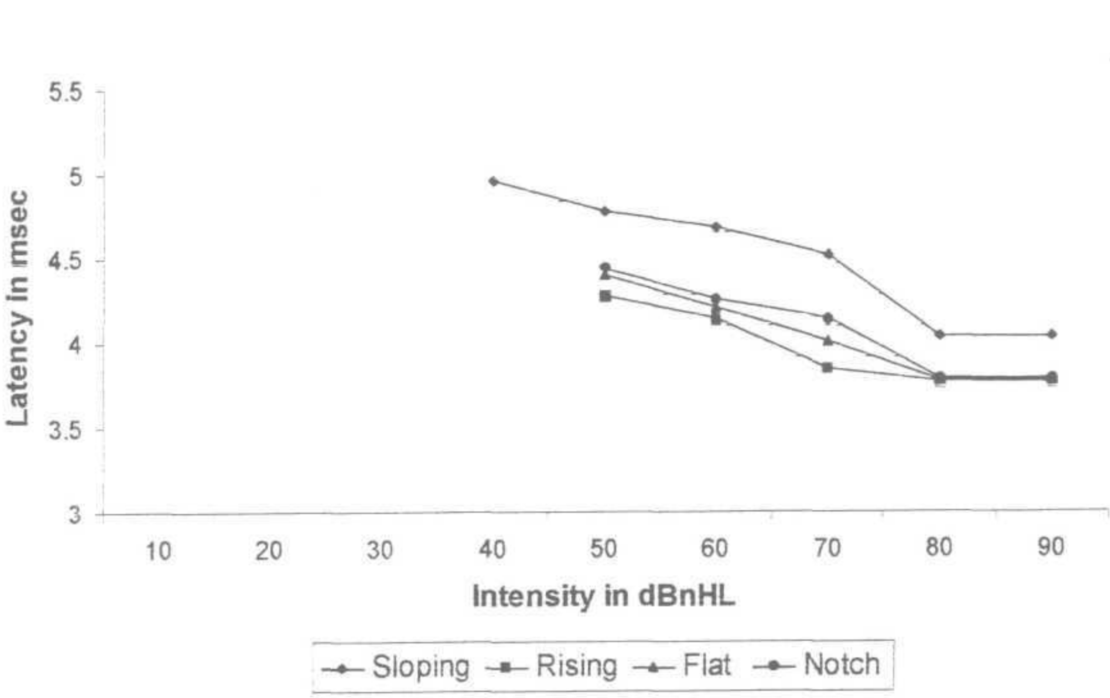


Figure 2: Showing L-I function for wave III across the configurations.

3. Slope of wave I:

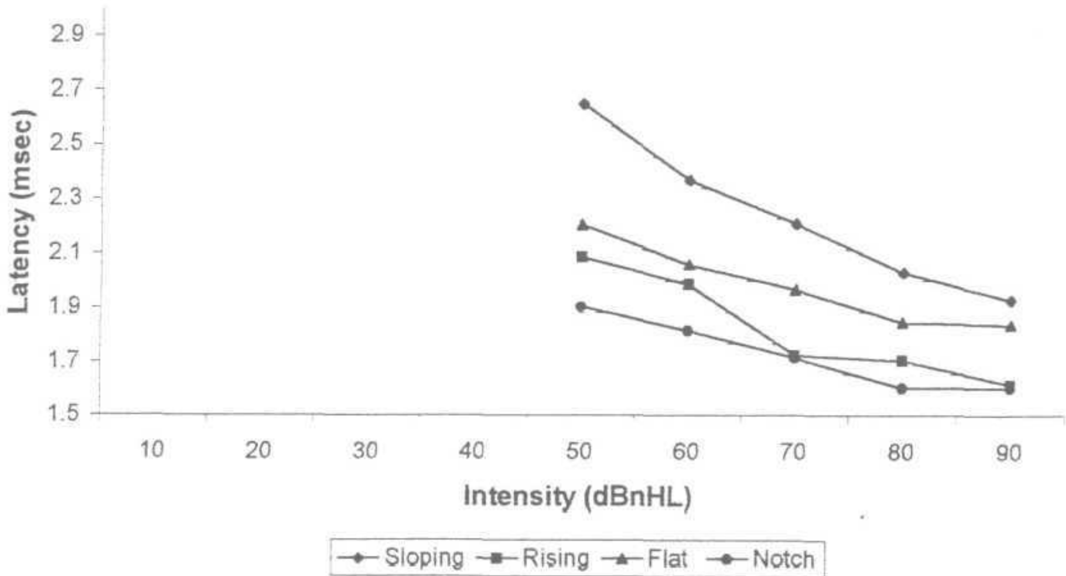


Figure 3: Showing L-I function for wave I across the configurations.

It can be observed from Figure 3 that the L-I function for wave I for subjects with sloping configuration was steeper than that of others. The slopes obtained using regression analysis were 21 usec/dB, 14 usec/dB, 11 usec/dB, and 10 usec/dB for subjects with sloping flat, rising and notched configurations respectively,

4, Slope of I-III IWI:

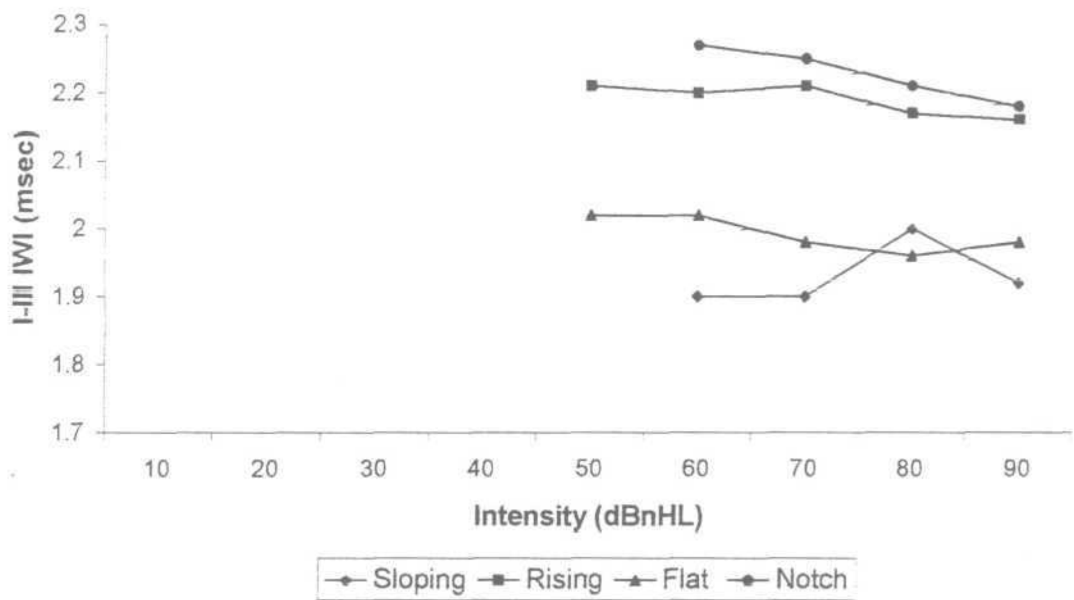


Figure 4: Showing L-I function for I - I I I IWI across the configurations.

Inspection of Figure 4 reveals that there was a slight increase in IWI with reduction in intensity and this change was greater for subjects with rising configuration. The slopes obtained by regression analysis were 2 usec/dB, 7 usec/dB, 5 usec/dB, and 2 usec/dB for subjects with sloping, rising, flat and notched configurations respectively.

5. Slope of **III-VIWI:**

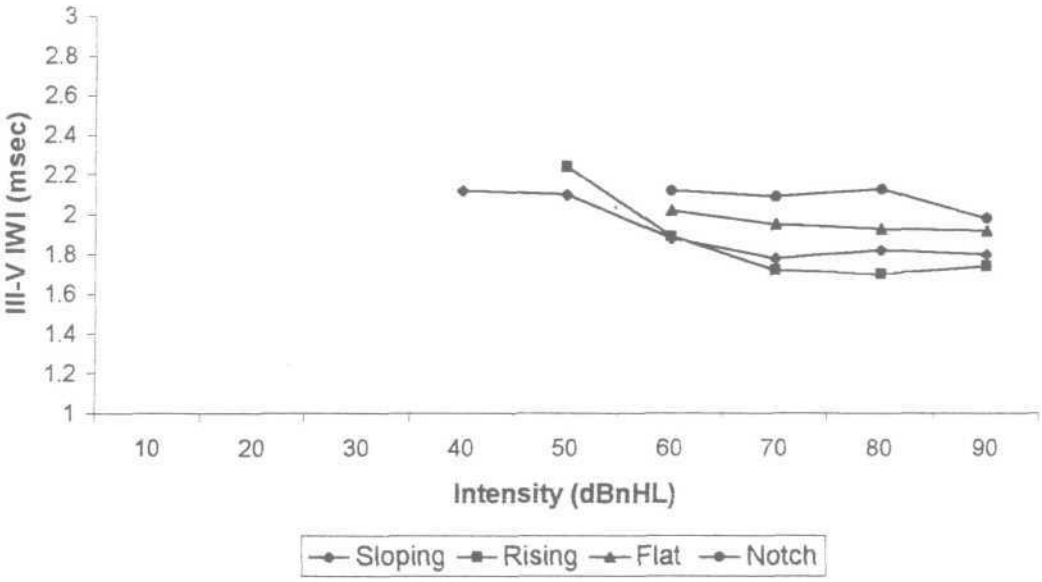


Figure 5: Showing L-I function for III-V IWI across the configurations.

Inspection of Figure 5 reveals that there was no definite trend for L-I function of III-V IWI. Hence the slopes were not calculated. But at lower levels there was an increase in interwave interval for all configurations.

6. Slope of I-V IWI:

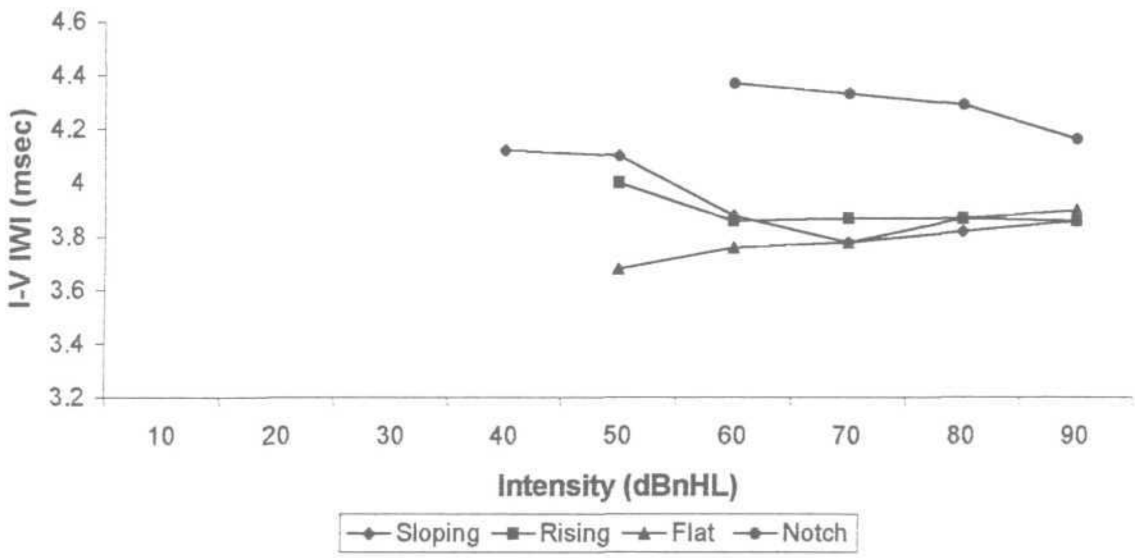


Figure 6: Showing L-I function for I-V IWI across the configurations.

A definite trend was observed for L-I function of I-V IWI (Figure 6). In subjects with sloping configuration, at high intensity I-V IWI did not change, but an increase in interval was observed at low levels. Similar changes were observed in subjects with rising configuration. There was a clear and gradual increase of IWI in subjects with notched hearing loss giving rise to increased IWI at low levels. The slopes obtained were 9 usec/dB, 3 fisec/dB, 6 fisec/dB, and 10 fisec/dB, for subjects with sloping, rising, flat and notched configurations respectively.

II. To study the effect of severity of hearing loss the group data was divided into three subgroups based on ABR threshold. The statistical analysis carried out for the combined group was repeated for the subgroups.

A. **1. Absolute latency of waves I, III and V:**

Table 13: Showing the M and SD for various peaks at 80 dB nHL for Group 1.

Category	**Absolute latency in msec**					
	I		III		V	
	M	SD	M	SD	M	SD
Sloping	1.853	0.21	3.902	0.24	5.690	0.33
Rising	1.613	0.07	3.673	0.11	5.520	0.12
Flat	1.813	0.06	3.765	0.17	5.646	0.23
Notched	1.600	0.31	3.802	0.10	5.760	0.13

Table 14: Showing the M and SD for various peaks at 80 dB nHL for Group 2.

Category	**Absolute latency in msec**					
	I		**III**		V	
	M	SD	M	SD	M	SD
Sloping	1.963	0.16	4.173	0.40	5.714	0.76
Rising	1.500	0.41	3.690	0.15	5.460	0.29
Flat	1.835	0.14	3.813	0.21	5.608	0.32
Notched	1.620	0.28	3.840	0.28	5.820	0.14

Table 15: Showing the M and SD for various peaks at 80 dB nHL for Group 3.

Category	**Absolute latency in msec**					
	I		**III**		V	
	M	SD	M	SD	M	SD
Sloping	2.140	0.14	4.39	0.45	6.252	0.31
Rising	1.790	0.34	4.06	0.38	5.750	0.38
Flat	1.960	0.10	3.96	0.10	5.986	0.35

The mean absolute latency and standard deviations for three groups Group 1, Group 2, and Group 3 are depicted in Table 13, 14 and 15 respectively. It can be observed that for Group 1 (ABR threshold $\leq$ 40 dB nHL), wave I was delayed in subjects with sloping configuration, but subjects with notched hearing loss had normal wave I latency. ANOVA revealed statistically significant difference at 0.05 level ($F = 3.824$). Duncan's past hoc test revealed that latency of wave I for subjects with notched configuration was significantly different from that of sloping and flat loss, where as it overlapped with that of rising configuration. On the other hand, the latency for subjects with rising configuration differed significantly from that of subjects with flat configuration and sloping configuration. There was no significant difference between latency of subjects with flat and sloping configurations.

Examination of latency of wave III revealed that the latency was maximum for subjects with sloping hearing loss followed by subjects with flat and notched configuration while subjects with rising configuration had minimum latency. However ANOVA revealed no significant difference for wave III among the configurations (F = 2.093,p = 0.122).

A glance at the latency values obtained for wave V, in group I, reveals that the maximum was obtained for subjects with notched configuration (5.646 msec). Minimum latency was that of subjects with rising configuration (5.52 msec), with subjects of other two configurations, namely flat and sloping configurations being placed in between. The ANOVA revealed no statistically significant difference for wave V(F = 1.154,p = 0.343).

Analysis of data of subjects in group II (Table 14) revealed that in subjects with sloping configuration, wave I was delayed whereas it occurred earlier in subjects with rising configuration. Subjects with notched category had a latency of 1.62 msec, while the subjects with flat configuration had absolute latency of 1.83 msec. ANOVA showed a main effect, significant at 0.000 level (F = 16.123). Duncan's post hoc test revealed that the latency of wave I in subjects with sloping loss was statistically different from that of subjects with rising and notched configurations but, overlapped with that obtained in subjects with flat configuration.

The latency of wave III was maximum in subjects with sloping configuration (4.13 msec) and minimum latency was obtained for notched configuration (3.74 msec). ANOVA revealed significant main effect at 0.05 level (F = 5.266) and Duncan's post-hoc test revealed that in subjects with sloping configuration the absolute latency was delayed significantly when compared to the other three groups.

The trend changed when absolute latency of wave V was considered. Subjects with notched configuration had delayed latency compared to other groups and subjects with rising configuration had least absolute latency. ANOVA revealed significant main effect at 0.037 level (F = 4.867). Duncan's post hoc test revealed that subjects with sloping hearing loss had significantly delayed latency when compared to subjects with rising and flat configuration, but not statistically different from subjects with notched configuration. The reduced absolute latency in subjects with rising configurations was significantly different from all the other three group.

A glance at Table 15 (Group 3) shows that even in Group 3, wave I had maximum absolute latency in subjects with sloping configuration followed by subjects with flat and rising configuration. Wave III was again delayed maximally in subjects with sloping configuration where as subjects with flat configuration showed shortest latency. Again latency of wave V was maximum in subjects with sloping configuration followed by subjects with flat and rising configurations. However, the variations latency of all the three waves was not statistically significant ('F' values were 1.142, 1.820 and 2.321 for waves I, III and V respectively).

Comparison of the latency across the groups i.e., with different degree of hearing loss, showed that as the severity increased, there was an increase in wave latency. Wave I had the maximum latency in subjects with sloping hearing loss in all the three groups. Also, wave V always occurred earlier in subjects with rising configurations except when the ABR threshold was ≥70 dB nHL. Wave V was delayed in subjects with notched configuration irrespective of severity.

Thus when severity' was controlled also, results obtained were similar to the combined data except for following changes.

> For Group 1, the main effect of configuration was not present for latency values for waves HI and V.

> Subjects with rising configuration in Group 3 had all the waves delayed.

> In Group 3 maximum latency for wave V was obtained for subjects with sloping hearing loss. (In this group there were no subjects with notched configuration).

2. Interwave intervals I-III, III-V, and I-V:

The interwave intervals I-III, III-V, and I-V for the Groups 1, Group 2 and Group 3 are depicted in Table 16, 17 and 18 respectively.

Table 16: Showing the M and SD for various IWI at 80 dB nHL for Group 1.

Category	IWI in msec					
	I-III		III-V		I-V	
	M	SD	M	SD	M	SD
Sloping	2.017	0.20	1.810	0.31	3.842	0.28
Rising	2.036	0.22	1.870	0.12	3.922	0.10
Flat	2.040	0.23	1.826	0.14	3.988	0.20
Notched	2.197	0.11	2.040	0.52	3.244	0.12

Table 17: Showing the M and SD for various IWI at 80 dB nHL for Group 2.

Category	**IWI** in **msec**					
	I-III		**III-V**		**I-V**	
	M	SD	M	SD	M	**SD**
Sloping	2.003	0.16	1.847	0.20	3.908	0.12
Rising	2.256	0.35	1.660	0.29	3.766	0.12
Flat	1.944	0.18	1.898	0.18	3.904	0.19
Notched	2.044	0.24	2.024	0.28	4.160	0.11

Table 18: Showing the M and SD for various IWI at 80 dB nHL for Group 3.

Category	IWI in msec					
	I-III		III-V		I-V	
	M	SD	M	SD	M	SD
Sloping	1.940	0.48	1.733	0.46	3.800	0.56
Rising	2.270	0.34	1.590	0.32	3.580	0.65
Flat	1.800	0.10	1.940	0.10	3.940	0.20

Scrutinizing the Table 16, it could be seen that in Group I, I-III IWI was greater than 2 msec for all the configurations with a maximum of 2.19 msec for subjects with notched configuration. The subjects of other three configurations sloping, rising and flat had I-III IWI of 2.01, 2.03 and 2.04 respectively. ANOVA revealed that the difference in interwave interval was not significant ($F = 1.868, p = 0.156$). The III-V IWI again was maximum (2.04 msec) for subjects with notched configuration, followed by subjects with rising, flat and sloping configuration with IWI of 1.87, 1.82 and 1.81msec respectively. However, the results of ANOVA showed that the variations were not statistically significant (F = 1.9000,p = 0.152). Similar trend was observed for I-V IWI. Subjects with notched configuration presented prolonged I-V IWI (4.24 msec) followed by subjects with flat, rising and sloping configurations respectively. ANOVA revealed main effect at 0.01 level (F = 6.657). The results of Duncan's post-hoc test revealed that the delayed I-V IWI for subjects with notched configuration was significantly different from other three configurations.

Examination of Table 17 (Group 2) revealed that I-III IWI for subjects with rising and notched configurations was prolonged, while for other two configurations it was reduced. ANOVA showed no significant mam effect at 0.05 level (F = 2.863,p = 0.056). The results of III-V IWI showed that there was a significant reduction in the interval for subjects with rising hearing loss where as it was increased in subjects with notched configuration. ANOVA was significant at 0.05 level (F = 3.112). The Duncan's post hoc test revealed that the III-V IWI of subjects with notched configuration was significantly delayed when compared with that of other subjects. The reduction in III-V interval seen for subjects with rising configuration was also statistically significant when compared to other three configurations. But there was no statistical difference between IWI for subjects with flat and sloping configuration.

It can be observed from Table 18 (Group 3) that there was a marked variation in I-III IWI obtained in subjects with different configurations.

Subjects with rising hearing loss had maximum I-III IWI, whereas it was minimum for subjects with flat configuration. ANOVA revealed a sigmficant mam effect at 0.05 level (F = 3377) and Duncan's post hoc test revealed that all the three groups were significantly different from each other. III-V and I-V IWIs were unaltered in subjects with flat hearing loss, but reduced for subjects with sloping and rising configurations. ANOVA for III-V IWI revealed no significant mam effect at 0.05 level (F = 0.336) ANOVA for I-V interval showed significant main effect at 0.05 level (F = 2.463) and Duncan's test revealed that all the groups were significantly different from each other.

To summarize, the following observations were noted when the severity of the hearing loss was controlled.

- In subjects with sloping configuration the shortened I-III, III-V and I-V IWI were maximum for Group 3.
- In subjects with rising configuration prolongation of I-III interval, reduction in III-V and I-V IWI were most pronounced in Group 3.
- In subjects with flat hearing loss configuration all the IWI were similar for all the groups.
- In subjects with notched configuration the increase in I-V IWI was similar for both Group 1 and Group 2 (there were no cases with notched configuration in Group 3).

B. Latency - Intensity functions:

1. L-I function / slope of wave I:

To see the effect of intensity on ABR parameters the L-I functions were plotted. The Figures 7, 8 and 9 show L-I functions of wave I for Groups 1, 2 and 3 respectively. It can be observed that for all the groups, there was very minimal shift in the latency at high levels whereas while there was a dramatic change in the wave latency at low intensities. This change in low levels was different for various configuration at different groups. This was the main reason for change in slope function for different groups. For Group 1, maximum slope of 16 usec/ dB was obtained for subjects with sloping configuration where as subjects with notched configuration had a minimum slope of 11 usec / dB. In Group 2, also subjects with sloping configuration had steeper L-I function than other groups (slope of 18 usec/dB) and minimum slope was obtained for subjects with notched and rising configuration (11usec/dB). Again in Group 3, subjects with sloping configurations had maximal slope of 24 usec/dB and minimum slope was obtained for subjects with rising configuration. The slope values of wave I for three groups across the configurations are depicted in Table 19.

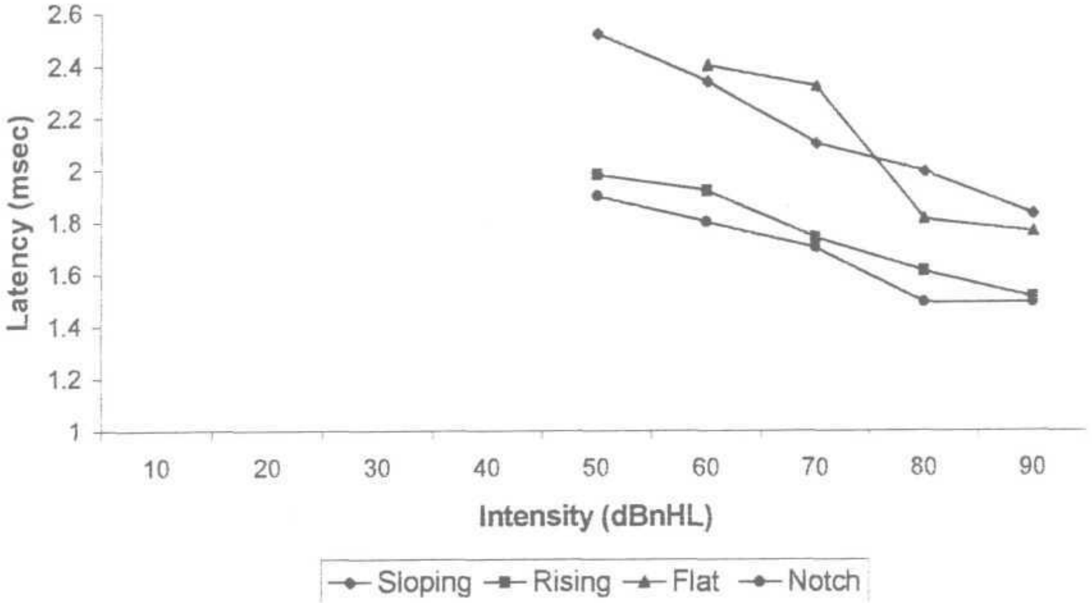


Figure 7: Showing L-I function for wave I across the configurations for Group 1.

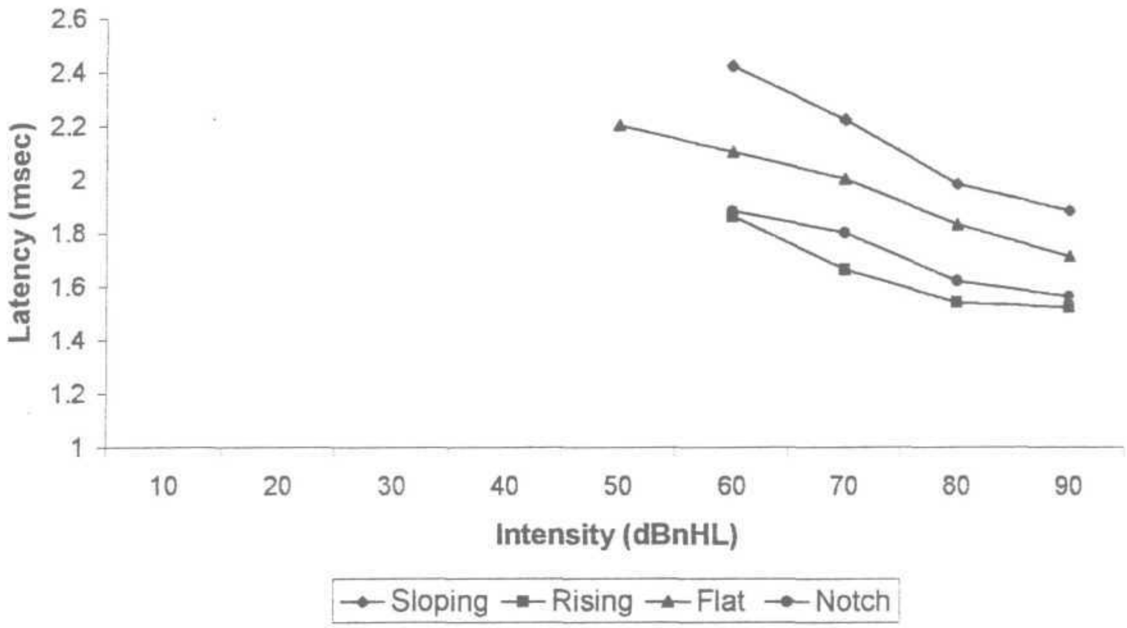


Figure 8: Showing L-I function for wave I across the configurations for Group 2.

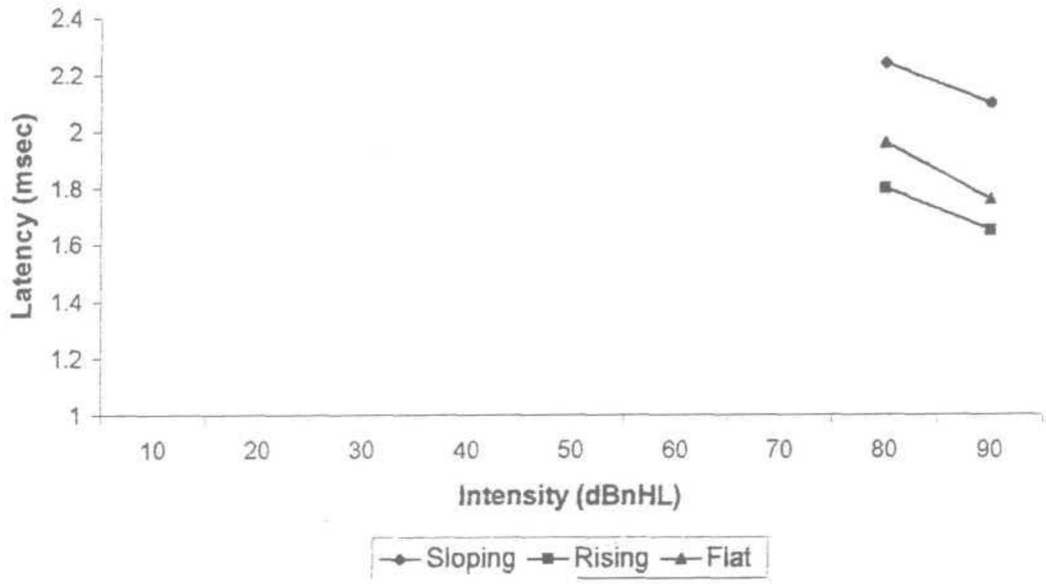


Figure 9: Showing L-I function for wave 1 across the configurations for Group 3.

Table 19: Showing slope values of wave 1 across the configurations for three groups of subjects.

Configuration	Group 1 (usec/dB)	Group 2 (usec/dB)	Group 3 (usec/dB)
Sloping	**26**	**28**	**34**
Rising	**12**	**11**	**15**
Flat	**16**	**26**	**30**
Notched	**11**	**11**	

2. Slope of wave III:

The L-I function of wave ill for Group 1, Group 2, and Group 3 depicted in Figures 10, 11 and 12 respectively. The slope values for three groups are shown in Table 20. There was a general increase in steepness of the L-l function with increase in severity. It was also evident that in Groups 1 and 3, subjects with sloping configuration had maximum slope while in

Group 2, subjects with flat and sloping configurations had maximum slope. Generally, the slope was minimum for subjects with rising configuration.

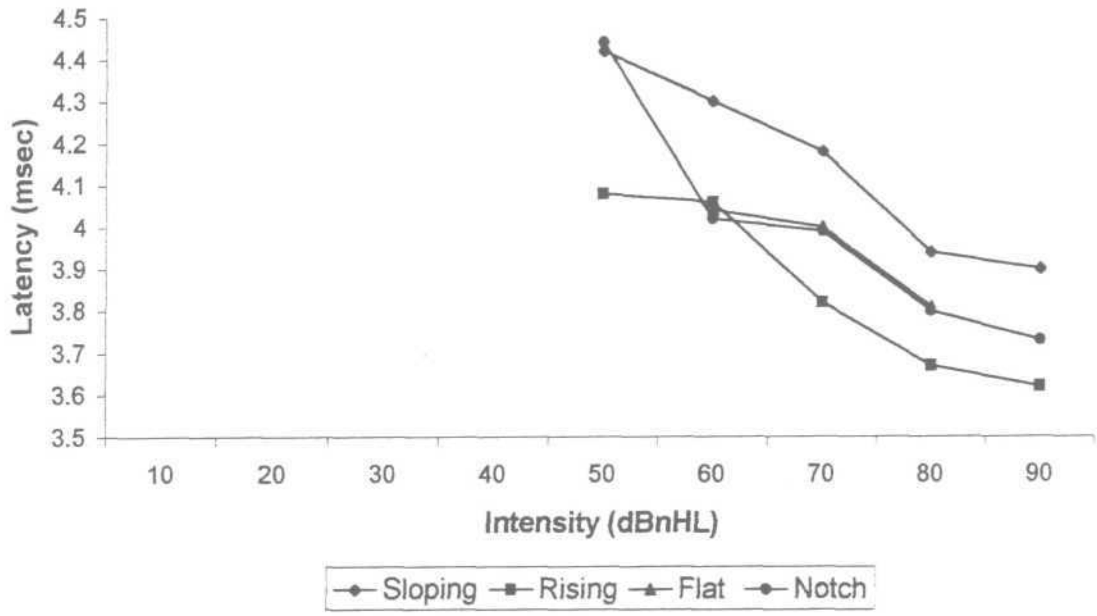


Figure 10: Showing L-I function for wave III across the configurations for Group 1.

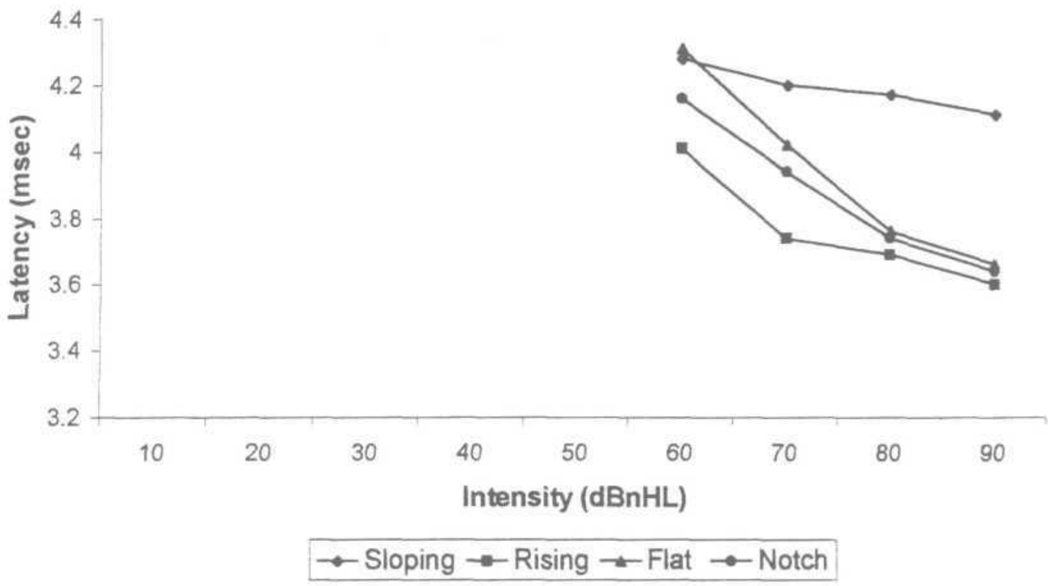


Figure 11: Showing L-I function for wave III across the configurations for Group 2.

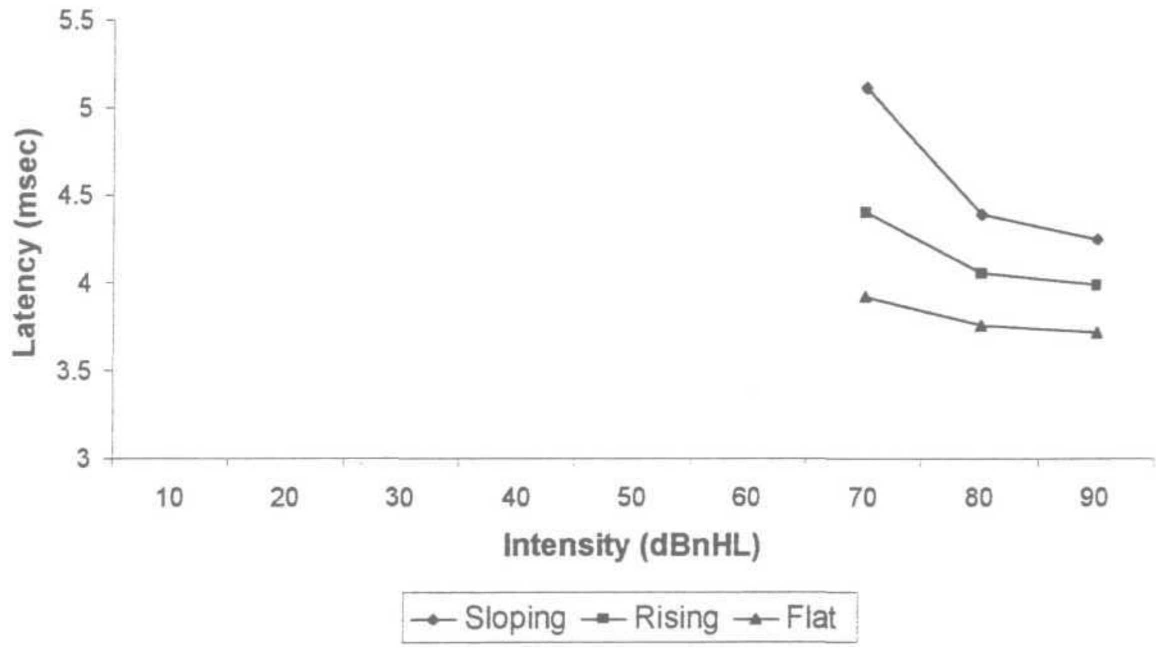


Figure 12: Showing L-I function for wave III across the configurations for Group 3.

Table 20: Showing slope values of wave III across the configurations for three groups of subjects.

Configuration	Group 1 (usec/dB)	Group 2 (usec/dB)	Group 3 (usec/dB)
Sloping	23	24	32
Rising	13	12	20
Flat	16	23	32
Notched	11	17	-

3. Slope of wave V:

The L-I functions of wave V for Groups 1, 2 and 3 are represented in Figures 13, 14 and 15 respectively. The slope values for these groups are shown are shown in Table 21.

L-I function of wave V again showed the general trend with increase in slope as the severity of hearing loss increased. Maximum slope was obtained for subjects with notched configuration in Group 1 and Group 2. While minimum slope was obtained for subjects with rising configuration. In Group 3 subjects with sloping configuration had minimum slope and the slope was maximum for subjects with rising configuration.

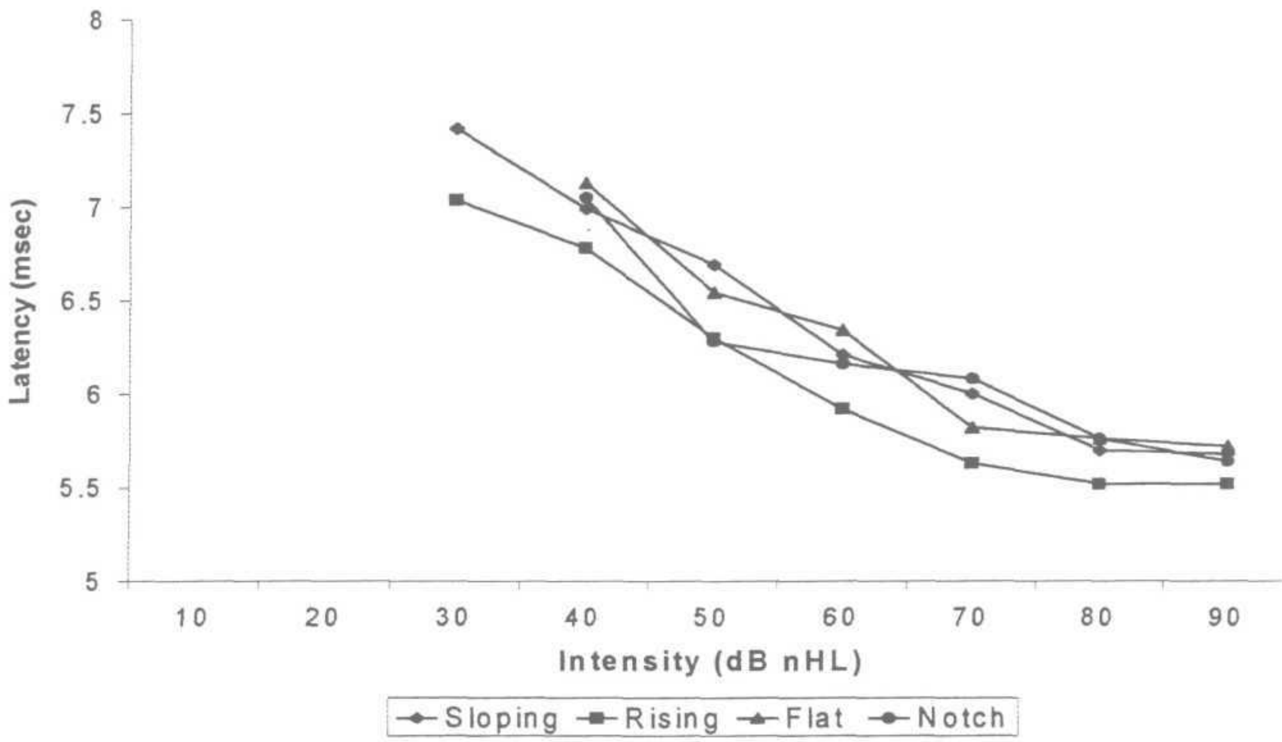


Figure 13: Showing L-I function for wave V across the configurations for Group 1.

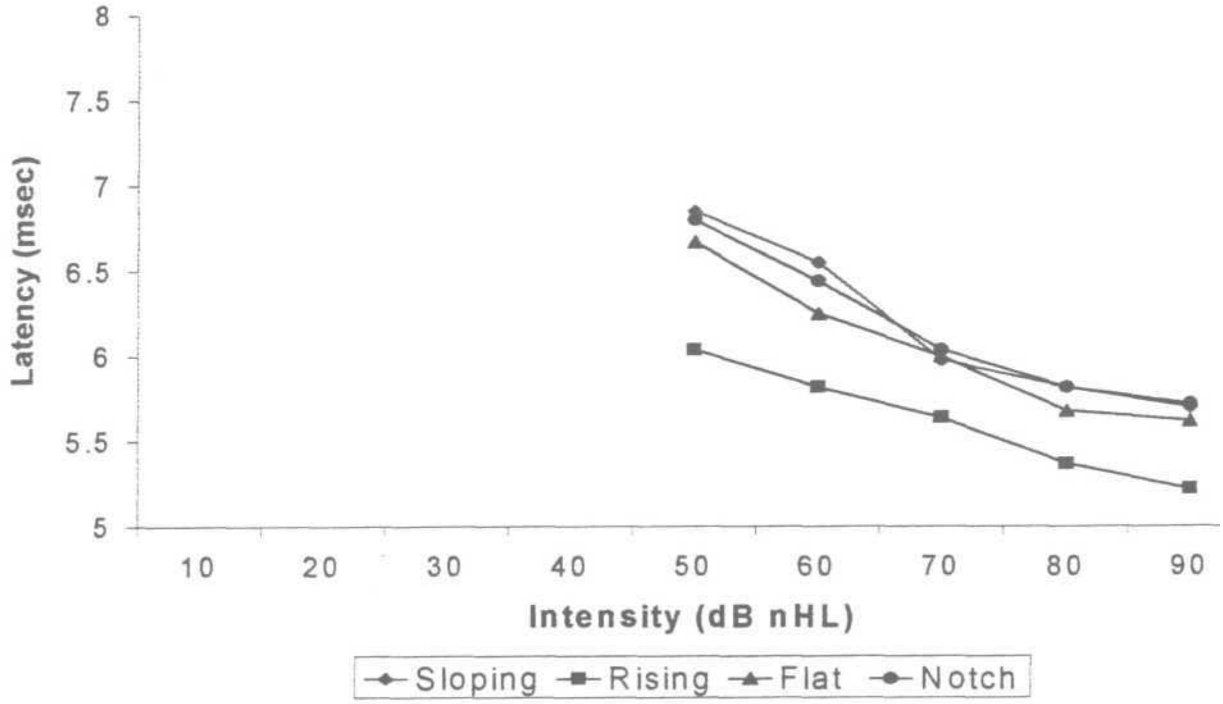


Figure 14: Showing L-I function for wave V across the configurations for Group 2.

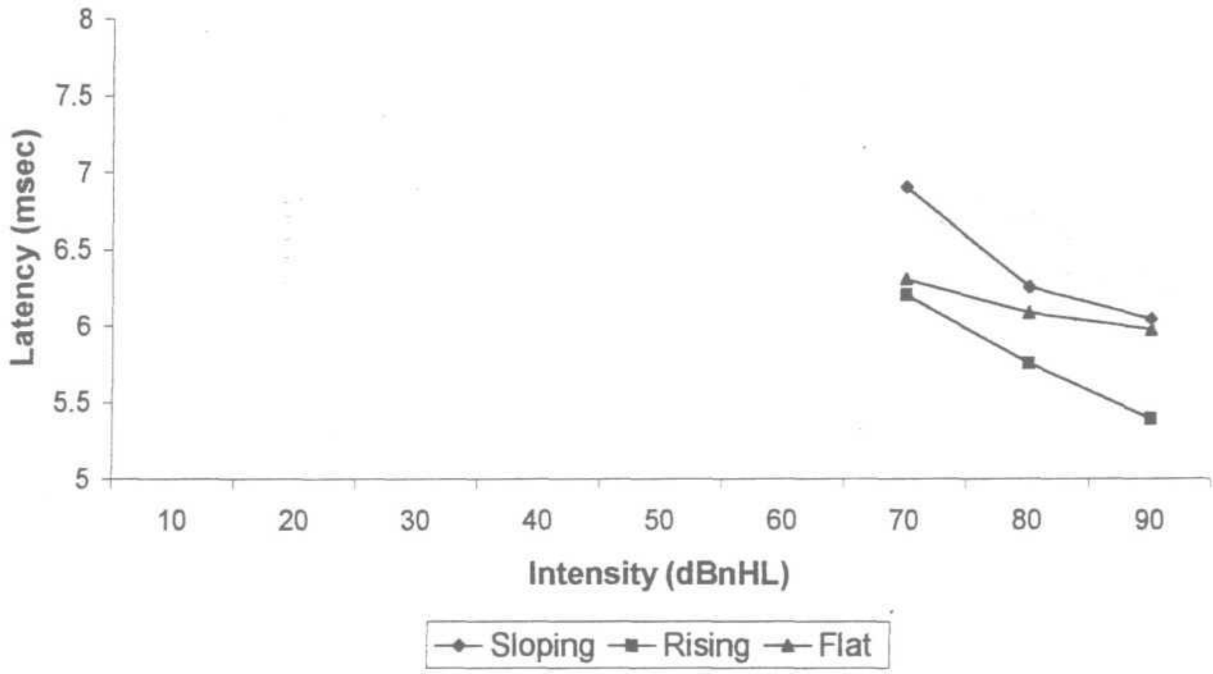


Figure 15: Showing L-I function for wave V across the configurations for Group 3.

Table 21: Showing slope values of wave V across the configurations for three groups of subjects.

Configuration	Group 1 (usec/dB)	Group 2 (usec/dB)	Group 3 (usec/dB)
Sloping	22	24	36
Rising	20	20	40
Flat	18	26	38
Notched	28	30	

4. Slope / L-I function of I-III IWI:

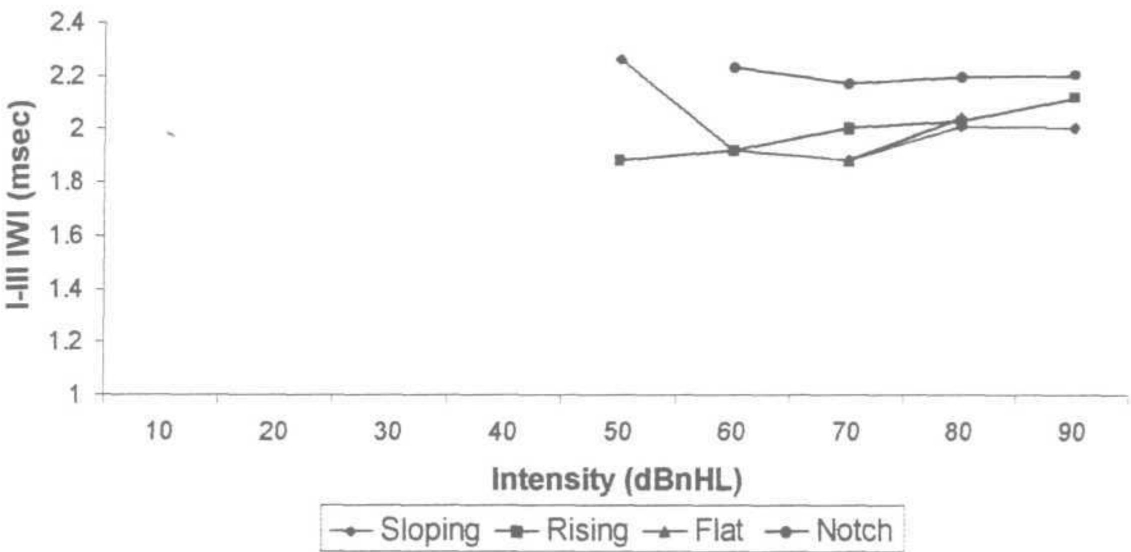


Figure 16: Showing L-I function for I-III IWI across the configurations for Group 1.

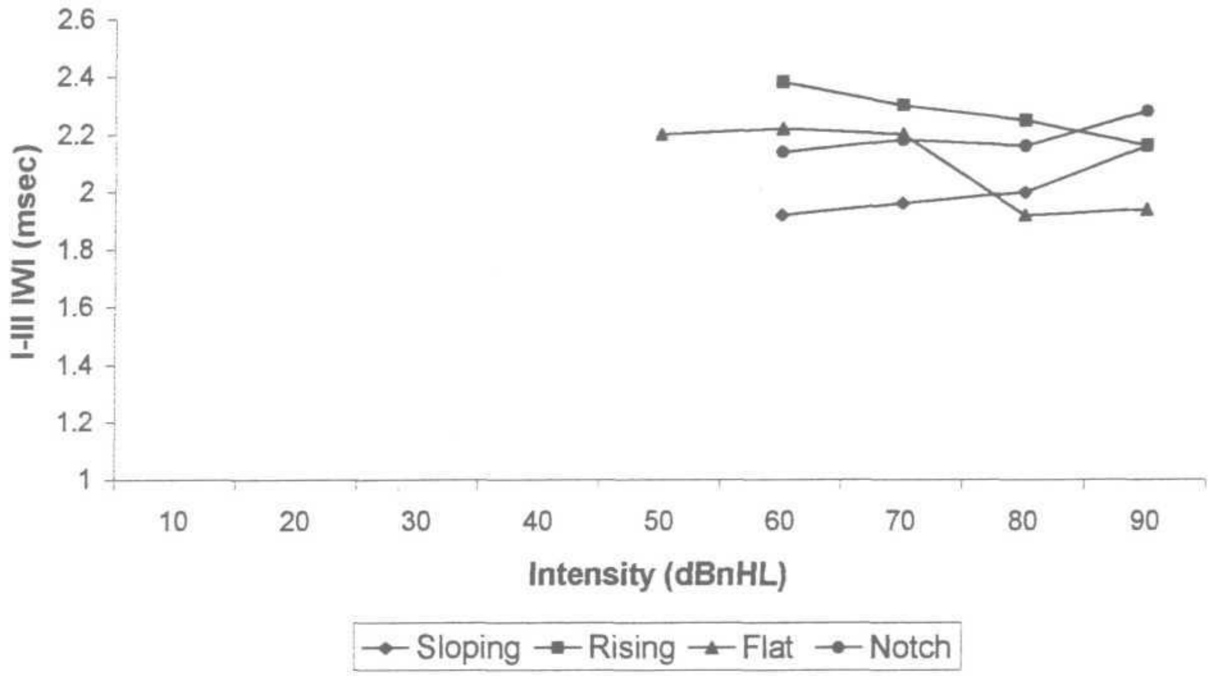


Figure 17: Showing L-I function for I-III IWI across the configurations for Group 2.

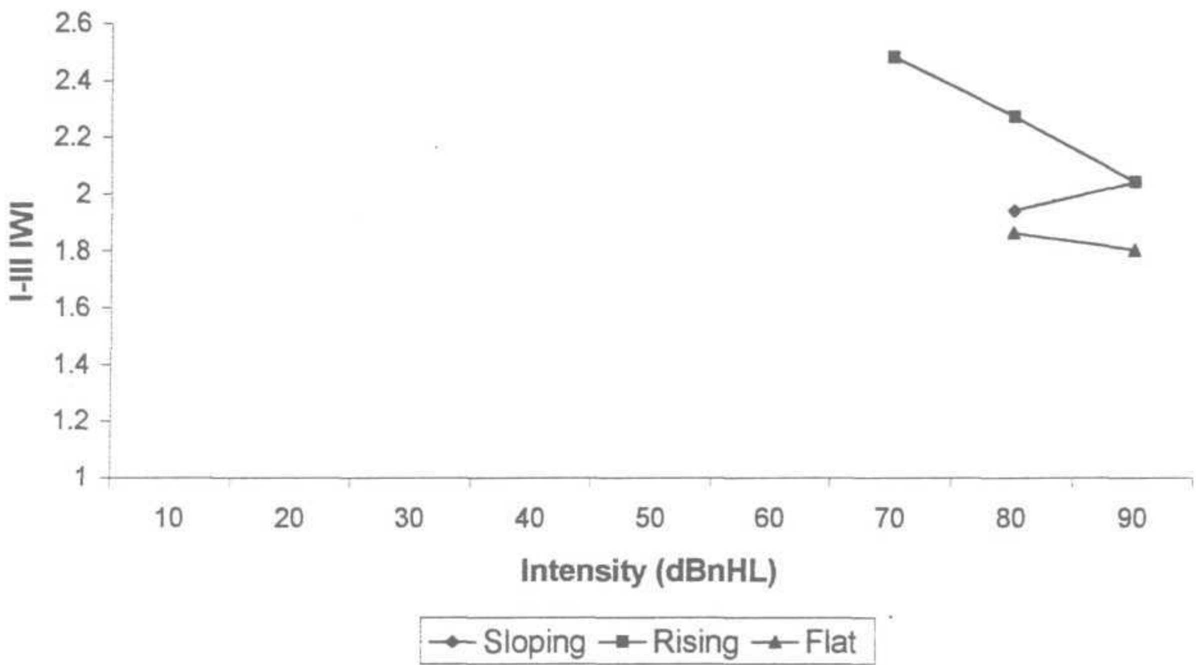


Figure 18: Showing L-I function for I-III IWI across the configurations for Group 3.

Table 22: Showing slope values of wave I-III IWI across the configurations for three groups of subjects.

Configuration	Group 1 (usec/dB)	Group 2 (usec/dB)	Group 3 (usec/dB)
Sloping	4.0	7.0	8.0
Rising	0.9	0.1	8.0
Notched	9.0	4.0	-

Examination of Figures 16, 17, 18 and Table 22 reveals that subjects with sloping configuration showed similar trends across the groups i.e., reduction in I-III IWI as the intensity was decreased, but the slope of this reduction was maximum for subjects in Group 3. In subjects with rising configuration also the pattern was similar across the groups i.e., increase in interval as the level was lowered. But the trend was more pronounced in Group 2 and 3 when compared to Group 1. In subjects with flat configuration the trend was not similar across the groups i.e., for groups 1 and 2 the I-III interwave interval remained unchanged at all the levels, but for Group 3 there was an increase in interval near the threshold. In subjects with notched configuration, there was no change in the trend i.e., in both Group 1 and 2, the I-III IWI remained unaltered across the levels.

5. Slope / L-I function of III-V IWI:

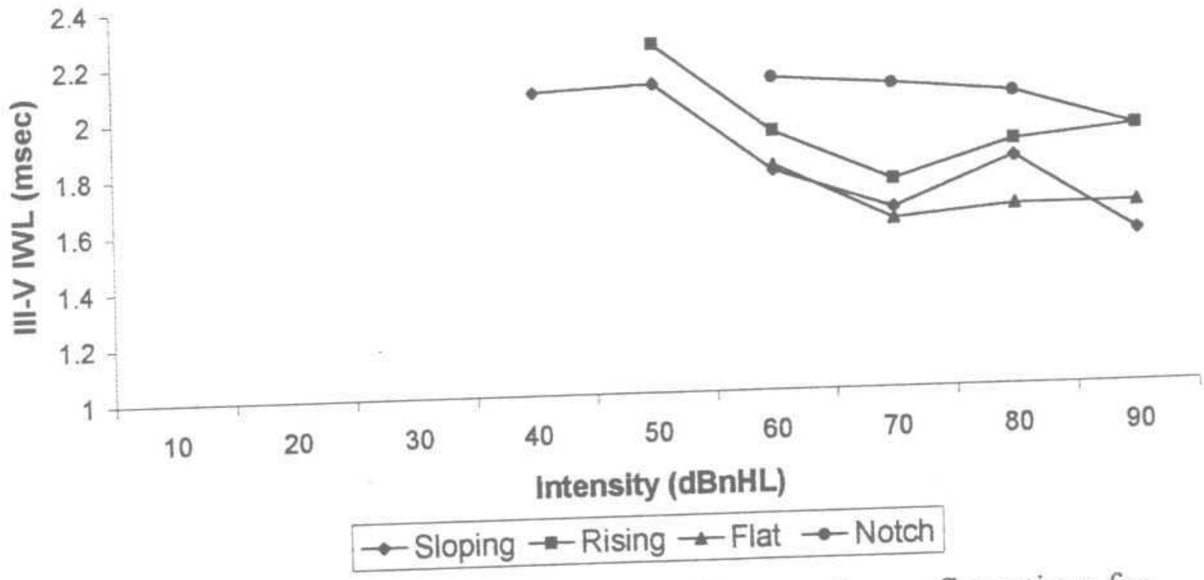


Figure 19: Showing L-I function for III-V IWI across the configurations for Group 1.

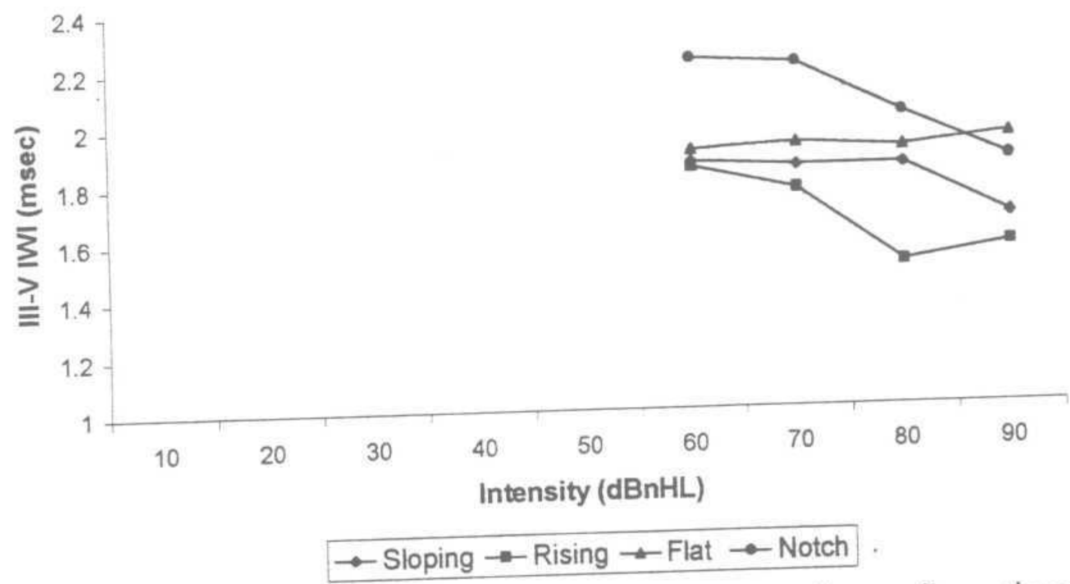


Figure 20: Showing L-I function for III-V IWI across the configurations for Group 2.

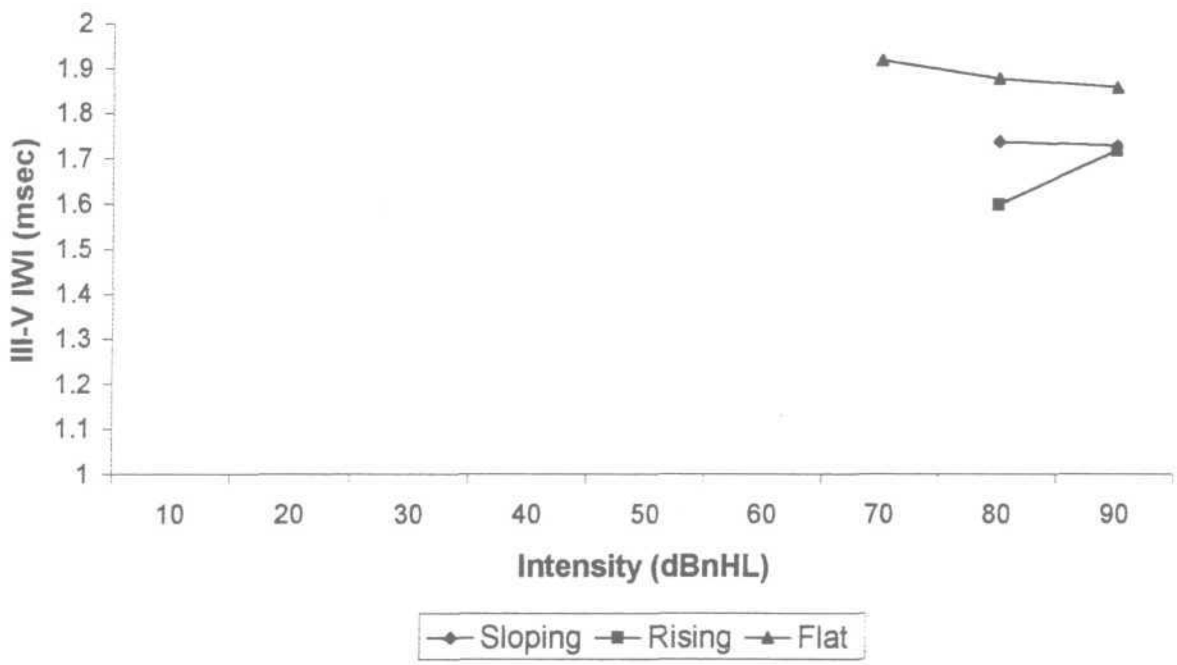


Figure 21: Showing L-I function for III-V IWI across the configurations for Group 3.

Table 23: Showing slope values of wave III-V IWI across the configurations for three groups of subjects.

Configuration	Group 1 (usec/dB)	Group 2 (usec/dB)	Group 3 (usec/dB)
Sloping	10	06	17
Rising	07	11	12
Flat	04	06	08
Notched	06	12	

It can be observed from Figures 19, 20, 21 and Table 23 that the trend was similar for all the configuration i.e., in all the groups the interval increased at lower levels for subjects with all the configuration. But this trend was not seen in the combined data. This shift or increase in interval was more pronounced in subjects of Group 3.

6. Slope / L-I function of I-V IWI:

In this parameter, subjects with sloping hearing loss in Group 1 and Group 2, displayed increase in I-V IWI with reduction in level, but in Group 3, the IWI remained almost unchanged across the levels. In subjects with rising configurations in Group 1, IWI was almost unchanged at high levels and there was a sudden increase in interval near threshold. On the other hand in the two groups (2 and 3), there was a gradual increase of I-V IWI as level was reduced. For subjects with flat configuration in groups 1 and 2 the IWI remained unchanged, but in Group 3 there was an increase in I-V IWI at low levels. Subjects with notched configuration in both Group 1 and 2 showed similar trend. In general the shift in the interval was maximum for Group 3. These results are shown in Figures 22, 23, 24 and Table 24.

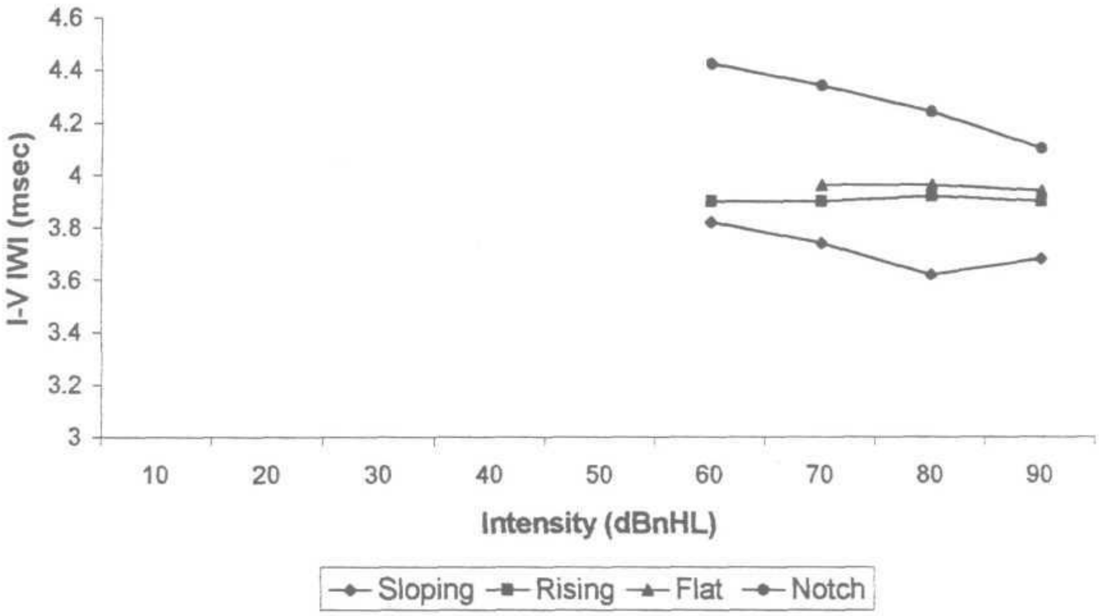
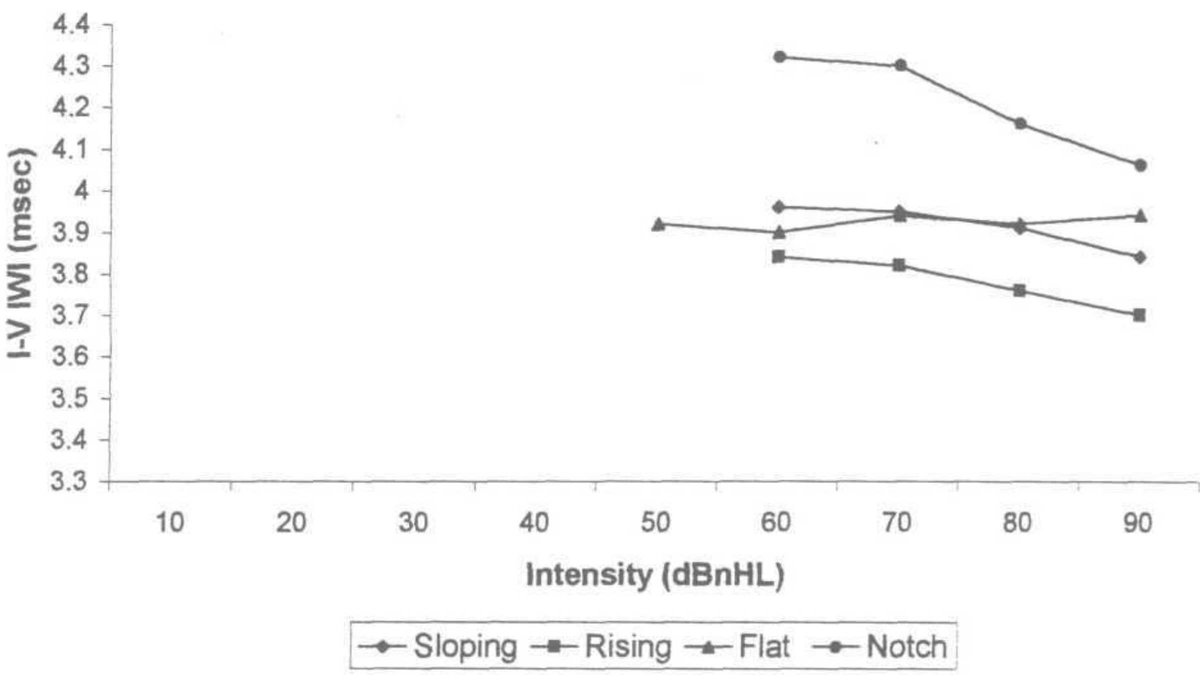


Figure 22: Showing L-I function for I-V IWI across the configurations for Group 1.



y

Figure 23: Showing L-I function for I-V IWI across the configurations for Group 2.

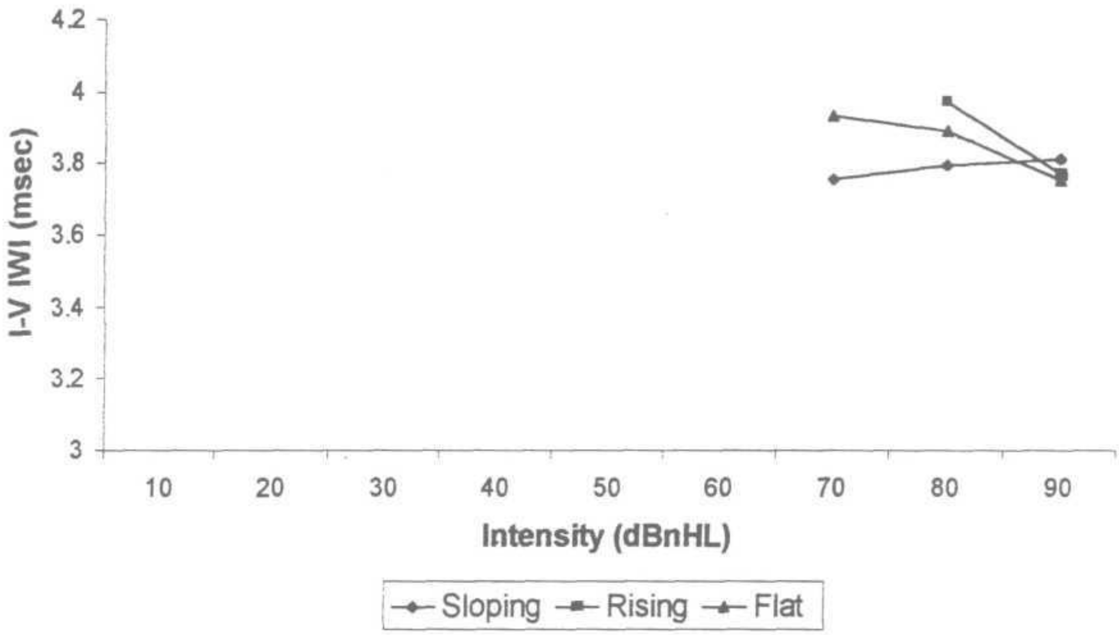


Figure 24: Showing L-I function for I-V IWI across the configurations for Group 3.

Table 24: Showing slope values of wave I-V IWI across the configurations for three groups of subjects.

Configuration	Group 1 (usec/dB)	Group 2 (usec/dB)	Group 3 (usec/dB)
Sloping	05	04	10
Rising	02	04	22
Flat	02	06	06
Notched	10	08	

CHAPTER V

DISCUSSION

The absolute latency of waves:

The results of the study clearly reflected the differential effect of audiometric configuration on different parameters of ABR. In subjects with sloping configuration, latency of all the waves were prolonged, but wave I was delayed more than wave III and wave V. These results agree with the previously reported results in literature (Keith and Greville, 1987; Rosenhammer et al., 1981). The results were similar even when the severity of the hearing loss was controlled. Also, as the severity increased this differential effect was more pronounced.

In subject with rising configuration wave I and wave V occurred earlier where as wave III was unaffected. The present results support the reports of Keith and Greville (1987). The results of Group 1 were similar to that of the combined data but latency of all the waves were delayed in Group 2 and Group 3.

In subject with flat configuration it was seen that all the waves were prolonged. These results are in agreement with previous reports (Keith and Greville, 1987; Moller and Blegvad, 1976; Rosenhamer et al., 1981). This was true for subjects in all the three subgroups. In other words, degree of hearing loss did not have an effect on the results.

Results obtained from subjects with notched configuration were also similar to that reported in literature (Keith and Greville, 1987 ; Bauch and Olsen, 1986; Sana, 1999). The wave V was delayed and wave I occurred earlier,but wave III was unaffected. The results were found similar for for subjects in all the groups.

Interwave Intervals:

In subject with sloping configuration I-III IWI was near normal and I-V IWI was shortened, III-V IWI was reduced. These results are in agreement with the results of previous investigation by Coats and Martin (1977), and Struzebecher et al., (1985) . The current results are not in agreement with results obtained by Keith and Greville (1987) and Rosenhammer et at., (1981) who reported no change in IWI in these subjects. Trends were similar for subjects with different severity of hearing loss was considered, but the reduction in IWI was maximum for subjects with severe hearing loss.

In subject with rising configuration I-III IWI was prolonged where as III-V and I-V were reduced. These results are in agreement with that of Keith and Greville (1987). Again similar trend was observed across different groups of severity.

Analysis of data of subjects with flat hearing loss revealed all IWI were within normal limits. These results agree with that of Keith and Greville (1987). When severity was taken into account, no difference was observed in this pattern.

In subjects with notched hearing loss all the IWI were prolonged. These results support the findings of prolonged IWI reported in literature (Keith and Greville, 1987; Saha, 1999; Bauch and Olsen, 1986). Even here there was no differential effect of severity on increased IWI.

Latency-Intensity functions:

In subjects with sloping configuration, the slope of the wave I was steeper then that of wave V and III. This in turn lead to greater reduction in IWI with decrease in intensity. These results agree with the previous results by Keith and Greville, (1987) and Kirsh et al., (1992). When severity was considered the slope trend was similar. As the severity increased the slope also increased. But, in Group 3 the shift in wave I was almost same as that of wave V giving rise to unchanged interval across the levels. This finding could be supported by Watson (1996) suggestion that wave I displayed latency extension with increasing levels of high frequency hearing loss, whilst for wave V increase in latency was dependent upon both degree and slope of hearing loss.

In subjects with rising configuration the slope of wave V L-l function was maximum followed by wave lll and wave l. These results are in agreement with that of Keith and Greville (1987). Because of this steeper wave V the reduction in latency in lWl was prominent at high levels and the interval tend to increase with decreasing level. When subjects with different severity were considered the trend did not differ. Also, the steepness increased with increase in severity.

In subjects with flat hearing loss configuration, the slope of L-l function for all the three waves remained almost same. These results are in agreement with that of Keith and Greville (1987). Results of groups 1 and 2, was similar to that of the combined data, but in Group 3 all the intervals were prolonged at low levels. Comparison of individual slopes showed that the slope of wave V was steeper than wave 111 and wave 1 giving rise to increased intervals at low levels.

In subjects with notched configuration also, the wave V had steeper L-l functions than other waves. These results are in consonance with that reported in literature (Keith and Greville, 1987; Sana, 1999; Bauch and Olsen, 1986). This steeper wave V latency resulted in increased 1W1 as the level was reduced. The results were similar for both the subgroups.

Thus, cochlear pathology giving rise to sloping audiometric configuration resulted in prolongation of wave 1 and reduction in l-V lWl. The L-l function was steep for all the waves and 1-V 1W1 reduced with increase in intensity. This effect could be attributed to the cochlear contribution to ABR. It has been hypothesized that narrow region of basilar membrane contributes to the wave 1 generation where as wave V has contributions by wider portion of basilar membrane (Klein, 1986, Goldstein and Kiang, 1958; Xu et al.,1998; Keith and Greville, 1987; Struzbecher et al.,1987;Sohmer et al.,1981; Don and Eggermont 1978). Because of this, wave 1 was affected more reducing 1-V 1W1. Also L-1 function was steeper for wave 1 than wave V resulting in reduced 1-V 1W1 as the level was decreased.

On the other hand rising audiometric configuration resulted in early occurrence of all the waves, reduced 1-V interval and steep L-1 function of wave V. The 1-V IW1 increased as level was lowered. The early occurrence of wave 1 and wave V could be the result of shift in the maximum excitation of basilar membrane towards the basal region of the cochlear portion as the apical area is affected (Keith and Greville, 1987). The reduced 1-V 1W1 could be explained on the basis of early occurrence of wave 1, unaffected wave 111 and very early occurrence of wave V. Also, because of the damage in the apical region of basilar membrane, the wave V L-1 function was steeper than that of wave 1 resulting in increased intervals as the level was reduced.

Most often in subjects with flat configuration all the waves were affected equally and 1-V 1W1 was unaltered. This equal effect on all the waves has been attributed to damage along the whole basilar membrane(Keith and Greville, 1987).

In subjects with 4 kHz dip, there was a prolongation of wave V, prolonged 1-V 1W1 and increase in 1-V 1W1 as the level was reduced. It has been well established that region responding to 4 kHz on basilar membrane is important for generation of wave V (Coats, 1978; Coats and Martin, 1977; Jerger and Mauldin, 1978), as the wave V latency increases with increase in behavioral threshold at 4 kHz. The early occurrence of wave I could be attributed to further basalward shift of wave I maximum excitation, as there was a damage to 4 kHz area (Keith and Greville, 1987). The increase in I-V IWI was due to delay in wave V and early occurrence of wave I. The selective lesion at the characteristic frequency of 4 kHz on basilar membrane also resulted in steeper wave V L-I function when compared to other peaks.

The results of the present study are enumerated in Table 25. This Table may be helpful in predicting audiometric configuration based on click evoked ABR in difficult-to-test population.

Table 25: Showing the summery for all the configurations which may be used for predicting audiometric configuration.

Configuration	Measures at 80 dB nHL						L-I functions					
	Wave I	Wave III	Wave V	I-III IWI	III-V IWI	I-V IWI	I	III	V	I-III	III-V	I-V
Sloping	+	+	+	-	-	-	S	S	S			
Rising	-	O	-	+	-	-	N	S	S			
Flat	+	+	+	O	O	O	S	S	S			
Notched	-	O	+	+	+	+	N	N	S			

Keys: '+' Prolonged, '-' Shortened, 'O' Unaffected, 'S' Steeper, 'N' Normal **Increase in level**

Reduction in IWI and Prolongation of IWI.

Exception for above table; The following exceptions were seen in subjects with ABR threshold **more than or** equal to 70 dB nHL.

1. In subjects with sloping configuration the I-V IWI was prolonged at low levels.
2. In subjects with rising configuration all wave I, III & V were delayed and I-V intervals was prolonged near threshold.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The ABR to broadband clicks is widely used for threshold estimation and neurodiagnosis. This click evoked ABR does not give information about audiometric configuration. It has been reported in literature that the different parameters of ABR are differentially affected in subjects with various configurations of hearing loss (Keith and Greville, 1987; Rosenhammer et al., 1981). However equivocal results have been reported in subjects with hearing loss due to cochlear origin. Also very few investigators have compared the effect of different audiometric configuration on ABR. It may be possible to predict audiometric configuration based on click evoked ABR if there is a definite trend seen in subjects with different configurations. In this context the present study was designed to investigate the effect of audiometric configuration on:

> Absolute latency of waves I, HI and V at 80 dB nHL
> L-I function of waves I, III and V
> Interwave intervals I-in, III-V, and I-V at 80 dB nHL
> L-I function of interwave intervals.

For this purpose ABR was recorded for click stimuli from 80 ears of sensory impairment and grouped into four categories namely sloping, rising, flat and notched configuration of hearing loss. One-way ANOVA and

Multiple regression analysis was carried out to investigate the aims of the study.

The results of the study indicated that:

1. In subjects with sloping configuration hearing loss, even though all the waves were delayed wave I was maximally delayed giving rise to reduced IWIs and wave I had steeper L-I function than wave III and wave V resulting in reduction in IWIs as the level was reduced.
2. In subjects with rising configuration, wave I occurred early or it was unaffected and wave V always occurred earlier giving rise to reduced I-V IWI. The wave V slope was greater than that of other waves resulting in increase in IWI as the level was reduced.
3. In subjects with flat configuration, all the waves were affected equally and all IWIs were unaltered.
4. In subjects with notched hearing loss (4 kHz notch), wave I occurred earlier, wave III was unaltered and wave V was delayed in latency resulting in prolonged I-V IWI. Also the slope of wave V was steeper than wave I giving rise to increased I-V IWI at all the levels.

REFERENCES

Bauch, C, & Olsen, W. (1986). The effect of 2000-4000 Hz hearing sensitivity on ABR results. Ear & Hearing, 7, 314-317.

Coats, A.C. (1978). Human auditory nerve action potentials and brainstem evoked responses: Latency-Intensity function in Detection of Cochlear and Retrocochlear Abnormality. Archieves of Otolaryngology, 104, 709-717.

Coats, A.C., & Martin, J.L. (1977). Human auditory nerve action potentials and brainstem evoked responses: Effect of audiogram shape and lesion location. Archieves of Otolaryngology, 103, 605-622.

Don, M., & **Eggermont, J.J.** (1978). Analysis of the click evoked brainstem potentials in man using high pass noise masking. JASA, 63. 1084-1092.

Durrant, J.D. (1983). Fundamentals of sound generation. In E.J. Moore (Ed.), Bases of auditory brainstem evoked responses. PP. 15-49. New York: Grime & Stratton.

Eggermont, J.J., Don, J., & Brackmann, D.E. (1980) Cited in JW Hall (1992). Handbook of Auditory evoked responses. Boston: Allyn and Bacon.

Goldstein, M.H., & Kiang, N.Y.S. (1958). Synchrony of neural activity in electric responses evoked by transient acoustic stimuli. JASA. 30, 107-114.

Gorga, M.P., Reiland, J.K., & Beauchaine, K.A. (1985) Auditory brainstem responses in a case of high frequency hearing loss. Journal of Speech and Hearing Disorders, 50, 346-450.

Gorga, M.P., & Thornton, A.R. (1989). The choice of stimuli for ABR measurements. Ear & Hearing, 10,217-230.

Hall, W.J. (1992). Handbook of Auditory evoked responses. Massachusetts. Allyn & Becon. A Division of Simon and Schuster, Inc.

Jacobson, J.T. (1994). Auditory brainstem responses; Principles and applications. San Diego; collage Hill Press.

Jerger, J.F., & Mauldin, L. (1978). Prediction of sensory-neural hearing level from the brainstem evoked responses. Archieves of Otolaryngology, 104,456-461.

Jerger, J., & Johnson, K. (1988). Interactions of age, gender, and sensorineural hearing loss on ABR latency. Ear & Hearing, 9, 168-176.

Keith, W.J., & Greville, K.A. (1987). Effects of audiometric configuration on the auditory brainstem response. Ear & Hearing, 8(1), 49-55.

Kirsh, I., Thornton, A., Buckard, R, & Halpin, C (1992). The effect of cochlear hearing loss on auditory brainstem response latency. Ear & Hearing, 13(4), 233-235.

Klein, A.J. (1986). Masking effects on ABR waves I and V in infants and adults. JASA, 79(3), 755-759.

Moller, K., & Blegvad, B. (1976). Brainstem responses in patients with sensorineural hearing loss. Scandinavian Audiology, 5, 115-127.

Oates, P., & Stapells, D.R. (1992). Interaction of click intensity and cochlear hearing loss on auditory brainstem response wave V latency. Ear & Hearing, 13(1), 28-34.

Rosenhall, U. (1981). ABR and cerebellopontine angle tumors. Scandinavian Audiology, 13, 115.

Rosenhamer, H. (1981). The auditory evoked brainstem electric response (ABR) in cochlear hearing loss. Scandinavian Audiology, 13 (Suppl.), 83-93.

Rosenhamer, H.J., Lindstrom, B., & Lundborg, T. (1981). On the use of click evoked electric brainstem responses in audiological diagnosis: IV. Interaural latency differences (Wave-V) in cochlear hearing loss. Scandinavian Audiology, 10, 67-73.

Saha, C. (1999). Effects of 4 kHz dip on auditory brainstem response. Unpublished dissertation. University of Mysore, Mysore.

Shepard, N.T., Webster, J.C, Bauman, M., & Schuck, P. (1992) Effect of hearing loss of cochlear origin on the auditory brainstem responses. Ear & Hearing, 13(3), 173-180.

Sohmer, H., Kinarti, R., & Gofni, M. (1981). The latency of auditory nerve-brainstem responses in sensorineural hearing loss. Archieves of Otolaryngology, 230, 189-199.

Stapells, D.R. (1989). Auditory brainstem responses assessment in infants and children. Seminars in Hearing, 10, 229-251.

Sturzebecher, E., Kevanishvili, Z., Werbs, M., Mayer, E., & Schmidt, D. (1985). Interpeak intervals of auditory brainstem responses, interaural differences in normal hearing subjects and patients with sensorineural hearing loss. Scandinavian Audiology, 14, 83-87.

Watson, D.R. (1996). The effect of cochlear hearing loss, age and sex on the auditory brainstem responses. Audiology, 35(5), 246-258.

Xu, M., Vivek. B, Vel. E.D. & **Cauwenberge, P.V.** (1998) Mechanisms in noise induced permanent hearing loss. An evoked otoacoustic emission and auditory brainstem response study. Journal of laryngology and otology. 112,1154-61.