Auditory Steady State Potentials and Word recognition Scores in Normal Hearing and Hearing Impaired Individuals with Sensorineural Hearing Loss

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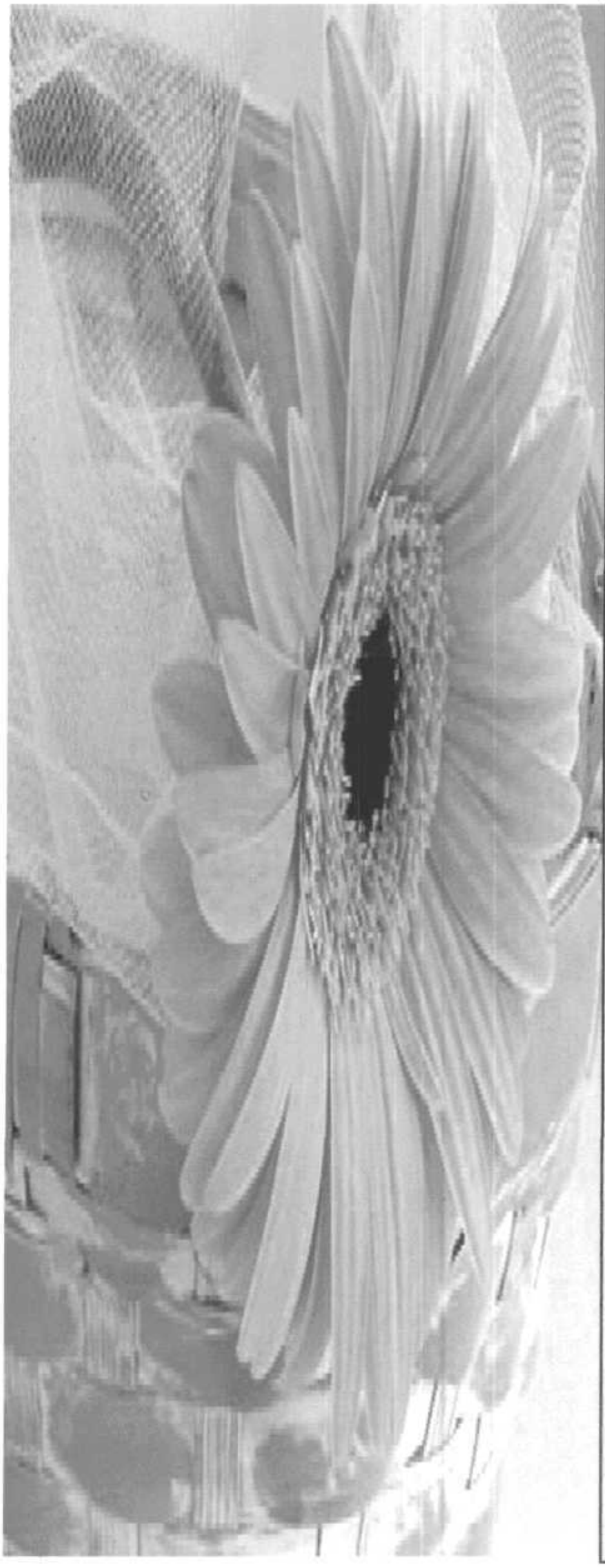

Dedicated To
Almighty,
Dad,
Mom,
Sister, Brother
&
My Guide

CERTIFICATE

This is to certify that the dissertation entitled **"Auditory Steady State Potentials and Word recognition Scores in Normal Hearing and Hearing Impaired Individuals with Sensorineural Hearing Loss"** is a bonafide work done in part fulfillment for the degree of Master of Science (Audiology) of the student with Register No: A0490006. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any other D iploma or Degree.

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DECLARATION

This dissertation entitled **"Auditory Steady State Potentials and Word recognition Scores in Normal Hearing and Hearing Impaired Individuals with Sensorineural Hearing Loss"** is the result of my own study under the guidance of Mr. Animesh Barman, Lecturer in Audiology, Department of Audiology, All India Institute of Speech & Hearing, Nimisham Campus, Mysore and has not been submitted earlier in any other university for the award of any Degree or Diploma.

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CHAPTER I

INTRODUCTION

The auditory evoked potentials have recently become very important tool in objective audiometry. A major goal of objective audiometry is to obtain a pure tone audiogram without requiring any behavioral response on the part of the subject. Thus, objective evoked potentials play a critical role in the assessment of hearing in infants, young children and in subjects who cannot or will not participate actively for the standard behavioral hearing assessment procedures.

Many different auditory responses can be recorded objectively from the human scalp and each may provide important information about the auditory function. The auditory evoked potentials may be classified as transient responses, sustained responses and steady state responses. A transient response is elicited by a rapid change in the auditory stimulus whereas a sustained response is elicited by the cont inuation of a stimulus. Transient and sustained responses are recorded using stimulus rates that allow the response to one stimulus to be finished before the next stimulus is presented. Steady state potentials however are elicited by stimuli presented at a sufficiently high rate to cause an overlapping of the responses to successive stimuli. This results in a periodic response with a constant phase relationship to the repeating stimulus (Stapells, Linden, Suffield, Hamel and Picton, 1984).

One of the most frequently used evoked potential that uses transient stimuli is Auditory Brainstem Responses (ABR). It can measure frequency specific thresholds using two main approaches (Stapells, Picton & Durieux-Smith, 1994). The first presents a click and isolates responses from different regions of the cochlea using high pass masking. The second and more widely used approach presents, brief tones with or without masking noise in order to limit the spectral splatter caused by the brevity of the stimulus. Stapel Is (2000a, 2000b) has reviewed the use of tone evoked brainstem responses to assess hearing thresholds in infants and young children. He concluded that estimating the audiogram using the tone evoked auditory brainstem responses has limitations such as:

- Recognition of the response is not always an easy task.

  The latency and morphology of the responses vary with (a) the type of brief tone used as a stimulus, (b) the intensity of the stimulus, (c) the frequency -band pass of the amplifiers and (d) the age of the subject.

- The thresholds are not precisely estimated.
- The procedure is time-consuming.

However, in recent years the Auditory Steady-State Responses (ASSR) have given us a different approach to measuring the brain's responses to sound. Rather than ref lecting the transient effects of a single stimulus, the steady-state responses represent the unchanging effects of a regularly repeated stimulus. Steady-state responses are evoked by rapidly recurring stimuli or by the regular modulation of a continuous to ne.

Steady state evoked potentials technique has several advantages over transient evoked potentials.

- The measurement of steady state response is simple (Regan, 1989), devoid of tester bias as the amplitude and phase of the response at the frequency of stimulation can be measured automatically by a computer and no judgment by an interpreter is needed (since no peaks need to be identified).
- There are clear statistical procedures to determine the presence of a response. These techniques compare the respon se at the particular modulation frequency to the noise at adjacent frequencies or assess the reliability of replicable responses.
- Steady state responses allow the use of steady state stimuli such as a continuous tone with a sinusodially -modulated amplitude (Kuwada, Batra & Maher 1986; Picton, Skinner and Champagne, 1987.). The frequency content of such an amplitude modulated (AM) tone is concentrated at the carrier frequency of a tone and at the two sidebands separated from the carrier frequency by the frequency of the modulation. The energy spread is much less than the spread of energy into frequencies other than the nominal frequency while using a brief tone.
- Steady-state stimuli can probably provide a better evaluation of hearing aids than brief transient stimuli. Because the hearing aid amplifiers are quite nonlinear, transient stimuli undergo significant distortion and it becomes difficult to relate responses to these stimuli with the ability of the hearing aid to transfer information for responses that change less rapidly (e.g. speech). Steady state responses are unlikely to be distorted when presented through a sound field speaker for assessing hearing aid benefit (Picton, Dimitrijevic, Van Roon, John, Reed & Finkelstein, 2002).

- It is observed that thresholds using steady state stimuli can be estimated with about the same accuracy and the same frequency-specificity (Aoyagi et al. 1999; Name & Vanaja, 2004) as when using tone -evoked auditory brainstem responses.
- Multiple responses can be recorded at the same time (Lins et al., 1996).
- The presentation level can be until 120dBHL with a frequency range from 250 Hz to 8 KHz.

It may be concluded that in the context of objective audiometry, the auditory steady - state responses offer some advantages over trans ient responses.

Apart from estimating behavioral pure-tone thresholds, it is observed that ASSR can assess the ability of the brain to detect changes in the frequency and amplitude of supra - threshold tones. The ASSR may thus provide an objective mea surement of the supra-threshold processes needed in the initial stages of speech perception.

Hearing thresholds are an essential part of the audiometric assessment, but the ability to discriminate supra-threshold sounds often provides more meaningful info rmation. An objective technique like ASSR that can measure supra -threshold hearing would therefore be very helpful in the investigation of a patient's ability to understand speech, in the selection and monitoring of hearing aids, and in studying disorders of auditory perception (Dimitrijevic, John, Van Roon and Picton, 2001).

To evaluate how well the auditory system processes differences in frequency and intensity at supra-threshold intensities, one can set an amount of modulation and decrease the intensity of the stimulus. Rather than this, one can set the intensity and then decrease the amount of modulation to obtain a threshold (or 'difference limen') for frequency or for intensity. John, Dimitrijevic, Van Roon, and Picton (2001) reported that Amp litude Modulation (AM) and Frequency Modulation (FM) thresholds obtained in this way were two to three times the behavioral thresholds. Another approach would be to present a set of stimuli with multiple modulations in amplitude and frequency and to determ ine how many of these modulations are detected by the auditory system. This could provide a measurement of how much information is available to be used for speech perception (Dimitrijevic, John, Van Roon and Picton, 2001). IAFM stimuli therefore show promise as an objective test for assessing supra-threshold hearing. Thus, in the present study this information is gathered by presenting an IAFM [a carrier that is modulated in amplitude and frequency, with different rates of modulation for the amplitude modul ation (AM) and frequency modulation (FM)] stimuli at a fixed level as well as at a variable level.

-y *Need for the Study*

A sound is 'intelligible' if it can be meaningfully understood. This involves both discriminating the sound from similar sounds and recognizing that it is equivalent to some stored template of a sound that has a meaning. These abilities are related mainly to three levels of processing in the auditory system; the ear (audibility), the brainstem (discriminability) and the cortex (intelligibility).

The most common clinically used test of supra-threshold auditory discrimination is the Word Recognition Score (WRS) for monosyllabic words (Martin, 1998). It has well been documented that the Auditory Steady state response to IAFM stimuli may p rovide us with some estimates of both the audibility and the discriminability of speech sounds.

The assessment of one's ability to discriminate supra-threshold sounds often provides more meaningful information because

1) It is the inability to hear speech normally is often the way that a patient recognizes a hearing problem.

2) An improvement in the ability to discriminate speech sounds is the way in which treatment is demonstrated and monitored.

Thus, such an objective technique to measure supra-threshold hearing would therefore be very helpful in investigating;

(a) A patient's ability to understand speech,

(b) In the selection and monitoring of hearing aids and cochlear implants,

(c) In understanding the relationship of the degree of hearing loss and auditory perception, which can be used for rehabilitative purposes.

(d) It also assess the ability of individuals with auditory processing disorder to perceive speech; (as it has well been documented that A SSR may not require the degree of neural synchrony need for the identification of transient waveform (Ranee, Dowell, Rickards, Beers and Clark, 1998).

Especially in infants, young children as well as older subject who cannot or will not participate actively for standard hearing assessment procedures.

One is exposed to background noise throughout his listening exposure. It has been demonstrated that both amplitude and frequency modulations provide independent yet complementary contributions to support robust speech recognition under realistic listening situations (Zeng et al., 2004). At present only through ASSR one can deliver a stimulus that is both frequency and amplitude modulated.

An attempt was made to use an objective test - The Auditory Steady State Response Audiometry (ASSR) using speech modeled IAFM stimuli to achieve the following aims.

This investigation was designed with the following aims:

- To find out the relationship between behavioral pure tone threshold and ASSR threshold using IAFM stimulus in normal hearing and hearing impaired adults with different degree of hearing loss.
- To study the correlation between IAFM responses and WRS in normal hearing and hearing impaired subjects for in noise and without noise conditions.
- To analyze independently with each frequency response to find out which has most contribution to or got the best correlation with WRS for both the conditions -in noise and without noise.

We must be clear that this test is not strictly related to speech perception but only to the discrimination of those acoustic parameters necessary for speech perception

CHAPTER II

REVIEW OF LITERATURE

Speech is a dynamically changing sound sequence with little exact repetition. Thus, it would be highly desirable to find brain measures of ongoing, rather than transient, stimulus - related activity associated with the perception of sound sequences. A major challenge for paradigms using ongoing stimulus presentations is to distinguish stimulus related activity from other brain signals recorded during an experimental session. This is possibl e using a brain response known as the 'auditory steady-state response'.

Auditory steady state response (ASSR) or steady state evoked potential (SSEP) is an auditory evoked potential, elicited with modulated tones, that can be used to predict hearing sensitivity in patients of all ages. The response itself is an evoked neural potential that follows the envelope of complex stimulus. It is evoked by periodic modulation, or turning on and off, of a tone i.e. the response is generated when the stimulus tones a re presented at a rate that is sufficient to cause an overlapping of transient potentials. The energy in the resultant response is at the modulation frequency and its harmonics, allowing response detection using automatic and objective analysis protocols (Cohen, Rickards & Clark 1991; Jerger, Chimel, Frost &Coker, 1986).

Auditory steady state evoked potentials were first suggested as an objective mean to assess hearing by Galambos and colleagues (1981, cited in Picton, Vajsar, Rodriguez & Campbell, 1987). ASSR has been recorded with various kinds of stimuli. Initial studies mainly recorded ASSR to clicks and tone burst stimuli. These stimuli have energy at multiple frequencies in the spectrum. Later studies used modulated tones to reduce the spectral energy.

Amplitude modulation (AM) is defined as the change in the amplitude of the carrier signal according to the strength of modulating signal. The depth of modulation is defined as the ratio of difference between the maximum and minimum amplitudes of the signal to the sum of the maximum and minimum amplitudes. The stimuli contain spectral energy at the carrier frequency and at the two sidebands on either side of the carrier, at a frequency separation equal to the modulation frequency. Amplitude of the side bands increases as the depth of modulation increases (Picton, John, Dimitrijevic & Purcell, 2003). The modulation depth has an effect on amplitude and phase of ASSR. Maximum amplitude reaches at 100 % of modulation depth. There is no effect of modulation d epth on phase of the response after the 25% modulation depth (John, Dimitrijevic, Van Roon & Picton, 2001).

Frequency modulation (FM) is defined as a change in the carrier frequency, which is determined by the modulating frequency. The amount or the depth of modulation is the difference between maximum and minimum frequency divided by carrier frequency (Picton, John, Dimitrijevic & Purcell, 2003). Like amplitude modulation, the response to frequency modulation is affected by depth of modulation. While recording ASSR for 40Hz and 80 Hz modulation tone, the response amplitude increases as the depth of modulation increases (Picton et al., 1987; John et al., 2001). FM is not usually preferred due to more spectral width that is more than a critical band.

A stimulus that is modulated for both amplitude and frequency is called as mixed modulation (MM). The spectrum of mixed modulation varies with the relative phase between two modulations, which is termed as modulation index. When the maximum amplitude and frequency occurs at same time then they are in phase. It has been reported in the literature that response to mixed modulation has higher amplitude than AM or FM alone when both AM and FM are in phase and leads to better detection of threshold (Cohen, Rickards & Clark, 1991; John et al., 2002). Cohen, Rickards & Clark, (1991) recommended the use of 90Hz modulation frequency with 100% of AM and 20% of FM

Modulating a tone using different modulation frequencies for amplitude and frequency gives "independent amplitude and frequency modulation" (IAFM). This allows two responses to be obtained for each carrier frequency. The response are slightly smaller than when the modulations only involve amplitude or frequency, but still readily recognizable. Dimitrijevic, John, Van Roon and Picton (2001), recorded ASSR responses using AM, FM and IAFM stimuli that were presented simultaneously. They observed that the steady state responses to the IAFM stimuli were attenuated by about 14 % as compared to the AM or FM alone responses.

The effects of carrier frequency are quite different for stimuli modulated at rates near 40Hz and near 80Hz. The 40Hz response significantly decreases in amplitude with increasing carrier frequency (Galambos, 1981 cited in Picton et al., 2003). For the 80Hz-100Hz responses, the amplitude is larger for mid frequency than for higher or lower frequencies. The noise levels also decrease as the frequency is increased which helps in better detection of response in high frequency (Cohen, Rickards & Clark, 1 991).

The effect of modulation rate on amplitude of the steady state response may vary with carrier frequency and with age of subject. Cohen, Rickards & Clark, (1991) reported that modulation frequency at which the ASSR was most efficiently recorded varie d with the carrier frequency. However, these effects are not large in adults. Rickards et al., (1994) found that the response amplitude in neonates was larger at lower modulation frequencies for low carrier frequencies, with optimal values of 72, 85 and 97 Hz for 500, 1500, 4000Hz, respectively. The thresholds estimated at low frequency are little higher than at higher frequency (Picton, John, Dimitrijevic & Purcell, 2003).

Dimitrijevic, John, Van Roon and Picton (2004) reported a consistent finding that t he lower carrier frequencies evoked larger responses than the higher carrier frequencies when an IAFM stimuli was used.

As the intensity of the signal increases, the amplitude of the response increases and latency decreases. The amplitude of the response increases by (3-9 nV/dB) is seen. The latency increase is quite linear (Lins, Picton &Picton, 1995).The effect of intensity are mediated by multiple physiological factors. Therefore, at lower intensities the number of samples required is more to get the response (Hardman & Stapells, 2003). Ranee, Rickards, Cohens, Vidi & Clark (1995) reported that ASSR estimates thresholds within 8 to 16 dB and as ASSR employs continuous stimuli, the maximum intensity that can be used is 120dBHL and thus helps in differentiation of severe and profound hearing loss.

ASSR can be obtained to a large range of modulation frequency (20 Hz - 200 Hz). The modulation frequency below 60 Hz is not widely recommended for threshold estimation due to the dependency on state of the subject. It has been reported that the response recorded is inconsistant and threshold is elevated by 10-15 dB during sleep (Stapells, Oates, 1997). Lins, Picton , Champagne & Durieux-Smith (1995) reported that response amplitude for the low modulation frequency decreased during sleep. This subject state dependency of response for modulation frequency below 60 Hz is attributed to generator sites similar to middle latency response (Cohen, Rickards & Clark, 1991). Large number of clinical reports show s that the higher modulation frequencies are best recorded during sleep state (Ranee, Dowell, Rickards, Beer, Clark, 1998; Rickards et al., 1994a). This may be due to the fact that modulation frequency higher than 60 Hz are generated from brainstem structu res similar to ABR (Cohen, Rickards & Clark,1991; Aoyagi et al., 1994a; Lins, Picton, Champagne & Durieux-Smith (1995). Lins, Picton, Champagne & Durieux-Smith (1995) reported that the response amplitude is unchanged for higher modulation frequency during sleep. However, Cohen, Rickards and Clark, (1991) reported that background EEG was reduced during sleep and improved the signal to noise ratio, which in turn improves the response detection.

Several investigators used ASSR to estimate the behavioral th reshold.

Rickards, Tan, Cohen, Wilson, Drew & Clark (1994) estimated the thresholds in 337 normal hearing infants at 500, 1500 and 4000 Hz. They used the modulation frequency of 72 Hz at 500 Hz, 87 Hz at 1500 Hz and 97 Hz at 4000 Hz. The mean thresholds e stimated were 41 dB HL at 500 Hz , 24 dB HL at 1500 Hz and 34.5 dB HL at 4000 Hz. Similar results were reported by Aoyagi et al (1994).

Lins et.al., (1996) evaluated the audiometric usefulness of steady state responses to multiple simultaneous tones amplitude modulated at 75 to 110 Hz in normal adults, well babies, normal adults with simulated hearing loss and adolescents with known hearing losses. They observed the thresholds for steady state responses to tones of 500,1000,2000 & 4000 Hz in normal adults to be 14+11,12+11, 11+8 & 13=11 dB respectively above behavioral thresholds for air conducted stimuli .In well babies tested in a quiet environment the thresholds were 45+13,29+10,26+8 & 29+10 dB SPL. In adolescents with known hearing losses, the steady state response thresholds predict behavioral threshold with correlation coefficients of 0.72, 0.70, 0.76 and 0.91 at 0.5, 1, 2, 4 KHz.

Aoyagi et al., (1999) have published audiograms, which highlight the usefulness of evoked response to tones that are amplitude modulated at 80 Hz in predicting thresholds. For a group of hearing impaired children and adults, with hearing loss ranging from mild to profound, the correlation between the pure tone and ASSR thresholds ranged from 0.0729 at 500 Hz to 0.915 at 4000 Hz. Similarly Lins and Colleagues (1996) observed correlation coefficient of 0.82 with the difference between pure tone and ASSR threshold ranging from 9 to 14 dB.

Perez-Abalo et al., (2001) evaluated the usefulness of the binaural Multiple frequency auditory steady state responses in hearing impaired children and normal hearing young adults. They observed that in normal hearing subjects the response thresholds at 500,1000,2000 & 4000 Hz were detectable on average between 11 and 15 dB above the behavioral threshold. However, these differences were significantly smaller in the hearing impaired (5 to 13 dB).

Thenmozhi & Barman (2004) studied the relationship between the behavioral pure tone threshold (AC & BC) and ASSR (AC & BC) threshold in subjects with n ormal hearing adults and in subjects with conductive or sensorineural hearing loss of varying degree and concluded that a strong relationship exist between the behavioral threshold and ASSR threshold with increasing frequency and increasing degree of loss. Also the subjects with hearing loss of higher degree show better agreement than the normals.

Name & Vanaja (2004) compared tone-burst ABR and ASSR thresholds in normal hearing and hearing impaired adults. He concluded that tone ABR and ASSR both es timate the behavioral thresholds reasonably well and both procedures predicts audiogram configuration accurately. However, the tone ABR thresholds were lower than ASSR thresholds and this difference was statistically significant.

Picton, Dimitrijevic, Perez-Abalo & Van Roon (2005) recorded ASSR using stimulus rates of 78-95 Hz in normal hearing adults, elderly and in elderly sensorineural hearing loss subjects. They observed that ASSR threshold were closer to behavioral thresholds for the hearing-impaired groups. They also reported a rapid increase in the amplitude of ASSR responses above the threshold for the hearing-impaired group and contributed it as electrophysiological recruitment.

Werff and Brown (2005) carried out a study to examine the correlation between auditory steady state response (ASSR) thresholds and behavioral thresholds in normal hearing and in hearing impaired adults with sensorineural hearing loss. Their second goal was to compare suprathreshold ASSR growth functions in these two sub ject groups. They demonstrated that a highly significant correlation exist between pure tone behavioral and ASSR thresholds for individuals with either sloping or flat audiometric configuration. However, there were more errors when behavioral threshold ar e in the normal as opposed to the 1000 to 4000 Hz range. Secondly, the form of the ASSR amplitude growth function did not distinguish between the two configurations of hearing loss.

Until now, all the studies demonstrate that ASSR thresholds can be c orrelated to behavioral thresholds. A good correlation exist more so for the hearing impaired individuals. It is also observed that as the hearing loss increases, the closer are the ASSR thresholds to the behavioral thresholds. Later the investigations s hifted towards the correlation between word recognition and ASSR using IAFM stimuli.

Auditory Steady State Response and Word Recognition *Scores:*

Acoustic cues in speech sounds allow a listener to derive not only the meaning of an utterance but also the speaker's identity and emotion. Most traditional researchers have taken a reductionist's approach in investigation of the numeral cues for speech recognition. Studies using either naturally produced whispered speech or artificially synthesized speech have isolated and identified several important acoustic cues for speech recognition. As a result, spectral and temporal acoustic cues have been interpreted as built in redundancy mechanisms in speech recognition. Traditional studies on speech recognition have focused on spectral cues such as formants but recently attention has been turned to temporal cues, particularly the waveform envelope or AM cue. Results from various studies have been over interpreted to imply that only the AM cue is needed for speech recognition. However Zeng et al., (2005) observed that the utility of the AM cue is seriously limited to ideal conditions (high -context speech materials and quiet listening environments).

The ability of the auditory system to follow rapid changes in the frequency or amplitude of the sound is assessed psychophysically by means of temporal modulation transfer functions (Viemeister, 1979). These functions are abnormal in patients with sensorineural hearing loss, particularly for higher frequencies of modulation (Bacon and Viemeister, 1985; Formby, 1987). Evaluating the steady state responses at a faster rates may help detect individuals who have problems processing rapid formant transitions in speech (Tallal et al., 1996). Because the temporal modulation of speech sounds may serve as cue to facilate the recognition of consonants (Shannon, Zeng, Kamath, Wygonski and Ekelid, 1995;

cited in Picton et al., 2003, Van Tasell, Soli, Kirby, and Widen, 1987), the ability of the steady state responses to follow rapid modulation frequencies may also relate to the ability of the auditory system to understand speech.

Amplitude modulation and frequency modulation are commonly used in communication but their relative contributions to speech recognition have not been full y explored. To bridge this gap, Zeng et al., (2004) derived slowly varying amplitude modulation and frequency modulation from speech sounds and conducted listening tests using stimuli with different modulations in normal hearing and cochlear implant subjec ts. They found that although amplitude modulation from a limited number of spectral bands may be sufficient for speech recognition in quiet, frequency modulation significantly enhances speech recognition in noise as well as speaker and tone recognition. A dditional speech reception threshold measures revealed that frequency modulation is particularly critical for speech recognition with a competing voice and is independent of spectral resolution and similarity. These results suggests that AM or FM provide independent yet complementary contributions to support robust speech recognition under realistic listening situations.
Thus, these days the focus is on studying speech perception through objective test such as auditory steady state responses, because one can use both amplitude and frequency modulated tones.

John, Dimitrijevic, Van Roon & Picton (2001) recorded multiple auditory steady state responses in normal hearing adults using tonal stimuli that were amplitude modulated (AM), Frequency modulated (FM) or modulated simultaneously in both amplitude and frequency.

They concluded that the AM and FM stimuli evoked responses that are relatively independent and that they add together to give the MM response. As the AM response occur slightly later than the FM responses, the largest MM response is recorded when the maximum frequency of the MM stimulus occurs just after the maximum amplitude.

Dimitrijevic, John, Van Roon and Picton (2001), reported that the ability to recognize speech clearly depends on ability of the auditory system to process changes in frequency and intensity. However, instead of measuring the modulation threshold for each of the AM and FM stimuli, they considered that the presence of a recognizable steady state response to a particular modulation indicate that it is adequately processed and the cortex uses this information in the perception of speech. They measured the human steady state responses to multiple Independent Amplitude and Frequency Modulation (IAFM) tones in twenty -one normal hearing subjects. The modulation depth was 50% for AM and 20% for FM that is typical for speech as reported by them and the complexity of speech was mimicked by presenting eight of these together. Out of three experiments carried out, one experiment related the IAFM response to the discrimination of monosyllabic words at intensity between 20-70 dB SPL and they found that the number of responses detected during multiple IAFM stimulation and the amplitude of these responses correlated significantly with the word recognition scores.

Picton, Dimitrijevic, Van Roon, John, Reed and Finkelstein (2002) evaluated the responses to IAFM stimuli in 10 normal subjects and in 14 mild to moderate elderly hearing impaired subjects wearing hearing aids. The stimuli were presented in free field rather than through insert phones. Each of the four carrier frequencies (500, 1000, 2000 & 4000 Hz) was amplitude modulated at a depth of 50 % and frequency modulated at a depth of 20 %. The modulation frequencies were around 80 Hz. The recording was carried out at the most comfortable level (MCL) and at intensities 10 and 20 dB below the MCL. For the hearing impaired group the recording was carried out at the aided MCL with the hearing aid and without the aid. They correlated the number of significant responses to the word recognition scores obtained at the same SPL. They observed a correlation of 0.52 for the hearing impaired subjects and 0.31 for the normal hearing subjects.

As this study was carried out at MCL, it could be possib le that the normal-hearing subjects set their MCL higher than the subjects with hearing aids. It was observed that the MCL was on average 43 dB above the SRT for normal subjects and 22 dB above the aided SRT for the hearing-impaired subjects. This difference is likely to be related to recruitment, which would bring the SRT and MCL closer together in the aided subjects. Thus, the high intensity levels used by the normal subjects may have obscured any correlation in this group since these subjects had very high WRS at MCL-10 and MCL-20 levels.

Dimitrijevic, John and Picton (2004) in order to improve the relationship between the physiological responses and the behavioral WRS adjusted the IAFM stimulus parameters such that it resembled the acoustic properties o f everyday speech. They separately measured WRS and IAFM responses at a stimulus intensity of 70dBSPL in three groups of subjects: young normal hearing, elderly normal hearing, and; elderly hearing impaired. Two series of

IAFM stimuli were used, one with modulation frequencies near 40Hz and the other with modulation frequencies near 80Hz.

The IAFM responses and WRS measurements were recorded in quiet and in the presence of speech masking noise at 67 dB SPL or 70 dB SPL. The hearing -impaired subjects were evaluated with and without their hearing aids to see whether an improvement in WRS would be reflected in an increased number of responses to the IAFM stimulus.

They observed that the correlations between WRS and the number of significant IAFM responses were between 0.70 and 0.81 for the 40Hz stimuli between 0.73 and 0.82 for the 80Hz stimuli, and between 0.76 and 0.85 for the combined assessment of 40 and 80Hz responses. In addition, the response amplitudes at 80Hz were smaller in the hearing im paired than in the normal hearing subjects. As the response amplitudes for the 40Hz stimuli varied with the state of arousal, it was not possible to compare amplitudes across the different groups. However, the hearing aids increased both the WRS and the nu mber of significant IAFM responses at 40Hz and 80Hz. Masking decreased the WRS and the number of significant responses.

They concluded that the IAFM responses significantly correlated with WRS and thus may provide an objective tool for examining the brain's ability to process the auditory information needed to perceive speech.

Narang & Vanaja (2005) investigated the minimum amplitude modulation and frequency modulation depth that could be perceived by normal hearing and hearing impaired adults (18-50years) .She concluded that in normal hearing individuals the AM depth threshold and the FM depth threshold increased with increase in the frequency of the signal (500-4000Hz) and the minimum AM and FM depth that could be perceived by some of them was 1%. It was also observed that in the individuals with hearing impairment there was an increase in AM depth threshold and FM depth threshold with the increase in the degree of hearing loss. However, for the AM depth threshold this effect was significant on ly at 500 and lOOOHz. The AM/FM depth threshold with the speech identification scores in quiet and in noise for both the groups was correlated and no significant correlation was observed at any frequency for any group.

CHAPTER III

METHOD

To accomplish the aim, the following method was adopted.

Subjects:

Two groups of subjects participated in the experiment. A young normal hearing group consisting of 30 subjects (mean age 28 year, range 20 to 35 years) formed the 'control group'. A young hearing-impaired group with different degrees of sensorineural hearing loss with age ranging from 20-35 years (mean age 28 years) formed the experimental group. The experimental group was further divided into three subgroups based on their severity of hearing loss. They were as follows:

Mild hearing loss N =6

Moderate hearing loss N=12

Moderately severe loss N=16

Where 'N' refers to the number of subjects.

All the subjects of both the groups were native speakers of Kannada.

Selection Criteria:

Apart from being a native Kannada speaker, the subjects had to fulfill the following criteria.

Table 7: Depicts the Mean and the SD of the Behavioral pure tone thresholds and the ASSR threshold across the frequencies for the hearing impaired individuals.

Hearing loss	Tests		500 Hz	1500 Hz	2000/2500Hz	4000 Hz
Mild hearing loss	Behavioral threshold	Mean	28.3	31.6	35.8	31.6
		SD	10.8	7.5	6.6	10.3
	ASSR Threshold	Mean	64.0	70.0	73.0	75.0
		SD	8.9	10.0	11.5	7.0
Moderate hearing loss	Behavioral Threshold	Mean	46.6	47.0	45.4	51.6
		SD	11.1	8.1	6.5	7.4
	ASSR Threshold	Mean	61.4	61.1	66.6	64.4
		SD	3.7	10.3	7.0	10.3
Moderately severe hearing loss	Behavioral Threshold	Mean	59.6	64	67.1	74
		SD	4.9	7.3	7.5	10.4
	ASSR Threshold	Mean	76	76.3	68	80
		SD	8.9	5.0	8.9	0.0

It is evident from Table 7, that in subjects with mild, moderate and moderately severe hearing loss, the ASSR thresholds were higher than the behavioral threshold at all the four frequencies for all the subjects. The ASSR thresholds were very high than the behavioral threshold for the mild hearing loss group. The difference between behavioral threshold and the ASSR threshold reduces with the increase in severity of hearing loss. However, the variations in ASSR threshold were less in the experimental groups than what is noticed in the control group.

The difference between ASSR threshold and behavioral threshold were calculated in subjects with normal hearing and with mild, moderate and moderately severe sensorineural hearing loss which can be seen in table 8.

Table 8: Depicts the Mean and the SD of difference between ASSR and behavioral threshold obtained in the control and experimental group

Groups		500 Hz	1500 Hz	2000/2500Hz	4000 Hz
Normal	Mean	47.4	42.0	46.2	48.2
	SD	17.4	14.9	23.4	20.9
Mild hearing loss	Mean	34.0	40.0	35.0	42.5
	SD	15.9	5.0	18.0	17.6
Moderate hearing loss	Mean	19.2	15.5	22.2	12.7
	SD	12.3	10.7	10.9	12.3
Moderately severe hearing loss	Mean	17	14.5	4.0	11.2
	SD	10.9	7.5	8.2	11.5

It is evident from the table-8, that the difference between the behavioral thresholds and ASSR thresholds was largest for the normal hearing and mild hearing loss subjects. The difference between the behavioral thresholds and ASSR thresholds decreases with increase in the degree of hearing loss from mild to moderately severe. The same trend was observed at all the frequencies that were evaluated.

A two-way analysis of variance was carried out to examine the effects of hearing threshold levels and frequency of the stimulus on the mean difference between ASSR and behavioral threshold. The main effect of hearing threshold level was highly significant [F (3,158) = 42.44, P< 0.001] suggesting that the hearing thresholds have a significant effect on the difference between the ASSR and behavioral threshold .The greater the hearing loss, the lesser is the difference between the ASSR and behavioral threshold. On Post hoc testing with Scheffee the individuals with normal hearing and mild hearing impaired differed significantly from those with moderate and moderately severe hearing impaired. However, there was no significant difference between the normal and the mild group or the moderate and moderately severe hearing loss group as shown in the figure below.

Table 9: Depicts the difference between the behavioral and ASSR threshold across the groups.

Hearing levels	Normal	Mild	Moderate	Moderately severe
Normal		NS	S	S
Mild			S	S
Moderate				NS

Where "S" refers to significant and "NS" refers to non-significant.

Thus, the mean difference in the behavioral threshold and ASSR threshold was significantly larger for the normal and the mild hearing impaired group as compared to the moderate and moderately severe hearing impaired groups. The main affect of the frequency of the stimulus on the mean difference in the behavioral threshold and ASSR threshold was non significant [F (3,158) = 0.080, P> 0.05] which showed that the difference in ASSR an d behavioral threshold was similar across the frequencies that were tested. Interaction between the frequency of the stimulus and the hearing threshold level was non - significant [F (9,158) = 0.608, P> 0.05] revealing similar effect of frequency of the sti mulus on the difference between ASSR and pure tone threshold for subjects with different hearing threshold levels. From the above findings we may conclude that the IAFM ASSR threshold obtained for the normal hearing and mild hearing loss subjects were much larger than behavioral threshold as compared to that of moderate and moderately severe hearing loss subjects. The difference between the behavioral threshold and ASSR threshold across the frequencies did not differ significantly irrespective of the severity of the hearing loss.

***Correlation between word discrimination scores and steady state** responses:*

The IAFM stimuli evoked two independent responses for each carrier frequency, one for the AM and one for the FM. These were then combined to give the IAFM responses. For **the** statistical analysis the amplitude of the AM, FM and IAFM were considered for two conditions. These amplitudes were correlated with the WRS to achieve the aim of the studying the correlation between IAFM responses and WRS in normal heari ng and hearing impaired subjects. Pearson product moment correlation coefficient was computed for the WRS and the amplitudes of the AM, FM, and IAFM responses for all the groups except the mild hearing loss group. As the subjects were less in number Spearm an correlation coefficients was carried out for this group. All the analysis was carried out for the two conditions i.e. ASSR obtained in the presence of noise and without noise.

To prevent floor effects in the amplitude correlations, the amplitude of any response that was not significantly different from the residual noise (i.e. was absent) was made equal to zero.

Table 10: Correlation coefficients for amplitude of the IAFM responses and WRS for the two conditions.

Subjects	Quiet WRS			Noise WRS		
	AM	FM	IAFM	AM	FM	IAFM
Normal	0.2	0.2	0.2	0.1	.0.1	0.1
Mild HL	0.3	0.1	0.1	0.8	0.8	0.8
Moderate HL	0.3	0.6	0.2	0.6**	0.7**	0.6*
Mod severe HL	0.1	0.1	0.1	0.5*	0.5*	0.5*

**-Correlation is significant at the 0.01 level (2-tailed).
* - Correlation is significant at the 0.05 level (2 -tailed).

Note: The term 'Quiet' in all the tables will refer to the ASSR and WRS that were obtained in without noise condition. The above mentioned correlation signi ficant levels will be the same for the following tables.

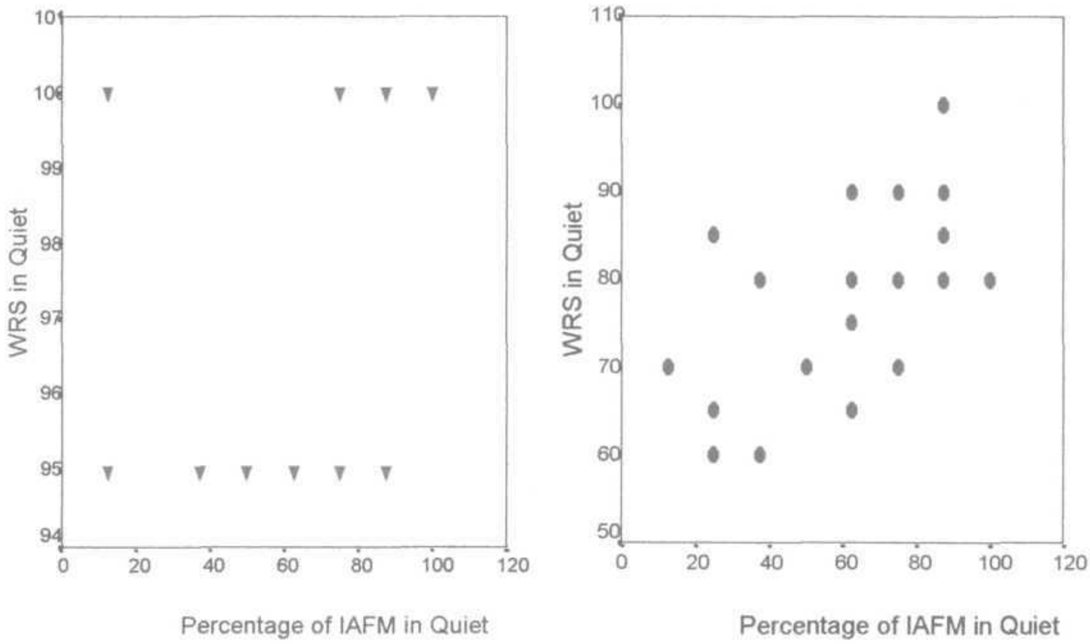
It is evident from the table 10, that a correlation exist between the behavioral WRS and the IAFM responses (AM, FM and IAFM amplitude) for all the groups and for both the conditions. But it is statistically significant only for the moderate and moderately severe hearing loss subjects for the responses obtained in the presengce of noise. Another observation is that in general the FM correlation values are slightly higher or equal to the AM and IAFM values. From the table we also observe that the correlation coefficient is high for the mild hearing loss subjects for the responses obtained in the presence of noise. However, they failed to reach a statistically significant level, which could be due to th e less number of su

As the amplitude changes from person to person depending on factors such as the thickness of the skull, orientation of the generator etc. to avoid such effects we also considered the total number of responses obtained from each subjects. Hence, for the IAFM stimuli there are 4 AM and 4 FM responses for the four carrier frequencies. For the analysis total number of responses present out of the 8 responses was considered and the percentage of the responses were calculated. The percentage of the responses were then correlated with the WRS using the Pearson's product moment correlation coefficient or the spearman correlation coefficient.

Table 11: Depicts the Correlation coefficients for number of the IAFM responses and WRS for the two conditions

Subjects	Quiet WRS			Noise WRS		
	AM	FM	IAFM	AM	FM	IAFM
Normal	0.03	0.2	0.1	0.1	0.1	0.1
Mild hearing loss	0.6	0.6	0.6	0.9*	0.8	0.8
Moderate hearing loss	0.1	0.5	0.2	0.6*	0.6*	0.6*
Mod-severe hearing loss	0.2	0.4	0.3	0.5*	0.6*	0.6*

It is evident from the table 11 that the WRS obtained in quiet did not show any significant correlation with the number of ASSR responses present for any group. However, there is a significant correlation between WRS obtained in the presence of noise and the number of ASSR responses obtained in the presence of noise and this is more evident as the severity of hearing loss increases.

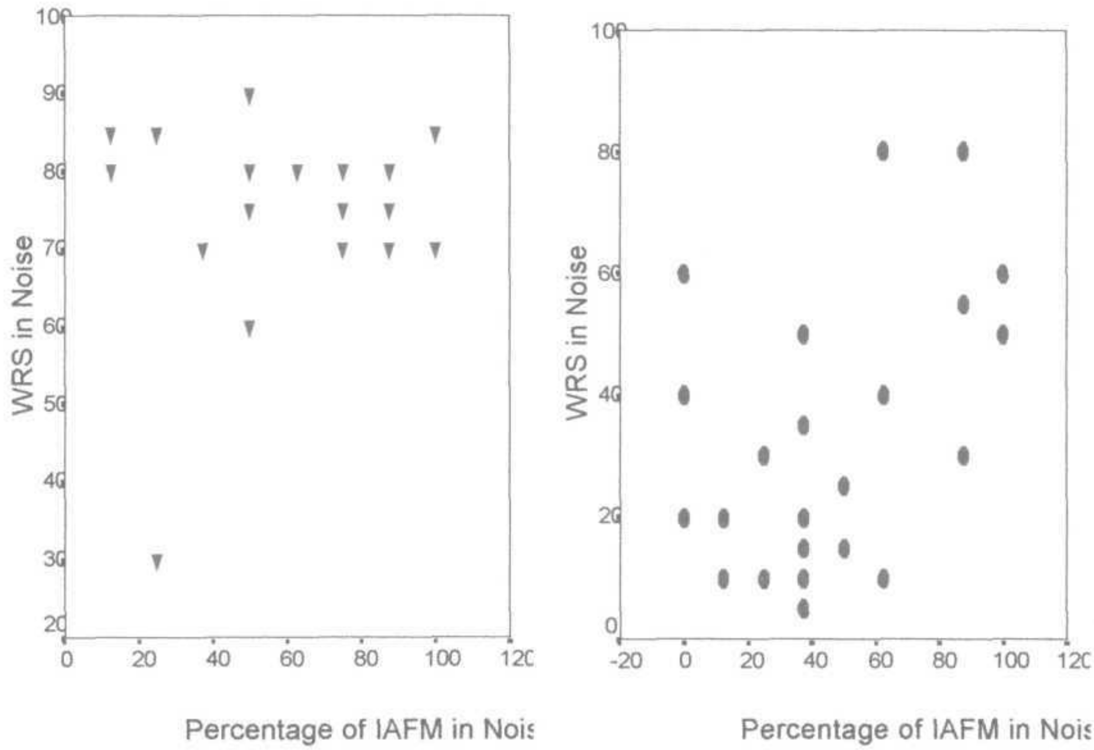


(1) (2)

Figure 1: Depicts a scatter plot of percentage of the number of ASSR responses (X-axis) and the WRS (Y-axis) obtained in quite for the normal hearing and the hearing impaired group respectively.

It is evident from the figure 1 that in normal hearing subjects (1) no increasing trend is observed. As can be observed in table 11 there was no statistical significant correlation for the normal hearing group. Thus, the same is depicted in the scatter plot.

For the overall hearing-impaired group (2) a significant correlation was observed between the WRS and the number of ASSR responses obtained in the absence of noise (0.5*).



(3) (4)

Figure 2: Depicts a scatter plot of percentage of the number of ASSR responses (X-axis) and the WRS (Y-axis) obtained in the presence of noise for the normal hearing and the hearing impaired group respectively.

It is evident from the figure 2 that in normal hearing subjects (3) no increasing trend is observed. As can be observed in table 11, there was no statistical significant correlation for the normal hearing group between the WRS and the number of ASSR responses obtained in the presence of noise. This is depicted in the scatter plot.

For the overall hearing-impaired group (4) a significant correlation was observed between the WRS and the number of ASSR responses obtained in the presence of noise (0.4*).

Thus, one can conclude that in the hearing impaired group as the number of IAFM responses increasing the WRS also increases for both the conditions. However i n the presence of noise there is relatively less correlation when the overall hearing -impaired subjects were considered.

Since there was a statistically significant correlation observed for the overall hearing impaired group regression was perform to estimate the regression equation to predict the behavioral WRS from ASSR using IAFM stimuli for the two conditions.

Table 12: Regression equations for the prediction of behavioral WRS from the ASSR responses.

Condition	Regression equation
Quiet	63.122+0.229 (% IAFM)
Noise	16.717+0.320 (% IAFM)

The table 12 gives the regression equation that can be used to predict WRS in hearing-impaired group based on IAFM ASSR response at 80 dB SPL.

From the above findings one may conclude that whether the amplitude of the ASSR response or the number of significant ASSR responses are considered and correlated with the WRS the findings are similar. For both the measurements (number or amplitude of the responses) it was observed that WRS obtained in quiet did not show any significant correlation with the number or amplitude of the ASSR responses for any group. However, when the number of responses for the overall hearing-impaired group was considered a significant correlation was observed between the WRS obtained in quite with the ASSR responses obtained in quiet.

There is a significant correlation between WRS obtained in the presence of nois e and **the** number or the amplitude of ASSR responses obtained and this is more evident as the severity of the hearing loss increases. However, when the number of responses for the overall hearing-impaired group was considered a significant correlation was o bserved between the WRS and the ASSR responses obtained in the presence of noise. But the correlation obtained in the presence of noise is lower as compared to the correlation obtained in quite condition.

Correlation between word discrimination scores and frequency specific steady state responses:

As the third aim of the study was to analyze independently all the frequencies to find out the frequency with the maximum correlation, the correlation was carried out at each frequency for all the conditions. For this purpose the amplitude of the AM, FM and IAFM where considered at each of the four frequencies.

The correlation was carried out at each frequency to observe which among the four frequencies had the highest correlation values. Pearson product moment correlation coefficient was computed for the WRS and the amplitudes of the AM, FM, and IAFM responses for all the groups except the mild hearing loss group. As the subjects were less in number Spearman correlation coefficients was carried out for this grou p. All the analysis was carried out for the two conditions i.e. ASSR obtained in the presence of noise and without noise.

Table 13: Depicts the Correlation of the amplitude of IAFM responses with the WRS at each frequency obtained in the Quiet condition.

Subjects	500			1500			2500			4000		
	AM	FM	IAFM	AM	FM	IAFM	AM	FM	IAFM	AM	FM	IAFM
Normal	0.1	0.2	0.2	0.3	0.2	0.3	0.1	0.1	0.1	0.1	0.1	0.1
Mild	0.2	0.6	0.5	0.3	0.3	0.6	0.2	0.2	0.1	0.1	0.2	0.2
Moderate	0.1	0.3	0.2	0.1	0.4	0.2	0.2	0.3	0.3	0.1	0.4	0.2
Mod sev	0.1	0.1	0.1	0.2	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1

It is evident from the tables 13 that though a correlation exist it is not statistically significant in the normal and hearing impaired group for the responses between the WRS and ASSR responses obtained in quiet for any of the frequencies.

Table 14: Depicts the Correlation of the amplitude of IAFM responses with the WRS at each frequency obtained in the presence of noise

Subjects	500			1500			2500			4000		
	AM	FM	IAFM	AM	FM	IAFM	AM	FM	IAFM	AM	FM	IAFM
Normal	0.2	0.1	0.1	0.2	0.3	0.3	0.2	0.1	0.2	0.1	0.1	0.1
Mild	0.5	0.8*	0.8*	0.8*	0.4	0.8	0.5	0.5	0.5	0.3	0.6	0.6
Moderate	0.6*	0.8*	0.8**	0.5	0.6*	0.6*	0.6	0.2	0.4	0.5**	0.7**	0.7**
Mod sev	0.8**	0.8*	0.8*	0.3*	0.3*	0.3*	0.1	0.1	0.2	0.4*	0.4**	0.5**

It is evident from the table 14 that the correlation is statistically significant for the hearing impaired group for the responses obtained in the presence of noise. For the moderate and moderately severe hearing loss groups all the frequencies except 2500 Hz had a statistically significant correlation. This observation is not evident for the mild hearing loss group. It is observed that for the mild hearing loss group the 500 and 1500 Hz frequencies have greater correlation values. It can also be observed that the highest correlation value was observed to be for the 500 Hz frequency for all the hearing impaired groups.

To predict the frequency of the IAFM responses that correlates the maximum with the word recognition scores, step wise multiple linear regression was carried out in the noise condition for the hearing impaired group. As there was no statistical significant correlation observed for the normal hearing subjects for either of the conditions they where not considered for regression.

Table 15: Depicts the Predictor frequency and percentage of its contribution to WRS

Group	Maximum contributing Frequency	Type of modulation (AM, FM & IAFM)	Percentage predicted from the linear regression
Mild	1500	FM	82%
Moderate	500	IAFM	72%
Moderately severe	500	IAFM	67%

It is evident from the table 15 that the maximum contribution of the IAFM frequency for the WRS in the moderate and moderately severe hearing loss group is from the contribution of 500 Hz.

From the findings it can be concluded that a significant correlation is observed for only the hearing impaired group for the responses obtained in noise. For the mild hearing loss subjects 1500 Hz frequency contributes the maximum though even 500 Hz frequency is statistically significant. In case of moderate and moderately severe hearing loss subjects the maximum contribution of the ASSR responses obtained in the presence of noise for the WRS is by the 500 Hz frequency, though other frequencies 1500 and 4000 Hz are also statistically significant.

CHAPTER V

DISCUSSIONS

Relationship between behavioral threshold and ASSR Thresholds

The ASSR thresholds were observed to be more elevated above the Behavioral thresholds in normal hearing subjects than in hearing impaired subjects. Similar findings were reported by Lins et al., 1996; Perez Abalo et al.,2001; Ranee and Rickards, 2002; Ranee, Rickards, Cohen, De Vidi and Clark, 1995.

The ASSR thresholds were elevated largely even for the mild hearing loss group, but no conclusive statement shall be made for this group because the numbers of subjects in this group were less.

Apart from high mean values, the Standard Deviation in the present study was observed to be very high among the normal hearing subjects than the values rep orted in the literature (Name, 2004; Richards et al., 1994; Aoyagi et al., 1999). The high SD values in the present study suggest that there was a high variability among the subjects. These variations in the mean and SD across studies may be attributed to the methodological variability such as the subject's state, the type of stimulus used and the modulation frequency of the stimulus. Cohen, Richards and Clark (1991) had observed that in REM sleep state (sedated sleep) the background EEG noise level was lower, in relaxed or first stage of sleep may obscure the ASSR response. In the present study subjects were requested to relax or sleep. Some of the subjects slept during testing but their stage of sleep was not controlled. This would have caused more variation and higher threshold than Ranee, Dowell, Rickards, Beer, Clark, 1998, who recorded ASSR on sedated subjects. It was observed that most of the normal hearing subjects slept while the recording because their recording took a long time.

The other reason for the higher difference between the ASSR and behavioral thresholds would be the stimulus that was used. In the present study, an IAFM stimulus was used. It has been reported in literature (Dimitrijevic, John, Van Roon and Picton, 2001) that the ASSR response using the IAFM stimuli are observed to be attenuated by about 14% from the responses to AM or FM alone.

The modulation frequency used in the present study was around 80Hz. Aoyagi et al., 1994 concluded that 80 Hz amplitude modulation following respo nse appears to be useful for assessing hearing in infants and children in their early teens, but it is not adequate for hearing assessment in adults. It is not appropriate to use high modulation frequency for adults, rather a low around 40 Hz modulation rate is advisable because generally adults are not sedated and are made to relax.

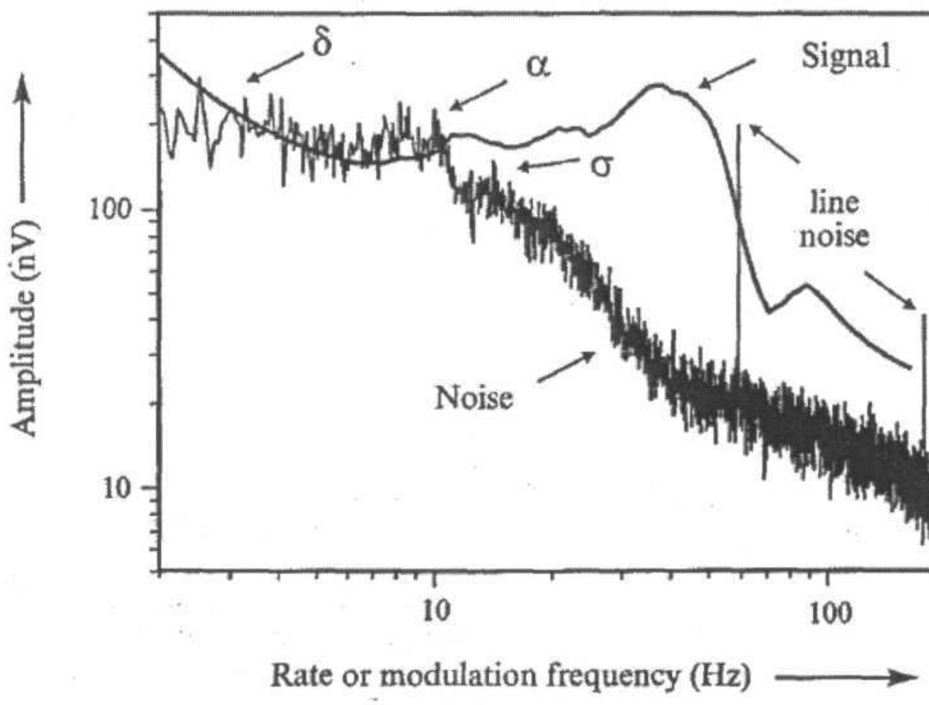


Figure 3: Measurement of signal to noise ratio of the ASSR response at different modulation frequencies.

It is evident from the figure 3, that the amplitude of the ASSR responses is higher near 40 Hz (Picton, John, Dimitrijevic & Purcell, 2003). It is also observed that as the modulation frequency increases there is a drastic reduction in the amplitude of the ASSR responses. When the noise levels are considered it is evident that noise levels also reduces as the modulation frequency increases. In spite of high noise level at 40 Hz, the amplitude of the response is so high at this modulation frequency that the respons e is quite evident even in the presence of high levels of noise. Thus, ASSR responses can be recorded much closer to behavioral threshold by using modulation rate around 40 Hz and the variation in the ASSR threshold would have also reduced.

In spite of all these methodological variability, a good relationship was observed between the behavioral thresholds and ASSR thresholds for moderate and moderately severe hearing loss subjects. In general, at low intensity levels the active mechanism plays a role and at high intensities the passive mechanism play major role. When the stimulus is of a higher SPL there is a broad activation of the basilar membrane, thereby resulting in excitation of more number of neurons. In cases with sensorineural hearing loss the act ive mechanism gets affected. Thus, in these cases the passive mechanism plays a significant role. As we know that the activation of passive mechanism results in greater area of neuronal excitation, thereby more number of auditory nerves get excited leading to high ASSR amplitude. This could be one of the reasons to achieve a better agreement between the ASSR thresholds for the sensorineural hearing impaired group. Similar findings were also reported by Picton, Dimitrijevic, Perez Abalo and Van Roon (2005). The same also would have led to reduction in SD for the hearing impaired group.

The difference between ASSR thresholds and behavioral thresholds was the same across the frequencies. These results are similar to those reported earlier in literature (John and Picton, 2000a). However Aoyagi et al., 1994a; Rance et al., 1995; Rickards, Tan, Cohen, Wilson, Drew & Clark, 1994; Name, 2004) report that the difference between ASSR threshold and the behavioral thresholds was higher at low frequency when compared t o high frequencies. This could be attributed to the stimulus used in the present study. The findings of the present study are consistent with some of the investigators (Dimitrijevic, John, Van Roon and Picton, 2004). They reported that at lower carrier fre quencies, the IAFM stimuli evoked larger responses than the high carrier frequencies. This is because the amplitude of the IAFM stimuli is larger for the lower carrier frequencies as they were based on the long-term average speech spectrum. This could be the reason for observing the mean threshold for the ASSR to be similar across frequencies.

Correlation of IAFM responses and WRS

A correlation was observed between the WRS and the IAFM response but was statistically significant only for the hearing impaired group (moderate and moderately severe) in the presence of ipsilateral noise. Picton et al., 2002 also observed a significant correlation for the hearing impaired group rather than for the normal hearing subjects. However Dimitrijevic et al., (2001, 2004) observed a good correlation between the WRS and the IAFM stimuli even for normal hearing adults. The discrepancy among the results could be attributed to the methodological variables. Dimitrijevic, John, Van Roon & Picton, 2001, used amplitude of 50 % and the frequency depth of 20 % and it was presented from 20 to 70 dB SPL. They then observed that total number of detected responses (out of a total number of eight responses). In his study all the subjects had at least six detectable responses at their highest levels of word discrimination score. In the present study the correlation between WRS and IAFM responses studied was at 80 dB SPL. At this high level of intensity the chances of distortions appear.

One possible reason for the absence of a significant correlation for the normal hearing subjects (in quiet and noise conditions) would be due to the subjects performing well on

WRS, leaving only a small WRS range for correlation. Also at high intensity levels chances of distortion are high (Picton et al., 2002).

In case of hearing impairment subjects, a statistically significant correlation was observed only for the noise condition when the amplitude of the responses where considered. The literature supports that the amplitude of the FM of the IAFM stimul i is relatively larger than the response of the AM response (Dimitrijevic et al., 2001, 2004). It is evident from research that in quiet, the AM responses play a major role and the FM responses play a major role in the presence of noise (Zeng et al., 2005). As the FM responses were larger than the AM in quiet conditions, the correlation was lower but in noise the FM responses would have significantly played the major role in word recognition score and thus there is a good correlation. It has also been reported that at high intensity levels the amplitude of the ASSR in the hearing impaired individuals' increases more rapidly than for the normal hearing subjects.

When the number of responses were considered it was observed that a correlation was again observed only for the hearing impaired group. When the number of significant responses was considered for the overall hearing impaired group, a statistical significant correlation was observed in quiet as well as in noise. However the correlation values were lower than that reported by Dimitrijevic, John & Picton, 2004.

In case of Mild hearing loss subjects the correlation values were observed to be high but where not statistically significant. This could be due to the less number of subjects in this group.

Correlation between word discrimination scores and frequency specific steady state responses:

When the regression was performed to estimate the predictor frequency for the behavioral WRS, the IAFM responses to 500 Hz frequency was observed to contribute t he maximum. Possible reasons for such a finding would be due to the fact that the carrier stimuli with lower frequencies have a broader activation pattern in the cochlea. Thereby, resulting in the activation of more number of neurons (Picton, John, Dimitrijevic & Purcell, 2003). For the correlation of WRS score with the ASSR amplitude, the ASSR recording was carried out at high intensity levels.

At a higher intensity level, it has been demonstrated that the hair cells and the auditory fibers respond better at a lower frequency than the characteristic frequency (Zwislocki, 1991; Smith, 1998). Also the FM stimuli are probably processed best by hair cells and neurons with characteristic frequencies lower than the carrier frequency of the stimulus. Dimitrijevic, John, Van Roon & Picton, 2001 also analyzed each frequency separately and observed the correlation to be high for the 1000 Hz frequency. But they did not carry out any statistical analysis for the prediction of the contribution of the frequency. It should be remembered that the stimuli used by them and the one used in the present study are different.

When there is a cochlear hearing loss, the tuning curves of the auditory nerve fibers are distorted exhibiting diminished tips and increased low frequency ta ils. These fibers may respond better to frequencies much lower than their characteristic frequency.

Though we can find the reason behind high contribution of IAFM response at 500 Hz the results cannot be confirmed because in the present study multiple sti muli were delivered. When the multiple stimuli occur together, processes such as suppression (in the cochlea) and lateral inhibition (in the central nervous system) may alter the neuronal specificity of the responses. The results of Herdman et al. 2002b, suggest that these processes do not significantly affect that responses when the stimuli are presented at moderate intensity levels. At higher intensities, significant interactions between all the stimuli may occur (John at al., 1998).

CHAPTER VI

SUMMARY AND CONCLUSIONS

Obtaining threshold and suprathreshold information by objective procedures has been important issue in diagnostic as well as rehabilitative audiology especially in infants and difficult-to-test population. One of the recent entry in the area of audiology is auditory steady state potentials (ASSR). The ASSR can be elicited using AM, FM, MM or IAFM stimulus. An IAFM stimulus consists of a carrier that is modulated in amplitude and frequency, with different rates of modulation for the AM and FM. It has been documented that this stimulus can be varied in parameters to depict the long term average of speech spectrum. If this is so then one can measure an individual's ability to perceive speech objectively. Thus a procedure to estimate threshold as well as suprathreshold processing together using one stimulus (IAFM) would be more advantageous. The present study was designed to find out whethe r the IAFM stimuli could be used for both the threshold and suprathreshold information, that is relationship between the ASSR threshold and word recognition score.

Thus, this investigation was designed to study the following aims:

- To find out the relationship between behavioral pure tone threshold and ASSR threshold using IAFM stimulus in normal hearing and hearing impaired adults with different degree of hearing loss.
- To study the correlation between IAFM responses and WRS in normal hearing and hearing impaired subjects in noise and without noise conditions. .

- To analyze independently with each frequency response to find out which has most contribution to or got the best correlation with WRS for both the conditions i.e. in noise and without noise.

To investigate the above 30 normal hearing adults and 35 hearing impaired adults were selected. They were divided into subgroups as mild, moderately and moderately severe sensorineural hearing loss based on the pure tone threshold. All the subjects were native kannada speakers.

A calibrated diagnostic audiometer was used to estimate pure tone behavioral threshold and word recognition score for all the subjects. Phonetically balanced word list developed by Vandana (1998) was played through a CD player to assess the word recognition score (WRS). WRS was obtained in quiet and in presence of speech babble noise at 0 SNR by using the CD developed by Peter, V (2004).

After the behavioral recording ASSR recording was carried out using the IAFM stimuli that was generated before the data collection. The depth of AM and FM was tried to match with the depth of modulation that takes place for speech. The ASSR recording involved the recording by varying the intensity in order to detect a threshold for the four carrier frequencies (500, 1500, 2500 and 4000 Hz) that the IAFM response consists of. Then a constant intensity (80 dB SPL) was presented and the ASSR recording was carried out using the same IAFM stimuli. Later white noise of 80 dB SPL was delivered to the test ear from an audiometer via. Insert receivers without the foam tip and the ASSR recording was repeated at 0 dB signal to noise ratio.

For a subject the behavioral threshold, the WRS with noise and without noise, the ASSR threshold, the amplitude of the AM, FM and IAFM at 80 dB SPL with noise and without noise condition constituted the data.

The behavioral threshold and ASSR threshold data was statistically analyzed. Descriptive statistics and ANOVA was carried out to see the difference between the two measurements of threshold estimation across the subjects and across the frequencies.
The WRS was correlated with the amplitude and the number of IAFM responses (at 80 dB SPL). Pearsons product moment correlation was used for all the groups except for the mild hearing loss group where spearman correlation was administered. If a statistically significant correlation was observed regression analysis was carried out.

The following conclusions were drawn based on the results of this study:

1. The IAFM thresholds are higher than the behavioral threshold for all the subjects, but the difference between the two is maximum for the normal hearing and mild hearing impaired subjects.
2. The mean difference between the ASSR and behavioral threshold are the same across the frequencies.

3. The amplitude of the IAFM response at 80 dB SPL significantly correlates with WRS for the noise condition for the moderate and moderately severe hearing impaired group.

4. The number of responses also significantly correlates with the WRS for the noise condition for the moderate and moderately severe hearing impaired group.

5. The number of responses significantly correlates with the WRS for without noise condition only when all the hearing impaired groups where considered together.

6. A good correlation has been observed for the frequencies 500, 1500 and 4000 Hz ASSR responses when it was correlated with word recognition score in noise.

7. The amplitude of the 500 Hz frequency of the ASSR response contributes the maximum to the word recognition scores.

CONCLUSIONS:

Thus, it can be concluded that normal hearing individuals and mild hearing loss group might not have good agreement between behavioral threshold and ASSR threshold. Word recognition scores obtained in quiet also may not show a good agreement with IAFM responses. But IAFM responses are likely to have a good correlation with the word recognition scores obtained in noise especially for the hearing loss population. ASSR response at 500 Hz might be a good predictor of the performance of individuals with hearing loss. However, the table 12 in results can be used to predict the word recognition scores based on the ASSR results.

IMPLICATIONS:

This study helps in understanding the relationship between ASSR and WRS.

- Information obtained in the study can be used to assess the performance of hearing aid users.
- The regression equation obtained from the present study can be used to estimate the WRS for the hearing impaired group.

Further Research

- The present study can be replicated on large population at 40 Hz modulation.
- Studies can be carried out on subjects with different types of hearing impairment.
- Similar study can be carried out with the hearing aid users.

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