# ASSESSMENT OF MODULATION DETECTION DEPTH THRESHOLD USING ASSR AND ITS RELATION WITH SPEECH IDENTIFICATION SCORES

**REGISTER NO. A0390013**

**A Dissertation Submitted in Part Fulfillment of**
**Final Year M.Sc. (Audiology)**
**University of Mysore**
**Mysore**

**ALL INDIA INSTITUTE OF SPEECH AND HEARING NAIMISHAM CAMPUS, MANASAGANGOTHRI**
**MYSORE – 570 006**

**MAY - 2005**

*DEDICATED TO*

*PAPA, MUMMA*

*&*

*DIDI*

# CERTIFICATE

This is to certify that this dissertation entitled **"ASSESSMENT OF MODULATION DETECTION DEPTH THRESHOLD USING ASSR AND ITS RELATION WITH SPEECH IDENTIFICATION SCORES"** is the bonafide work in part fulfillment for the degree of Master of Science (Audiology) of the student with **(Reg. No. A0390013).** This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any university for the award of any other degree or diploma.

Place: Mysore
May 2005

**Prof. M. Jayaram**
Director
All India Institute of Speech & Hearing
Naimisham campus,
Manasagangothri,
Mysore 570006

# CERTIFICATE

This is to certify that this dissertation entitled **"ASSESSMENT OF MODULATION DETECTION DEPTH THRESHOLD USING ASSR AND ITS RELATION WITH SPEECH IDENTIFICATION SCORES"** has been prepared under my supervision and guidance.

Place: Mysore.

May 2005

Guide

**Dr.** C.S. **Vanaja**
Lecturer,
Department of Audiology,
All India Institute of Speech & Hearing
Naimisham campus,
Manasagangothri,
Mysore 570006

# DECLARATION

This dissertation entitled **"ASSESSMENT OF MODULATION DETECTION DEPTH THRESHOLD USING ASSR AND ITS CORRELATION WITH SPEECH IDENTIFICATION SCORES ",** is the result of my own study under the guidance of **Dr. C.S. Vanaja,** Lecturer, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in any university for any other Diploma or Degree.

Place: Mysore. **Reg.No.A0390013**

May, 2005

# Acknowledgements

I would like to express my heartfelt thanks, and my sincere gratitude to my guide Dr. C.S. Vanaja,Lecturer, Department of Audiology, AIISH, Mysore for her constant support, guidance & for constantly encouraging me. Thanks for being the source of strength.

I am thankful to Professor M. Jayaram, Director AIISH for permitting me to carry out this study.

I extend my sincere gratitude to Dr. Asha Yathiraj, HOD, Department of Audiology, AIISH Mysore, for granting me permission to use the instrument.

Papa, Mumma & Didi, you have always been a source of support & inspiration for me in all my endeavours. Thanks for the confidence you have in me. Thank you for being the special parents, thankyou for always being there, for your care and understanding.

Hari, I am lucky you were there by my side throughout these years. Thanks for being there for constant support, encouragement, advice....thanks for being such a wonderful friend.

Hari, Pooja, Sudhakar, Ashly, Charlie's Angel ( Deema ), Nuzha thanks for patiently listening to my troubles, complaints & offering me advices and suggestions.

Chatur naar (Amy), Meenakshi &, I am going to miss our dance parties and the funny steps...thank you for making my stay in AIISH memorable.

Bela, thanks for your valuable suggestions. Thanks for being there to lend me a shoulder to cry on.

Gulabo/ Zhaiji/ Hasmukh bai (Mani) & cutey Zhalli (Tessy), I wish I had met u guys earlier and we could be together for long. I will miss our NSP, gossips regarding right, left, east and west, late night talks, terrace…

Nikku, I will always remember your Kadi Pakoda, thanks for your jokes…the fun refresh my mind all the time.

Ajith sir, Sandeep sir, Vinay sir & Sairam sir, thanx for your timely help.

I thank all my classmates for making my stay at AIISH pleasurable and memorable one. I will always cherish the time spent with you guys, the fun & laughter…

Heartfelt thanks to library staff- Mr. Mahadeva, Mr. Lokesh, Mr. Chandrashekhar, Mr. Unni Krishnan.

I am thankful to Mr. Shivappa who shaped this Dissertation.

I thank all my subjects for their cooperation and patience.

I would like to thank all who helped me achieve through the milestones of this dissertation.

I thank God for keeping me enduring and persistent throughout the study

# TABLE OF CONTENTS

## LIST OF TABLES

# INTRODUCTION

Electrophysiological measures play a critical role in assessment of hearing in infants and young children, as well as in other subjects who cannot or will not participate actively in standard hearing assessment procedures. A major goal of objective audiometry is to obtain a pure tone audiogram without requiring any behavioral response on the part of subject. Objective methods to evaluate hearing include the Auditory Brainstem Response. (Galambos, Wilson & Silva 1994; Sininger & Abadalda, 1996; Sininger, Cone Wesson, & Folsom 2000; Stevens, 2001) and Otoacoustic emissions (white and Behrens, 1993; Norton et al. 2000). One of the recent entries into this battery is Auditory Steady State Response (ASSR).

Auditory steady state response 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 are 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 means to assess hearing by Galambos and colleagues (1981, cited in Picton, Vajsar, Rodriguez & Campbell, 1987) who demonstrated that a 40 Hz steady state response was easy to identify at intensity levels just above behavioral thresholds. However, some limitations of using 40 Hz evoked potential for objective audiometry are as follows:

- The response diminishes with decreased levels of arousal owing to sleep or anesthesia (Linden, Campbell, Hamel & Picton, 1985; Jerger, Chmiel, Frost & Coker, 1986; Cohen, Rickards & Clark, 1991; Dobie & Wilson, 1998).
- The responses cannot be reliably recorded in infants (Stapells, Galambos, Costello & Makeig 1988; Maurizi, Almadori & Paludetti 1990).
- Response amplitude diminishes when several stimuli are presented simultaneously (John, Lins, Boucher & Picton 1998).

Recent work has therefore concentrated on steady state response at higher rates of stimulus presentation. Cohen & colleagues (1991) showed that in adults, responses could be evoked at stimulus rates greater than 70 Hz and that these responses were little affected by sleep. Furthermore, these responses can be easily recorded in infants and young children (Rickards, Tan, & Cohen, 1994; Lins et. al., 1996; Savio, Cardenas & Perez-Abalo, Gonzalez, Valdes, 2001).

The frequency of modulation and neural generators of ASSR are thought to be closely linked e.g. modulation rates of 20 Hz or less will result in a response dominated by those generators that are responsible for the late cortical evoked potential, specifically primary auditory cortex and association areas. For modulation rates higher than 20 Hz but lower than 50 Hz, response characteristics are similar to those found for the middle latency auditory evoked potential with generators generally thought to be auditory midbrain, thalamus and primary auditory cortex. Modulation rates higher than 50 Hz will be dominated by evoked potentials from brainstem sites, including wave V and the negativity following wave V, sometimes identified as SN-10.

Factors which affect ASSR include age, modulation frequency, carrier frequency, state of arousal etc. (Linden, Campbell, Hamel & Picton, 1985, Jerger, Chimel, Frost & Coker, 1986; Cohen, Rickards & Clark 1991; Dobie & Wilson, 1998). Dimitrijevic, John & Picton (2004) reported that the reduction in 40 Hz response amplitudes during the sleep was greater in younger subjects than in elderly. They also reported that 80 Hz FM responses in young normal subjects were greater than AM response.

Audiogram estimation or threshold estimation is clearly the most important clinical application of SSEP at present. It has been well established that it can provide a reasonably accurate prediction of behavioral thresholds. (Cohen, Rickards & Clark, 1991; Rance, Rickards, Cohen, DeVedidi & Clark 1995; Lins et. al.,1996). Picton et al. (1998) showed that SSEP could be used to estimate threshold when the stimuli were transduced by a hearing aid. While there were discrepancies between behavioral (aided) threshold and SSEP threshold, they appeared to be no greater than those found when stimuli were transduced by earphones. Their finding suggests that it would be possible to measure the functional gain of the hearing aids on the basis of SSEP threshold estimates.

Recent investigations indicate that ASSR may be useful in evaluation of suprathreshold perception. Dimirijevic, John, and Picton (2004) demonstrated that the response obtained using ASSR not only depends on the perception of carrier frequency but also on the perception of AM or FM in the signal. As speech contains modulations, they correlated the presense or absense of ASSR responses to AM and FM at different frequencies with word recognition scores. They found a positive correlation and hence concluded that ASSR may provide an objective tool for examining the brain's ability to process the auditory information needed to perceive speech. These results suggest that in future ASSR would be used as an objective test to evaluate suprathreshold hearing to assess the ability of a child in understanding speech. It would help in selection and monitoring of hearing aids and can be used as an objective test to assess auditory processing disorder.

**Need For the Study**

It has been well established that ASSR thresholds give information regarding the detection of sounds at different frequencies (Rance, Rickards, Cohen, DeVedidi & Clark,1995). It is a well known fact that measurement of suprathreshold hearing is often far more important than just estimating the thresholds. Rosen (1992, cited in Grant, Summers and Leek, 1998) reported that, presence of fast AM is a cue to voicing and tracking variations in AM indicate changes in intonation and stress. Some investigators have studied modulation detection threshold behaviorally (Patterson, Davies, Milroy, 1978; Viemeister, 1979; Demany & Semal, 1989; Grant, Summers & Leek, 1998) but neurophysiological detection thresholds have not been investigated. Recent investigators have indicated that the perception of AM & FM can be assessed using ASSR. (Dimitrijevic, John, Van Roon & Picton 2001). There are no norms for neurophysiological thresholds for AM & FM depth threshold. Hence, there is a need to establish norms for AM depth threshold and FM depth threshold. These norms would help us in assessment of suprathreshold functioning in clinical population.

Behavioral studies have indicated that in hearing impaired subjects, the modulation depth threshold for both amplitude and frequency, is higher compared to normal subjects, especially at high modulation rates. (Grant, Summers & Leek,1998). If these changes can be detected neurophysiologically, it would help us in evaluation of difficult to test population. Hence there is a need to investigate if these changes can be detected using ASSR.

Recent investigations have indicated that the amplitude of ASSR responses for AM and FM signal correlates with Word Recognition Scores. (Dimitrijevic, John & Picton 2004). However no study investigated the relationship between the AM depth threshold and FM depth threshold, as measured by ASSR, with Speech Identification Scores.

**Aims of the Study**

This investigation was designed with following aims:

1. To develop norms for threshold of AM depth and FM depth perception using ASSR.
2. To investigate the difference in AM depth threshold and FM depth thresholds between normals and hearing impaired.

3. To study the correlation of FM depth threshold and AM depth threshold with speech identification scores in quiet and in noise.

# REVIEW OF LITERATURE

Speech is a complex signal, and, it contains multiple Amplitude and Frequency modulations. These Amplitude Modulations (AM) and Frequency Modulations (FM) transmit an important amount of information. The relative intensities, different frequencies and the way in which these frequencies and intensities change over time determine how we perceive an important stimulus like speech. (Dimitrijevic, John, Van Roon & Picton 2001).

The most obvious problem faced by hearing impaired individuals in understanding speech is, inaudibility of speech cues in the acoustic signal. However, even when hearing aids provide sufficient amplification so that speech is above the detection thresholds, problems in speech understanding may still persist, especially in noisy backgrounds (Plomp, 1978). Many of these problems appear to be related to signal distortions generated during the processing of sound in the impaired cochlea Moore (1995, cited in Grant, Summers and Leek, 1998). One such distortion that has received a great deal of attention is smearing or smoothening of spectral peaks (e.g. speech formants) making it difficult to discriminate one spectral shape from another (Leek, Dorman & Summerfield, 1987). This kind of distortion is associated with the abnormal frequency selectivity and broader than normal auditory filter bandwidths often accompanying sensorineural impairment (Leek and Summers 1993). When the hearing loss is such that the analysis of spectral details is impaired, non spectral cues such as amplitude modulations in the speech waveform may take an added importance for speech perception.

The sensitivity of human ear to detect changes in the frequency and intensity can be measured behaviorally by detecting the continuous frequency modulation and amplitude modulation or continuous change in frequency of uninterrupted tone i.e. the threshold at which AM and FM becomes detectable can be used to assess the ability of the auditory system to recognize changes in intensity and frequency (Dimitrijevic, John, Van Roon & Picton 2001). Viemeister (1979) reported that an empirical function that relates some measures of the ability to follow or resolve sinusoidal amplitude modulations to the frequency of that modulation is called Modulation Transfer Function. It was also reported in the study that the psychophysical measure typically used is the modulation threshold, and is usually defined as the depth of modulation necessary to just allow discrimination between the modulated and an unmodulated waveform. They observed that, as the modulation frequency increases, the amplitude fluctuations become increasingly smoothened and the observer thus require greater amplitude change in order to resolve fluctuations.

**Perception of the AM and FM in normal hearing individuals**

The ability to detect waveform modulations is a function of the rate of modulation, the depth of modulation and the shape of modulating waveform. In general, modulation threshold (i.e. the depth of modulation required for detection) increases with modulation rate. For normal hearing listeners and sinusoidal amplitude modulation at very low rates (1-10 Hz), the modulation depth required for detection is approximately 2%-5% (-33 to 26 dB). The very low rates of modulation are important for speech in that they reflect the number of syllables spoken per second. At higher rates (e.g. above 80

Hz), modulation thresholds are approximately 15%-20% (at about -15 dB), whereas at still higher rates (above 800 Hz – 1000 Hz) modulation thresholds are approximately 50% or- 6 dB. ( Viemeister, 1979; Formby, 1985).

Patterson, Davies & Milroy (1978) measured the modulation threshold, that is, the modulation depth required to discriminate a sample of amplitude modulated noise from a sample of unmodulated noise. These measurements were made as a function of modulation rate (16-320 Hz), modulator waveform (sine or square) and the bandwidth of amplitude modulated noise (0.5-8 kHz). The AM noise was partially masked by either a low pass or band stop noise to restrict the spectral region of the amplitude modulated noise available to the observer. They found that modulation threshold increases monotonically with modulation rate, sine wave thresholds were greater than the square wave thresholds, and threshold rises as the bandwidth of the Amplitude Modulated signal decreases. They also compared the modulation threshold with the pitch thresholds gathered under precisely the same conditions in order to find whether pitch and modulation detection threshold are based on same underlying auditory mechanism. Pitch thresholds, or alternatively, rate thresholds were taken to be the modulation depth required to decide which of the two samples had higher modulation rate; the rate difference was 20%. In the region of about 70 Hz, rate threshold is essentially a constant multiple of modulation threshold, indicating that the primary constraint on rate threshold is the audibility of modulation. Below 70 Hz, rate and modulation threshold diverge.

Wakefield & Viemeister (1990) measured discrimination thresholds for an increment in the modulation depth for a wideband noise carrier as a function of modulation depth, modulation frequency and intensity of the noise. They found that discrimination thresholds are approximately constant for standards with the modulation depths that are within 10 dB of the detection threshold. For modulation depths greater than 10 dB above detection threshold, discrimination threshold increases rapidly. In addition, once the standard exceeds the threshold by about 5 dB, discrimination thresholds are relatively independent of modulation frequency. Here a wide band carrier, which has advantage over tones, was used. Patterson, Johnson-Davies, & Milroy (1978) demonstrated that the rate discrimination of broadened AM signal requires depth between 15 % and 30% and larger depths are required when listening bandwidth was reduced by presence of masking noise.

Lee and Bacon (1997) investigated the discrimination of the change in depth of sinusoidal amplitude modulation as a function of stimulus duration. They found that for all modulation rates, the detection and discrimination threshold show similar trends at large stimulus durations. At shorter durations there is separation of detection and discrimination functions, which they attributed to the inherent difficulty of the task i.e. for modulation detection, subject needs only to determine which of the two stimuli are modulated whereas, for modulation task subject must determine which of the two stimuli had the greater modulation depth. Hence a better internal representation is required which might be adversely affected by shorter durations. They also found that the threshold for discriminating modulation depth decreased with increase in stimulus duration. In this study, only three normal hearing subjects were taken. One of the subjects was the investigator himself. Hence, there the results could be biased.

Demany and Semal (1989) measured detection threshold for sinusoidal frequency modulation as a function of carrier frequency (fc from 250 Hz to 4000 Hz) and modulation frequency (from 1 to 64 Hz), in four normal hearing subjects. They found that the effect of carrier frequency and modulation frequency, significantly differ from subject to subject. They noticed that overall, the effect of modulation frequency is quiet small and almost 2 Hz up to 64 Hz. In addition, for any value of modulation frequency, thresholds tend to increase with carrier frequency but at lower rate than carrier frequency itself. In this study also investigators participated and it was found that they responded better than the other two subjects.

John, Dimitrijevic, Van Roon and Picton (2001) measured the physiological threshold for amplitude and frequency modulation using tones of 1000 Hz, modulated at the rate of 82 Hz. The amplitude modulation or the limen was 20% for physiological responses and 6% for behavioral responses. For frequency modulations, the limen was 5% and 1.4% for physiological responses and behavioral responses respectively. These results indicate that physiological response have higher threshold than behavioral response. Viemeister (1979) reported that a threshold of 2%-6% is obtained at slow rates of modulation and this increases as a factor of 2-3 for modulation frequencies near 40 Hz.

Hence, in normal hearing individuals the modulation detection threshold varies with modulation rate, modulator waveform, frequency of modulation, carrier frequency and bandwidth of the modulated signal. In addition, the modulation detection thresholds are smaller for FM signal than AM signal.

**Effect of hearing loss on perception of AM and FM**

The most debilitating aspect of hearing loss is the difficulty in speech perception. Speech perception is typically measured by presenting phonetically balanced monosyllabic words at 30 dB to 50 dB above subject's pure tone threshold and scoring the percentage of words that are correctly recognized – the Word Recognition Scores (WRS). A necessary first step in the perception of word is to discriminate changes in the frequency and amplitude of sound. For example, the |ga| & |da| sounds differ only in the rapid frequency change of the 2$^{nd}$ formant at the beginning of the syllable and |da| and |ta| sounds differ only in amplitude of voicing.

Formby (1987, cited in Grant, Summers and Leek, 1998) reported that the modulation detection thresholds for hearing impaired listeners tend to be similar to normal hearing listeners at a very low modulation rates (below 60 Hz) but deviate more and more from normal hearing thresholds as modulation rate increases. These detection threshold differences between normal hearing and hearing impaired listeners have been attributed to differences in the audible bandwidth of the modulated signals, with hearing impaired listeners having a more spectrally restricted signal due to there hearing loss. When normal hearing listeners are presented with modulated signals with a similarly restricted bandwidths (by using low–pass or band pass carriers), modulation detection threshold increase and become more like those for hearing impaired listeners. (Bacon & Viemeister, 1985).

Grant, Summers and Leek (1998) found that the discrimination threshold increased with decrease in modulation depth and increase in frequency of modulation.

Also, they observed that several hearing impaired subjects were unable to perform the discrimination task at high modulation rates and shallow modulation depths, even though most were able to detect the modulation. In this study, the modulation detection threshold was measured for three different ranges of modulation depths: full (100%), mid (70%-80%) and low (40%-60%). They reported that the data obtained for mid and low depth conditions are of particular interest because they represent more realistic conditions of modulation. When, modulated signal like speech are subjected to noise and/or reverberation. e.g. signal to noise ratios between 3.7 to 6.0 dB would reduce the signal with 100% modulation to one with 70% to 80% modulation (a 20%-30% modulation reduction),whereas signal to noise ratio between 1.8 and -1.8 dB would result in modulation reduction of 40% to 60%. Since noise and reverberation are common to most listening environments, rate thresholds obtained at these lower modulation depths are more indicative of subject performance in the real- world situation than are thresholds obtained at 100% modulation (which would occur only in non reverberant quiet settings). In this study signal was presented at 80 dBSPL to normal hearing group and group with moderate sloping sensorineural hearing loss. Hence, the hearing impaired subjects were probably limited to effective overall bandwidth of 2 kHz.

Henderson, Salvi, Pavek & Hamrnik (1984), determined how high frequency hearing loss influences shapes of AM function. They estimated the temporal resolution from normal hearing chinchillas with high frequency hearing loss using sinusoidal amplitude modulated noise. Shock avoidance conditioning procedure was used. They found a degradation of amplitude modulation function. They attributed these changes in the amplitude modulation function to both reduction in sensation level of noise carrier and a reduction in the effective hearing bandwidth. Thus, the elevation of modulation threshold must be due to high frequency hearing loss. Hence, the results suggest that the high frequency region in the cochlea may play an important role in temporal resolution.

Thus, the review of literature indicates that hearing impairment has an effect on the perception of AM and FM particularly at high modulation rates and this in turn effects the perception of speech in them.

**Objective Assessment of Perception of AM and FM using ASSR**

Attempts have been made to determine the modulation detection threshold objectively using Auditory Steady State Evoked Response. In a study by Kuwada, Batra and Maher (1986), it was found that the amplitude of response evoked by 50 Hz modulation decreased with decreasing modulation depth but could still be recognized at a depth of 11%. Picton, Skinner, Champange, Kellett and Maiste (1987) assessed the relation of response to the depth of modulation. They recorded steady state responses to sinusoidal modulation of amplitude and frequency of tone, from human scalp. They found that with increasing modulation depth at 40 Hz both the AM and FM responses increased in amplitude, but the AM responses tended to saturate at large modulation depths. They recorded an average AM threshold of 5% at 1 kHz and FM threshold of 28 Hz at 40 Hz modulation frequency. Neither response showed any significant change in phase with changes in modulation depth. In the study the formulas for calculating AM and FM are not equivalent. The amount of AM was calculated as $(A_{max} – A_{min}) / (A_{max} + A_{min})$ whereas the amount of FM was calculated using the formula $(F_{max} – F_{min}) / F_{carrier}$.

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 cortex use 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 in the study, one experiment related the IAFM response to the discrimination of monosyllabic words at intensities between 20-70 dBSPL and they found that the number of responses detected during multiple IAFM stimulation and the amplitude of these responses correlated significantly with word discrimination.

Dimitrijevic, John and Picton (2004) related the number of steady state responses evoked by IAFM of tones to the ability to discriminate speech sounds as measured by Word Recognition Scores (WRS) in young normal hearing group, elderly normal hearing group and elderly hearing impaired group. IAFM stimulus parameters were adjusted to resemble the acoustic properties of everyday speech to see how well responses to these speech modeled stimuli were related to word recognition scores. Word recognition scores and IAFM responses at a stimulus intensity of 70 dBSPL were measured in three groups of subjects using 40 Hz and 80 Hz modulation frequency. ASSR was recorded for four carrier frequencies each independently modulated in frequency and amplitude domain.

They recorded IAFM responses and word recognition scores measurements in quiet and in the presence of the speech masking noise at 67 dBSPL or 70 dBSPL and evaluated hearing impaired subjects with and without hearing aids. They found a significant correlation between IAFM and WRS. Response amplitude at 80 Hz was smaller in hearing impaired than the normal hearing subjects. They also found that with use of hearing aid there was an increase in word recognition scores and number of significant IAFM responses at 40 Hz and 80 Hz .Masking decreased word recognition scores and number of significant IAFM responses. They did not correlate AM and FM independently with word recognition scores.

Thus, the review of literature indicates that the response evoked by IAFM stimuli relates to the ability of the subject to discriminate speech. Therefore, it may be helpful in setting an objective test for suprathreshold hearing.

# METHOD

Subjects: Two groups of subjects, a control group and an experimental group were considered for the study. Control group included a sample of 30 normal hearing Kannada speakers between 18 and 50 years of age. Experimental group included 20 ears of age matched subjects with minimal to moderate sensorineural hearing loss

➢ Criteria for selection of normal hearing subjects were as follows:

- No symptom or history of any otological or neurological disorder.
- Pure tone threshold within 15 dB across frequencies from 250Hz to 8 KHz.
- 'A' type tympanogram with reflexes present at normal levels.

➢ Criteria for selection of hearing impaired subjects were as follows:

- Devoid of any otological or neurological symptoms.
- air-bone gap was less than 10 dB. No middle ear pathology was revealed by immittance evaluation.

Instrumentation: Calibrated diagnostic audiometer, ORBITER OB922 was used for estimation of pure tone threshold both air conduction and bone conduction, Speech Recognition Threshold (SRT), Speech Identification Scores (SIS) and Uncomfortable level (UCL) was estimated. Calibrated middle ear analyzer (GSI Tympstar / GSI33) was used for immittance measurements. Audera GSI ASSR system version 1.0.2.2 (Audera DSP software version 2) was used for recording ASSR.

Material: The following materials were used for the study:

- A CD containing phonetically balanced word list in Kannada developed by Vandana (1998) was used for estimating speech identification in quiet.

- A CD developed by Vargese Peter (2004) was used for estimating Speech Identification in Noise (SPIN). This CD has been developed by recording speech identification test in Kannada developed by Vandana (1998) and the speech babble in Kannada developed by Anita (2003) with a signal to noise ratio of 0 dB.

**Test environment: All tests were carried out in an acoustically treated room. ASSR** testing was done during sleep or the subject was instructed to avoid extraneous movements of head, neck, or jaw while recording.

Procedure**:** Pure tone thresholds were obtained at octave intervals between 250 Hz to 8000 Hz for air conduction stimuli and between 250 Hz to 4000 Hz for bone conduction stimuli using modified Hughson Westlake method (Carhart & Jerger). Speech Reception Threshold (SRT) was obtained using paired words in Kannada. The minimum intensity at which 50% scores were achieved was considered as SRT. Speech Identification in quiet and SPIN was carried out at 40 dBSL (re: SRT). Phonetically Balanced list developed by Vandana (1998) was presented and subjects were asked to repeat the words. Each correct response was given the score of one. Total number of correct responses was calculated. Tympanometry and reflexometry was carried out to rule out any middle ear pathology.

Subjects were made to sit comfortably on a reclining chair and were instructed to relax, close their eyes and sleep if possible while recording ASSR. The site of electrode placement was prepared with skin preparing gel. Silver chloride (AgCl) electrodes were placed with conducting gel. Two channel recording was done by placing inverting electrodes on the mastoids of test ear and non test ear, non inverting electrode at high forehead and common electrode at lower forehead. The electrode impedance was checked and it was ensured that impedance at each electrode site and interelecrode impedance was less than 5KΩ. Amplitude and frequency modulated tones modulated at 80 Hz were presented through supra aural TDH 39 earphones to estimate AM and FM depth threshold. Response detection was determined objectively. The instrument automatically determined the presence or absence of response based on phase coherence of the responses.

*Estimation of Amplitude Modulation Depth Threshold*: Depth of frequency modulation was kept constant at 0 % and depth of amplitude modulation was varied in order to find the minimum depth at which ASSR could be recorded. This was labeled as physiological Amplitude Modulation Depth Threshold. This measurement was done at four different carrier frequencies i.e. 500 Hz, 1 kHz, 2 kHz & 4 kHz.

*Estimation of Frequency Modulation Depth Threshold***:** Depth of amplitude modulation was kept constant at 0% and depth of frequency modulation was varied, in order to find minimum depth at which ASSR could be recorded. It was labeled as physiological Frequency Modulation Depth Threshold, and this measurement was also done at four different carrier frequencies as Amplitude Modulation Depth Threshold.

# RESULTS AND DISCUSSION

To investigate the aims of the present study, statistical analysis for obtained data was carried out using SPSS software (version 10.0). The statistical analysis included mean, standard deviation and range for amplitude modulation depth threshold and frequency modulation depth threshold. One way ANOVA was carried out to find the effect of degree of hearing loss on amplitude and frequency modulation depth threshold. Duncan post hoc test was carried out, if main effect was observed in ANOVA. Correlation between neurophysiological amplitude modulation depth threshold and frequency modulation depth threshold with behavioral speech identification scores in quiet and in noise was found using Pearson product moment correlation coefficients.

## Amplitude modulation depth thresholds and frequency modulation depth thresholds in normals

In the present study, 35 normal subjects were taken and physiological AM depth threshold and FM depth threshold was estimated using ASSR. Out of 35 subjects, AM depth threshold of 28 subjects and FM depth threshold of 30 subjects were considered for analysis, because recordable ASSR could not be obtained for AM signal in seven subjects and FM signal in five subjects. The reason for the absence of ASSR in normal subjects is not known, but such observation has been reported earlier also in literature (Narne, 2004). Descriptive statistics of amplitude modulation depth threshold and frequency modulation depth threshold is shown in Table 1 and 2.

Table 1

*Mean, SD of Amplitude Modulation Depth Threshold for subjects with normal hearing*

| Carrier frequency | N | Mean (%) | SD |
|---|---|---|---|
| 500 Hz | 28 | 7.3 | 7.08 |
| 1 kHz | 28 | 16.6 | 12.6 |
| 2 kHz | 28 | 23.5 | 19.3 |
| 4 kHz | 28 | 41.5 | 35.7 |

Table 2

*Mean, SD of Frequency Modulation Depth Threshold for subjects with normal hearing*

| Carrier frequency | N | Mean (%) | SD |
|---|---|---|---|
| 500 Hz | 28 | 3.14 | 1.79 |
| 1 kHz | 28 | 4.5 | 2.89 |
| 2 kHz | 28 | 5.7 | 4.0 |
| 4 kHz | 28 | 7.2 | 4.1 |

As shown in Table 1 and 2 the AM depth threshold and FM depth threshold were higher at higher frequencies. At 500 Hz, the physiological AM depth threshold was found to be 1% where as at 1 kHz, 2 kHz & 4 kHz the minimum depth, which could be perceived by normal hearing individuals, was 3%. The minimum FM depth threshold which could be perceived was 1%. The range of AM depth threshold and FM depth threshold broadened at high frequencies. At 500 Hz, the AM depth threshold and FM depth threshold range was 1 to 27 and 1 to 8 respectively. At 1 kHz, it was 3 to 58 and 1 to 12, at 2 kHz 3 to 72 and 1 to 15 & at 4 kHz 3 to 94 and 1 to 15.

These results are similar to those reported in investigations using behavioral measures. Demany and Semal (1989) presented modulated tones of 500 Hz, 1 kHz, 2 kHz and 4 kHz to four normal hearing subjects and observed similar trend of increase in amplitude and frequency jnd with increase in frequency. The frequency jnd was measured using steady tones and by varying the duration of the stimulus. Picton, Christopher, Skinner, Champagne, Kellet & Maiste (1987) recorded an average AM threshold of 5% and FM threshold of 28 Hz at 1 kHz at 40 Hz. They found that that the threshold recognizing AM response was not significantly different from psychoacoustic thresholds. The difference between the evoked potential and behavioral threshold varied across subjects between -3% and +2%. They also reported that, the amplitude of ASSR is more at low frequencies compared to high frequencies at any modulation depth when a constant intensity of amplitude modulated signal is given. Higher amplitude of the response probably leads to lower depth threshold. Similar findings are reported by Kuwada et al. (1986). Grant, Summers and Leek (1998) have reported an average modulation detection threshold as 20.7 at 80 Hz modulation rate for a square wave modulated noise.

**Amplitude modulation depth threshold and frequency modulation depth threshold in hearing impaired**

In this study, 20 hearing impaired subjects were taken and the data of all 20 subjects was considered for analysis. This experimental group was subdivided into three groups: minimal, mild and moderate, based on pure tone threshold at respective frequency. Descriptive statistics for AM depth threshold and FM depth threshold is shown in Table 3 and 4. In minimal hearing impaired group, at 4 kHz, standard deviation and range could not be obtained, as there was only one subject who had minimal hearing loss at 4 kHz. It can be seen that, as the degree of loss increased, AM threshold and FM depth threshold increased.

Table 3

*Mean, SD of Amplitude Modulation Depth Threshold for subjects with hearing loss*

| Degree of HL | 500 Hz | | | 1 kHz | | | 2 kHz | | | 4 kHz | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | Mean | SD | N | Mean | SD | N | Mean | SD | N | Mean | SD |
| Minimal Hg Loss | 7 | 3.5 | 2.2 | 4 | 9.2 | 3.7 | 3 | 4.3 | 1.5 | 1 | 3.0 | |
| Mild Hg Loss | 7 | 7.7 | 3.7 | 9 | 5.6 | 3.5 | 6 | 4.1 | 2.7 | 4 | 3.7 | 2.0 |
| Moderate Hg Loss | 6 | 15.6 | 6.1 | 7 | 41.7 | 38.7 | 11 | 16.27 | 13.8 | 15 | 22.9 | 3.89 |

Table 4

*Mean, SD of Frequency Modulation Depth Threshold for subjects with hearing loss*

| Degree of HL | 500 Hz | | | 1 kHz | | | 2 kHz | | | 4 kHz | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | Mean | SD | N | Mean | SD | N | Mean | SD | N | Mean | SD |
| Minimal Hg Loss | 7 | 3.9 | 3.9 | 4 | 6.7 | 4.5 | 3 | 10.0 | 7.0 | 1 | 5.0 | |
| Mild Hg Loss | 7 | 3.5 | 3.5 | 9 | 7.1 | 3.0 | 6 | 1.6 | 1.0 | 4 | 5.0 | 6.7 |
| Moderate Hg Loss | 6 | 2.3 | 2.3 | 7 | 6.7 | 2.2 | 11 | 6.8 | 3.4 | 15 | 6.0 | 4.2 |

**Effect of degree of hearing loss on AM and FM depth threshold**

At 500 Hz, one way ANOVA was done to evaluate the significant difference between the means of different groups. It revealed a main effect of group [$F (3, 44) = 4.4$, $p<0.05$], which was significant at 0.008 level. Post hoc test was carried out to investigate the difference between different groups. As shown in Table 5, the AM depth threshold of subjects with moderate hearing loss differed significantly from that of normals and subjects with minimal hearing loss. There was no significant difference between AM depth threshold of subjects with mild and moderate hearing loss. AM depth threshold of subjects with minimal and mild hearing loss did not differ significantly from that of normal hearing subjects. For FM depth threshold ANOVA revealed F (3, 44) = 0.74, p> 0.05 which was not significant.

Table 5

*Post hoc test for Amplitude Modulation Depth Threshold at 500 Hz between groups*

| Group | Mean difference | Standard error | Significance |
|---|---|---|---|
| Normal vs. Minimal | 3.7 | 2.5 | 0.471 |
| Normal vs. mild | -0.35 | 2.5 | 0.999 |
| Normal vs. Moderate | -8.3 | 2.7 | 0.022 |
| Minimal vs. mild | -4.1 | 3.2 | 0.592 |
| Minimal vs. Moderate | -12.0 | 3.4 | 0.005 |
| Mild vs. moderate | -12.0 | 3.4 | 0.108 |

At 1 kHz also ANOVA revealed a main effect of group [F (3, 44) = 6.1, p<0.05] which was significant at 0.001 level. Results of post hoc test shown in Table 6 are similar to those obtained for 500 Hz. There was a significant difference at level of 0.001 between the scores of subjects with normal hearing and subjects having moderate hearing loss, but no significant difference was found between normal hearing subjects and subjects with minimal and mild hearing loss.

Table 6

*Post hoc test for Amplitude Modulation Depth Threshold at 1 kHz between groups*

| Group | Mean difference | Standard error | Significance |
|---|---|---|---|
| Normal vs. Minimal | 704 | 9.3 | 0.85 |
| Normal vs. mild | 11.0 | 6.7 | 0.36 |
| Normal vs. Moderate | -25.0 | 7.3 | 0.008 |
| Minimal vs. mild | 3.5 | 10.5 | 0.98 |
| Minimal vs. Moderate | -32.4 | 10.9 | 0.025 |
| Mild vs. moderate | -36.0 | 8.8 | 0.001 |

This shows that, even at 1 kHz also, the perception of amplitude modulation was similar in normal hearing individuals and individuals with minimal-mild hearing loss. As the degree of hearing loss increases to moderate, the AM depth threshold increases i.e. the perception of AM becomes poorer at 1 KHz. One way ANOVA for FM depth threshold did not reveal a main effect of group [F (3, 44) = 2.561, p>0.05].

At 2 kHz, there was no significant effect of hearing loss on AM depth threshold [F (3, 44) = 3.164, p>0.05] and FM depth threshold [F (3, 44) =3.683, p>0.05]. At 4 kHz also there was no significant effect of degree of hearing loss on AM depth threshold [F (3, 44) = 2.631, p>0.05] and FM depth threshold [F (3, 44) = 0.512, p>0.05].

Thus, it can be seen that, with increase in hearing impairment, amplitude modulation depth threshold increased significantly, at 500 Hz and 1 KHz. There was an increase in AM depth threshold at 2 kHz and 4 kHz also, but it was not statistically significant. An increase in FM depth threshold with increase in degree of impairment was also seen at all frequencies but it was not significant. At 500 Hz, some normal hearing individuals and some individuals with minimal hearing loss could perceive the minimum depth of 1% in AM signal, whereas no subject with mild and moderate hearing loss could perceive a depth of 1%. Minimum depth which could be perceived by some of the subjects with mild and moderate hearing loss was 2% and 8% respectively. Similarly, at other frequencies also there was an increase in the mean as well as the lower limit of the range of AM depth threshold. The results indicate that hearing loss affects AM depth threshold more than FM depth threshold.

The increase in depth threshold with increase in hearing loss may be attributed to differences in the audible bandwidth of the modulated signals. Formby (1987, cited in Grant, Summers and Leek, 1998) reported that hearing impaired listeners have more spectrally restricted signal due to hearing loss and this results in increase in depth threshold. Similar results were found in an animal study by Handerson, Salvi, Pavek & Hamernik (1984) in which three normal chinchillas were exposed to four different bands of noise over a period of four weeks. The series of noise exposure was chosen to produce a high frequency loss that spread over lower frequencies with each ensuing week. Amplitude modulation thresholds were measured using shock avoidance conditioning procedure and it was found that there was an elevation of amplitude modulation detection threshold after first exposure. Successive noise exposures extended the temporary hearing loss toward lower frequencies, but there was little further deterioration in amplitude modulation function. They also found that the modulation threshold decreased with increase in modulation frequency.

The results of Viemeister (1979) who reported that, as modulation frequency increases, the amplitude fluctuations become increasingly smoothened and the observer thus requires greater amplitude change in order to resolve the fluctuations, is contrary to the above findings. Similar findings were demonstrated by Patterson, Johnson-Davies & Milroy (1978). In their study, they used amplitude modulated wide band noise, which was partially masked by either a low pass masker, or a band stop noise to restrict the spectral region. They reported that as the modulation rate increases the low pass filter stage is not able to follow the fluctuations in the envelope of AM noise; modulation depth is efficiently reduced and has to be increased to maintain detectability. Increase in modulation threshold with increase in modulation frequency was also demonstrated by Grant, Summers and Leek (1998). In their behavioral study, they did not find a significant difference between the amplitude modulation depth threshold of normal hearing and hearing impaired subjects at 80 Hz modulation rates whereas it was significantly different at higher rates of 160 Hz and 320 Hz. In the present study neurophysiolgical thresholds were established and this depends not only on the perception but also on neural firing. It is possible that in hearing impaired subjects there was a decrease in number of neurons firing for the stimulus and the subjects could perceive the stimulus but the neural firing was not strong enough for response to be generated.

**Correlation of AM depth threshold & FM depth threshold with speech identification scores in normals**

One of the aims of the study was to correlate FM depth threshold and AM depth threshold with speech identification scores in quiet and in noise. Hence, Pearson's product moment correlation was used at different frequencies with speech identification scores in quiet and in noisy conditions. As shown in Table 7 and 8, no significant correlation was found between speech identification scores (in both quiet and noise situations) and amplitude modulation depth threshold and frequency modulation depth threshold at any frequency.

Table 7

*Correlation of AM depth Threshold and FM depth threshold with Speech Identification scores in quiet*

| Carrier frequency | AM | FM |
|---|---|---|
| 500 Hz | -0.323 | -0.182 |
| 1 kHz | -0.076 | -0.218 |
| 2 kHz | 0.137 | -0.121 |
| 4 kHz | 0.067 | -0.054 |

Table 8

*Correlation of AM depth threshold and FM depth threshold with speech identification scores in noise*

| Carrier frequency | AM | FM |
|---|---|---|
| 500 Hz | -0.214 | -0.009 |
| 1 kHz | -0.131 | -0.271 |
| 2 kHz | 0.295 | -0.012 |
| 4 kHz | 0.218 | 0.080 |

Absence of significant correlation of speech identification scores in quiet with AM depth threshold and FM depth threshold can be attributed to the ceiling effect, as most normal hearing individuals get 100% scores in quiet situation. It was hypothesized that AM depth threshold and FM depth threshold may correlate with speech identification scores in adverse listening conditions but this hypothesis has been rejected based on the results of this study. It is known that there are many other cues that are used in order to perceive speech. The results of the present study indicates that perception of AM and FM is not a major cue for speech perception in noise in normal hearing individuals.

**Correlation of amplitude modulation depth threshold and frequency modulation depth threshold with speech identification scores in subjects with hearing impairment**

The result of Pearson product moment correlation of modulation depth threshold with speech identification in quiet and in noise in hearing impaired individuals is shown in Table 9 and 10 respectively. No significant correlation was found between speech identification scores (both quiet and noisy situation) and AM depth threshold and FM depth threshold.

Table 9

*Correlation of AM depth threshold and FM depth threshold with speech Identification scores in quiet*

| Carrier frequency | AM | FM |
|---|---|---|
| 500 Hz | -0.547 | -0.114 |
| 1 kHz | -0.030 | 0.083 |
| 2 kHz | -0.249 | -0.243 |
| 4 kHz | -0.419 | -0.344 |

Table 10

*Correlation of AM depth threshold and FM depth threshold with speech Identification scores in noise*

| Carrier frequency | AM | FM |
|---|---|---|
| 500 Hz | -0.361 | -0.149 |
| 1 kHz | -0.277 | -0.046 |
| 2 kHz | -0.204 | -0.083 |
| 4 kHz | -0.250 | 0.073 |

Though not significant, with increase in frequency there is slight increase in correlation value for both AM and FM depth threshold. This supports the consensus that high frequencies are more important for speech perception. Articulation indices give more weightage to high frequencies as these are more important for the perception of speech. Skinner (1980) demonstrated that the listeners performed best when the level of speech energy in a high frequency band (2-4 kHz) was approximately 0 to +15 above that in low frequency band (500 Hz-1000 Hz). Barfod, Christenen, and Pedersen (1971) found that amplification, which partially compensates for high frequencies hearing loss is associated with significantly better identification of nonsense words. Dimitrijevic, John & Picton (2004) reported that the depth of AM and the depth of FM are different in vowel, consonant-vowel and fricatives. They have reported that, for perception of vowels, CVs and fricatives, AM depth and FM depth required is low at higher frequencies compared to lower frequencies. Hence a slight impairment in the perception of AM and FM my also lead to poor speech identification scores in hearing impaired individuals.

Inspection of raw data showed that the subjects with poor AM depth threshold or FM depth threshold had poorer speech identification scores especially in moderate hearing loss group. Results of ANOVA also revealed that moderate hearing loss had a significant effect on AM depth threshold but minimal and mild hearing loss did not have a significant effect on depth threshold. Hence, the absence of correlation could be attributed to the inclusion of subjects with minimal and mild hearing loss in analysis of correlation, as their perception of AM depth threshold and FM depth threshold was comparable to normals. Therefore, Pearson's product moment correlation of speech identification scores with AM depth threshold & FM depth was found only in subjects with moderate hearing loss. The results in quiet and in noise are shown in table 11 and 12.

Table 11

*Correlation of AM depth threshold and FM depth threshold of subjects with moderate hearing loss with speech identification scores in quiet*

| Carrier frequency | AM | FM |
|---|---|---|
| 500 Hz | -0.830* | -0.179 |
| 1 kHz | 0.293 | 0.623 |
| 2 kHz | 0.024 | 0.024 |
| 4 kHz | -0.334 | -0.429 |

* significant at 0.05 level

Table 12

*Correlation of AM depth threshold and FM depth threshold of moderate hearing loss with speech identification scores in noise*

| Carrier frequency | AM | FM |
|---|---|---|
| 500 Hz | 0.631 | 0.125 |
| 1 kHz | 0.042 | 0.358 |
| 2 kHz | 0.357 | 0.357 |
| 4 kHz | -0.105 | -0.436 |

Even though a significant correlation was not obtained at all the frequencies, comparison of correlation values for subjects with moderate hearing loss and overall hearing impaired group shows that there was better correlation when only moderate hearing loss group was considered. Further study should be carried out with a larger group to confirm these findings.

Picton et al (2002, cited in Dimitrijevic, John & Picton, 2004) observed an overall correlation of 0.05 between the number of significant IAFM responses and word recognition scores in the hearing impaired population with and without hearing aids. Dimitrijevic, John and Picton (2004) found significant correlation between word recognition scores and ASSR response. Both these studies used Independent Amplitude and Frequency Modulated signal and this stimulus was speech modeled or speech like. However, in the present study attempt was made to correlate amplitude modulation depth threshold and frequency modulation depth threshold separately with speech identification scores in quiet as well as in noisy situations in both normal hearing and hearing impaired individuals. Comparison of the results of the present study with the other studies which used IAFM stimuli suggest that perception of IAFM stimuli correlates better with speech identification scores compared to only AM or FM stimulus.

Hence, it can be concluded that hearing impairment leads to poorer perception of amplitude and frequency modulation, but its correlation with speech probably depends on other stimulus factors. In addition, the effect of pure tone threshold is greater when hearing impairment is more than 40 dBHL. In the present study, there is a poor correlation of speech identification score with AM depth threshold & FM depth threshold, but results suggest that a better correlation may be observed if large group of subjects with moderate hearing loss is investigated.

# SUMMARY AND CONCLUSIONS

One of the recent entries in the audiological test battery is Auditory Steady State Evoked Response (ASSR). Presently, these auditory steady state evoked responses evoked by modulated tones have been extensively used as an objective means to estimate behavioral pure tone thresholds. Individuals with sensorineural hearing loss, in addition to increased absolute threshold exhibit deterioration in suprathreshold sound processing. It is a well known fact that measurement of suprathreshold hearing is often far more important than the estimation of threshold to understand a subject's speech identification abilities. It has been reported that suprathreshold measures like perception of AM and FM can be assessed through ASSR. However, there are no norms developed for neurophysiological threshold for AM and FM. It has been reported that amplitude of ASSR to AM and FM signal correlates with word recognition scores, but the relationhip of the depth at which AM and FM becomes detectable has not been correlated with speech identification scores. Hence, this study has been taken with the aim to develop norms for AM and FM depth and to investigate the effect of hearing loss on the same. The correlation between AM and FM depth threshold with speech identification scores in quiet and in noise has been studied.

Two groups of subjects were selected. The first group consisted of normal hearing subjects (n = 30) with the age ranging between 18 and 50 years. The second group consisted of subjects with different degrees of sensorineural hearing loss (n = 20) with age range between 18 and 50 years. They were divided into subgroups as minimal hearing loss, mild hearing loss and moderate hearing loss based on the pure tone threshold.

A calibrated diagnostic audiometer was used to estimate pure tone threshold and speech identification scores for all the subjects. Phonetically balanced word list in Kannada developed by Vandana (1998) was played through a CD player to assess Speech Identification Scores (SIS). SIS was obtained in quiet and in the presence of speech babble noise with SNR of 0 dB. Calibrated middle ear analyzer GSI 33/GSI Tympstar was used to assess middle ear status. GSI Audera ASSR system was used to assess modulation depth thresholds for AM and FM signals. For assessment of AM depth threshold, FM was kept at 0% and AM signal was varied to find out the minimum depth at which response could be recorded. Similarly FM depth threshold were assessed by keeping the AM depth 0% and by varying the FM depth.

The data was statistically analyzed and mean, standard deviation and range was calculated. One way ANOVA was used to see the effect of hearing loss on AM and FM depth threshold. The following conclusions were drawn based on the results of this study:

1. In normal hearing individuals, the AM depth threshold and the FM depth threshold increased with increase in frequency of the signal. The minimum AM and FM depth which some normal hearing individuals could perceive was 1%.
2. In hearing impaired individuals, there is an increase in AM depth threshold and FM depth threshold with increase in degree of loss. However the effect was significant only at 500 Hz and 1 kHz for AM depth threshold.

3. No significant correlation was observed between speech identification scores and AM/FM depth thresholds when all hearing impaired subjects were considered in the group. The correlation coefficient was higher for subjects with moderate hearing loss.

**Implications:**

1. Norms obtained in the present study can be used for the assessment of suprathreshold functioning in hearing impaired individuals.
2. Behavioral studies indicate that the perception of AM and FM is affected in subjects with auditory processing disorder. Hence, these norms may help in the evaluation of auditory processing disorder in difficult to test population.
3. It has been reported that ASSR can be used in hearing aid selection by comparing aided and unaided threshold. Including assessment of AM/FM depth threshold in this battery would help in assessment of suprathreshold functioning in hearing aid users.

# REFERENCES


Anita, R. (2003). *The effect of speech babble of different languages on speech identification scores*. Unpublished Independent Project. Mysore, University of Mysore.

Bacon, S.P., & Viemeister, N.F. (1985). Temporal modulation transfer functions in normal hearing and hearing impaired listeners. *Audiology*. 24, 117-134.

Baford, J., Christensen, A., & Pedersen, O.J. (1971). Design of hearing aid frequency response for maximum speech intelligibility of patients with high-tone loss. Scandavian Audiology, 1, 54-60.

Carhart, R., & Jerger, J.F. (1959). Preferred method for clinical determination of pure tone thresholds. *Journal of Speech and hearing Disorders, 24, 330-345.*

Cohen, L.T., Rickards, F.W. & Clark, G.M. (1991). A comparison of Steady state evoked potentials to modulated tones in awake and sleeping humans. *Journal of Acoustic Society of America*, 90, 2467-2479.

Demany, L., & Semal, C. (1989). Detection thresholds for sinusoidal frequency modulation. *Journal of Acoustic Society of America*, 85(3), 1295-1301.

Dimitrijevic, A., John, M.S., & Picton, T.W. (2004). Auditory steady state response and word recognition scores in normal hearing and hearing impaired adults. *Ear and Hearing*, 25(1), 68-84.

Dimitrijevic, A., John, M.S., Van Roon., P., & Picton, T.W. (2001). Human auditory steady state response to tones independently modulated in both frequency & amplitude. *Ear and Hearing*, 22, 100-111.

Dobie, R.A., & Wilson, M.J. (1998). Low level steady state auditory evoked potentials: effects of rate and sedation on detectability. *Journal of Acoustic Society of America*, 104, 3428-3488.

Formby, C. (1985). Differential sensitivity of tonal frequency and to the rate of amplitude modulation of broadband noise by normally hearing listeners. *Journal of Acoustic Society of America, 78, 70-77.*

Galambos,R., Wilson, M.J., & Silva. (1994). Identifying hearing loss in the intensive care nursery: a 20 year summary. *Journal of Acoustic Society of America*, 5, 151-162.

Grant, K.G., Summers, V., & Leek, M.R. (1998). Modulation rate detection and discrimination by normal hearing and hearing impaired listeners. *Journal of Acoustic Society of America*, 104 (2), 1051-1060.

Henderson, D., Salvi, R., Pavek, G., & Hamernik, R.(1984). Amplitude modulation thresholds in chinchillas with high frequency hearing loss. *Journal of Acoustic Society of America*, 75(4), 1177-1183.

Herdman, A.T., Stapells, D.R. (2001). Threshold determined using the monotic and dichotic multiple auditory steady state response technique in normal-hearing subjects. *Scandavian Audiology*, 30, 41-49.

Jerger, J., Chmiel, R., Frost, J.D., & Coker, N. (1986). Effect of sleep on auditory steady state evoked potential. *Ear and Hearing*, 7, 240-245.

John, M.S., Dimitrijevic,A., Van Roon, P., & Picton, T.W. (2001). Multiple auditory steady state responses to AM and FM stimuli. *Audiology &*

*Neuro Otology, 6, 12-27.*

John, M.S., Lins, O.G.,Boucher, B.L., & Picton T.W. (1998). Multiple auditory steady state responses (MASTER): stimulus and recording parameters. *Audiology*, 37, 59-82.

Kuwada, S., Batra, R., & Maher, V.L. (1986). Scalp potentials of normal and hearing impaired subjects in response to sinusoidally amplitude modulated tones. *Hearing Research*, 21, 179-192.

Lee, J., & Bacon, S. (1997). Amplitude modulation depth discrimination of a sinusoidal carrier: Effect of stimulus duration. *Journal of Acoustic Society of America*, 101(6), 3688-3693.

Leek, M.R., Dorman, M.F., & Summerfield, Q. (1987). Minimum spectral contrast for vowel identification by normal-hearing and hearing impaired listeners. *Journal of Acoustic Society of America, 81, 148-154.*

Leek, M.R., & Summers, V. (1993). Auditory filter shapes of normal hearing and hearing impaired listeners in continuous broadband noise. *Journal of Acoustic Society of America*, 94, 3127-3137.

Linden, R. D., Campbell,K.B., Hamel,G., & Picton, T.W. (1985). Human auditory steady state potentials during sleep. *Ear and Hearing*, 6, 167- 174.

Lins, O.G., Picton, T.W., Boucher, B., Derieux-Smith, A., Champagne, S.C., Moran, L.M., Perez-Abalo, M.C., & Savio, G. (1996). Frequency specific audiometry using steady state responses. *Ear and Hearing*, 17, 81-96.

Maurizi, M., Almadori, G., & Paludetti, G. (1990). 40-Hz steady state response in newborns and in children. *Audiology*, 29, 322-328.

Narne, V.K., & Vanaja, C.S. (2004). *Comparison of tone-ABR and ASSR in prediction of behavioral thresholds*. Unpublished Masters Dissertation, University of Mysore, Mysore.

Norton, S.J., Gorga, M.P., & Widen, J.E., Folsom, R.C., Sininger, Y.S., Cone-Wesson, B., Vohr, B.R., & Fletcher, K. (2000). Identification of neonatal hearing impairment: evaluation of transient evoked Otoacoustic emission, distortion product Otoacoustic emission and auditory brainstem response

Patterson, R.D., Johnson-Davies, D., & Milroy, R. (1978). Amplitude-modulated noise: The detection of modulation versus the detection of modulation rate. *Journal of Acoustic Society of America,* 63(6), 1904-1911

test performance. *Ear and Hearing,* 21, 508-528.

Peter, V. (2004). *Effects of age and related hearing loss on some aspects of auditory processing.* Unpublished Masters Dissertation, University of Mysore, Mysore.

Picton, T.W., Christopher, R., Skinner, C. R., Champagne, S.C., Kellett, A.J.C., & Maiste, A.C. (1987). Potentials evoked by the sinusoidal modulation of the amplitude or frequency of a tone. *Journal of Acoustic Society of America,* 82(1), 165-177.

Picton, T.W., Durieux-Smith, A., Champagne, S.C., Whittingham, J., Moran, L.M., Giguere, C., & Beauregad, Y. (1998). Objective evaluation of aided threshold using auditory steady state responses. *Journal of American Academy of Audiology,* 9, 315-331.

Picton, T.W., Vajsar, J., Rodriguez, R., & Campbell, K.B. (1987). Reliability estimates of steady state evoked potentials. *Electroencephalography and Clinical Neurophysiology*, 68, 119-131.

Plomp, R. (1978). Auditory handicap of hearing impairment and the limited benefit of hearing  aids. *Journal of Acoustic society of America, 63, 533-549.*

Rance, G., Rickards, F.W., Cohen , L.T., DeVedidi, S., & Clark, G.M. (1995). The automated prediction of hearing thresholds in sleeping subjects using auditory steady state evoked potentials. *Ear and Hearing*, 16, 499-507.

Rickards, F.W., Tan, L.E.,& Cohen, L.T., (1994). Auditory steady state evoked potential in newborns. *British Journal of Audiology,* 28, 327-337.

Savio, G., Cardenas, J., Perez-Abalo, M., Gonzalez, A.,& Valdes, J.  (2001). The low and high frequency auditory steady state responses mature at different rates. *Audiology Neuro Otology,* 6, 279-287.

Sininger, Y.S., & Abadalda, C. (1996). Hearing threshold as measured by auditory brainstem response in human neonates. *Ear and Hearing,* 17, 395-401.

Sininger, Y.S., Cone-Wesson, B., & Folsom, R.C. (2000). Identification of neonatal hearing impairment: auditory brainstem responses in the perinatal period. *Ear and Hearing,* 21, 383-399.

Skinner, M.W. (1980). Speech intelligibility in noise-induced hearing loss: Effects of high frequency compensation. *Journal of Acoustic Society of America*, 67(1), 306-317.

Stapells, D.R., Galambos, R., Costello, J.A., & Makeig, S. (1988). In consistencies of auditory middle latency & steady state responses in infants. *Electroencephalography and clinical neurophysiology*, 71, 298-295.

Stevens, J. (2001). Stare of the art neonatal hearing screening with auditory brainstem response. *Scandavian Audiology suppl*, 52, 10-12.

Vandana, S. (1998). Speech identification test for Kannada speaking children. Unpublished Master's Dissertation., University of Mysore, Mysore.

Viemeister, N.F. (1979). Temporal modulation transfer functions based upon modulation thresholds. *Journal of Acoustic society of America*, 66(5), 1364-1380.

Wakefield, G.H., & Viemeister, N.F. (1990). Discrimination of modulation depth of sinusoidal amplitude modulation SAM noise. *Journal of Acoustic Society of America*, 88, 1367-1373.

White, K.R., & Behrens, T.R. (1993). The Rhode Island hering assessment project. *Seminars in Hearing*, 14, 1-119.