# Functional relationship among cochlea, auditory brainstem and auditory cortex in younger and middle aged adults.

Vineetha C V

**Register No: 13AUD031**

**This Dissertation is submitted as part fulfillment for the Degree of Master of Science in Audiology University of Mysore, Mysore**

**May 2015**

## CERTIFICATE

This is to certify that this dissertation entitled "**Functional relationship among cochlea, auditory brainstem and auditory cortex in younger and middle aged adults**" is a bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student (Registration No.: 13AUD031). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any of the University for the award of any other Diploma or Degree.

Mysore

**May, 2015**

**Dr. S. R. Savithri**

**Director**

All India Institute of Speech and Hearing

Manasagangothri, Mysore -570 006.

**CERTIFICATE**

This is to certify that this dissertation entitled "**Functional relationship among cochlea, auditory brainstem and auditory cortex in younger and middle aged adults**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any Diploma or Degree.

Mysore

**May, 2015**

**Dr Sujeet Kumar Sinha**

**(Guide)**

Lecturer in Audiology

All India Institute of Speech and Hearing

# DECLARATION

This is to certify that this dissertation entitled "**Functional relationship among cochlea, auditory brainstem and auditory cortex in younger and middle aged adults**" is the result of my own study under the guidance of Dr Sujeet Kumar Sinha, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

**Mysore** **Register No.: 13AUD031**

**May, 2015**

*Dedicated to*

"YOU"

*yes ,you the reader!!!*

# Acknowledgment


"There is no such thing as self-made man. We are made up of thousands of others"

**–Gerroge Mathew Adam**

*Once upon a time who were being cared ,nursed and taught by their's have done more to me, to whom my words would be infinite to thank , who stands as alps for me ie., **Amma and Appa.***

*My hearty thanks to loving brother **vinanna** ,who is the greatest gift, given bymy parents .*

*I am grateful to my institution **AIISH** which gave me an opportunity to shape my carrier. With its very ideals and inspiration for having provided us with the facilities, which has made this project a success. Proud to be an AIISIAN.*

*I express my sincere gratitude **to Dr S R Savithri,** Director,**Dr Ajith Kumar** ,Hod of Audiology and to all the **Faculties of AIISH,** who have always been a great source of support and inspiration.*

*My immense gratitude to, **Dr Sujeet Kumar Sinha,** the mentor. Who encouraged my positive approach, giving shape to my vision and correcting my every clanger as learning experience. I found myself evolving both professionally and personally under your guidance. Thank you so much sir.*

*"Everybody is a genius. But if you judge a fish by its ability to climb a tree it will live its whole life believing that it is stupid*

My gratitude to my teachers **Mr Vishal ,Mrs Anitha,Mrs shruthi kaul, Mr Ganapathy and Mrs Sudha,** for recognizing my ability and providing opportunity to improve myself throughout my professional life .Trusting your blessings to last forever.

My gratefulness to **Dr Ajith kumar** an acme in his brilliance, from whom we can gain lots and lots of treasure.

A token of love and acknowledgement to my uncle **K T Rajashekar**, who is privilege to my life. Who's words "Understand, Follow and Finish" helping me throughout my life .

**"Friends forever" - Aisha ,Bebek, Cv, Prakash and kiran**. Thank you guys for the good times, the days filled with pleasure and fond memories with you all, that i always reminiscent.

"You" highlighted the speech hiding behind the Pure tone. A special thanks to u **Preeta** , for providing a second meaning to life :P (Courtesy : Ms Bhuvana )

I could afford to be sad because, I knew you were there to cheer me up. Glad to have u both **Bhu** and **Vino**.

"Friend in need is a friend indeed". Thanks to you buddys ; **Divya, Nithya, Arav, Ranju ,Nikli ,lekha,Supp,pawan, Akil, Rohan, Ambaa, Pg, Suman, zeena, Akashy, Guna, kapali, supreeth ,Swathi** it goes on and on ......(sorry space limit)for enriching this quote.

Best things are found when **friends** and **family** are together .Thank you my **dear friends** Anu di ,Sabreesh chetan , laxmi akka ,Merin chechi , kumaran anna, Varsha , gowtham, keshav ,Mangal, nikitha for being as **my family**. I treasure your joy, love and care each and every day.

***"The slient Shores", "Master-Stay-Coneeted", "The motofafallia"*** *and my* ***"co-pros"****-Thank you for being there are always and making student life a memorable one.*

*It would be a incomplete if forget to thank the pillars of EP lab* ***Dr Sandeep sir and Nike sir*** *for providing a platform for the research in auditory evoked potentials.*

*Acknowledgments to all the* ***participants*** *of the study. Your participation was very valuable to me.*

*Thanks to all the Library staffs ,clinical and non-teaching staffs of AIISH and JSSISH .*

*I sincerely thank all all those who have, directly or indirectly, helped or encouraged or motivated me in successful completion of this disseratation.*

*Hey Thank* ***"YOU"****. A non-writing writer's words would be just words till you bring the life ,by your glance .*

Abstract

Ageing is one of the main factors that have the systematic effect on processing in auditory system. Even with the normal audiometric thresholds middle-aged listeners report difficulty in conversing in social environment which could be attributed to influence of ageing in throughout auditory system from cochlea, brainstem and at the central system. The current study aimed to investigate correlation between cochlea, brainstem and cortical auditory processing in normal young adults and middle aged individuals. A total of thirty subjects were divided into two groups (younger and middle aged groups) based on the age of individual. The transient oto acoustic emission (TEOAEs), Speech evoked auditory brainstem response (S-ABR) and speech evoked late latency response for /da/ stimulus were obtained. Results reveled that reduction in amplitude of TEOAEs from 1.5 k Hz to 4k Hz, reduction in amplitude of fundamental frequency, first formant frequency encoded at brainstem level and also prolonged latency of P1 and increased amplitude at N1 in middle aged group. There were no correlation among the audiological test that was carried out among these three levels of auditory system; however some of the parameters had the correlation. Thus it could be advisable that routine evaluations at all the three levels of auditory system are necessary in middle individuals.

**Table of Contentss**

## List of Tables

## List of Figures

Chapter 1

# Introduction

Hearing loss associated with older individuals in one of the main complaint among the geriatric subjects. The hearing loss associated with presbycusis often results in significant changes in speech perception abilities of individual even when these individuals do not have a significant hearing loss with increase in age (Pichora Fuller etal., 2006). Several anatomical, physiological and cognitive changes take place in these individuals and these changes might lead to hearing and speech perception related difficulties (Pichora Fuller et al,.2006).

Speech identification is one of the major problems in elderly individuals. The problem of speech perception in adverse listening conditions increases in elderly subjects (Ewertsen & Birk-Nielsen, 1971; Gelfand et al., 1986; Kim et al., 2006). Elderly subjects perform poor on different auditory task such as, perception of interrupted speech (Bergman, 1971),time-compressed speech (Vaughan and Letowski, 1997), and perception of dichotically presented speech (Barr &Giambra, 1990; Martin & Cranford, 1991; Jerger et al., 1994). These affects are also seen in middle aged subjects in comparison to younger individuals but better than older individuals (Nabelek& Robinson, 1982).Jerger and Hayes (1977) attributed the difficulty on the SSI-ICM task to a central auditory nervous system deficiency in elders.

Otoacoustic Emission provides information about the outer hair cells condition and hence it may be provide information about age related changes in outer hair cells. Generally the amplitude of Otoacoustic emission has been reported to reduce in older individuals with normal hearing sensitivity (Bonfrietal., 1988). The amplitude of OAE has been reported to be reducing after the age of 40 years (Uchindaet al., 2008). The reduction in amplitude of OAE with aging has been reported with variousstimuli such as click and tone burst (Betroli, 1997).

Speech evoked ABR has been utilized as an objective tool to study the brainstem encoding of speech sound (Runo et al., 2004, Sinha and Basavaraj 2010a,b). Speech evoked ABR provides information about neural timing and encoding of various speech cues at the brainstem level (Krishna, 2002, Akhoun et al, 2008). Speech ABR represents the neural representation offrequency and neuronal synchronous firing which declines as age progress and several studies have shown reduced representation of sinusoids at the sub cortical level (Moushegian et al., 1973; Davis & Hirsh, 1976; Sohmer et al., 1977). It also have been evidenced to assess speech-in-noise perception in older adults (Anderson, Parbery- Clark, Yi & Kraus, 2011), encoding of speech at the brainstem in individuals with sensorineural hearing loss (Pyler & Ananthanarayan, 2001), encoding of speech at the brainstem inchildren with Learning disability and poor reading skills (Nicol, Zecker, Bradlow & Kraus, 2001; Cunningham, Hayes, 2003).

Speech evoked auditory cortical potentials (P1-N1-P2) are also commonly used to study the neural representation of speech-sounds as the speech signals contains neural representation of temporal and spectral cues that are necessary for speech perception which may declines as age progress. In elderly subjects there are evidences which showthe prolongation of N1 and P2 latencies. These changes are indicative of delays in synchronous firing among neural populations generating N1 and P2 responses as the age increases (Tremblay et al. 2002).

## 1.1 Need for the study

### *1.1.1 Need for studying age related changes in normal middle aged individuals*

Effect of age-related changes (40-50 years) in auditory system reflects changes in both peripheral and central auditory systems (Geal-Dor et al., 2006).Even with the normal audiometric thresholds middle-aged listeners report difficulty in conversing in social environment (Helfer& Wilber, 1990; Wingfield et al, 2006). Studies have informed poor performance in task such as speech perception in noise (Ewertsen&Birk-Nielsen, 1971; Plomp& Mimpen,1979; Era et al, 1986; Gelfand et al., 1986) or in reverberation (Nabelek& Robinson, 1982), auditory event-related potential (Alain et al., 2004; Geal-Dor et al., 2006) and gap detection ability (Helfer et al., 2009).Thus there is need to study effect of age related changes in normal middle aged individuals.

### *1.1.2 Need for studying TEOAES in normal middle aged individuals*

Changes in cochlea with respect to age related changes is based on the anatomical changes that involves sensory, neural, metabolic and mechanical active process, which results in decreased number of OHCs,effect on afferent and efferent system, degeneration of striavasculariss, stiffness of basilar membrane,spiral ligament and other structures are responsible for loss of sensitivity respectively, which might effect on OAE generation Scholtz et al., 2001).Loss of both inner and outer hair cells has been reported after the age of 45 years (Engstorm et al. 1987), whereas for the subjects above the age of

60 years, degeneration was widespread along all the cochlear turns (Scholtz et al. 2001). Thus, TEOAEs may provide information about the changes occurring in the outer hair cells in middle aged individuals and hence there is a need to study TEOAEs in middle aged individuals.

*1.1.3 Need for studying speech stimulus to record brainstem and cortical potentials*

Speech is a complex stimulus that contains spectral distributions of both transient and sustained measures of timing and rapid temporal changes than the non-speechsounds, neural detection of these cues are necessary for speech perception (Russo et al., 2004).Several studies which have utilized speech and non-speech stimuli to record auditory evoked potentials,have reported that ageing effects are more pounced for speech than the non-speech stimulus(Tremblay et al.2003; Tremblay, Billings &Rohila, 2004). Bellis, Nicole&Kraus (2000) reported a pattern of hemispheric asymmetry for speech stimuli which different in older and younger subjects i.e, the amplitude of event related potentials for speech stimuli, over the left hemisphere was larger compared to right hemisphere in younger subjects.However, same hemisphere pattern was not recorded in older subjects. Thus, there is a need to study the speech stimulus to record the brainstem and the auditory cortical potentials.

## 1.2 Aim of the Study

To investigate correlation between cochlea, brainstem and cortical auditory processing in normal young adults and middle aged individuals.

## 1.3 Objectives of the study

1) Effect of age related changes in TEOAE
2) Effect of age related changes in brainstem encoding of speech stimulus.
3) Effect of age related changes in auditory cortical response to speech stimulus.
4) Correlate the TEOAE, speech ABR and Speech LLR responses in normal adults and middle aged individuals.

Chapter 2

## Literature Review

Aging can be defined as the biological process of growing old, regardless of Chronological age (Timiris, 2003). Intrinsic (nature) and extrinsic (nurture) factors, as well as their interactions, impact the degree and rate of ageing which leads to communication impairment. Older adults frequently complain: „„„I can hear you, but I can‟‟t understand you.‟‟‟‟ (Kelly Tremblay and Bernhard Ross, 2007).It is generally accepted that some of the communication impairments are associated to age-related declines in spectral and temporal resolving power of the auditory system (Andersen, 1982; Schneider, 1997).

Structural and physiological changes occur throughout the auditory system with age. These changes occur throughout the auditory system involving the outer ear, middle ear, inner ear and the central auditory pathway. The influence of these changes can lead to the decreased hearing sensitivity and other auditory processing deficits.Presbycussis is the hearing loss associated with ageing is the common complaint among the elderly population.

Age is the greatest risk factor for sensorineural hearing loss. Both prevalence and severity of hearing loss increase with age, as demonstrated by large-scale epidemiological studies. In most studies, elderly listeners are defined as age 60 or above. However, the range for being considered elderly ranges across studies from age 40 to age 70. Certainly, individuals in their 40's or even 50's are not usually considered by society as being old. A more reasonable, lower age limit for "elderly" would be age 60 or 65. However, the effects of aging may be seen at an earlier age. It is frequently noted that approximately a third of those >65 years of age have significant hearing loss however; the relationship between aging and hearing loss becomes even clearer when viewed within finer stratifications. In the Beaver Dam epidemiology of hearing loss study, almost 90% of those >80 years of age demonstrated significant hearing impairment. Other more recent analyses indicate a 75% prevalence of high-frequency hearing loss among elders. The prevalence of auditory processing increases from 20 % to 95 % as the age increase from 50 to 80 years (Stach ,Speilnjak, jerger 1990).

Auditory processing abnormalities can occur independent of peripheral hearing loss, which leads to the poor speech perception in older individuals. Older individuals, tend to have more difficulty than younger listeners in adverse condition such as in noise, reverberation or the other temporal manipulation.

**2.1 Pure tone audiometry**

Ageing is one of the factors that influence the communication impairment. The loss increases gradually at first and then accelerates more rapidly with increasing age, especially for the higher frequencies (Berger et al., 1977; Corso, 1963; Glorig& Nixon, 1960; Glorig& Nixon, 1962; Glorig& Roberts, 1965; Robinson & Sutton, 1979; Spoor, 1967), and is bilaterally symmetrical .

Uchida et al. (2003) conducted longitudinal study on relationship of audiometric threshold in a middle aged to elderly population using population based sample of 2150 adults. the group was divided into four groups 40-49 years (538) ,50-59 years (539),60-69 years (544) and 70 -79 years (529) . Air conduction pure tone audiometry was carried out at octave interval from 500 Hz to 8kHz and bone conduction from 500 Hz to 4kHz in both ears .The results revealed as the ageing advances there was a decrement in hearing threshold .a significant reduction was seen in the age range from 50 -59 years exhibited the mild hearing loss and above 60 -69 years exhibited the significant reduction in threshold above 4kHz (threshold > 25 dB).The results of self-perceived hearing difficulty reveled that middle aged group tend to underestimate their hearing difficulty than younger adults. This result throws the light on the middle aged are proven to get effected by the ageing which further get worse in elderly population.

Jonsson and Hall (1988) conducted a longitudinal study of presbycusis on 376 people during 20 years‟ time span of the hearing assessment study. The subjects were divided into three groups; Group1 consisted of age range below 80 years, Group 2 consisted of age range from 80 to 90 years and Group 3 consisted of age range 80-90 years. The air conduction thresholds were measured from 0.25, 0.5,1,2,4 and 8kHz (for group three included the 6 kHz).The mean threshold decline at each frequencies for 70-81 and 81-90 years of age was calculated .The men of the study showed a decline of approximately 2dB/year between the age of 70 to 81 years; most adverse at 2kHz.The decline was less than 1dB/year in age range from 81 to 90 years. Overall the pure tone decline was slight in the low frequency area and increased linearly to 8kHz.In the age range above 81 years, it was observed more in the area of ≥1kHz.

Demeester and Heying (2009) studied the prevalence of audio logical configuration in 1147(549 males and 598 females) subjects between the age range of 55 to 65years.air conduction thresholds were measured at 125, 250, 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz and bone conduction thresholds at 500, 1000, 2000 and 4000 Hz. The audio logical threshold elicited reveled the decreasing in the threshold as the ageing progress. It revealed the different configuration of losses, where „Flat configuration‟ was most dominantly seen (37%) and that low frequency and mid frequency configuration were minimally seen (less than 1%).Never the less, it showed the relatively high frequency loss configuration (35%).the present result indicated that at least three different types of audiometric configuration are very frequently represented in the age range from 55-65 years.

Brant and Larry (1990) examined the pure tone audiometry in 213 males and 265 women aged 62-90 years. The hearing thresholds were recorded in both ears from 250 to 8000 Hz air conduction and bone conduction from 500 to 4000 Hz. The results show the age effect and gender effect. It revealed that elevation in the hearing threshold in each frequency with increasing age, the sole exception being in the loss for bone conduction at 1000Hz. Not every age group showed a significant increase in hearing threshold elevation when compared to the age group immediately preceding. However threshold in persons of 80 years and over significantly greater than that in persons of 62-64 years in all frequency in both genders except in men at 500 Hz by air conduction and 1000Hz by bone conduction .However elevation in hearing threshold were observed in higher frequency of 2000Hz and above in males and at all frequency in females.

Pertti, Jukka and Eino (1986) carried out the pure tone audiometry in three groups of men (31-35, 51-55, and71-75 years). The air conduction thresholds were measured from 125 to 8000Hz and pure tone averages were taken from 500 to 400Hz. In the pure tone thresholds there was significant difference between age groups at all the frequency. The prevalence of hearing sensitivity decrement of 30dB was seen at 500-1000-2000 Hz and level of 60dB at 4000Hz was 58 and 52.1% from youngest to the oldest group respectively. Furthermore there was also highly significant difference in speech in understanding test between the two groups. This effect could be manifested to the pure tone average and hearing threshold at 4000Hz.

Larry and Brant (1988) studied the hearing thresholds from 813 subjects across the age range from 20 to 95 years. The air conduction hearing thresholds obtained were analyzed in frequency range from 125Hz to 8 kHz. Results revealed that average longitudinal loss of 5.7-7.6 for 20 year old, 10.0-12.7 for 50 years old and 69-84.5 dB for 80 years old. The rate changes in threshold were faster in 70 years and above at the highest frequencies ranging above 4000Hz.

Changes in hearing ability initiates at the middle age around 40 to 45 years of age and get worsen as the age increases .Study done by Ankur et al. (2013) reported the occurrence of hearing loss in men hearing loss of mild grade was present in 17 (37.8%) cases between the age of 41 to 60 years while hearing loss of mild grade was also present in 48 (87.2%) of cases between the age of 61 to80 years. In women hearing loss of mild grade was present in 14 (28%) between 41 to 60 years (Group III) while hearing loss of mild grade was also present in 45 (75%) between 61 to 80 years.

**2.2 Acoustic Immitance**

More than a few investigators have found that the middle ear system becomes increasingly compliant up to middle age and then stiffens with further aging (Alberti&

Kristen, 1972; Jerger, Jerger & Mauldin, 1972). There is dearth of information available on tympanometry findings in the older populations .The study by Newbonne, Schow and Bliss (1978) have reported that presence of excessive negative middle are pressure among the elderly population.

Several authors have reported that decreased admittance values at the tympanic membrane in older individuals. Beaty and Leamy (1975) has investigated the Static admittance using 660Hz probe tone in on two groups consisting of 20 of subjects in each .Group 1 ageing from 17-29 years and other group 60-78 years. The result reveled that older group had the larger value (5.25 mmho) when compared the younger group (3.43 mmho).

Hall (1979) investigated the effect of age on static compliance vales in older individuals. He reported that Static compliance are greatly noticed between 31 to 40 years, then reduces relatively linearly with increasing the age. Similar study by Hall in 1979 reported that below the age of 30 years of age in females static compliance were greater and 30 to 60 years of age, men showed the larger static compliance. However above 60 years of age static compliance were equivalent in both males and females. The findings are supported by the other several authors (Jerger,Jerger& Mauldin , 1972; blood & Greenberg ,1977)

Blood and Greenberg (1976) cited in Thompson ,Sills,Recks,Bui (1979) has done the studied the 220 Hz acoustic admittance on 20 persons in three age category 50-59 years,60-69 years and 70 years and above. Result indicated that as the age progresses there is decrease in mean acoustic admittanceas the increase in for the age 50-59 years was 0.85 mmho,0.81mmho for the 60-69 years and 0.60 mmho for the age group of 70 years and over.

Nevertheless, there are other several studies which have investigated that no change in the static admittance values in the elderly population. Osterhammel (1979) reported that no change in admittance values across different age groups and across the different genders.

**2.3 Otoacoustic emission**

Among factor affecting the OAE, subjective factor such as age which plays a major role in outcome of the OAE .Age differences are seen due to the developmentalchanges that take place as the age increases and also the changes are associated with advanced ageing. As the ageing advances the amplitude of OAES decreases as the thresholds increases with age. This reduction in amplitude could be mainly seen in for higher frequencies.

Bonfils et al. (1988) conducted a study on age related changes of evoked acoustic emissions (EAE) in 151 ears of people ranging in age from 2 to 88 years. EAE s were evoked by rarefactions clicks delivered at repetition rate of 21/sec. The analysis was based on nonlinear saturating response and discrete frequency specific maxima in FFT. The result reveled that EAEs were present in 138 out of 151 subjects tested. The presence of EAEs varied across the age. EAEs were present in all subjects below 60 years of age and incidence was reduced to 35% in above 60 years of age. The spectrum analysis revealed two types of spectral peaks. The first one with wide continuous frequency band varying between 500 and 2500 Hz with maximum amplitude at 1000 and 2000Hz, which was present in all subjects. The second type of spectral frequency consisted of narrow band isolated frequency peaks superimposed on broad band spectra. The incidence varied with age, below the age of 50 years it varied between 41.6 and 66 % whereas after the age of 50 years, the incidence of the isolated peaks ere 14 % and reached to 0% after 60 years of age. However EAE thresholds did not vary until the age of 40 years but increased linearly after 50 years of age.

Prathasarathy (2001) investigated the ageing effect on transient evoked oto acoustic emission. The study was conducted on 30 normal hearing subjects, the age ranged between 20 to 79 years. The groups were divided into six decade age groups; 20 to 29 years; 30 to 39 years; 40 to 49 years; 50 to 59 years; 60 to 69 years and 70 to 79 years subjects were five in each group. The TEOAEs were recorded using conventional nonlinear conventional nonlinear click delivered at about 80 dB peak SPL at a repetition rate of 50 clicks/sec .For the contralateral suppression of TEOAEs were recorded with and without broad band noise ranging from 40 to70 dB HL in 10-dB steps. The results revealed that TEOAs were present in all the age groups .The mean overall emission levels as a function of age measured without the CBBN ranged from 10 to 12 dB SPL. The TEOAEs as a function of age and hearing threshold did not showed the significant difference. Never the less in individual between the suppression effect on TEOAE levels with broad band noise at 60 and 70 dB HL was significantly greater for subjects in the age range between 20 and 59 years of age than for subjects between 60 and 69 and 70 and 79 years of age.

Yilmaz, Sennaroglu and Kose (2007) studied the influences of age on contralateral suppression of transient evoked emission (TEOAEs) and its suppression. The study consisted of 53 women and 48 men. Participants were aged 10 to 69 years and were divided into six age groups (10-19, 20-29, 30-39, 40-49, 50-59 and 60-69 years). TEOAEs were elicited using nonlinear clicks of 80-microsecond duration, delivered at a peak sound pressure level of 83+3 dB. An average of two transient evoked otoacoustic emission waveforms, composed of 260 accepted click trains, was automatically cross correlated and used to determine the reproducibility of the measured TEOAEs. The recording was first conducted without noise stimulation from the opposite direction. It was then repeated by applying 40 dB SL contralateral speech noise. The results revealed that TEOAE amplitudes reduced with age. These amplitudes were significantly lower in the 50–59 and 60–69 year age ranges, compared with other age ranges. The amplitudes in the 4 and 5 kHz frequency bands were significantly lower than those in the 1, 2 and 3 kHz frequency bands. Contralateral transient evoked otoacoustic emission suppression with respect to age and test frequency band was found to decline with age however, this decline was not statistically significant.

Stover and Norton (1993) aimed at to investigate the influences of ageing on oto-acoustic emission. OAEs were measured in 42 normal hearing individuals age ranging from 20 to 80 years old. For each participant TEOAEs were measured using 100 µs click-evoked, tone-burst-evoked stimulus frequency and emissions were measured across a wide intensity range for frequencies between1 and 3 kHz. All stimuli were presented at levels ranging from 9-75 dB pe SPL in 6-dB steps. I/O functions across all subjects for each of the five frequencies showed the evidence of saturation beginning at approximately 50 dB pe SPL. The lower frequencies (1 and1.5 kHz) have greater output magnitude than the higher frequencies but the stimulus levels at which saturation occurs are similar. However there was a lower output for the older age groups, particularly at the higher frequencies. The response to a click is broad band levels for COAEs were calculated for the bandwidth from 1 to 3 kHz.

The saturation was less pronounced in both groups which were lesser than that obtained with tone burst OAEs. It indicated that there are significant differences between age groups however no age affect independent of hearing sensitivity on any type or parameter of otoacoustic emissions (OAE). The effect of increasing age is confounded with the effect of decreasing sensitivity on otoacoustic emissions. Even within the range of audio metrically normal hearing, OAE characteristics vary with threshold for all age groups.

Collet et al. (1990) sought to circumvent the confounding effects of threshold shift by measuring only normal-hearing subjects (i.e., audiometric threshold better than 25 dB HL re: ANSI, 1969). They report data from 93 subjects ranging in age from 6 weeks to 83 years. The incidence of COAEs was 60% in subjects over 70 years. Similarly Quaranta et a1. (2001) found TEOAEs in 40% of female subjects above 70 years of age in a controlled study of both ears in 15 guests of a retirement home, using ILO 92. The cut-off wyias set at a signal to noise ratio of 10 dB, and a wave reproducibility of 70% (Quaranta et al, 2001). Collet et a1 (1990) found a diminishing presence of TEOAEs in

10 subjects above 60 years of age from a larger sample of 93 subjects from 6 to 83 years of age.

Bertoli and Probst (1997) studied the prevalence of TEOAEs in older individuals. The hearing threshold evaluation and nonlinear click evoked TEOAEs were recorded among 511 participants age ranging from 18 to 70 years of age .The study found a prevalence of 60% of TEOAEs when the PTA (0.5, 1 and 2 kHz) was 30 dB HL or better in their sample of 201 volunteers above 60 years of age who had hearing complaints. A similar study was conducted by Castor et a1 (1994) found a prevalence of 91 % for TEOAEs after the age of 70 years in a controlled study of 20 subjects who were audio metrically normal for their age in both ears, with no known history of ear disease or any other audio logical complaints .

**2.4 Auditory brainstem response**

Mauizi, Altissimi, Ottaviani, Paludetti and Bambini (1982) conducted a study on 86 subjects age range between 60 to 86 years. All subjects were classified into four groups. Group 1 (60-65 years), group 2 (66-70 years), group 3 (71-75 years), group 4 (76-86 years).Auditory brainstem responses were recorded using click and tone bust (500Hz to 4 kHz) stimulus. The analysis of waveform reveled that discrepancy between the mean auditory threshold and the ABR wave form, overall reduction of ABR waves and also progressive prolongation of V-I interval values.

McCandless and Walter in 1982 studied the changes that oocurs in the ageing auditory system using electro physiological measurement. The study was conducted on 30 elderly and 30 young participants. Age of elderly group ranged from 60 to 80 years and younger group from 17 to 31 years. Based upon the hearing sensitivity elderly subjects were matched with a control subjects. For all the subjects pure tone audiometry, speech perception and auditory brainstem response (ABR ) were elicited. The ABR was recorded using unfiltered clicks at rate of 10 clicks per sec. The clicks were presented at 80 and 50 dB nHL to each ear which was used to compare the latencies because high frequencies elevation in threshold was expected in elderly individuals. The analysis of ABR waveform reveled that mean latencies of wave I-V was slightly longer than those of younger subjects. Additionally influence of elevation in hearing threshold at high frequency on latency wave V by grouping at 4000Hz reveled prolongation of wave V latency in elderly subjects. The interpeak latency of elderly was significantly prolonged between wave I and III when compared to younger group by 0.22 msec.

Jerger and Hall (1980) investigated the effect of age on auditory brainstem response in 182 male and 137 female subjects across the chronological age range. The click evoked ABR waveform analysis revealed that age had effect on both latency and amplitude of wave V. In subjects with normal hearing, latency increased about 0.2 ms over the age range from 25 to 55 years and also there was a decrement in wave V amplitude by 10% in males. Similarly in female subjects 0.2 msec shorter in wave V latency, 25 % increase in amplitude.

Psatta and Matei (1988) studied chronological ageing effect on auditory brainstem response in normal hearing subjects. The age ranged from 20 to 70 years of age. ABR was recorded using click stimulus at 80 dB nHL. From the study it revealed that there is decline in latency and amplitude of wave V ABR were statistically significant, although there were no significant differences in early wave form wave I and III in group age ranged below 45 years .However more reduction was observed in amplitude rather in latency of the waveform between age ranges from 50 to 70 years.

Chu (1985) investigated the effect of age on the auditory brainstem evoked potentials. The study consisted of 156 subjects both male and females with age range from 18 to 76 years. The click evoked ABR was done. Analysis of the waveform reveals that prolongation of the latencies of peaks I-V and inter peak latencies of I-III,III-V and I-V with ageing. However females had a shorter latencies and increased amplitude than males. There was existence of correlation between ageing and inter peak latencies of III-V and I-V interval but III-V had no correlation with ageing.

Oku and Hasegewa (1997) conducted study on 92 subjects aiming to study the effect of advancement inn ageing on auditory brainstem response. The participant exhibited the normal hearing sensitivity and mild hearing loss above 4000Hz .The subjects‟ age ranged between 50 to 80 years .The auditory brainstem responses was elicited using click stimulus in both ears in all subjects. The analysis of waveform reveals that delay in wave I,III and V and also prolonged of inter peak intervals of wave III-V and I –V in 50 to 79 years subjects. It also reported that poor morphology of waveform were seen in the age range above 50 years of age.

Rosenhall, Bjorkman, Pederson and Kall (1985) investigated the auditory brainstem potentials in 62 subjects which were divided into two groups based upon the age. The group consisted of younger participant‟s age ranging from 20-49 years and older group from 50 to 80 years of age. The ageing effect was studied using electrophysiological measure such as ABR using click stimulus in both ears. The wave form analysis reveals that latencies of wave I ,III and V had prolonged latency by 0.1 to 0.2 msec with increase in age .They also found not much difference in inter peak latency of wave I-V in both groups .This provides knowledge on effect of ageing on detoriation on functioning of the auditory system .

Costa, Benna, Bianco, Ferraro and Bergamasco (1990) did a study using auditory brainstem response as evidence for reporting the changes in auditory system as function of ageing process. The study was conducted on 152 normal hearing subject"s age ranging from 50 to 80 years of age. The ABR was recorded using the click stimulus. The analysis results revealed that significant reduction in the amplitude of the wave V in older individuals and also significant difference in latency of wave I. There was no significant difference in wave III, however older participants did showed the prolongation in latencies.

**2.5 Speech evoked brainstem response**

Anderson, Clark, Gyol and Kraus (2011) neural basis at subcortical representation of speech in older adults. The study was done on participants 28 adults with age range from 60–73 years. The participants were grouped according to their speech perception scores using aided scores when applicable for those with hearing loss. They conducted the study neurophysiologically using speech-evoked auditory brainstem responses (S-ABR) recorded in quiet and in background noise. The S-ABR were recorded using synthesized speech stimulus [da] at 20 kHz using a Klatt synthesizer with a duration of 170 msec.The background noise stimulus was created from syntactically correct nonsense English sentences spoken by six talkers (four females) in a conversational style. The analysis of F0 and RMS amplitudes of S-ABRs in quiet and noise conditions were done. The F0 magnitude differences were present between groups of poor and good scorer of SPIN scores in quite only condition. However group differences in RMS were significant for both the quiet and the noise conditions. There was no main effect of group for the responses to higher harmonics were seen. Thus the study focuses on the importance of encoding of Fo in speech perception especially in the presence of noise in older adults. There was stronger linear relationship in ageing effect between subcortical response measure and behavioral measures of speech perception.

Vander Werff and Burns (2010) conducted the speech evoked ABR in 19 normal hearing ages 20 to 26 yrs and 18 older adults aged between 61 to 78 years, using 40 msec

/da/ stimulus. The electrophysiological data were taken for both groups. Click evoked and speech evoked ABR were recorded using 100-μs clicks presented at a rate of 11.1/sec at 80 dB nHL and synthesized syllable /da/ of 40-msec duration The latency, amplitude representing onset, off set and sustained response for vowel context were analyzed. Results reveled between two age group there was a significant differences in the amplitude and latency of transient peaks and all so in the components of the sustained response of the S-ABR. In precise, the older adult group exhibited prolonged latency at response offset and reduced amplitude for the onset and offset peaks compared with their younger adult equivalents. Even though the individual peak latencies were not significantly different between groups within the sustained portion for all peaks of the S-ABR, significant group differences in the stimulus-response lag and spectral amplitudes related to the fundamental frequency, first formant, and High frequency components of the frequency following response.

Anderson, White-Schwoch and Kraus (2012) investigated the effect of ageing in 17 normal younger adults (18-30 years) and 17 older adults (60-67 years).The electrophysiological study was conducted .Speech ABR was recorded for synthesized speech /da / stimulus of 40 msec duration .The analysis of both transient and sustained responses reveled that larger variability and prolonged auditory brainstem response, especially in response to rapidly changing formant transition in older adults. However there was not much difference was seen in sustained response than transient response. Thus it also reveals that decreased phase locking and smaller response in older adults than the younger adults which are evidenced by speech evoked electrophysiological responses.

Rishiq (2013) conducted the study on effect of ageing and spectral shaping on brainstem coding of contrastive stop consonants. Study conducted on 16 younger adults (<50 years) and 11 older (> 50 years) participants. Speech evoked ABR was recorded using 100 msec/b-d-g/ consonant-vowel exemplars in unshaped and shaped conditions, for a total of six stimuli. The duration of both the F1 and F2 formant transitions was 40 msec. Speech ABR analysis revealed amplitudes of onset peaks, there were no obtained group differences between younger and older adults.

Spivak and Malinoff (1990) studied the neural representation of speech at subcortical level. The study compared the amplitude of spectra of ABR in both 40 younger (20-35) and 40 older (59-70 years) subjects. The recorded speech evoked ABR was subjected to spectral analysis it revealed that older subjects have a significant greater amount of low frequency energy than younger group. Also the study revealed that there is prolongation of onset responses in amplitude and latencies in older group compared to the younger group.

**2.6 Auditory late latency response**

Tremblay, Bilings and Rohila (2004) studied the effect of age on speech evoked cortical potentials. A total of 20 normal hearing participants were selected, who were divided into two groups according to age (10 subjects in each group). The younger group consisted an age range of 21–33 years, and the older group consisted an age range of 63–79 years. The speech evoked cortical responses were elicited using the /pa/ stimulus of 180 msec. The fundamental frequency of the stimulus began at 120 Hz and fell to 100 Hz during the steady-state portion of the vowel. The formant transition was 40 msec in duration. To simulate a burst, a turbulent noise source 10 msec in duration and 60 dB in amplitude was added. The spectrum of the burst was centered around 2500 Hz to 4000 Hz. All stimuli were presented to the right ear at 74 dB SPL. For the speech stimulus, significant latency differences were found for N1 and P2 .And also no significant main effect or interaction effect were seen for the P1, N1 amplitude However there was decreased in P2 amplitude were noticed. Hence the N1-P2 complex is used to compare the neural representation of speech stimuli in comparing the age effect.

Iragui, Kutas, Mitchiner and Hillyard (1993) investigated effect of age on the event related potentials .The study consisted of 71 individuals age range from 18 to 82 years. The result revealed that significant delay in N1 and P2 peaks with age advancement. However in general reduced negativity of N2 and increased positivity of P3 over anterior scalp portion and reduced P3 over posterior scalp portion represented the ageing process in the auditory system.

Pfefferbanum, Ford, Roth and Koppel (1980) investigated the cortical potentials in 24 participants. The participants were divided into elderly and younger groups based on age .The study were conducted using speech stimuli. The results of analysis of the waveform revealed that early component N1 did not differ significantly between the groups. However there was effect of age on later peaks such as P3 was more affected than P2. These results were further supported by the following study .Henderson and Starr (1978) conducted the study on 40 participants consisting of both younger (20) and older (20) subjects. It revealed the systematic effect of age advancement in reduction in cortical potential amplitude and increase in latency such as both N1 and P2 peaks.

Anderer, Semlistch and Saletu (1996) studied the effect of ageing on event related potentials(N1,P2,N2 and P300). The study consists of 172 normal healthy subjects aged between 20 to 88 years. The result reveled that with advancing age prolongation of the all N1, P2 and N2 peaks all over the scalp. With advancing age amplitude were enhanced frontally 0.03mv/year for N1; 0.07 mv/year for P2 and reduction in amplitude of N2 ;0.11mv / year.

Bellis, Nicol and Kraus (2000) studied aimed at investigating the influence of age on cortical potentials. The neurophysiological response to speech stimuli in 3 groups of normal hearing individuals was carried out .The groups were divided into three groups based on age range .Group 1 (8-11 years),Group 2(20-25 years) and Group 3 (>55 years).The analysis of evoked potential reveled that group one and two had larger P1 –N1 evoked response amplitude. And also reported that P1-N1 evoked responses amplitude were larger in left hemisphere elicited than in right hemisphere. Thus authors reports that representation of the sound structure at cortical structures reflects the behavioral speech perception problems in elderly.

A mendo and Diaz (1998) conducted a study on age influence on N1-P2 complex elicited by non-target stimuli, similarly N2 and P3 elicited by target stimuli across 20 electrode sites. The study consisted of 20 to 86 years. Result reveled that with increase in age there was increase in amplitude linearly at Fz position.P2 amplitude decreased in younger subject, but remain unchanged in middle and older individuals. Latency of N2 and P3 increased linearly with advancing age.

Harkrider et al. (2005) study to evoke obligatory N1-P2 cortical responses in normal-hearing older adult population. Prolonged P2 latencies and larger N1 amplitudes were obtained for the unshaped stimuli in their older adults. However, P2 latencies were more similar to those of younger adults once spectral-shaping was introduced onto the stimuli. N1 amplitudes remained larger in older adults for the spectrally-shaped stimuli. The similar results are supported by other authors. Tremblay et al., (2002, 2003) examined the neuronal and perception of voice onset time that differs the perception of /b/ and /p/ in older individuals. Results revealed abnormal N1-P2 responses in older individuals.

The ageing not only has the effect on ability to process the temporal cues available in speech sounds. Tremblay, Piskosz and Souza (2002) investigated voice onset time a temporal that distinguishes voiced from voiceless sound .the neural representation of voice onset time. Recorded late latency response from 10 younger (10-32 years) and 10 older (61-79 years) adults were analyzed. The result reveals that older individuals have longer N1 and p2 latency compared to younger individuals. It suggested that speech perception difficulties that are faced by the older individuals.

Chapter 3

# Method

The present study conducted with an aim to investigate the functional relationship among cochlea, auditory brainstem and auditory cortex in younger and middle aged adults. To achieve the aim following method was carried out.

## 3.1 Participants

Two groups of participants were included in the study. Group 1 (younger adults) included of 15 subjects (15 ears) age ranged between 18 to 30 years (Mean age range =25.7) .Group 2 (Middle aged adults) included of 15 subjects (15 ears) aged ranged between 45 to 60 years (Mean age range =54.2)

### *3.1.1 Participant's selection criteria*

- All the participants had hearing sensitivity within normal limits (≤15 dBHL thresholds) at octave frequencies from 250 Hz to 8000 Hz for air conduction and from 250 Hz to 4000 Hz for bone conduction.
- All participants had „A" type tympanogram on immitance evaluation and presence of both ipsilateral as well as contralateral reflexes at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz indicative of normal middle ear functioning.
- Participants didn"t have any history/presence of relevant otological and neurological dysfunction and also didn"t have any exposure to occupational noise and usage of ototoxic drugs.
- None of the participants had history /presence of systematic medical illness (Diabetes/hypertension)

- All participants had presence of TEOAEs with a criteria of signal to noise ration of >6dB in baseline averaged response of TEOAES.
- Participants having SPIN scores of ≥60% at 0dB SNR were taken into the study.
- No evidences of any abnormality on click evoked auditory brainstem responses in all the participants indicative of absence of retro cochlear pathology.

**3.2 Instrumentation**

The following instruments were used to carry out the study.

1. The two channels calibrated diagnostic audiometer with TDH 39 earphones housed with MX/41 AR ear cushion and B 71 radio ear bone vibrator used to establish pure tone averages.
2. Tympanometric and acoustic reflex threshold (ART‟s) measures were obtained using calibrated GSI TYMPSTAR middle ear analyzer.
3. Otodynamics ILO-v6 used for recording TEOAE.
4. Auditory brainstem response and cortical evoked responses were recorded using Biologic Navigator Pro EP system.

**3.3 Stimulus Materials used for testing**

The Stimulus for Speech evoked auditory brainstem and auditory cortical response used synthesized speech syllable /da/ stimulus of 40 msec .The time domain waveform of the stimulus is depicted in the figure1.The stimulus was produced using KLATT synthesizer (Klatt, 1980), which is available with BIOLOGIC NAVIGATOR PRO instrument in the BIOMARK protocol. The fundamental frequency (F0) of the /da/ stimulus with voicing beginning at 5 ms and an onset noise burst during the first 10 msec linearly rises from 103 to 125 Hz .The first formant (F1) rises from 220 to 720 Hz, while the second formant (F2) decreases from 1700 to 1240 Hz over the duration of the stimulus. The third formant (F3) falls slightly from 2580 to 2500 Hz, while the fourth (F4) and fifth formants (F5) remain constant at 3600 and 4500 Hz, respectively.

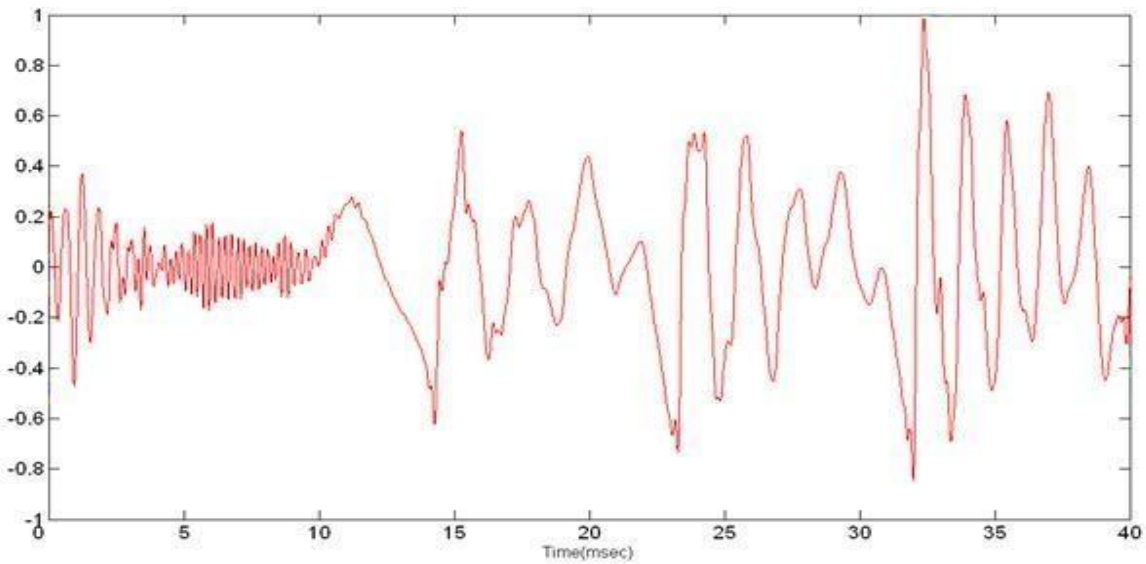


**Figure 3:1:** Time domain waveform of the 40 ms /da/ stimulus.

### 3.5 Test Environment

All the test measurement were carried out in a acoustically treated double room situation The ambient noise levels were within permissible limits according to ANSI(1996)

**3.6 Procedure**

The following procedure was carried out for both the groups.

*3.6.1 Pure tone audiometry*

Pure tone thresholds at octave frequencies from 250 Hz to 8000 Hz for air conduction and from 250 Hz to 4000 Hz for bone conduction thresholds were elicited using modified Hughson Westlake procedure (Carhart& Jerger, 1959)

*3.6.2 Immitance evaluation*

A standard 226 Hz probe tone tympanometry was carried out to establish the type of tympanogram. Acoustic reflexes thresholds of both ipsilateral and contralateral reflexes were measured at 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz.

*3.6.3 Oto acoustic emission*

The nonlinear TEOAE‟s were recorded. Subjects were made to sit comfortably on a chair in sound treated room. The ILO88 acoustic probe, fitted with a disposable plastic tip, was inserted into the patient‟s ear to obtain flat frequency stimulus response. After obtain good probe fit, standard click stgimulus having broad frequency spectrum between 1000 and 4000 Hz was delivered by the probe in the ear resulting in a 0.3 pascal peak stimulus (84 ± 3 dB pe SPL). On termination of the test the accumulated response displayed as waveform and frequency spectrum based on averaging method. The two averaged TEOAE waveforms of each memory buffer consists of 260 accepted click stimulus, were cross correlated automatically by the software to determine the reproducibility. Response were accepted with a SNR of +6 dB and with response reproducibilty of ≥ 80 %.

*3.6.4 Auditory evoked potential recording*

The participants were comfortably seated in a reclining chair with relaxed posture in order to minimize the artifacts. Electrode site was cleaned using skin preparatory gel and silver chloride electrodes were placed with conductive and adhere paste. Placements of the electrodes were based on 10-20 system. It was ensured that the impedance of the electrode site within 5 kΩ and inter electrode site within 2 kΩ. The convention vertical montage was used to record evoked potentials. Non inverting electrode on Cz, inverting and ground electrode on two mastoids (M1 & M2 or M2 & M1). Each recording was recorded twice in order to check for reliability and replicability. The stimulus was presented through ER 3A insert. All the recordings were done monoaurally i.e., for half of the participants right ear and other half of the participants left ear recording was done. Closed captioned animated movie was played while recording cortical potentials.

*3.6.4.1 Recording of speech evoked auditory brainstem responses*

The speech evoked auditory brainstem response was recorded in single channel, using 40 msec /da/ speech stimuli at 80 dB SPL. The stimulus was presented with alternating polarity, at 10.1 per second repetition rate through biologic insert earphones. The responses were recorded for 70 msec stimulus period along with 10 msec pre-stimulus period. The recorded responses were then amplified one lakh times and band pass filtered between 100 Hz to 3000 Hz. The responses were averaged for 2000 stimuli. The speech evoked ABR was twice to ensure the replicability of the response.

*3.6.4.2 Recording of Auditory Cortical evoked Response*

The speech evoked auditory late latency response was recorded in single channel, using 40 msec /da/ speech stimuli at 80 dBSPL. The stimulus was presented with alternating polarity, at 1.1 per second repetition rate through biologic insert earphones. The responses were recorded for 433 msec stimulus period along with 30 msec pre-stimulus period. The recorded response was then amplified fifty thousand times and band pass filtered between 1 Hz to 30 Hz. The responses were averaged for 200 stimuli. The speech evoked ABR was recorded twice to ensure the replicability of the response.

## 3.7 Data Analysis

### *3.7.1 Analysis of Oto-acoustic emission*

The presence of TEOAEs was accepted with a SNR of +6 dB .The averaged nonlinear TEOAEs were analyzed in terms of amplitude of frequencies from 1000Hz to 4000Hz.

### *3.7.2 The analysis of Speech evoked ABR*

Latency of wave V was measured for younger and middle aged individuals. Amplitude of fundamental frequency, first formant frequency and second formant frequency for younger and older individuals was also obtained.

To analyze the amplitude of F0,F1 and F2 Fast Fourier Transform (FFT) was done. The objective FFT analysis was done using a custom made program in the MATLAB software. According to Russo et al. (2004) the values of the fundamental frequency,first and second formant frequency values were expressed in terms of amplitude in the arbitrary units. As per the guidelines given earlier in studies (Cunningham et al., 2001; Johnson, Nicol, Zecker& Kraus, 2008; Russo et al., 2004)

.Fourier analysis was Performed to extract information regarding the coding of fundamental frequency, first formant frequency and second formant frequency on 11.4 - 40.6 msecepoch of the FFR which gives the information about the amount of activity occurred at these three frequencies. Activity occurred in the frequency range of the response corresponding to the fundamental frequency of the speech stimulus (103– 121 Hz), first formant frequencies of the stimulus (220-720 Hz) and second formant frequency was measured between 720 Hz – 1100 Hz for all the subjects for both young and middle aged individuals. For the analysis of the auditory evoked response from the subjects was required to be above the noise floor in order to be included in the analysis .Analysis was done A 2 ms on 2 ms off Hanning ramp applied to the waveform (this is done to prevent the frequency splattering during the Fourier analysis, Russo et al., 2004).The spectral magnitude of the pre stimulus period was compared with the response. Zero-padding was employed to increase the number of frequency points where spectral estimates were obtained. The responses were considered to be above the noise floor, if the magnitude of the F0 , F1 and F2 component of the FFR divided by that of the pre-stimulus period was greater than one.The raw amplitude value of the F0 , F1 and F2 frequency component of the response FFR were then noted. All the FFT analysis was done using a custom made program in the MATLAB software. All the parameters included for the FFT analysis here in the present study is based upon the previous studies conducted at Northwestern University (Russo et al., 2004; Wible et al., 2004; Dhar et al., 2009).

*3.7.3 Analysis of Speech evoked LLR*

The analysis of speech evoked LLR was done in terms of analyzing the latency for P1,N1 and P2 peaks and similarly amplitude f P1,N1 and P2 peaks of speech evoked LLR in both younger and middle aged adults.

.

Chapter 4

# Results

The present study aimed at investigating functional relationship among cochlea, auditory brainstem and auditory cortex in young and middle aged adults. To achieve aim of the study Speech in noise scores, Transient Oto acoustic emission, latency and amplitude of Speech evoked ABR and speech evoked LLR responses for /da / stimulus between the two groups were taken. FFR was done to analyze the strength of encoding of fundamental (Fo), formant frequency (F1, F2) of /da/ syllable in Speech evoked ABR.

The data from 30 subject (Younger adults group: 15, middle aged group: 15). All the participant had the presence of Speech evoked ABR and Speech evoked LLR responses. The data obtained for both the groups were subjected to statistical analysis. Following statistical analyses were carried out using SPSS Version 20.

- ❖ Descriptive statistics was carried out to find out the mean and standard deviation of TEOAE amplitude for both the groups
- ❖ Descriptive statistics was carried out to find out the mean and standard deviation of latency of wave V for speech evoked ABR for both the groups.
- ❖ Descriptive statistics was carried out to find out the mean and standard deviation of amplitude of F0,F1 and F2 for speech evoked ABR for both the groups.
- ❖ Descriptive statistics was carried out to find out the mean and standard deviation of latency and amplitude of P1, N1 and P2 peaks for both the groups.
- ❖ Repeated measure ANOVA with groups as within subject variable was done to find out a significant main effect of age on TEOAE amplitude.

- ❖ Repeated measure ANOVA with groups as within subject variable was done to find out a significant main effect of age on latency of Wave V and amplitude of F0, F1, and F2 of speech ABR.
- ❖ Repeated measure ANOVA with groups as within subject variable was done to find out a significant main effect of age on latency and amplitude of P1,N1 and P2 peaks.
- ❖ Multiple analyses of variance was done to compare the main effect of age on groups for TEOAE amplitude.
- ❖ Multiple analyses of variance was done to compare the main effect of age on Wave V and amplitude of F0, F1, and F2 for speech evoked ABR.
- ❖ Multiple analyses of variance was done to compare the main effect of age on latency and amplitude of P1, N1 and P2 peaks of Speech evoked LLR.
- ❖ Independent sample „t‟ test was done to compare the significant difference two groups for TEOAE amplitude.
- ❖ Independent sample „t‟ test was done to compare the significant difference two groups for latency of wave V and amplitude of F0,F1 ,and F2 for speech evoked ABR. .
- ❖ Independent Sample „t‟ test was done to compare the significant difference two groups for latency and amplitude of P1, N1 and P2 peaks of Speech evoked LLR.
- ❖ Pearson‟s correlation to find out the correlation among the TEOAEs amplitude, Wave V latency, amplitude of F0,F1 ,F2, of speech evoked ABR, amplitude and latency of P1,N1 and P2 peaks of Speech evoked LLR in younger adults group.

- ❖ Pearson‟s correlation to find out the correlation among the TEOAEs amplitude, Wave V latency, amplitude of F0,F1 ,F2, of speech evoked ABR, amplitude and latency of P1,N1 and P2 peaks of Speech evoked LLR in middle aged group.

**4.1 Effect of age on Transient evoked otoacoustic emissions**

Transient evoked otoacoustic emission was recorded for all the participants in both the groups. The transient evoked otoacoustic emission was found to be present for all the participants in both the groups. The amplitude of otoacoustic emission was calculated for both the groups. Descriptive statistics was done to find out the mean and standard deviation for the TEOAE amplitude for both the groups. Table-4.1 shows the mean and standard deviation of TEOAE amplitude for both the groups.

**Table 4.1** : Mean and Standard deviation of TEOAES amplitude in both groups.

| **Groups** | **Amplitude 1kHz (µv)** | | **Amplitude 1.5kHz (µv)** | | **Amplitude 2kHz (µv)** | | **Amplitude 3kHz (µv)** | | **Amplitude 4kHz (µv)** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **MEAN** | **SD** | **MEAN** | **SD** | **MEAN** | **SD** | **MEAN** | **SD** | **MEAN** | **SD** |
| **Young adults** | 9.833 | 4.94 | 13.15 | 6.70 | 11.88 | 5.14 | 10.55 | 5.05 | 8088 | 5.05 |
| **Middle aged** | 7.640 | 1.75 | 6.26 | 2.73 | 6.40 | 1.99 | 5.036 | 2.78 | 3.58 | 2.85 |

It can be seen from Table-4.1 that the mean amplitude of the TEOAE for all the frequencies were higher for the younger group compared to the middle aged group. It can also be seen that within the younger group the amplitude of TEOAE is higher for 1.5 kHz compared to other frequencies whereas in the middle aged group the amplitude is more for 1 KHz compared to the other frequencies. The same can be seen in figure-4.1

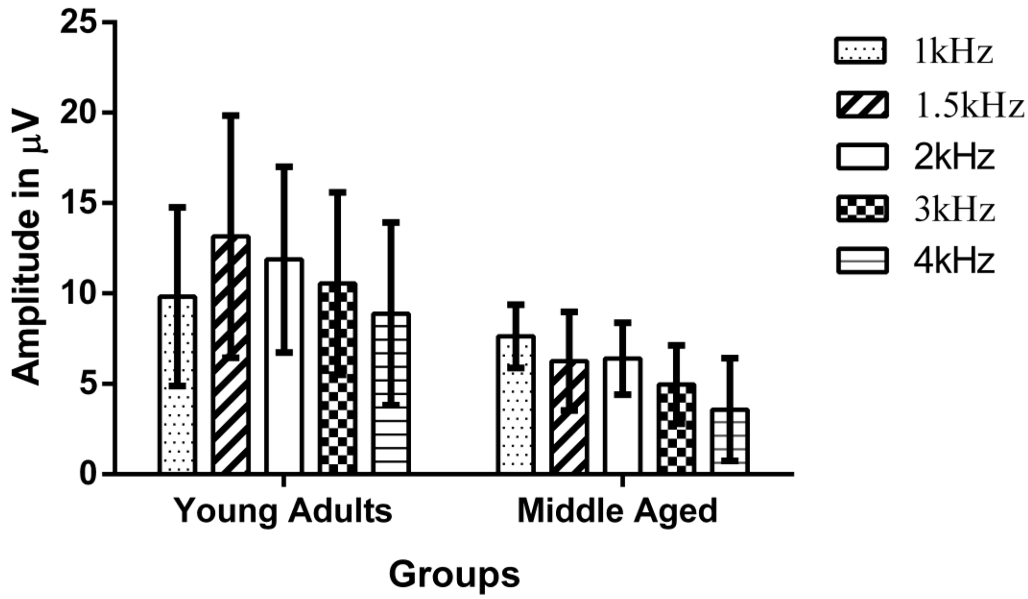


**Figure 4:1 :** Mean and Standard deviation of TEOAES amplitude in both groups.

As the age had an influence on TEOAE amplitude, a repeated measure ANOVA was administered to see the significant main effect of age and also significant interaction across variable on TEOAE amplitude. Repeated measure ANOVA analysis revealed a significant main effect of age for amplitude of TEOAEs [$F(4,112)=4.892, p<0.01$], Repeated measure ANOVA also revealed a significant main effect of groups on TEAOE amplitude [$F(1,28)=22.364, p<0.001$]. However, repeated measure ANOVA did not reveal any significant interaction between TEOAE amplitude and groups [$F(4,112)=1.980, p>0.05$].

Since the groups showed a main effect on OAE amplitude, Multivariate analysis of variance was done to see the age effect for OAE amplitude. Multivariate analysis of variance revealed significant main effect for TEOAE amplitude at 1.5 kHz [F(1,28)=13.562,p<0.01],2kHz[F(1,28)=14.838,p=0.01], 3kHz [F(1,28)=13.703,p<0.01], and 4 kHz [F(1,28)=12.519, p<0.001]. However, Multivariate analysis of variance no significant main effect of age on TEOAE amplitude at 1 kHz [ F (1,28)=2.624, p>0.05].

Further to understand the significant difference between two groups for TEOAE amplitude an Independent sample T test was done. Independent sample T test revealed significant difference between two groups for TEOAE amplitude at 1.5 kHz frequency [t(28) =3.683, p<0.01], 2 kHz frequency [t(28) =3.852, p<0.01], 3 kHz frequency [t (28) =3.769, p<0.0)] and 4kHz frequency[t (28) =3.538, p<0.01]. However, Independent sample t test revealed no significant difference at 1 kHz [t (28) =1.620, p>0.05].

**4.2 Effect of age on speech evoked on Speech evoked ABR**

Speech evoked ABR was recorded for all the participants in both the groups. The Speech evoked ABR was found to be present for all the participants in both the groups. The latency of wave V and amplitude of sustained portion (F0, F1 & F2) was calculated for both the groups. The following graph 4.2 and 4.3 represents the Speech evoked ABR grand average waveform containing both the transient and sustained response in younger and middle aged adults respectively.

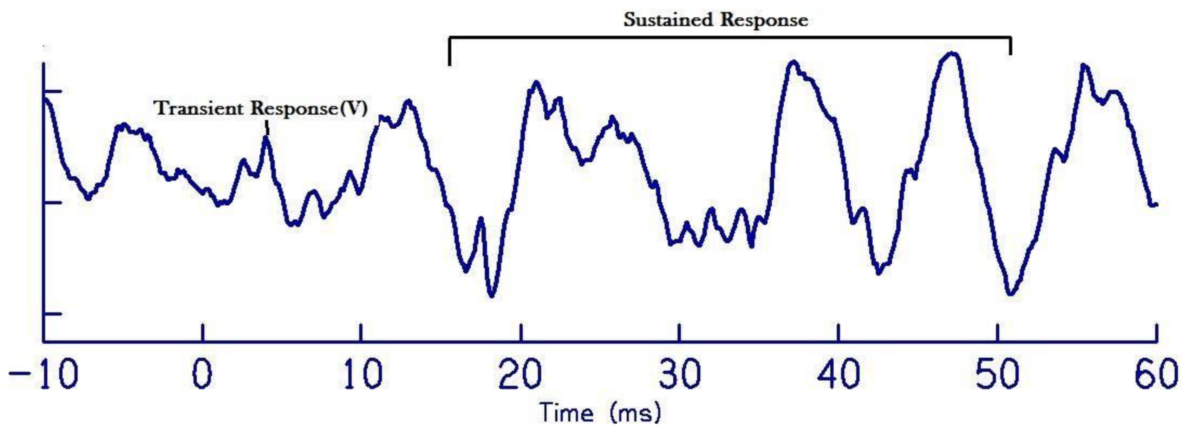


**Figure 4:2:** Grand average waveform of Speech evoked ABR in younger adults.

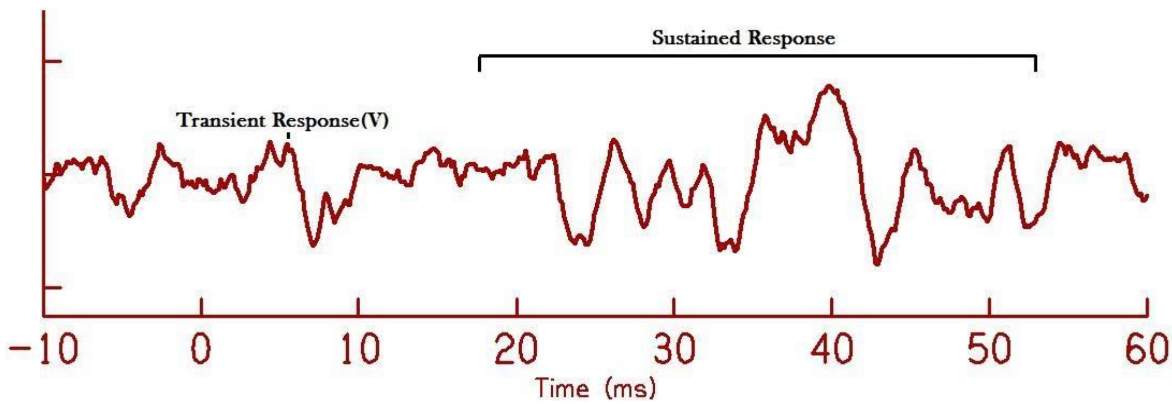


**Figure 4:3:** Grand average waveform of Speech evoked ABR in middle aged adults.

*4.2.1 Effect of age on speech evoked on wave V latency*

The latency of wave V was calculated for both the groups. Descriptive statistics was done to find out the mean and standard deviation for the wave V latency for both the groups. Table-4.2 shows the mean and standard deviation of wave V latency for both the groups.

**Table 4.2 :** Latency of wave v in young and middle aged individuals in both groups.

| Groups | Mean (msec) | Standard deviation |
|---|---|---|
| **Young adults** | 6.806 | 0.4891 |
| **Middle aged** | 7.090 | 0.842 |

It can be seen from Table-4.2 that the mean wave V latency was better for the younger group compared to the middle aged group. The same can be seen in figure-4.4

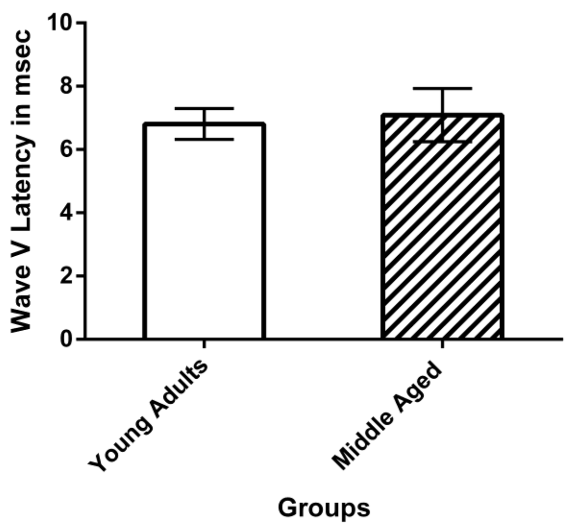


**Figure 4:4:** Latency of wave v in young and middle aged individuals in both groups.

As the age had an influence on wave V latency, a repeated measure ANOVA was administered to see the significant main effect of age and also significant interaction across variable on wave V latency. Repeated measure ANOVA analysis revealed a no significant main effect for wave V latency [$F(1,28)=2.91, p>0.05$] but Repeated measure

ANOVA revealed a significant main effect on groups for wave V latency [$F(1,28)=14.16$, $p<0.05$]. Repeated Measure also revealed significant interaction effect between wave V latency and groups [$F(1, 28)=16.265$, $p<0.05$].

Since the groups showed a main effect of age on wave V latency. Multivariate analysis of variance revealed significant main effect for wave V latency [$F(1, 28)=1.37$, $p>0.05$].

Further to understand the significant difference between two groups for wave V latency an Independent sample „t" test was done. Independent sample„t" test revealed no significant difference [$t(28)=-1.170, p>0.05$] between two groups .

*4.2.2 Effect of age on amplitude fundamental frequency (F0), first formant frequency (F1) and second formant frequency (F2)*

The amplitude of fundamental frequency (F0), first formant frequency (F1) and second formant frequency (F2) was calculated for both the groups. Representative waveforms of the spectral analysis for both groups are shown in figure 4.5 and 4.6 for younger and middle aged respectively.

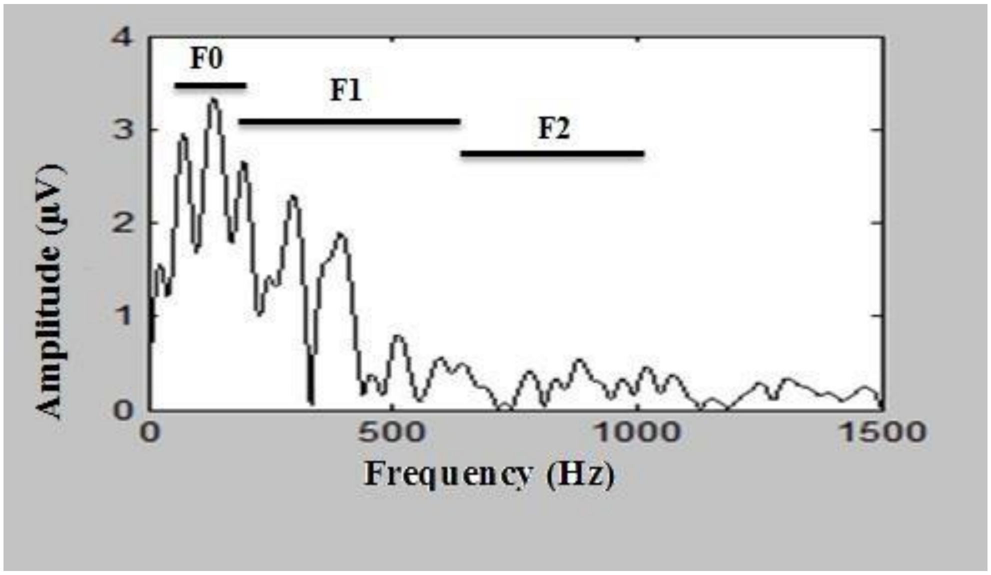


**Figure 4:5:** FFT analysis for younger group

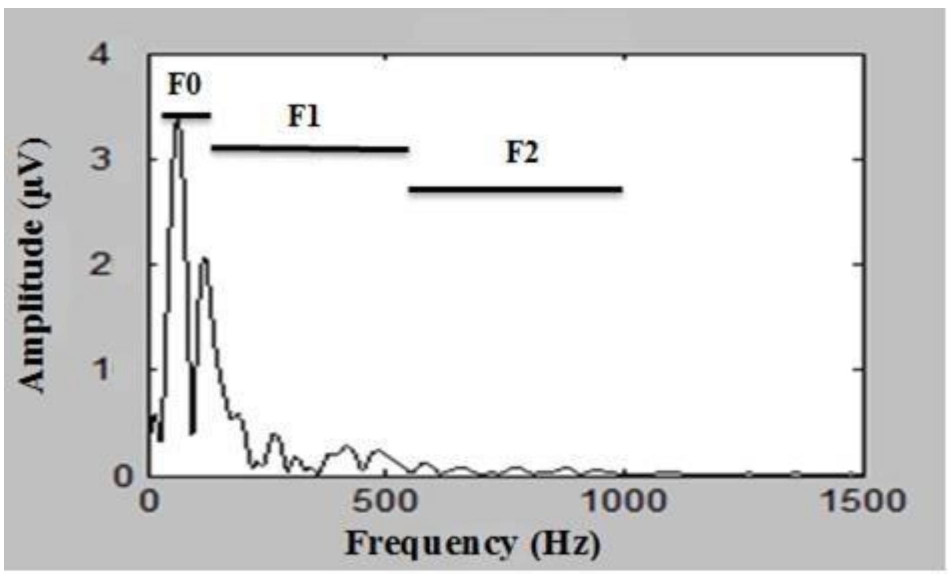


**Figure 4:6:** FFT analysis for middle aged group

Descriptive statistics was done to find out the mean and standard deviation for the fundamental frequency (F0), first formant frequency (F1) and second formant frequency (F2) for both the groups. Table-4.3 shows the mean and standard deviation of fundamental frequency (F0), first formant frequency (F1) and second formant frequency (F2) for both the groups.

**Table 4.3:** Mean and standard deviation of fundamental frequency (F0), first formant frequency (F1) and second formant frequency (F2)

| **Groups** | **Amplitude of F0** | | **Amplitude of F1** | | **Amplitude of F2** | |
|---|---|---|---|---|---|---|
| | **MEAN (µv)** | **MEAN (µv)** | **SD** | **MEAN (µv)** | **SD** | **MEAN (µv)** |
| **Young adults** | 11.546 | 1.12 | 0.427 | 0.376 | 0.103 | 1.12 |
| **Middle aged** | 4.859 | 0.513 | 0.103 | 0.315 | 0.114 | 0.513 |

It can be seen from Table-4.3 that the mean amplitude of fundamental frequency (F0), first formant frequency (F1) and second formant frequency (F2) higher for the younger group compared to the middle aged group. The same can be seen in figure-4.7 and 4.8

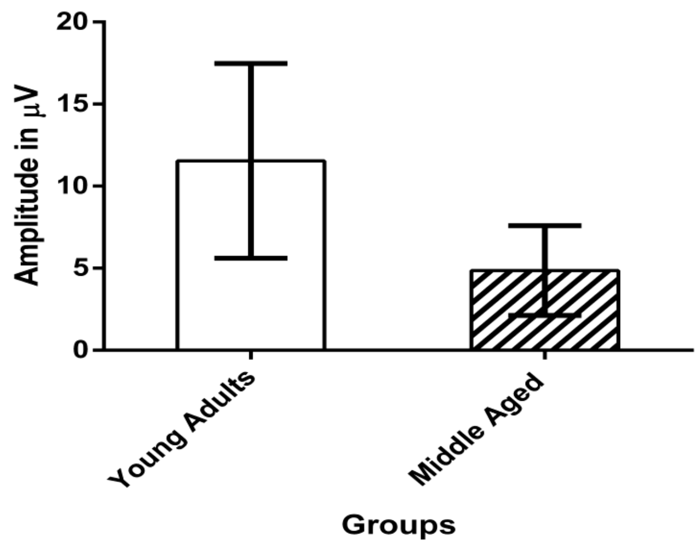


**Figure: 4:7:** Mean and standard deviation of fundamental frequency (F0) in both groups.

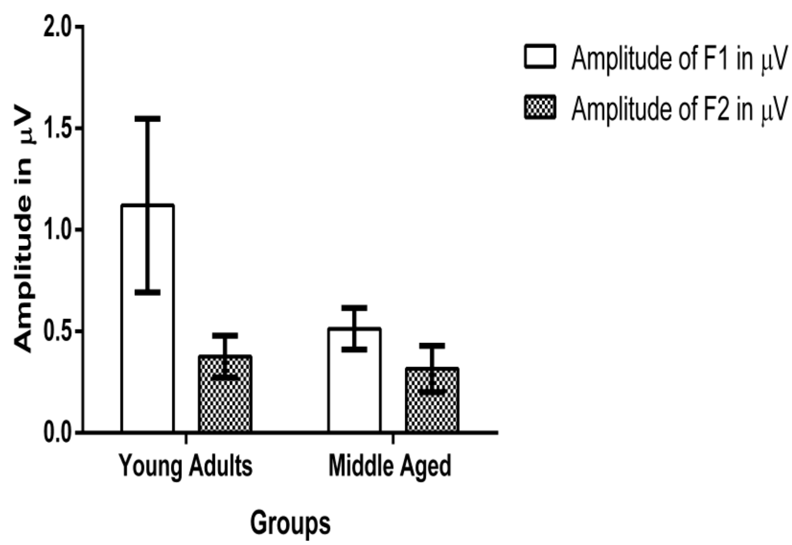


**Figure 4:8 :** Mean and standard deviation of first and second formant frequency (F1& F2) in both groups.

As the age had an influence on F0,F1 and F2 amplitude, a Repeated measure ANOVA was administered to see the significant main effect of age and also significant interaction F0,F1 and F2 amplitude and groups. Repeated measure ANOVA analysis revealed a significant main effect of age on amplitude of sustained responses[F(2,56)=81.943,p<0.001], repeated measure ANOVA also revealed a significant main effect of group of amplitude of sustained portion [F(1,28)=18.618,p<0.000]. However, Repeated measure ANOVA did not reveal any significant between amplitude of F0, F1 and F2 and groups [F(2,56)=14.039,p<0.001].

Since the groups showed a main effect on F0,F1 and F2 amplitude, Multivariate analysis of variance was done to see the age effect on amplitude of F0,F1 and F2 amplitude. Multivariate analysis of variance revealed significant main effect of age on F0 [F(1,28)=15.521,p<0.001]. MANOVA also revealed significant main effect of age on F1 amplitude [F(1,28)=28.816,p<0.001] . However, Multivariate analysis of variance revealed no significant main effect of age on F2 amplitude [F(1,28)=2.348, p>0.05].

Further to understand the significant difference between two groups for F0, F1 and F2 amplitude, an Independent sample „t" test was done. Independent sample „t" test revealed significant difference between two groups for F0 [t(28)=3.940, p<0.001], F1 [t(28)=5.368, p<0.001], and but Independent sample „t" test failed to show a significance difference for F2 formant frequency. [t(28)=1.532, p>0.05] between the two groups.

**4.3 Effect of age on speech evoked on Speech evoked LLR**

Long latency response (LLR) for speech stimulus such as /da/ were present in all the individuals in both groups .Latency and amplitude of P1,N1 and P2 peaks were calculated for both groups.The following graph 4.9 and 4.10 represents the Speech evoked ABR waveform containing both the transient and sustained response in younger and middle aged adults respectively.


**Figure 4:9:** Grand average waveform of Speech evoked LLR in younger adults.


**Figure 4:10:** Grand average waveform of Speech evoked LLR in middle aged group.

*4.3.1 Effect of age on latency and amplitude of P1,N1 and P2 peaks*

Descriptive statistics was done to find out the mean and standard deviation for the P1,N1 and P2 latencies for both the groups. Table-4.4 shows the mean and standard deviation P1,N1 and P2 latencies for both the groups.

**Table: 4.4** Mean and standard deviation of Latency of P1, N1 and P2 in both groups.

| Groups | Latency of P1 | | Latency of N1 | | Latency of P2 | |
|---|---|---|---|---|---|---|
| | **MEAN (ms)** | **SD** | **MEAN (ms)** | **SD** | **MEAN (ms)** | **SD** |
| **Young adults** | 52.97 | 9.815 | 108.269 | 23.642 | 170.04 | 36.689 |
| **Middle aged** | 66.024 | 8.913 | 121.45 | 12.95 | 187.74 | 22.320 |

It can be seen from Table-4.4 that middle-aged individuals have prolonged latency compared to the younger individual at all the peaks. The same can be seen in figure-4.11

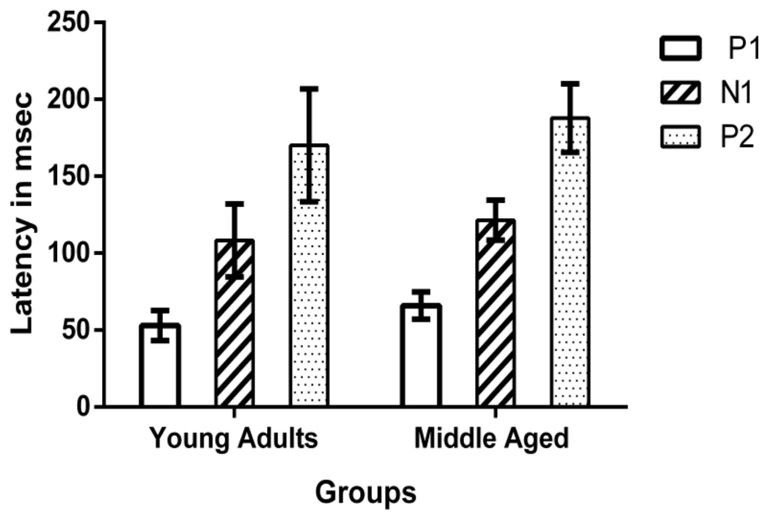


**Figure 4:11:** Mean and standard deviation of Latency of P1,N1 and P2 in both groups.

As the age had an influence on latency of P1, N1 and P2, a Repeated measure ANOVA was administered to see the significant main effect of age and also significant interaction between latency of P1, N1 and P2 and groups. Repeated measure ANOVA analysis revealed significant main effect of age on LLR latency of [F (1,28)=1296.017, p<0.001], Repeated measure ANOVA also revealed a significant main effect of age on the groups [F(1,28)=5.644, p<0.05]. However, Repeated measure ANOVA failed to show any significant interaction between group and the LLR latency [F (1, 28) =3.861, p>0.05].

Since the groups showed a main effect on latency of P1, N1 and P2, Multivariate analysis of variance was done to see the age effect on latency of P1, N1 and P2. MANOVA revealed significant main effect of age on P1 latency [F (1, 28) =14.533, p<0.05]. However MANOVA did not show any significant main effect of age on N1 latency [F(1,28)=3.589, p>0.05], and P2 peaks [F(1,28)=2.529, p>0.05].

Additional to understand the significant difference between two groups for latency of P1, N1 and P2 Independent sample„t" test was done. Independent sample„t" test revealed significant difference for P1 latency [t(28)=3.812, p<0.05] and no significance for N1 [t(28)=1.895, p>0.05] and P2 [t(28)=1.590, p>0.05) latencies.

*4.3.2 Effect of age on amplitude of P1, N1 & P2 peaks*

Descriptive statistics was done to find out the mean and standard deviation for the P1, N1 and P2 amplitude for both the groups. Table-4.5 shows the mean and standard deviation P1, N1 and P2 l amplitude for both the groups.

**Table: 4.5** Mean and standard deviation of amplitude of P1, N1 and P2 in both groups.

| Groups | Amplitude of P1 | | Amplitude of N1 | | Amplitude of P2 | |
|---|---|---|---|---|---|---|
| | **MEAN (µv)** | **SD** | **MEAN (µv)** | **SD** | **MEAN (µv)** | **SD** |
| **Young adults** | 1.326 | 0.7755 | 1.878 | 1.03 | 1.89 | 1.67 |
| **Middle aged** | 1.1773 | 1.311 | 2.65 | 0.88 | 1.25 | 1.02 |

It can be seen from Table-4.5 that the mean amplitude of P1and P2 was higher for the younger group compared to the middle aged group and lesser for N1. It can also be seen that amplitude of P1 is lesser for compared to other peaks in both groups. The same can be seen in figure-4.12

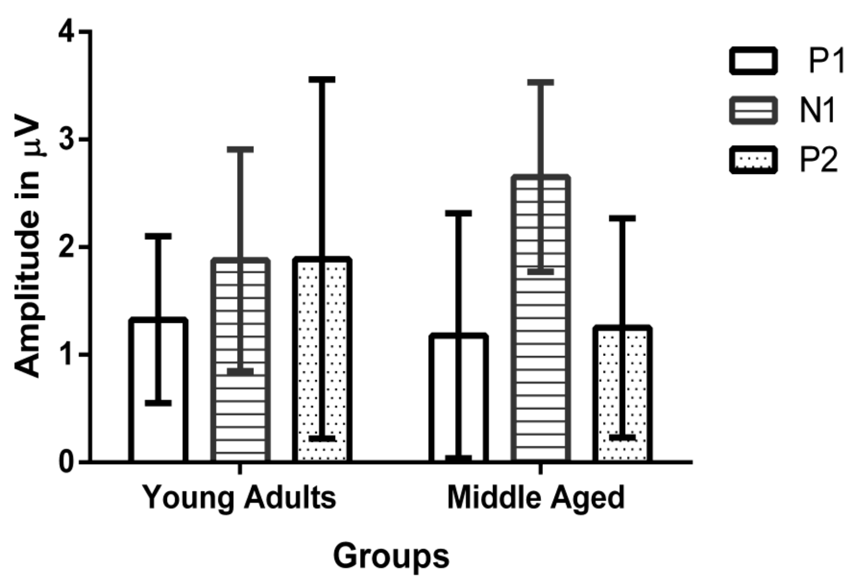


**Figure 4:12:** Mean and standard deviation of amplitude of P1,N1 and P2 in both groups.

As the age had an influence on amplitude of P1, N1 and P2, Repeated measure ANOVA was administered to see the significant main effect of age and also significant interaction across variable on amplitude of P1, N1 and P2. Repeated measure ANOVA analysis revealed significant main effect for LLR amplitude [$F(1,28)=1296.017$, $p<0.001$], Repeated measure ANOVA also revealed a significant main effect of group on LLR amplitude [$F(1,28)=5.644, p<0.05$] . However there was no significance interaction between group and the amplitude of LLR peaks [$F(1,28)=3.861$, $p>0.05$].

Since the groups showed a main effect on amplitude of P1, N1 and P2, Multivariate analysis of variance was done to see the age effect on amplitude of P1, N1 and P2. MANOVA revealed significant main effect of age on N1 amplitude [$F(1,28)=4.808$, $p<0.05$] and no significant main effect of age on amplitude of P1 and P2 peaks [$F(1,28)=0.175$, $p>0.05$], [$F(1,28)=1.425$, $p>0.05$] respectively.

Further to understand the significant difference between two groups for amplitude of P1, N1 and P2 Independent sample „t" test was done. Independent sample „t" test revealed significant difference for N1 [$t (28) =-2.193$, $p<0.05$] and no significance for P1 [$t (28) =0.418$, $p>0.05$] and P2 [$t(28)=1.194$, $p>0.05$).

### 4.4 Correlation between TEOAEs, speech evoked ABR and Speech evoked LLR in both younger and middle aged groups

#### *4.4.1 Correlation between TEOAEs amplitude, wave V latency and amplitude of F0,F1 and F2 ,amplitude and latency of P1, N1,P2 peaks in younger group.*

Pearson"s correlation analysis was done to find out the correlation of TEOAEs amplitude, Wave V latency, amplitude of F0, F1, F2, of speech evoked ABR and latency, amplitude of P1,N1 ,P2 of speech evoked LLR in younger group. The correlation of TEOAEs amplitude and Wave V latency, amplitude of F0, F1, F2, of speech evoked ABR and latency, amplitude of P1,N1 ,P2 of speech evoked LLR in younger group are given table 4.6 below.

From the table 4.6 it can be seen that there was no correlation between any of the audio logical test except for, TEOAE amplitude at 2k Hz and 3 kHz with P1 amplitude, 3 kHz with first and second formant frequency amplitude and also first formant frequency with P1 amplitude in younger adults.

**Table. 4.6:** Pearson Correlation test for Correlation in younger participants

| | 1k | 1.5 | 2k | 3k | 4k | Wave V | F0 | F1 | F2 | P1-L | N1-L | P2-L | P1-A | N1-A | P2-A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1k** | | | | | | r =0.18 | r =0.34 | r =0.194 | r =0.91 | r =-0.117 | r =-0.250 | r =-0.494 | r =-0.40 | r =-0.28 | r =-0.22 |
| **1.5k** | | | | | | r=-0.061 | r=0.458 | r=0.386 | r=0.087 | r=-0.205 | r=0.083 | r=-0.255 | r=-0.396 | r=-0.074 | r=0.023 |
| **2k** | | | | | | r=0.075 | r=0.341 | r=0.417 | r=0.140 | r=-0.132 | r=-0.060 | r=-0.450 | **r=0.822**** | r=0.031 | r=-0.278 |
| **3k** | | | | | | r=0.330 | r=0.030 | **r=0.522*** | **r=0.52*** | r=-0.001 | r=-0.060 | r=-0.057 | **r=-0.650**** | r=-0.909 | r=-0.271 |
| **4k** | | | | | | r= 0.137 | r=0.208 | r=0.422 | r=0.427 | r=0.168 | r=0.223 | r=-0.062 | r=-0.208 | r=0.123 | r=0.079 |
| **Wave V** | | | | | | | | | | r=0.100 | r=0.089 | r=0.055 | r=-0.168 | r=-0.082 | r=-0.505 |
| **F0** | | | | | | | | | | r=-0.357 | r=-0.335 | r=-0.376 | r=-0.029 | r=-0.108 | r=-0.121 |
| **F1** | | | | | | | | | | r=0.254 | r=0.030 | r=-0.085 | **r=-0.595*** | r=-0.255 | r=-0.191 |
| **F2** | | | | | | | | | | r=0.490 | r=0.018 | r=0.151 | r=-0.324 | r=-0.247 | r=-0.348 |
| **P1-L** | | | | | | | | | | | | | r=0.230 | r=0.044 | r=0.024 |
| **N1-L** | | | | | | | | | | | | | r=0..115 | r=0.112 | r=0.245 |
| **P2-L** | | | | | | | | | | | | | r=0.475 | r=0.223 | r=0.441 |
| **P1-A** | | | | | | | | | | | | | | | |
| **N1-A** | | | | | | | | | | | | | | | |
| **P2-A** | | | | | | | | | | | | | | | |

**4.4.2** *Correlation between TEOAEs amplitude, wave V latency and amplitude of F0,F1 and F2 ,amplitude and latency of P1, N1,P2 peaks in middle aged group.*

Pearson"s correlation analysis was done to find out the correlation of TEOAEs amplitude, Wave V latency, amplitude of F0, F1, F2, of speech evoked ABR and latency, amplitude of P1,N1 ,P2 of speech evoked LLR in middle aged group. The correlation of TEOAEs amplitude and Wave V latency, amplitude of F0, F1, F2, of speech evoked ABR and latency, amplitude of P1,N1 ,P2 of speech evoked LLR in middle aged group are given table 4.7 below.

From the table 4.7 it can be seen that there was no correlation between any of the audio logical test except for TEOAE amplitude at 1 kHz with F0 and 4 k Hz with N1 latency . There was also correlation of F1 and F2 with P1 amplitude in middle aged group.

**Table. 4.7:** Pearson Correlation test for Correlation in middle aged participants

| | **1k** | **1.5** | **2k** | **3k** | **4k** | **Wave V** | **F0** | **F1** | **F2** | **P1-L** | **N1-L** | **P2-L** | **P1-A** | **N1-A** | **P2-A** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1k** | | | | | | r =0.121 | **r =0.644**** | r=0.110 | r =0.300 | r =-0.230 | r =-0.429 | r =-0.212 | r =0.268 | r =-0.142 | r =-0.369 |
| **1.5k** | | | | | | r=-0.197 | r=0.111 | r=0.105 | r=-0.009 | r=-0.388 | r=-0.377 | r=-0.005 | r=-0.332 | r=0.168 | r=-0.075 |
| **2k** | | | | | | r=-0.412 | r=0.312 | r=0.283 | r=-0.228 | r=0.310 | r=-0.072 | r=0.177 | r=0.075 | r=-0.146 | r=-0.485 |
| **3k** | | | | | | r=0.089 | r=0.082 | r=0.258 | r=0.110 | r=0.172 | r=0.034 | r=0.175 | r=-0.046 | r=0.151 | r=-0.170 |
| **4k** | | | | | | r=0.469 | r=-0.212 | r=0.121 | r=-0.348 | r=0.449 | **r=-0.550*** | r=0.015 | r=-0.360 | r=-0.366 | r=-0.150 |
| **Wave V** | | | | | | | | | | r=-0.201 | r=-0.318 | r=0.054 | r=-0.287 | r=-0.049 | r=-0.007 |
| **F0** | | | | | | | | | | r=-0.374 | r=0.31 | r=0.177 | r=0.265 | r=0.256 | r=-0.367 |
| **F1** | | | | | | | | | | r=-0.048 | r=0.193 | r=0.148 | **r=0.310*** | r=0.297 | r=-0.305 |
| **F2** | | | | | | | | | | r=-0.313 | r=0.116 | r=-0.180 | **r=0.543*** | r=0.461 | r=-0.030 |
| **P1-L** | | | | | | | | | | | | | r=0.089 | r=-0.146 | r=0.109 |
| **N1-L** | | | | | | | | | | | | | r=0.144 | r=0.309 | r=0.256 |
| **P2-L** | | | | | | | | | | | | | r=-0.42 | r=-0.108 | r=-0.054 |
| **P1-A** | | | | | | | | | | | | | | | |
| **N1-A** | | | | | | | | | | | | | | | |
| **P2-A** | | | | | | | | | | | | | | | |

To summarize the results of the present study revealed reduction in TEOAE amplitude from 1.5 kHz to 4 k Hz and there was no statistical significant difference in amplitude of TEOAE at 1 kHz between middle aged group and younger adults. The wave V showed a prolongation in latency in middle aged adults than that of the younger, though it was not significantly significant. The amplitude of F0,F1 and F2 was higher in younger adults than middle aged individual however there was no statically significant difference for F2 amplitude between the two groups. The delayed latencies were noticed in P1, N1 and P2 peaks nevertheless only P1 latency showed the significant difference. The amplitude of P1, N1 and P2 peaks indicated larger amplitude for N1 peak, although P1 and P2 failed to show the statically significant difference in amplitude between younger and middle aged groups. The study did not show correlation among the audio logical test. Although correlation for few parameters were obtained in each group.

Chapter 5

# Discussion

The present study was conducted with an aim to investigate the functional relationship among cochlea, auditory brainstem and auditory cortex in young and middle aged adults. The study was carried out with evidences using Transient Oto acoustic emission, Speech evoked auditory brainstem response and Speech evoked auditory late latency response in both groups.

## 5.1 Effect of age on Transient evoked otoacoustic emissions

*The amplitude of Transient Oto acoustic emission (TEOAEs) in younger group was higher when compared to that of middle aged group form 1.5 k Hz to 4 kHz ,however no statistical significant difference was found at 1 kHz. TEOAEs amplitude in younger group was higher for 1.5 kHz compared to other frequencies whereas in the middle aged group the amplitude is more for 1 kHz compared to the other frequencies.*

Present study is in agreement with earlier studies which reported the reduction in amplitude of evoked acoustic emission with advancement in ageing. A study done by Bertoli and Probst (1997) done thequantitative and qualitative changes that occur in transient-evoked otoacoustic emissions (TEOAEs) in 201 subjects aged 50 years and older. The result revealed that the overall lower amplitudes of TEOAEs. Similarly a study done by Quaranta ,Debole and Girolamo (2001 )studied the effect of ageing on TEOAES on five age groups: 20-34 years, 35-44 years, 45-54 years , 55-64 years and 65-78 years. They reported that mean TEOAE amplitude decreased with age, and linear regression analysis showed a significant negative correlation between age and TEOAE amplitude.

Roberta, Oliveira and Fernandes(2009)also investigated influence of age on TEOAES in 75 adult subjects group divided into: group 1 (20 - 30 years), group 2 (30 - 40 years), group 3 (40 - 50 years), group 4 (50 – 6 0 years), and group 5 (over 60 years). It revealed a statistically significant difference in the result values of TEOAEs in group 1 and 4 participants.

In contrast Karzon, Garcia, Peterein, and Gates (1994) obtained OAEs in 129 ears of 71 older participants (age 56-93 year) and in 16 ears of eight young adults (age 19-26 yr) with normal pure-tone thresholds (PTTs). The OAES were obtained in both groups. Result reveled that amplitudes of OAEs did not decrease significantly with age, when matched for PTTs. Similarly Strouse et al. and Dorn et al (2001) demonstrated that when the degree of peripheral hearing loss is sufficiently controlled, advanced age has no direct effect on acoustic emission measures.

This reduction in amplitude in could be due to the intrinsic aging of the auditory system. The inner ear associated with aging can be affected in many ways. The organ of corti is the structure most susceptible to age related histopathologic changes (Schuknect, 1993). Both types of hair cells undergoes degenerative changes in the basal turn of the cochlea with apical and mid cochlear involvement of the outer hair cells as well (Willot, 1991). The decrease in the hair cells population is greatest in persons over 70 years of age and is most pronounced for outer hair cells. That is, hair cell population is less in older adults, especially for outer hair cells. However, there is significant reduction in the outer hair cell population in the mid age itself. The population of outer hair cells reduces to 78% in the age between 50-60 years. Loss of inner hair cells and outer hair cells have been reported after 45 years of age (Engstorm et al. 1987), whereas for the subjects aged more than 60 years the degeneration was widespread along all the cochlear turns (Scholtz et al. 2001). As we know that otoacoustic emission reflects the functioning of the outer hair cells, these changes in outer hair cells due to aging reflects reduced functions and hence a lower amplitude of TEOAE in middle aged participants.

**5.2 Effect of age on speech evoked on Speech evoked ABR**

*5.2.1 Effect of age on speech evoked on wave V latency*

*The analysis of wave V latency reveled no significant differences in latency of wave V between younger and middle aged groups.*

The wave V of speech evoked ABR is similar to the click evoked ABR and reflects the synchronized neural responses to speech stimulus. The present study in accordance studies which have reported that minimal or no effect of advancing age on ABR latencies in middle aged group (45-60 years) (McClelland & McCrea 1979; Otto &McCandless 1982; Jerger& Johnson 1988; Anias et al. 2004). Otto and McCandless (1982) associated ABR latencies in young and older participants with similar degrees of high-frequency hearing loss. No differences were found between groups. Beagley and Sheldrake (1978) did not find latency deviations in older adults with normal hearing. Similarly Rowe (1978) described that all ABR waves had no differences in latencies in older adults (51–60 years old) compared to young adults (17–33 years old). Gates, Feeney & Mills (2008) studied on 241 subjects also revealed the no differences in wave V latency between younger and older participants.

In contrast Clinard and Tremblay (2010) presented results from a study, investigating the ABR in response to the same 40-msec synthetic /da/ stimuli in three groups of adults: older, middle, and younger (N=32, age range 22 to 77 yrs). Their subjects revealed significant latency delays and decreased amplitudes for the transient onset and offset components of the ABR with advancing age. Clark, Anderson, Hittner & Kraus (2012) evaluated 170msec /da/ stimulus. ABR in older and younger participants in the age range of 45-65 years and 18 to 32 years respectively. All the participants in both the groups had normal hearing sensitivity. They revealed that the older participants had significant latency delay for wave V and for the waves elicited by transition portion of the stimuli. Vander-Werff and Burns (2011) reported that latency of wave V, wave F and wave O was significantly larger in older participants compared to the younger participants.

The no differences in wave V latency between younger and middle aged could be due to different age groups studied in these studies and also the different amount of hearing sensitivity of the participants in these studies. In many studies of presbyacusis, hearing levels of young and older participants are not always closely matched, making it difficult to determine if aging effects could be a result of threshold changes between groups. Stimuli are regularly presented at high sensation levels (SLs) to overcome variations in hearing levels between young and older groups (Allison et al., 1983, 1984), but such methods can lead to misunderstanding of results. In others, solitary certain frequencies have been matched between groups in the hearing sensitivity. In the present study all the participants had normal hearing sensitivity and hence it is assumed that in individuals with normal hearing among the aged group may not have much anatomical differences compared to the younger population.

*5.2.2 Effect of age on amplitude fundamental frequency (F0), first formant frequency (F1) and second formant frequency (F2)*

*The present study revealed that the reduction in amplitude of sustained response of F0, F1 and F2 formant frequencies in middle aged group compared to the younger group. However there no significant difference in second formant frequency.*

The study is in supporting to previous studies in reporting of significant reduction of F0, F1 in the middle aged group (>50 years).Anderson et al.(2012) reported the significant reduction in amplitude of F0 in older individuals with normal hearing sensitivity when compared to the younger group. Similarly study by Anderson et al.(2011) studied the coding of F0 in 28 participants with age range of (60-73 years) who had a elevated haring threshold .The study reported that reduction in amplitude of F0 with increase in age. However the present contained all the participants with normal hearing threshold in both the groups.

Clinard et al (2010) also reported the reduction in F0 encoding below 500 Hz in older individuals, similarly study by Clinard, Tremblay and Krishnan (2010) reported decline in encoding of F0 below 1000 Hz. From these study it can be inferences that increase in difference limen for frequency, indicates the possible decline in encoding of pitch of the stimulus in older individuals.

This significant reduction in amplitude of F0 in middle aged could be due to the reduced phase locking ability in these individuals. This also could be due to changes in neural synchrony of the peripheral auditory nerves (Clinard et al .2010).These alteration in neural synchrony may arises due to age related variation in metabolic activity of the cochlea or may be due to the reduction in number of auditory nuclei (Mills et al. 2006). These reduction in ability of inner hair cells may leads to the damage to synapse between inner hair cells and the auditory nerve (Moser et al. 2006 ).

The reduction in amplitude could also be due to the decrease in GABA inhibition. This reduction in GABA may lead to the temporal processing at the brainstem level (Casparyet al.2005) which mainly help in encoding of the acoustic feature of the stimulus. It has been reported that reduction in GABA neuro transmitters occurs after 40 years of age (Arnesen 1982;Hinjosa&Nelso , 2011)

The study reported by Hornickel et al. (2009), who recorded the response in 23 adults using a 60-msec /ba/ stimulus. Clinard and Tremblay (2010) and Clinard et al (2010) have reported evidence of weaker neural representation of frequency in older adults in the following response for both the sustained portion of the S-ABR and in response to simple speech stimuli. Even mild peripheral hearing loss seems to further reduce these following responses. Age-related changes in perceptual measures involving processing of *F*0 differences (Lam & Sanchez 2007; He et al. 2008; Clinard et al. 2010; Souza et al. 2011) and in a frequency discrimination task using cortical evoked potentials (Harris et al. 2008) support the idea of decreased neurophysiological representation of frequency in older adults.

*One of the most interesting finding in the present study was that even though the transient responses does not show the any age related changes, the encoding of F0 and F1 shows an age related deficit.*

This is an interesting finding in the present study, as the earlier studies reporting the reduced amplitude of F0 and F1 have always reported a delay in wave V latency (Clinard& Tremblay, 2010; Clinard et al. 2010). At present it is difficult to define this finding, with more studies in this area with more number of participants will throw light on this.

**5.3 Effect of age on speech evoked on Speech evoked LLR**

*The results of the study revealed that prolongation of latencies and reduction in amplitude of all the peaks in (P1, N1 and P2 ) speech evoked auditory late latency response (LLR). However the result showed the significant difference of prolonged latency of P1 latency and increased N1 amplitude of Speech LLR in middle aged individual.*

Earlier studies employing LLR in older participants have reported prolongation of N1 and P2 response latencies in older participants compared to the younger participants (Lister et al. 2011). Therefore, longer N1 and P2 latencies in older individuals compared to younger adults. Several authors have suggested age-related decrease in synchronous firing among the neural ensembles that generate N1 and P2components (Walton et al. 1998, 2002; Walker et al. 2008). Iragui, Kutas, Mitchiner and Hillyard (1993) also recorded auditory event related potentials in 71 healthy individuals between 18 to 82 years of age. The peak latencies of both the N1 and p2 component were slightly but significantly delayed with age. Also Goodin, Squires, Henderson and Starr (1978) reported increasing age results in a decrease in evoked potentials amplitude and increase in latency of both N1 and P2 cortical evoked potentials. This was based on results of 20 young and 20 elderly healthy individuals with normal hearing.

However, in the present study, only the latency of P1 peak was prolonged compared to the N1 and P2 in middle aged adults. Some of the previous study have reported P1 to be a biomarker for measurment of auditory system development in children with sensorineural hearing loss and auditory neuropathy(Campbell, Cardon, &Anu Sharma 2011). Another study by Thabet and said (2012 ) also reported the importance of P1 latency as a clinical utility in extent to which the central auditory pathways may have helped from amplification or implantation by reflecting the developmental trajectory for maturation of a given patient‟s central auditory system over the course of the treatment.

The result from above studies conclude that normal P1 outcomes in these studies assisted as a confirmation that the auditory cortex was being adequately stimulated and indicated inadequate auditory stimulation that led to abnormal auditory central pathway maturation. Thus, from the result of the present study it can be concluded that probably P1 can be used to know the central auditory degeneration in older population. The delay in latency of P1in older participants might indicate an inadequate stimulation of the auditory cortical system in these participants and thus a significant delay in latency was obtained.

Also, the amplitude of N1 was higher in the middle aged participants compared to the younger participants. The current study is in correlation with study by Amenedo and Diaz (1999) who reported enhanced N1 peak amplitude in older adults compared to younger adults. Whereas several studies indicated the age-related differences in the waveform of auditory evoked N1 and P2 components during selective attention tasks have shown inconsistent findings.

In contrast others do not find such differences (Brown et al. 1983; Picton et al. 1984; Barrett et al. 1987; Woods 1992; Iragui et al. 1993). The same inconsistency can be found concerning the P2 component. Whereas some authors found increased peak amplitudes in older adults (Anderer et al. 1998; Friedman et al. 1993; Pfefferbaum et al. 1984).

Additionally, Pfefferbaum et al. (1984) measured enhanced N1 amplitude in the explicit speech task, as compared to the non speech task in older groups. This could be due to the N1 amplitude in humans marks the transition zone between perceptual processes partly driven by stimulus characteristics and partly affected by cognitive operations. It is often associated with cognitive functions such as stimulus encoding and the formation of a trace in the sensory memory (Picton 1987; Posner & Driver 1992). Explicitly focusing on specific characteristics of the paradigm, namely, speech stimuli, may lead to an increased neural responsiveness and therefore to stronger activation when processing the attended stimulus. The present observation of stronger N1 amplitudes in older adults versus younger group could be interpreted as a compensatory mechanism in the aging brain. By virtue of the recruitment of additional neurons, middle aged maintains their potential synchronous neural firing.

**5.4 Correlation between TEOAEs amplitude, wave V latency and amplitude of F0,F1 and F2 ,amplitude and latency of P1, N1,P2 peaks in younger and middle aged group.**

*The present study revealed there was no correlation between any of the audio logical test except for, TEOAE amplitude at 2 kHz and 3 kHz with P1 amplitude, 3 kHz with first and second formant frequency amplitude and also first formant frequency with P1 amplitude in younger adults and TEOAE amplitude at 1 kHz with F0 and 4 k Hz with N1 latency. There was also correlation of F1 and F2 with P1 amplitude in middle aged group.*

The decline in otoacoustic emission could be evidence for peripheral changes that are occurring the middle aged individuals. Examination has demonstrated that atrophy of the striavascularis was the main component in the auditory periphery with loss of hair cells as an infrequent and sporadic finding (Mills, et al., 1990). Strial atrophy is well recognized in aged human temporal bones (Schuknecht, et al. 1974); the loss of outer hair cells commonly seen in the same material raises the issue of unrecognized noise damage as a confounding factor rather than a primarypart of auditory aging.

The pathology of aging in the central auditory system is poorly delineated for corpus callosum atrophy (Chmiel & Jerger, 1996). This indicates that, middle aged individuals are at the strting phase of central auditory processing dysfunction, over and above the changes in peripheral input, is a major component over the age of 50 yrs. The possibility is raised of different mechanisms at work in the "aging" process with the auditory processes served by the higher cortical and association cortex levels deteriorating with age faster than the peripheral auditory mechanism.

Tremblay et al. (2004) revealed that older individuals exhibited delays in N1 and P2 latency compared with young adults for speech stimuli but not for a 1000 Hz tone .Thus, the lack of an age effect for the late potentials in the present study does not preclude the possibility of age effects for late potentials evoked by speech stimuli that may be related to the decline in performance on central auditory speech-test materials. These evidences of neuronal dysfunction and loss of synchronicity at brainstem could also be observed. In the present study its evidenced as there was reduction in amplitude 0f F0,F1 encoding at brainstem for speech stimuli. And also TEOAEs change as much with age (Gates, et al. 2002), it is likely that it is not the outer hair cells or striavascularis that are contributing to the excess decline in thresholds. Given the relative stability of neuralfunction, a prime target for this excess decline wouldbe dysfunction of the inner hair cell or primary synapse or both.

Thus at all the three levels from cochlea, brainstem and cortical processing have shown to affected in middle aged individuals. However in present study a definite pattern of correlation could not be observed in both younger and older participants between different audiological test results. No correlation between the different audiological tests results suggests independent changes in the different levels of the auditory system in the older participants. Also, it might reflect the individual variations occurring in different potentials recorded from different levels of the auditory system.

# Chapter 6

# Summary and Conclusion

## 6.1 Summary

Ageing is the biological process that alters the structural and physiological process of the auditory system. This age related change represents changes in both peripheral and central auditory systems (Geal-Dor et al., 2006). The changes can be noticed at cochlea which is based on the anatomical changes that involves sensory, neural, metabolic and mechanical active process. Similarly changes at the higher system such as brainstem and cortical structures also undergo the both structural and physiological changes that results in reduced neuronal function.

The complex stimuli such as speech stimuli reflect neural detection of transient and sustained measures of temporal cues are necessary for speech perception (Russo et al., 2004). The age related alterations are more adverse at age of above >60 years ,however these variations with the normal audio logical threshold could be noticed in middle aged adults (40-60 years),which further gets worsened above with advances in ageing.

Thus this study was studied with a aim to investigate correlation between cochlea, brainstem and cortical auditory processing in normal young adults and middle aged individuals.

The study was conducted on two groups of participants. Group 1 (younger adults) included of 15 subjects (15 ears) age ranged between 18 to 30 years (Mean age range =25.7) .Group 2 (Middle aged adults) included of 15 subjects (15 ears) aged ranged between 45 to 60 years (Mean age range =54.2). The nonlinear TEOAES, Speech evoked

ABR and Speech evoked LLR was carried out using the 40 msec /da/ stimulus. The analysis of TEOAES was done based upon the amplitude measure. The wave v of the speech evoked ABR was analyzed interns of latency. The FFT was carried out to obtain the spectral analysis in terms of amplitude for FO, F1 and F2 formant frequency. The FFT was carried out program developed using MATLAB software. The analysis was carried out for all the subjects in both younger and older groups.

The obtained data for all the measures for both younger and middle aged groups was statically analyzed. The analysis of the data reveals that

- The reduction of TEOAE amplitude were noticed in middle aged group from 1.5 k Hz to 4 kHz .However there was no statically differences in amplitude were noticed at 1 kHz between younger and middle aged adults.
- The wave V latency showed no statistical difference in latency in middle aged group.
- The reduction in amplitude of F0, F1 and F2 were noticed in middle aged adults compared to younger, but F2 amplitude showed no significant difference between two groups.
- The analysis of latency and amplitude of P1,N1 and P2 peaks analyzed reveals that prolongation of all the latencies in middle aged adults, however statistically significant difference are noticed only at P1 latency. The amplitude of P1, N1 and P2 peaks indicated larger amplitude for N1 peak, although P1 and P2 failed to show the statically significant difference in amplitude between younger and middle aged groups.

- The correlation of TEOAEs amplitude and Wave V latency, amplitude of F0, F1, F2, of speech evoked ABR and latency, amplitude of P1,N1 ,P2 of speech evoked LLR in younger group reveled that no correlation between any of the audio logical test except for ,TEOAE amplitude at 2k Hz and 3 kHz with P 1 amplitude,3 kHz with first and second formant frequency amplitude and also first formant frequency with P1 amplitude in younger adults.
- The correlation of TEOAEs amplitude and Wave V latency, amplitude of F0, F1, F2, of speech evoked ABR and latency, amplitude of P1,N1 ,P2 of speech evoked LLR in middle aged group reveled no correlation between any of the audio logical test except for TEOAE amplitude at 1 kHz with F0 and 4 k Hz with N1 latency . There was also correlation of F1 and F2 with P1 amplitude in middle aged group.

**6.2 Conclusion**

The present study concluded that middle age individual shows the age related changes in the auditory system. The changes were noticed at all levels of the auditory system. There was a reduced cochlear function in middle aged individuals as reflected in reduced OAE amplitude, although the wave V latency was normal the encoding of the F0 and F1 was affected in the middle aged individuals, also there was a latency delay in P1 peak of LLR. Together these results suggest an age related decline at various levels of the auditory system. However, a definite trend of degeneration in the auditory system could not be observed.

### 6.3 Implication of the study

- ✓ The study can be utilised to evaluate the encoding of speech at the brainstem in younger and elderly population.
- ✓ Amplitude of F0 and F1 reduced significantly above 55 years of age and it suggests degeneration at the brainstem structures in these individuals. One of the reason for the poor speech identification in older individuals could be because of the poor encoding of F0 and F1 in the older individuals.
- ✓ Outcome of this study could lead to development of objective diagnostic tests as well as techniques to monitor the effectiveness of intervention in the elderly population.

**References**

Aiken, S. J., & Picton, T.W. (2008). Envelope and spectral frequency-following responses to vowel sounds. *Hearing Research, 245, (*1-2), 35-47.

Akhoun, I., Gallego, S., Moulin, A., Menard, M., Veuillet, E., Berger-Vachon, C., et al. (2008). The temporal relationship between speech auditory brainstem responses and the acoustic pattern of the phoneme /ba/ in normal-hearing adults. *Clinical Neurophysiology, 119*, 922– 933.

Alain, C., McDonald, K. L., Ostroff, J. M., & Schneider, B. (2004). Aging: a switch from automatic to controlled processing of sounds? *Psych Aging, 19,* 125–133.

Allison, T., Wood, C.C., & Goff, W.R. (1983). Brainstem auditory, pattern reversal visual and short-latency somatosensory evoked potentials: latencies in relation to age, sex, brain and body size. *Electrencephalography and Clinical Neurophysiology, 55(6),* 619-636.

Amenedo, E., & Diaz, F. (1998). Aging related changes in processing of non target and target stimuli during an auditory odd ball task. *Biological Psychology, 48,* 235-267.

American National Standards Institute. (1991). *American National Standard Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms*. ANSI S3.1- (1991). New York: American National Standards Institute.

Anderer P., Semlitsch H. V., & Saletu B. (1996). Multichannel auditory event-related potentials: effects of normal aging on the scalp distribution of N1, P2, N2 and P300 latencies and amplitudes. *Electroencephalography and Clinical Neurophysiol*ogy, 99(5), 458-72.

Anderson, S., & Kraus, N. (2010). Objective neural indices of speech-in-noise perception. *Trends in Amplification*, 14, 73-83.

Anderson, S., Clark, P.A., White-Schwoch, T., & Kraus, N. (2012). Aging affects neural precisions of speech encoding. *The Journal of Neuroscience, 32,* 14156-14164.

Anderson, S., Clark, P.A., White-Schwoch, T., & Kraus, N. (2012). Aging affects neural precisions of speech encoding. *The Journal of Neuroscience, 32,* 14156-14164.

Anderson, S., Clark, P.A., Yi, Han-Goyl., & Kraus, N. (2011). A neural basis of speech in noise perception in older adults. *Ear and Hearing, 32*, 750-757.

Anderson, S., Skoe, E., Chandrashekharan, B., & Kraus, N. (2010). Neural timing is linked to speech perception in noise. *Journal of Neuroscience, 30*, 4922-4926.

Arnsesn, A.R. (1982). Presbycucsis: Loss of neurons in cochlea nuclei. *Journal of Laryngology and Otology, 96(6),* 503-514.

Babkoff, H., Muchnik, C., Ben-David, N., Furst, M., Even-Zohar, S., & Hildesheimer, M. (2002). Mapping lateralization of click trains in younger and older populations. *Hearing Research*, 165, 117–127.

Banai, K., Hornickel, J.M., Skoe, E., Nicol, T., Zecker, S., & Kraus N. (2009). Reading and subcortical auditory function. *Cerebral Cortex, 19(11),* 2699-2707.

Banai, K., Nicol, T., Zecker, S., & Kraus N. (2005). Brainstem timing: Implications for cortical processing and literacy *Journal of Neuroscience, 25(43),* 9850-9857.

Barr, R. A., & Giambra, L. M. (1990). Age-related decrement in auditory selective attention. *Psycholololgy of Aging, 5,* 597–599.

Beagley, H. A., & Sheldrake, J. B. (1978). . Differences in brainstem response latency with age and sex. *British Journal of Audiology, 12,* 69-77.

Beasley, D. S., & Beasley, D. L. (1973). Auditory reassembly abilities of black and white first and third grade children. *Journal of Speech & Hearing Research*, *16*, 213-221.

Briner, W., & Willott, J.F. (1989). Ultrastructural features of neurons in the C57BL/6J mouse anteroventral cochlear nucleus: young mice versus old mice with chronic presbycusis. *Neurobiology of Aging, 10(4),* 295-303.

Bellis, T.J., Nicol, T., & Kraus, N. (2000). Aging affects hemispheric asymmetry in the neural representation of speech sounds. *Journal of Neurosciences, 20(2),* 791-797.

Bergman, M. (1971). Changes in hearing with age. *Gerontologist, 11,* 148–151.

Betroli, S., & Probst, R. (1997). The role of transient evoked otoacoustic emission testing in the evaluation of the elderly persons. *Ear and Hearing, 18,* 286-293.

Blood, I., & Greenberg, H. J. (1977). Acoustic admittance of the ear in the geriatric person. *Journal of the American Audiological Society, 2,* 185-187.

Calais, L.L., Russo, I.C., & Borges, A.C. (2008). Performance of elderly in a speech in noise test. *Ear and Hearing, 20(3),* 147-153.

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

Chu, N.S. (1985). Age-related latency changes in the brain-stem auditory evoked potentials. *Electroencephalography and Clinical Neurophysiology, 62(6*), 431-439.

Clark, P.A., Anderson, S., Hitmer, A., & Kraus, N. (2012). Musical experience offsets age related delays in neural timing. *Neurobiology of Aging, 33,* 1481-1483.

Clinard, C.G., Tremblay, K.L., & Krishnan, A.R. (2010). Aging alters the perception and physiological representation of frequency: Evidence from human frequency following responses recordings. *Hearing research, 264,* 48-55.

Costa, P., Benna, P., Bianco, C., Ferrero, P., & Bergamasco, B., (1990). Aging effects on brainstem auditory evoked potentials. *Electroencephalography and Clinical Neurophysiology, 30(8),* 495-500.

Cunningham, J., Nicol, T., Zecker, S. G., Bradlow, A., & Kraus, N. (2001). Neurobiologic responses to speech in noise in children with learning problems: deficits and strategies for improvement. *Clinical Neurophysiology*, *112*(5), 758–767.

Davis, H., & Hirsh, S. K. (1976). The audiometric utility of brain stem responses to low frequency sounds. *Audiology, 15,* 181–195.

Davis, A. (1994). *Hearing in adults.* London: Whurr Publishers Ltd.

Debruyne, F. (1986). Influence of age and hearing loss on the latency shifts of the auditory brainstem response as a result of increased stimulus rate. *Audiology*, *25*, 101–106.

Dhar, S., Abel, R., Hornickel, J., Nicol, T., Skoe, E., Zhao, W., & Kraus N. (2009). Exploring the relationship between physiological measures of cochlear and brainstem function. *Clinical Neurophysiology,* 120, 959-966.

Divenyi, P. L., & Haupt, K. M. (1997). Audiological correlates of speech understanding deficits in elderly listeners with mild-to-moderate hearing loss. II. Correlation analysis. *Ear and Hearing, 18*, 100–113.

Don, M., Allen, A., & Starr, A. (1977). Effect of click rate on the latency of auditory brain stem responses in humans. *Annals of Otology, 86,* 186–195.

Don, M., Ponton, C.W., Eggermont, J.J., & Masuda, A. (1994). Auditory brainstem response (ABR) peak amplitude variability reflects individual differences in cochlear response times. *Journal of the Acoustical Society of America, 96(6),* 3476-3491.

Dorn, P. A., Piskorski, P., Keefe, D. H., Neely, S. T., & Gorga, M. P. (1998). On the existence of an age/threshold/frequency interaction in disortion product otoacoustic emissions. *Journal of Acoustical Society of America, 104,* 964–971.

Dubno, J. R., Horwitz, A. R., & Ahlstrom, J. B. (2002). Benefit of modulated maskers for speech recognition by younger and older adults with normal hearing. *Journal of Acoustical Society of America, 111,* 2897–2907.

Engström, B., Hillerdal, M., Laurell, G., & Bagger-Sjöbäck, D. (1987). Selected pathological findings in the human cochlea. *Acta-otolaryngologica, 436,* 110-116.

Era, P., Jokela, J., Qvarnberg, Y., & Heikkinen, E. (1986). Pure-tone thresholds, speech understanding, and their correlates in samples of men of different ages. *Audiology, 25,* 338–352.

Ewertsen, H. W., & Birk-Nielson, H. B. (1971). A comparative analysis of the audiovisual, auditive and visual perception of speech. *Acta Otolaryngologica, 72,* 201–205.

Galbraith, G.C., Arbagey, P.W., Branski, R., Comerci, N., Rector, P.M. (1995). Intelligible speech encoded in the human brain stem frequency-following response *Neuroreportology, 27,* 2363-7.

Gandolfi, A., Horoupian, D.S., & De Teresa, R.M. (1981). Quantitative and cytometric analysis of the ventral cochlea nucleus. *Journal of Neurological Sciences, 50(3),* 443-455.

Gates, G. A., Cooper, J. C., Kannel, W. B., & Miller, N. J. (1990). Hearing in the elderly: The Framingham cohort, 1983 – 1985. *Ear and Hearing, 11, 247 – 256.*

Geal-Dor, M., Goldstein, A., Kamenir, Y., & Babkoff, H. (2006). The effect of aging on event-related potentials and behavioral responses: comparison of tonal, phonologic and semantic targets. *Clinical Neurophysiology, 117,* 1974–1989.

Gelfand, S. A., Piper, N., & Silman, S. (1986). Consonant recognition in quiet and in noise with aging among normal hearing listeners. *Journal of the Acoustical Society of America*, *80,* 1589–1598.

Giraud, A. L., Lorenzi, C., Ashburner, J., Wable, J., Johnsrude, I., Frackowiak,R., & Kleinschmidt, A. (2000). Representation of the temporal envelope of sounds in the human brain. *Journal of Neurophysiology*, *84,* 1588–1598.

Goodin, D. S., Squires, K. C., Henderson, B. H., & Starr, A. (1978). Age related variations in evoked potentials to auditory stimulus in normal human subjects. *Electroencephalography and Clinical Neurophysiol*ogy, *44,* 447-458.

Greenberg, S., Marsh, J. T., Brown, W. S., et al. (1987). Neural temporal coding of low pitch. I. Human frequency-following responses to complex tones. *Hearing Research*, *25*, 91–114.

Greenwald, R., & Jerger, J. (2001). Aging affects hemispheric asymmetry on a competing speech task. *Journal of the American Academy of Audiology, 12(4),* 167-173.

Grose, J.H., & Mamo, S.K. (2010). Processing of temporal fine structure as a function of age. *Ear and Hearing, 31(6),* 755-60.

Hall, J. W. (1979). Effects of age and sex on static compliance. *Archives of Otolaryngology 105,* 153-156.

Hall, J.C. (1999). Gabergic inhibition shapes frequency tuning and modifies responses properties in the auditory midbrain of the leopard frog. *Journal of Composite Physiology, 183,* 479-491.

Harkins, S.W., McEvoy, T.M., & Scott, M.L.(1979). Effects of interstimulus interval on latency of the brainstem auditory evoked potential. *International Journal of Neuroscience, 10,* 7-14.

Harris, C.K., Mills, J.H., He, N., & Dubno, J.R. (2008). Age-related differences in sensitivity to small changes in frequency assessed with cortical evoked potentials. *Hearing Research, 243(1-2),* 47-56.

Harris, R.W., & Swenson, D.W. (1990). Effects of reverberation and noise on speech recognition by adults with various amounts of sensorineural hearing impairment. *Audiology, 29(6),* 314-321.

Haskins, S.W. (1981). Effects of age and interstimulus interval on the brainstem auditory evoked potential. *International Journal of Neuroscience, 15*, 107-118.

Helfer, K. S., & Wilber, L. A. (1990). Hearing loss, age and speech perception in reverberation and noise. *Journal of Speech and Hearing Research, 33,* 149–155.

Iragui, V. J., Kutas, M., Mitchiner, M. R., & Hillyard, S. A. (1993). Effects of aging on event related potentials and reaction times in an auditory oddball task. *Psychophysiology, 30(1),* 10-22.

Jerger, J., Darling, R., & Florin, E. (1994). Efficacy of the cued-listening task in the evaluation of binaural hearing aids. *Journal of the American Academy of Audiology, 5,* 279–285.

Jerger, J., Jerger, S., & Mauldin, L. (1972). Studies in impedance audiometry I. Normal and sensorineural ears. *Archives of Otolaryngology, 96,* 513-523.

Jerger, J., & Hayes, D. (1977). Diagnostic speech audiometry. *Archives of Otolaryngology, 103(4),* 216-22.

Johnson, K.L., Nicol, T.G., Zecker, S.G., Bradlow, A., Skoe, E., & Kraus N. (2008) Brainstem encoding of voiced consonant-vowel stop syllables. *Clinical Neurophysiology 119*, 2623-2635.

Johnson, L.G., & Hawkins, J. E. Jr. (1972) Sensory and neural degeneration with aging as seen in microdissections of the human inner ear. *Annals of Otology Rhinology and Laryngology, 81*, 179–193.

Kim, S., Frisina, R. D., Mapes, F. M., Hickman, E. D., & Frisina, D. R. (2006). Effects of age on binaural speech intelligibility in normal hearing adults. *Speech Communication, 48*, 591–597.

Kraus, N., & Nicol, T. (2005). Brainstem origins for cortical “what” and “where” pathways in the auditory system. *Trends in Neurosciences*, *28(4),* 176–181.

Krishnan, A. (1999). Human frequency-following responses to two-tone approximations of steady-state vowels. *Audiology and Neurotology, 4,* 95–103.

Krishnan, A. (2002). Human frequency-following responses: Representation of steady-state synthetic vowels. *Hearing Research*, *166*, 192– 201.

Krishnan, A., Xu, Y., Gandour, J., et al. (2005). Encoding of pitch in the human brainstem is sensitive to language experience. *Brain Research Cognitive Brain Research*, *25*, 161–168.

Larry L.J & Brant J.L (1990). Age changes in puretone hearing thresholds in a longitudinal study of normal human aging.. *Journal of the Acoustical Society of America, 88(2*), 813-820.

Martin, D. R., & Cranford, J. L. (1991). Age-related changes in binaural processing: II. Behavioral findings. *American Journal of Otolaryngology, 12,* 365–369.

Moushegian, G., Rupert, A. L., & Stillman, R. D. (1973). Scalp-recorded early responses in man to frequencies in the speech range. *Electroencephalography and Clinical Neurophysiology, 35,* 665–667.

Maurizi, M., Attissimi, G., Ottaviani, F., Paludetti, G., & Bambini, M. (1982). Auditory brainstem responses (ABR) in the aged. *Scandivian Audiology, 11(4),* 213-221.

Nabelek, A. (1988). Identification of vowels in quiet, noise, and reverberation: Relationships with age and hearing loss. *Journal of the Acoustical Society of America, 84,* 476–484.

Oku, T., & Hasegewa, M. (1997). The influence of aging on auditory brainstem response and electrocochleography in the elderly. *Journal of Otorhinolaryngology and Related Specialities, 59,* 141-146.

Osterhammel, D., & Osterhammel, P. (1979). Age and sex variations for the normal stapedial reflex thresholds and tympanometric compliance values. *Scandivian Audiology, 8,* 153-158.

Patterson, J.V., Michalewski, H.J., Thompson, L.W., Bowman, T.E., &Litzelman, D. K. (1981). Age and sex differences in the human auditory brainstem response. *Journal of Geronotology, 36,* 455-462.

Pertii, Jukka & Eino . (1986). Hearing acuity variations among Negros and whites. *Eugen Quart**ile**, 11*, 65-81. Pfefferbaum, A., Ford, J. M., Roth, W. T., & Kopell, B. S. (1980). Age related changes in auditory event related potentials. *Electroencephalography and Clinical Neurophysiol*ogy, *49,* 266-276.

Plomp, R., & Mimpen, A. M. (1979). Speech-reception threshold for sentences as a function of age and noise level. *Journal of the Acoustical Society of America, 66,* 1333–1342.

Plyler, P. N., & Ananthanarayan, A. K. (2001). Human frequency-following responses:Representation of second formant transitions in normal-hearing and hearing impaired listeners. *Journal of the American Academy of Audiology, 12,* 523–533.

Psatta, D.M, & Matei, M. (1988). Age-dependent amplitude variation of brain-stem auditory evoked potentials. *Electroencephalography and Clinical Neurophysiology, 71(1),* 27-32.

Ross, B., Fujioka, T., Tremblay, K. L., & Picton, T. W. (2007). Aging in binaural hearing begins in mid-life: evidence from cortical auditory-evoked responses to changes in interaural phase. *Journal of Neuroscience, 27,* 11172–11178.

Russo, N., Nicol, T., Musacchia, G., & Kraus, N. (2004). Brainstem responses to speech syllables. *Clinical Neurophysiology, 115 (9),* 2021–2030.

Scholtz, AW., Kammen-jolly, K.,Felder E., Kristen, S. (2001).Selective aspects of human pathology in high-tone hering loss of ageing in inner ear. *Hearing Research, 157(1-2),* 77-86.

Sinha, S.K., & Basavaraj, V. (2010a). Speech evoked auditory brainstem responses: a new tool to study brainstem encoding of speech sounds. *Indian Journal of Otorhinolaryngology, 62(4),* 395-399.

Sinha, S.K., & Basavaraj. (2010b). Brainstem responses to forward and reversed speech sounds. *Journal of All India Institute of Speech and Hearing. 109,* 101-109.

Sohmer, H., Pratt, H., & Kinarti, R. (1977). Sources of frequency following responses (FFRs) in man. *Electroencephalography and Clinical Neurophysiology, 42*, 656–664.

Song, J., Banai, K., Russo N. M., & Kraus, N. (2006). On the relationship between speech- and nonspeech-evoked auditory brainstem responses. *Audiology and Neuro-Otology*, *11*(4), 233–241.

Stach, B., Spretnjak, M., & Jerger, J. (1990). The prevalence of central presbycusis in clinical population. *Journal of the American Academy of Audiology, 1*, 109-115.

Thompson, D. J., Sills J. A., Recke, K. S., Bui, D. M. (1979). Acoustic admittance and the aging ear. *Journal of Speech and Hearing Research, 22*, 29-36.

Tremblay, K. L., Piskosz, M., & Souza, P. (2002). Aging alters the neural representation of speech cues. *Neuroreport, 13(15)*, 1865-1870.

Tremblay, K. L., Piskosz, M., & Souza, P. (2003). Effects of age and age related hearing loss on neural representation of speech cues. *Clinical neurophysiology, 114(7)*, 1332-1343.

Tremblay, K.L., Billings, C., & Rohilla, N. (2004). Speech evoked cortical potentials: effects of age and stimulus presentation rate. *Journal of the American Academy of Audiology, 15(3)*, 226-237.

Tremblay, K., & Burkard, R. (2007). In Burkard, R., Don, M. & Eggermont, J. (Eds.), *Auditory Evoked Potentials: Basic Principles and Clinical Application* (1st ed., pp. 736). Philadelphia: Lippincott Williams & Wilkins.

Tsai, H.K., Fong-Shyone, C., & Tsa-Jung, C. (1958). On changes in ear size with age. *Journal of Formous Medical Association, 57*, 105-111.

Tun, P. A., O‟Kane, G., & Wingfield, A. (2002). Distraction by competing speech in young and older adult listeners. *Psychological Aging, 17(3)*, 453–467.

Uchida, Y., Ando, Y., Shimokata, H., Sugiura, S., Ueda S., and Nakashima, T. (2008). The effects of aging on distortion-product otoacoustic emissions in adults with normal hearing. Ear and Hearing, 29, 176-184 .

Vander-werff, K.A., & Burns, K.S (2011). Brainstem responses to speech in younger and older adults. *Ear and Hearing, 32,* 168-180.

Van Rooij, J. C., & Plomp, R. (1990). Auditive and cognitive factors in speech perception by elderly listeners. II: Multivariate analyses," *Journal of the Acoustical Society of America, 88*, 2611-2624.

Van Rooji, J., & Plomp, R.(1992). and cognitive factors in speech perception by elderly listeners. III: Additional data and final discussion. *Journal of the Acoustical Society of America, 91*, 1028-1033.

Vaughan, N. E., & Letowski, T. (1997). Effects of age, speech rate, and type of test on temporal auditory processing. *Journal of Speech Language and Hearing Research, 40,* 1192–1200.

Wan, I.K., & Wong, L.L. (2002). Tympanometric norms for Chinese young adults. *Ear and Hearing, 23(5),* 416-21.

Wang, Y., & Manis, P.B. (2005). Synaptic transmission at the cochlear nucleus endbulb synapse during age-related hearing loss in mice. *Journal of Neurophysiology, 94(3),* 1814-24.

Walton, J.P. (2010). Timing is everything: temporal processing deficits in the aged auditory brainstem. *Hearing Research, 264,* 63–69.

Walton, J.P., Frisina, R.D., Ison, J.R., & O‟Neill, W.E. (1997). Neural correlates of behavioral gap detection in the inferior colliculus of the young CBA mouse. *Journal of Composite Physiology, 18(12),* 161-176.

Whitehead, M.L., Kamal, N., Lonsbury-Martin, B.L., & Martin, G.K (1993). Spontaneous otoacoustic emissions in different racial groups. *Scandivian Audiology*, *22(1),* 3-10.

Wible, B., Nicol, T., & Kraus, N. (2004). Atypical brainstem representation of onset and formant structure of speech sounds in children with language-based learning problems. *Biological Psychology, 67*(3), 299–317.

Wiley, T. L., Cruickshanks, K. J., Nondahal, D.M., Tweed, T.S., Klein, R., & Klein, B.E (1996). Tympanometric measures in older adults. *Journal of the American Academy of Audiology, 7,* 260-268.

Willot, J.F. (1991). Central physiological correlates of ageing and presbycusis in mice. *Acta Otolaryngologica, 111,* 153-156.

Yilmaz, S.T., Sennaroglu, G., Sennaroglu, L., & Kose, S.K. (2007). Effect of age on speech recognition in noise and on contralateral transient evoked otoacoustic emission suppression. *The Journal of Laryngology & Otology, 121,* 1029-1034.