A RETROSPECTIVE STUDY ON AUDIOLOGICAL PROFILING OF INDIVIDUAL WITH AGE RELATED HEARING LOSS

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AUGUST, 2022

CERTIFICATE

This is to certify that this dissertation entitled **'A retrospective study on audiological profiling of individual with age-related hearing loss'** is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number:20AUD025. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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This is to certify that this dissertation entitled **'A retrospective study on audiological profiling of individual with age-related hearing loss'** has been prepared under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **‘A retrospective study on audiological profiling of individual with age-related hearing loss’** is the result of my own study under the guidance of Dr. Animesh Barman, Professor in Audiology, All India Institute of Speech and Hearing and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru,
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This Dissertation

is dedicated to

My Family

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Abstract

Age-related hearing loss, generally referred to as Presbycusis, is characterized by symmetrical deterioration of hearing abilities which are usually progressive in nature. This deterioration in hearing abilities is caused due to changes evident in the outer ear, middle ear, inner ear, and CANS. These changes can alter the results of various audiological tests. Therefore, the present study was taken up with an aim to profile the audiological tests in individuals older than 50 years of age with SNHL and mixed hearing loss who reported to AIISH between January 2019 and December 2020. The study was carried out in 288 ears (M: 176; F: 102), divided into SNHL and mixed hearing loss. These groups were further classified based on the audiogram configuration (sloping and flat) of hearing loss. SIS in quiet and tympanometric findings were also noted and assessed across age groups for all the types and configurations of hearing loss. The results suggest a gradually sloping configuration is most common among the SNHL group and a flat configuration for the mixed hearing loss group. SIS scores showed a decline with increase with age for all the types and configurations of hearing loss. There were changes in all tympanometric parameters with an increase in age, which was significant for mixed hearing loss groups. In contrast, the gender difference was not evident for any audiological tests assessed in the present study. Thus, the present study explains how the audiological test results vary with aging for SNHL and mixed hearing loss in older individuals

Chapter 1

Introduction

Age-related hearing loss generally referred to as Presbycusis, characterized by symmetrical deterioration of hearing abilities which is usually progressive in nature. The main cause for presbycusis is aging but other factors like environmental and genetic can also accelerate the hearing loss seen in presbycusis (Fischer et al., 2016). Presbycusis is very common among individuals over 60 years of age and has been detected in 100% population who are older than 80 years of age based on the pure tone average classification specified by WHO (2018). Cruickshanks et al. (1998) reported the prevalence of age-related hearing loss is 46% for adults aged between 48-92 years and the majority of individuals predominantly show mild followed by a moderate degree of hearing loss. Same authors also reported that men are more likely to be affected than females. Even in the Indian scenario, a survey conducted by National Sample Survey (NSS, 2002), suggests hearing loss is the most prevalent condition in older adults affecting as much as 62% and 56% of the population in rural and urban areas respectively. The difficulties faced by older individuals with hearing impairment include speech understanding in both quiet as well as in noisy conditions and tinnitus (Löhler et al., 2019). Age related hearing loss not just leads to difficulties in understanding speech but also causes other complications like depression, anxiety, lethargy, and social dissatisfaction thereby impacting their quality of life (Dalton et al., 2003; Eyken et al., 2007).

Age related hearing loss in majority of the population leads to a sensorineural type of hearing loss, due to which quite a large number of studies have mainly focused on knowing the changes happening within inner ear. Thus, the most of the researcher have observed degeneration of various inner ear structures (Fischer et al., 2020a). Inner ear undergoes numerous changes with aging like, degeneration of Outer hair cells (OHCs) and Inner hair cells (IHCs). This loss of IHCs is more evident in basal turn of cochlea which can explain the reason for more high frequency loss in presbycusis individual (Gates & Mills, 2005). Degeneration of stria vascularis or strial atrophy is also evident with aging (Wu et al., 2020). There is a decline of 100 spiral ganglion cell per year which is marked even in a healthy human cochlea (Makary et al., 2011). Lastly, other changes are also marked in other parts like tectorial membrane, reissner's membrane, supporting cells as well as in central auditory nervous system which further regress with increase in age (Ouda et al., 2015).

Although there are studies in bulk, which have investigated the changes in inner ear, there are quite a few studies as well which have shown changes in middle ear structures which can supplement the hearing loss due to aging. Changes that are evident in the middle ear as age progress and those associated with tympanic membrane includes change in thickness, vascularity, elastin, collagen, and cellularity (Etholm & Belal, 1974). The most common changes that happen in elderly includes, osteoporosis (OP). As a result of OP various structures in middle ear are compromised like incudomalleolar joint (IMJ), incudostapedial joint (ISJ) and tympanic membrane (TM). OP in these middle ear structures leads to stiffening of all these structures and hence causing a decrease in hearing abilities as well as in middle ear transfer function (Zhou et al., 2019). Evidence even point out possible existence of mass dominated middle ear with progress in age. Roychowdhury et al. (2021) have found wider incudomalleolar joint separation in presbycutic ear compared to the normal ear, wherein the presbycusis cases showed no degenerative changes within inner ear as well as in CANS. Therefore, there is a feasible chance of more effect on hearing abilities due to changes occurring within middle ear as a result of ageing.

All these changes happening in various parts of ears would reflect in different audiological tests. Generally, the most common findings that are observed in pure tone audiometry include high frequency sloping hearing loss, which manifests the effect of aging more towards the inner ear structures. Milne and Lauder (1975) have observed more high frequency hearing loss in males when compared to females and more low frequency loss in females compared to males. The authors also observed an increase in hearing thresholds as the age of the person progress. The threshold at all frequencies start to deteriorate with an average rate of 1 dB/octave specially after the age of 60 years. This collapse in threshold is found even in extended high frequency audiometry, and the rate at which threshold deteriorate is not much affected by factors like previous noise exposure (F. S. Lee et al., 2005).

At the same time, this increase in thresholds at various frequencies have even found to affect the speech perception in older individuals as well. The speech perception is affect in both the conditions without and with the presence of noise as well (Dlouhá et al., 2017). Not just the increase in pure tone thresholds lead to reduced speech perception but speech perception was found to be related to cognitive impairment also. Older individuals with associated mild cognitive impairment along with hearing loss tends to perform poorer in speech perception compared to normal older adults (Aimoni et al., 2015). This reduction in speech recognition is mainly found due to the SNR loss that increases as the age of the older individual progress (Decambron et al., 2022).

As various middle ear changes are also seen in the geriatric population, these anatomical changes could even influence the results of various audiological tests like immittance findings, which is particularly used to assess middle ear status. There are equivocal amounts of studies that infer changes in immittance findings and studies that conclude no change in tympanometry findings. Sogebi, 2015 have observed that on an average 39.3% elderly individuals display abnormal tympanometric findings and 38% shows absence of acoustic reflexes. A decrease in static compliance was also observed which was more evident after the age of 40 years (Hall, 1979a). Also, a decrease in ear canal volume and an increase in tympanogram width (TW) have been observed (Wiley, 1996a). On the contrary, Sinha et al., 2021 observed no change in tympanometry parameters like static admittance, equivalent ear canal volume, and tympanometric peak pressure across older age groups and no significant difference observed across gender as well.

These variations in findings across studies can possibly be reflected due to different types and configurations of hearing loss in respective studies. Thus, it is essential to find the relationship between type and configuration of hearing loss, immittance findings, and speech identification scores (SIS).

1.1 Need for the study

Emerging clinical investigation have confirmed that there is widening of incudomalleolar joint and incudostapedial joint in older individuals (Roychowdhury et al., 2021), which can lead to high-frequency conductive hearing loss due to an increase in the admittance and a decrease in stiffness of the middle ear and hence affect other audiological tests also (Feeney & Sanford, 2004). Other changes evident concerning the middle ear includes osteoporosis (OP). OP has been seen to compromise incudomalleolar joint (IMJ), incudostapedial joint (ISJ), and tympanic membrane (TM). OP in these middle ear structures leads to stiffening, hence causing a decrease in hearing abilities and middle ear transfer function (Zhou et al., 2019). This stiffening of the middle ear can lead to a decrease in hearing thresholds, predominantly seen in lower frequencies.

These mass and stiffness-related changes marked in the various middle ear structures can significantly alter the configuration pattern seen in the audiogram. All the previous studies have only considered the sensory and neural components while studying the configuration seen in individuals with age-related hearing loss. Due to this, the age-related changes concerning the middle ear which can influence the audiogram's configuration and type of hearing loss were neglected. Therefore, there is a need to compare the configuration of hearing loss commonly seen between mixed hearing loss and SNHL in older individuals to get an idea if changes in middle ear are sufficient to alter the audiogram configuration.

Similarly, to the best of our knowledge, no prior research examining changes in immittance results in older persons have compared SNHL with mixed hearing loss (without a history of middle or outer ear disorders) as a result of ageing. And all the previous studies have only taken individuals with SNHL or normal individuals to study immittance changes in older individuals and have observed changes in static admittance as well as in equivalent ear canal volume (Wiley, 1996b). Similarly, Golding et al. (2007) by including individual with SNHL and normal older individuals has also observed a decrease in static admittance with increase in age. Whereas, age related changes occurring in middle ear can also lead to a mixed hearing loss (Roychowdhury et al., 2021b; Zhou et al., 2019). Thus, there is a need to study changes in tympanometric findings between mixed hearing loss and SNHL individuals across older age groups. And also, to compare the tympanometric findings within SNHL and mixed hearing loss across older age groups.

Lastly, the changes in the configuration as a consequence of changes within the middle ear can further change the speech identification scores (SIS) for older individuals. Therefore, there is a need to study the SIS in older individuals between SNHL and mixed hearing loss across different configuration patterns.

1.2 Aim of the study

The present study aimed to retrospectively profile the audiological findings (type and configuration of hearing loss, SIS, and immittance findings) of the individual with hearing loss due to aging. To compare all these audiological findings between SNHL and mixed hearing loss and SIS across different configurations and different types of hearing loss.

1.3 Objectives of the study

1. To compare the tympanometric findings between SNHL and mixed hearing loss in older individuals across age groups.
2. To compare the audiogram configuration obtained in SNHL versus that obtained for the mixed HL group in older individuals.
3. To compare the immittance findings obtained in the current study with the normative provided by Wiley (1996).
4. To discover the correlation of type and configuration of hearing loss with SIS findings.

Chapter 2

Review of literature

Information from the literature regarding characteristics, prevalence, structural changes of ear and various audiological findings with aging was gathered. All the information has been given in brief under different headings in following sections for reader's clarity.

2.1 Characteristics and Prevalence of Age-related hearing loss

Age-related hearing loss (ARHL), also known as presbycusis, is a symmetrical decline in hearing ability that is often gradual in nature and mainly brought on by aging. However, environmental and genetic variables can also hasten hearing loss (Fischer et al., 2016). Since most people with age-related hearing loss have sensorineural hearing loss, a significant number of research have primarily focused on understanding the changes occurring within the inner ear. Therefore, several researchers have noted the deterioration of different inner ear components (Fischer et al., 2020). The inner ear experiences several changes with age, including the decline of inner hair cells (IHCs) and outer hair cells (OHCs). This IHC loss is more pronounced in the cochlea's basal turn, which may cause a presbycusis patient's more significant high-frequency loss.

Various risk factors are associated with age-related hearing loss and hence can lead to rapid progress in hearing loss caused due to aging. De Sousa et al. (2009) conducted an observational cross-sectional study to know possible risk factors associated with presbycusis. The principal goal of this study was to determine the prevalence of presbycusis and link potential risk variables in a population sample of adults aged 40 and older, whether or not they had hearing loss complaints. A total of 625 individuals aged 40 years and older without any history of middle ear pathology or otological surgery, any cause of SNHL other than presbycusis were not considered for the study, and individuals with noise exposure were also not included in the study. All these patients were investigated for various possible risk factors like sex, age, profession, a genetic history of age-related or idiopathic hearing loss, dyslipidemias (cholesterol and triglyceride levels), diabetes mellitus, arterial hypertension, long-term use of medication, use of hormones, alcohol consumption (two or more times a week) and smoking. It was observed in the results that diabetes mellitus, engineers, systemic arterial hypertension, and family history have been found to have a positive association with presbycusis. In contrast, no association was found between presbycusis and other factors like smoking, alcohol consumption, hormonal therapy, and dyslipidemias. Therefore, we can conclude from this study that other factors also contribute to age-related hearing loss.

Some studies have even attempted to find the association of age-related hearing loss with the fall history of older individuals. A study by Lin and Ferrucci. (2012) focused on hearing loss and falls among older adults in the United States. The study's main aim was to examine the cross-sectional relationship between audiometric hearing loss and self-reported falls in a sample of the US population aged 40 to 69 who took part in the National Health and Nutrition Examination Survey (NHANES). A total of 2017 individuals between the age range of 40 and 69 years underwent pure tone audiometry, and a questionnaire was administered to ascertain the history of falls. Results revealed that the prevalence of hearing loss (PTA greater than 25 dB) was seen in 14.3% of the individuals, and 4.9% of individuals showed a history of falls in the last 12 months of span. When the association between hearing loss and falls was investigated, it was found that hearing loss and falls are positively associated, and with every 10 dB increase in pure tone average frequency of fall increase by 1.4 folds. Thus, we can conclude that age-related hearing loss can lead to other symptoms.

Another problem older individuals face due to hearing impairment is reduced quality of life. Hyams et al. (2018) studied the effect of hearing loss on the quality of life of older individuals. The study's main objectives were to compare the quality of life in older individuals who have hearing loss and are using hearing aids and older individuals with hearing loss who are not using hearing aids. The study was conducted on 100 individuals older than 60 years who were divided into 3 groups: group 1 included individuals with hearing loss who use a hearing aid; group 2 included those with hearing loss who don't use hearing aids; and group 3 had older individuals with normal hearing. All the participants underwent a Short Form-36 Health Survey wherein quality of life was judged in 3 different domains: general health, mental health, and physical functioning. Results suggest that individuals with hearing loss without hearing aid use perform have significantly reduced quality of life compared to older individuals with hearing aids or older individuals with normal hearing. No significant difference was observed in the quality of life for older hearing aid users and normal older individuals. Therefore, from this study, it can be concluded that older individuals with hearing loss have reduced quality of life especially if they are not hearing aid users.

Various prevalence studies have been carried out to determine the proportion of the older population having hearing loss. Homans et al. (2017) attempted to assess the prevalence of hearing loss in older individuals in the Netherlands. The study's main aim was to determine the current state of hearing loss due to age in an unscreened general sample of older Dutch individuals and determine if the prevalence or severity has changed over time. 4,743 individuals (2679 males and 2064 females) aged above 50 years participated in that study. AC and BC thresholds were obtained for each participant between 0.25 to 8 kHz and 0.5 to 4 kHz, respectively. The results suggest a total prevalence of 30% after age 65; the prevalence in men was found to be 33% and 31% in women above 65 years.

Another study by Rodríguez-Valiente et al. (2020) evaluated the prevalence of presbycusis in otologically normal populations. The study was carried out on a total of 4290 individuals (2160 females and 2130 males) between the age range of 5 to 90 years and was grouped into 5- and 10-year intervals. The individuals had no problem with the middle ear or any otologically related surgery. Results revealed that mild hearing loss starts to appear by the age of 60 years, and the prevalence of presbycusis is 100% for individuals above 80 years. The prevalence of presbycusis increases as the person ages. Therefore, it can be concluded that the prevalence of presbycusis is very high for older individuals older than 80, and prevalence increases with age.

In the Indian population, Giri et al. (2010) conducted a study to assess the Otorhinolaryngological disorders in. the geriatric population in rural parts of India. The main aim of this study was to ascertain the incidence of otorhinolaryngological problems in the elderly population and their connection with sociodemographic parameters. It was retrospective-based research in which 1270 patients (784 males, 486 females) aged 60 years and above were evaluated for all otorhinolaryngological disorders. Results revealed that presbycusis was the most prevalent (53.9%) otorhinolaryngological disorder among older individuals. Other common otological-related problems after presbycusis were presbyacusis, otitis, and tinnitus, accounting for 10.2%. Therefore, it can be concluded that hearing loss is the most common otorhinolaryngological disorder seen in the geriatric population.

Due to this large prevalence seen in older individuals, many studies have focused on studying various different parts of ear in which the effect of aging can be evident using various audiological tests discussed in the following sections.

2.2 Age related structural changes

Due to aging all the structures of ears undergo several changes as discussed earlier in introduction section. In the following sections changes evident according to various studies in outer, middle and inner ears are discussed in detail.

2.2a Age related changes in inner ear and central auditory nervous system

Review study was conducted by Gates & Mills, (2005) for understanding changes happening in cochlea due to aging. The main aim of the present study was to review the structural and functional changes happening in cochlea in older individuals with presbycusis. The results of the study suggests that the stria vascularis is most prominent structure within the inner ear that gets most affect due to aging followed by sensory structure of inner ear (OHCs and IHCs). The authors have also concluded that due to stria vascularis degeneration the steeply sloping configuration is predominantly seen in older individuals. Therefore, from this study we can come to a conclusion with increase in aging there is degeneration of stria vascularis and sensory hair cells leading to alteration in configuration of audiogram pattern.

An another review study was carried out by K.-Y. Lee, (2013) to investigate the changes taking place in inner ear and central auditory pathway. The findings of this study have reported degeneration OHCs which is more commonly seen at the basal turn of the cochlea leading to a sensory presbycusis. Other changes which are also evident in cochlea and CANS includes decline in the number of auditory neurons, atrophy of stria vascularis, decrease in Endo cochlear potential, degenerative changes in superior olivary complex and dorsal cochlear nucleus. Therefore, from the findings of this study it can be concluded that there are various changes evident in inner ear and CANS that can result is alteration of various audiological test findings.

Similar findings were also reported in review study conducted by Fischer et al., (2020), who reported degeneration of stria vascularis, organ of Corti, auditory neuron and spiral ligament with increase in the age. Further they reported that, 100 spiral ganglion cells are lost every year with increase in age even in a healthy cochlea. Hence, it can be inferred from the study that changes in almost all the structures of inner ear are evident which can significantly cause a decline in audiological test findings.

2.2b Age related changes in middle ear and external ear

Ruah et al. (1991) carried out a study to investigate the changes happening in tympanic membrane (TM) with increase in age. The main aim of the study was to address the changes happening in TM with aging. A total of 46 normal human temporal bone aged between 2 days to 97-year-old were studied with the help of light and electron microscopy. The results obtained suggest a decrease in the thickness of pars flaccida layer and posteriosuperior quadrant of pars tensa. The authors also reported degeneration of thin elastic fibres with aging whereas no changes were noticed for thick elastic fibres with aging. Therefore, it can be concluded that with aging there are various age-related changes taking place in TM including decrease in elasticity, vascularity and cellularity.

Zhou et al. (2019) studied the effect of aging on middle ear transfer function. The aim of the study was to assess the middle ear transfer function due to various changes like osteoporosis (OP) and stiffening of soft tissues caused due to aging. Middle ear transfer function was determined using a finite element model. The density and Young's modulus of all the 3 ossicles were decreased in the model by 30% to simulate the OP changes as seen in older individuals. Results of the study revealed a decrease in the middle ear transfer function in lower frequency due to stiffening of middle ear structure but this decrement was not significant. Other findings suggest due to stiffening changes in ossicles the performance at high frequencies increase but is also accompanied with risk of ossicles fractures due to reduced density. Therefore, from the study we can conclude that stiffening changes in middle ear has the ability to alter the middle ear transfer function though it was not significant.

A histopathological study was conducted by Roychowdhury et al. (2021) on incudomalleolar joint. The main aim of the study was to analyse and compare the incudomalleolar joint in young and older individuals with indeterminate presbycusis. A total of 17 ears of older individuals and 13 ears of young normal individuals were considered in the study. Older individuals with sloping moderate to profound SNHL and without any histopathological evidence of sensory, neural, strial, or mixed presbycusis were included in study. The width of the incudomalleolar joint was analysed for both the older presbycutic individuals and young normal individuals. The results of the present study revealed that older individuals with indeterminate presbycusis demonstrated wider incudomalleolar joint when compared to young individuals. The widening of incudomalleolar joint in older individuals can also be a cause for high frequency hearing loss due to increase in the compliance of middle ear. Therefore, from this study we can conclude that age related changes in incudomalleolar joint can also be a possible cause for high frequency hearing loss in older individuals.

Ito et al. (2001) made an attempt a morphological study for human auricular cartilage with aging. The main aim of the study was to observe the ultrastructure changes in elastic fibres of human auricle. Human auricular cartilage was obtained from a total of 26 subjects (16 males and 10 females) aged between 16 and 79 years. Auricular cartilage was examined using light and electron microscopy. It was observed that elastic fibers in the cartilage were homogeneous in diameter whereas for older individuals the cartilage was heterogenous in thickness and collagen like fibres and small vesicles was surrounding the elastic fibres. Therefore, from this study it can be concluded that due to all these changes happening in cartilage of external ear it leads to expansion of auricle with aging.

Sullivan et al. (2010) carried out a morphometric study of external ear canal. The main purpose of the study was to show the anatomical differences in external ear canal with aging as well as to asses the differences between male and female external ear canal. A total of 123 (89 females and 39 males) subjects were studied between the age of 18 and 65 years various anatomical changes like total ear height, lobular heigh, lobular width and distance from lateral palpebral commissure to the root of the helix was analysed. It was observed in the results that lobule was the only structure which changed significantly with aging. Also collapsed in the ear canal was also observed more prominently in older individuals. Results of the study also suggest significant decrease in the lobular width with aging. Hence from the present study it can be concluded that various changes are happening in external ear, thereby affecting the audiological tests findings.

2.3 Pure Tone audiometry in older individuals

A longitudinal study on conventional pure tone audiometry and extended high-frequency audiometry was conducted in older individuals by Lee et al. (2005). The objectives taken up in the study was to evaluate longitudinal changes, i.e., the rate with which threshold changes happen on both types of audiometry across different gender, age, and people with a positive history of noise exposure. A total of 188 subjects (91 females and 97 males) between the age of 60 to 81 years participated in the study and were evaluated with both conventional pure tone audiometry (0.25 to 8 kHz) and extended high-frequency audiometry (9 to 18 kHz) every 2-3 years. Participants with a positive history of conductive pathologies like ear discharge and ear pain were excluded from the study. The study results show that the rate with which thresholds deteriorate was 0.7 dB per year at 0.25 kHz, increasing to 1.2 dB per year at 8 kHz and 1.23 dB per year at 12 kHz. Individuals with a positive history of noise exposure showed an increased rate at which thresholds become poor. Males exhibited more rapid changes than females in conventional pure tone audiometry and extended high-frequency audiometry mainly due to more exposure to the noisy situation than females. Thus, it can be concluded that both conventional pure tone audiometry and extended high-frequency audiometry display worsening of thresholds which are mainly seen due to the positive effect of aging, and also the impact of aging is more profoundly seen in males than in females.

A study was carried out by Aazh & Moore (2007) in which they investigated the possibility of a dead region at 4KHz; also, they analyzed the relation of this dead region with absolute threshold, steepness of audiogram, and pure-tone Average in elderly adults. The present study aimed to assess the prevalence of dead regions at 4KHz in older adults and to analyze whether it is possible to judge the presence or absence of dead regions based on the absolute threshold at 4KHz, pure tone average, or based on the configuration of loss. Sixty-three patients (98 ears) between the age range of 63–101 years who had sloping SNHL with an absolute threshold of 60-85 dB HL at 4KHz were included in the study. The individuals with any evidence of conductive pathology were not included in the study. Threshold-equalizing noise (TEN) test

(Moore et al., 2004) was used to determine and confirm the presence or absence of a dead region at 4KHz. The results obtained in the study suggest a potential prevalence of 37% (36 out of 98 ears) at 4KHz. Still, neither audiogram slope below and above 4KHz nor absolute thresholds at 4KHz can be a possible indicator of a dead region. Therefore, we can conclude there are high chances of dead regions being present at a higher frequency, which can further cause problems with speech perception in elderly adults. Hence, we need to evaluate and identify the presence of a dead region.

Chaitra et al. (2020) studied the effect of aging on hearing thresholds and compared the changes across gender in the individual of city Bangalore. The main objectives taken up in the study were to examine the changes in hearing thresholds in both males and females and to even compare the rate at which the threshold changes for both genders. A total of 100 individuals volunteered for the study, of which 46 were males, and 54 were females. Participants between the age range of 20-60 years participated in the study. Each individual was provided with a questionnaire to fill, which included questions to rule out any history of otorrhea, head trauma, noise exposure, diabetes, and hypertension. All the individuals who met the inclusion criteria were evaluated using an ARPHI 500 MK 1 audiometer, and pure tone thresholds were obtained from 0.25 to 8KHz in all the octave frequencies. Results showed the mean hearing thresholds decreased from 17.82 to 14.02 in frequencies 0.5 kHz to 2 kHz in males and 15.18 to 12.50 in frequencies 0.25 kHz to 1 kHz in females. The mean rate of increase in threshold was 0.30 dB per decade for males and 0.40 dB/decade for females at 0.25KHz, whereas the mean rate of growth in the threshold at 8KHz was found to be 0.62 dB/ year and 0.27 dB/ year for males and females respectively. Therefore, in this study, we can clearly see the influence of gender on age-related hearing loss. And it can be concluded that females display a faster rate at which thresholds worsen at low frequencies. On the other hand, males display a rapid increase in thresholds which is more significant at higher frequencies (4KHz and 8KHz).

Audiometric characteristics for older individuals were analyzed in a study by Saqulain et al. (2021). The main aim of the study was to examine the audiometric aspects, mainly the configuration and degree of hearing loss in individuals with presbycusis. A descriptive cross-sectional research design was used to carry out the study. A total of 192 subjects (129 males and 63 females) between the age of 50 to 80 years (mean age: 65.85 ± 7.36 years) with no infections in the outer and middle ear, otosclerosis, Meniere's disease, tympanosclerosis, ototoxicity, and acoustic neuroma were considered for the study. Pure tone audiometry was done for all the subjects for all the octaves frequencies from 0.25 to 8 kHz. Results showed the predominant number of individuals with the gently sloping type of audiogram configuration, which was seen in 58 (30.2%) and 65 (33.9%) audiograms for right and left ears, respectively, which was followed by steeply sloping configuration. They also found a relation between the configuration of the audiogram and the age of the individuals, the majority of individuals who showed the presence of a gently sloping audiogram were between the age of 60 to 70 years, whereas steeply sloping audiogram was more predominantly seen in individuals after the age of 70 years. Regarding the severity of hearing loss, the majority, 77 (40.10%) and 71 (36.98%) of the right and left ears, respectively, had moderately severe hearing loss. In contrast, the second-most prevalent kind, severe HL, impacted 60 (31.25%) and 70(36.46%) of the right and left ears, respectively. Thus, we can conclude that the most frequent configuration of an audiogram was a high frequency gently sloping curve, followed by a high frequency sharply sloping curve. The most frequent hearing loss, in terms of severity, was moderately severe, followed by severe hearing loss.

2.4 Speech audiometry findings in older individuals

A study conducted by Dlouhá et al. (2017) assessed the speech recognition of older individuals in the presence of noise. The principal aim of the study is to compare speech recognition ability in the presence of noise in different age groups of older individuals. 423 subjects participated in the study; these participants were divided into two groups based on age. The first group, labeled as young, consisted of 191 subjects between the age of 40 to 65 years (Mean age: 55.8 years), and the second group, i.e., the older group, consisted of 232 individuals between the age of 66 to 85 years (mean age: 75.4 years). The participants of both groups did not have any significant middle ear or outer ear infection history. Speech audiometry tests were conducted for both the groups in 2 conditions first in the absence of speech babble and second in the presence of speech babble. In the second condition, the sentences and the competing signal were both presented at 65 dB SPL. A significant difference was observed between the younger and the older groups, with younger group having better speech recognition scores in both conditions when compared to the older group. Thus, it can be inferred from this study that the speech recognition scores decline with age in both the presence and absence of a competing signal.

Another common problem that is usually associated with aging is cognitive issues. Aimoni et al. (2015) studied the effect of mild cognitive impairment in speech recognition tests in the presence of noise in older individuals. The study's principal objective was to compare the speech perception scores in presence of noise between older adults with mild cognitive impairment, older adults without mild cognitive impairment, and younger individuals without cognitive impairment. 48 subjects volunteered for the study; they were divided into 3 different groups: the first group consisted of sixteen elderly subjects with amnesic mild cognitive impairment (mean age: 78.6 years), the second group consisted of sixteen elderly subjects without cognitive impairment (mean age: 76 years) and the third group consisted of sixteen normally hearing young individuals (mean age: 22.5 years). A speech recognition test was done for subjects of all the groups in the presence of 3 different types of noise: speech noise, ICRA (International Collegium of Rehabilitative Audiology) noise, and continuous discourse stimuli. It was observed in the results that older adults with mild cognitive impairment performed poorer compared to the other 2 groups. But it was also observed that elderly subjects without cognitive impairment also had less speech recognition scores when compared with the younger group. Therefore, it can be concluded that speech recognition scores in the presence of noise get affected in elderly individuals with or without cognitive impairment. Speech recognition scores become poorer if cognitive impairment is also present.

Decambron et al. (2022) performed a study to measure the SNR loss happening as age progresses. The current study's objective was to offer typical SNR Loss values on rapid speech in noise tests for persons with normal hearing, as defined by ISO 7029, for each age group. A total of 200 individuals between the age of 20 and greater than 70 years participated in the study. All of these individuals were assessed using pure tone audiometry, and individuals with normal pure tone average as specified by ISO 7029 were only considered. Participants were even screened to rule out any possible conductive pathology. Rapid speech in noise test was done in all these participants using a loudspeaker situated in at 0º azimuth and other 5 loudspeakers at 0º, +60º, +120º, −60º, and −120º azimuth at varying intensity. Spearman-Kärber equation was used to measure the SNR loss across all the age groups. Age had a significant impact on SNR Loss, with a difference of more than 6 dB between the youngest (20–30 years old) and oldest (> 70 years old) groups. However, no difference in SNR loss was observed between the gender. Therefore, from this study, SNR Loss readings for each age group may serve as a foundation for interpreting the test according to the patient's age. Finally, SNR Loss scatter grew with age, probably due to extra central causes accelerating the aging of the peripheral inner ear.

Tereza de Matos Magalhães et al. (2007) conducted a study to assess the speech discrimination index in elderly individuals. The main goal of the experiment was to assess the audiometric level and configuration of presbycusis and to correlate speech ability with Speech Recognition Test (SRT) and speech identification scores (SIS). 50 subjects (27 male and 23 female) between the age range of 60 to 97 years (mean age: 73.6 years) were selected for the study. None of the individuals had a history of ear discharge, ear surgery, and any outer and middle ear infections. Pure tone audiometry, SRT, and SIS were done on these individuals. Based on the SIS scores, individuals were categorized as normal limits (100% to 92%), slight difficulty (88% to 80%), moderate difficulty (76% to 60%), poor discrimination (56% to 52%) and very poor discrimination (below of 50%). When the correlation between SRT and SIS was computed, it presented a mixed result; even if the hearing loss was minimal, the discrimination was occasionally quite poor, or in the case of substantial auditory losses, they showed normal limits of SIS. From this study, it can be inferred that SRT may not always function as a factor in predicting the SIS scores that individuals acquire.

2.5 Immittance Audiometry Findings in older individuals

Wiley. (1996**)** attempted to check for various changes than can possibly happen in tympanometric tests as a result of aging. The main objectives that were taken up in this study were to study the age effect as well as gender effect in various parameters of tympanometry. In this study, 1240 adults (2147 ears) ranging in age from 48 to 90 years which included 825 male ears and 1322 female ears, were taken up. All the selected participants did not have any significant history of ear discharge, ear surgery, head trauma and their air bone gap were not more than 15 dB. Tympanometry was administered in all the subjects, and various parameters were considered like peak compensated static acoustic admittance, equivalent ear canal volume, and tympanometric width. The results showed peak static admittance tended to decline with age, suggesting the middle ear becoming stiffness dominated with aging; however, the age trend was no longer significant when correcting for gender. Equivalent ear canal volume tends to decrease with age; even after accounting for gender, this tendency remained substantial. Tympanometric width increased as a function of age and was significant even after adjusting for gender. A gender effect was present in peak static admittance and equivalent ear canal volume, with admittance value significantly higher for males compared to females and females having significantly smaller ear canal volumes. However, there was no significant difference in tympanometric width in males and females. Therefore, it can be concluded that changes in the middle ear due to aging lead to alteration in the tympanometric findings.

The study mentioned above concluded that changes in different tympanometric parameters with aging are observed. On the contrary, there are equivocal sets of studies that have reported no change in tympanometric findings as age progresses. One of the studies by Stenklev et al. (2014) was conducted to check the effect of aging on tympanometric results. The study's principal objective was to assess different tympanometric parameters with aging and to compare the tympanometric data of age-matched males and females. 60 elderly individuals with age greater than 60 years participated in the study. ENT expert and an experienced audiologist screened all the subjects to rule out any possibility of middle ear pathology in these subjects. These individuals underwent tympanometric evaluation, and the following parameters were considered from tympanometry: tympanometric peak pressure, static admittance, and equivalent ear canal volume. The findings revealed no significant changes in tympanometric peak pressure, static admittance, and equivalent ear canal volume across all ages. In contrast, there were substantial differences in equivalent ear canal volume and static admittance between males and females, with males having higher equivalent ear canal volume and static admittance compared to females. But tympanometric peak pressure was not different in males and females. Therefore, according to this study, we can infer that the changes happening within the middle ear due to aging are not sufficient enough to alter the tympanometric findings in older individuals.

In another retrospective study conducted by Sinha et al. (2021), tympanometric parameters were assessed in older individuals in the Indian population. The main aim of the study was to evaluate the tympanometric characteristics of older individuals in the Indian population. A total of 593 individual case files, 342 females and 252 males between the age of 50 to 98 years, were taken for the study. All the individuals reporting complaints related to hearing loss were included in the study. Tympanometry was administered in all the individuals, and the following parameters were studied: tympanogram type, tympanometric peak pressure, static admittance, and equivalent ear canal volume. Results showed no significant difference in male versus female and right ear versus left ear up to the age of 61 years. Whereas, between the age of 61 to 70 years, there was a significant difference noted in the equivalent ear canal volume of the right ear and left ear between males and females, with males having higher ear canal volume compared to females. Between the age of 71 to 80 years, equivalent ear canal volume was significantly higher in males compared to females in both the ears, tympanometric peak pressure was significantly higher for females compared to males in the right ear, and static admittance was significantly higher for males for the right ear. Thus, we can conclude from this study that there are changes observed between males and females in a few age groups, but these changes do not show any consistent trend across the age groups.

Due to the more negligible effect of aging seen in standard tympanometry, various authors have tried to explore the possibility of checking for age-related changes in multi-frequency tympanometry. Wiley (1999) studied the effect of aging on the resonant frequency of older individuals using multi-frequency tympanometry. The main goal of the current study was to assess how age and gender affected variations in middle ear resonance in older persons. In this study, 404 participants (180 males and 224 females) between the age of 48 to 90 years without any middle ear pathology and an air-bone gap less than 15 dB were considered for the study. Using a computer-based measuring device, sweep-frequency tympanograms at probe frequencies ranging from 250 to 2000 Hz were recorded in one ear (assigned at random) of each participant. The results revealed no significant changes in the mean middle ear resonant frequency in older individuals among the age groups (48-59, 60-69, 70-79, and 80-90 years). Middle ear resonance frequencies in older people were more significant for females than for males after controlling for the age group. In summary, the results of this study did not show any significant effect of aging on the resonant frequency of the middle ear though the gender effect was significantly evident.

A study by Lo. (2020), made an attempt to establish the normative data for older individuals in multi-frequency tympanometry in the Chinese population. The primary purpose of this study was to produce the normative data for standard and multiple frequency tympanometry in Chinese young and older individuals. The impact of age and gender was also examined in this study. A total of 200 participants were considered in the study and were divided into 2 groups based on age. Group 1 included 100 individuals (50 males and 50 females) between the ages of 55 and 85 years, and group 2 had 100 individuals (50 males and 50 females) between the ages of 20 and 35 years. Standard tympanometry at 226Hz and multi-frequency tympanometry in 3 different probe tone frequencies was performed at 226Hz, 678Hz, and 1KHz. The pattern of susceptance and conductance was noted at all the probe tone frequencies and categorized according to the Vanhuyse model, which was 1B1G, 3B1G, 3B3G, and 5B3G. It was observed in results that for standard tympanometry only difference that was significantly seen was a larger ear canal volume for older adults compared to young individuals. In contrast, other parameters like static admittance and tympanometric peak pressure did not show any significant change between young and older adults. In the case of multi-frequency tympanometry, it was observed that all the participants had a 1B1G pattern when a 226 Hz probe tone was used, irrespective of the participant's age. In comparison, a significant number of older adults displayed the presence of a 3B1G pattern for 678Hz probe frequency compared to young adults, who showed more individuals with 1B1G even at 678 Hz probe frequency. There was no difference seen between 2 groups when a 1 kHz probe frequency was used. The difference was even seen with respect to the resonant frequency, with older individuals having significantly lower resonant frequency than the young group. Therefore, it can be concluded with this study that the effect of age can only be substantially seen on ear canal volume for standard tympanometry. Whereas, for multi-frequency tympanometry, it can be inferred that older individuals show more complex Vanhuyse patterns even for low-frequency probes compared to young adults. It can also be concluded that resonant frequency decreases with aging.

Therefore, as discussed existing literature have equivocal number of studies which have suggested involvement of various structures of ear with aging. The literature suggests there are high possibility for older individuals to have a mixed hearing loss associated with aging as well due to involvement of middle ear. However, all the previous studies in literature have neglected the mixed hearing loss and only studied various audiological tests in individuals with SNHL as age increases. And hence, the present study was taken up to assess and compare the configuration, SIS and various tympanometric parameters in both mixed hearing loss and SNHL across different age groups in older individuals.

Chapter 3

Methods

The focus of the study was to profile the audiological findings of individuals with age-related hearing loss who reported to the All-India Institute of Speech and Hearing (AIISH) with complaints of reduced hearing sensitivity. To arrive at the objectives of the study following methodology was adopted.

Research design

The current study employed a retrospective register-based research design to determine the pattern of audiological test findings and correlate the outcomes of various audiological test findings in older individuals.

Participants Selection Criteria

144 subjects' case files, who reported to AIISH between January 2019 to December 2020 were extracted. Individuals who satisfied the criteria mentioned below were taken up for the study. The case files were extracted from the AIISH clinical database based on the following criteria.

Inclusion Criteria:

1. All participants older than 50 years were considered for the study.
2. Participants with complaints of reduced hearing sensitivity along with or without Tinnitus were included in the study.
3. Participants with all the degree of hearing loss were considered for the study.
4. Participants with associated conditions like diabetes, hypertension, and thyroid were also included in the present study.

Exclusion criteria:

1. Participants with complaints or a history of middle ear pathology like otorrhea, otalgia, blocking sensation, and head trauma was not considered for the study.
2. Participants with suspected middle ear problems observed by an experienced ENT specialist were excluded from the study.
3. Participants with the abnormal tympanogram type except ‘A,’ ‘Ad,’ and ‘As’ were also not considered for the study.

Procedure:

The research was divided into 2 phases:

Phase 1: Case files were extracted using AIISH Client Database Management Software (CDMS) after obtaining permission from the concerned authority. The filter settings used to extract the case file from the AIISH database were based on the inclusion and exclusion criteria mentioned above.

Table 3.1

Key words used to retrieve case file from AIISH CDMS.

Details	Eligibility criteria
1. Date	January 2019 to December 2020
2. Age	50 years and older.
3. Gender	Male and Female
4. Complaints	• Reduced hearing sensitivity • Reduced hearing sensitivity and Tinnitus.
5. Degree of hearing loss	All degree

After applying the aforementioned filter parameters, a total of 300 case files were selected and scanned for further shortlisting. Out of these 300 case files, 156 case files were rejected considering inclusion and exclusion criteria. 48 case files were rejected because middle ear pathology was suspected by an ENT expert, 91 cases were due to a history of ear discharge being present, and the remaining 17 cases were due to a history of ear surgery. Finally, 144 case files were considered for data collection, which included 93 male and 51 female participants between the age of 50 to 100 years.

Phase 2 involved categorizing the participants and inscribing the results of different audiological tests. The information taken from the case file was as follows:

- Demographic information: Client's name, age, gender, and occupation.
- Client's complaints.
- Duration of complaints.

- Associated problems and course of associated issues.
- Pure tone audiometry threshold on octave frequencies between 250Hz and 8KHz for air conduction (AC) mode, from 250Hz to 4Khz for Bone conduction (BC) mode, and pure tone average.
- Speech identification scores (SIS) and Uncomfortable level (UCL) from speech audiometry test results.
- Different parameters of the tympanograms, such as tympanometric type, equivalent ear canal volume (EECV), tympanometric peak pressure (TPP), tympanometric width (TW), and static admittance (SA).

Based on the type of hearing loss observed in the pure tone audiometric data, participants were divided into two groups (Figure 3.1):

Group-1: Consisted of 137 ears with SNHL. Individuals with both AC and BC thresholds greater than 15 dB but with air bone gap within 10 dB were included in this group. Group-1 was further subdivided into two subgroups, i.e., group-1a (G-1a) and group-1b (G-1b); based on the audiogram configuration. G-1a consisted of 45 ears with flat hearing loss; audiogram configuration was considered flat if the AC thresholds between octaves did not differ by more than 5 dB. G-1b consisted of 92 ears with sloping hearing loss; configuration was considered sloping if the AC threshold per octave progressively increased at a rate of 5-10 dB/octave. Carhart's (1945) specified protocol was considered while dividing individuals based on the configuration.

Group- 2: Consisted of 151 ears with Mixed Hearing Loss (MHL). The criteria for diagnosing MHL were based on AC and BC thresholds and also air-bone gap. Individuals with both AC and BC thresholds affected and air bone gap (ABG) greater than 10 dB were considered in this group. However, the group- 2 was not further subdivided based on the configuration of the audiogram pattern.

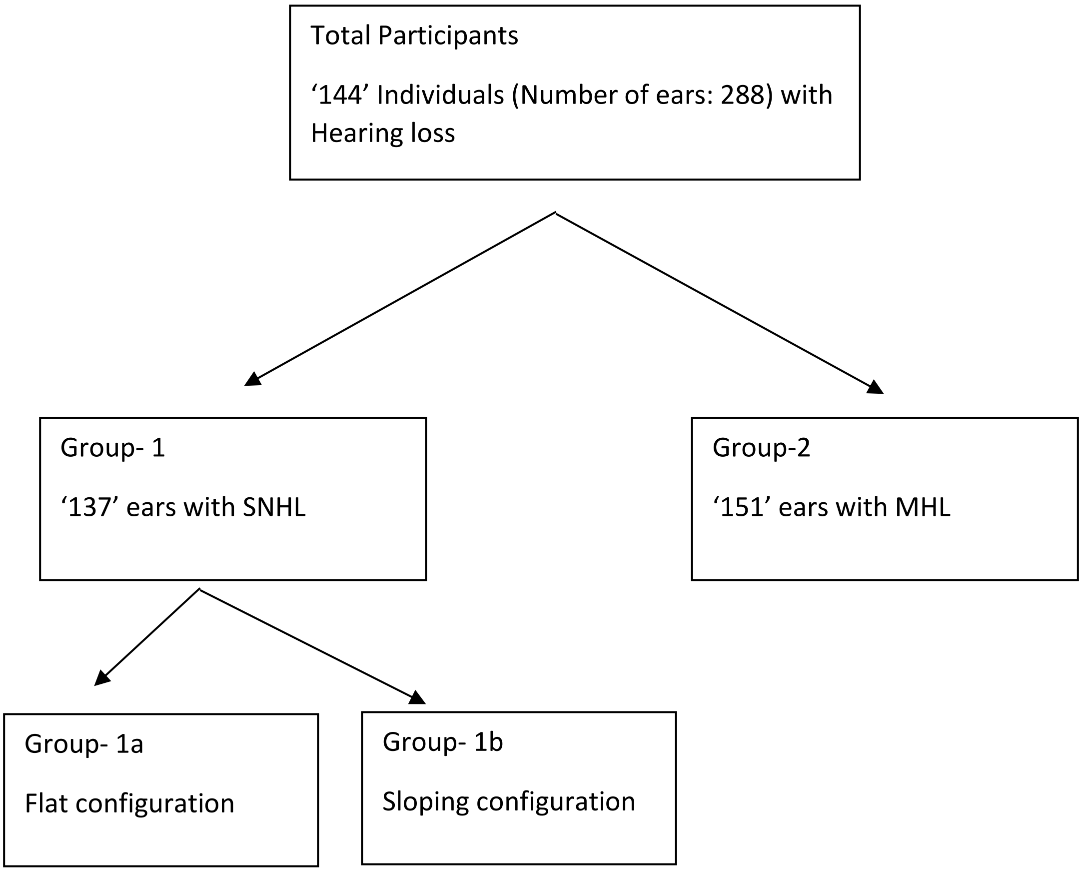

Figure- 3.1: *Summary of participants groups.*

The Tympanometry values noted were used to designate the tympanometric type. SA and TPP were used for labeling the type. Tympanometry type 'A' was labeled if SA was between 0.5 to 1.75 mmho and TPP between -100 to +60 dapa, 'As' type if SA was less than 0.5 and TPP between -100 to +60 dapa, 'Ad' type if SA was greater than 1.75 with TPP between -100 to +60 dapa.

Data Analysis

Utilizing the proper descriptive statistical methods, the data was examined after being gathered via the retrospective case file analysis. Descriptive analysis was carried out for various factors that were present in the case file. Afterward, descriptive statistics were performed comparing the audiogram pattern configuration obtained between SNHL and mixed hearing loss. Tympanometric parameters (static admittance, equivalent ear canal volume, and tympanometric peak pressure) were compared between mixed and sensorineural hearing loss groups as well as across different age groups. SIS findings were compared across age groups, between SNHL and mixed hearing loss groups as well as between different audiogram configurations of SNHL (sloping and flat configuration). Lastly, the tympanometric findings obtained in the present study were compared with the study of Wiley (1996b). An attempt was even made to compare the various audiological test findings between males and females.

Chapter 4

Results

The study aimed to investigate different audiological test findings in SNHL and mixed hearing loss group due to aging. Demographic details and various audiological findings like audiogram configuration, speech identification score, tympanometric findings (static admittance, tympanometric peak pressure, and equivalent ear canal volume) were obtained from the client's clinical files. All these data obtained were analyzed and compared using various descriptive and inferential statistical tools. The results are explored in the following sections.

4.1 Demographic Details

Total number of individuals who participated in study were 144 (no. of ears: 288), these participants were divided into 4 categories based on their age: 50 to <60 years (Total=26; M: 12 and F: 14), 60 to <70 years (Total=35; M: 20 and F: 15), 70 to <80 years (Total=40; M: 28 and F: 12) and 80 years and above (Total=43; M: 33 and F: 10).

The majority of the individuals in the present study were males who were 93 in number (65.58%). On the other hand, there were 51 (35.42%) female participants. Table 4.1 shows the distribution of male and female participants across different age groups.

Table 4.1

Distribution of male and female participants in each age group.

		Gender		
		Male	Female	Total
Age	50- <60 years	12	14	26
	60- <70 years	20	15	35
	70- <80 years	28	12	40
	80 years and above	33	10	43
Total		93	51	144

4.2 Type of Hearing loss in male and female ears across age

The total number of ears in all the age groups was further divided into 2 groups based on the type of hearing loss viz. SNHL and mixed hearing loss. Data from 288 ears were taken, including 102 female and 186 male ears. There were 137 ears (M: 88 and F: 49) with SNHL and 151 ears (M: 98 and F: 53) with mixed hearing loss. The total number of ears having mixed hearing loss and SNHL in male and female participants across different age groups is represented in figure 4.1.

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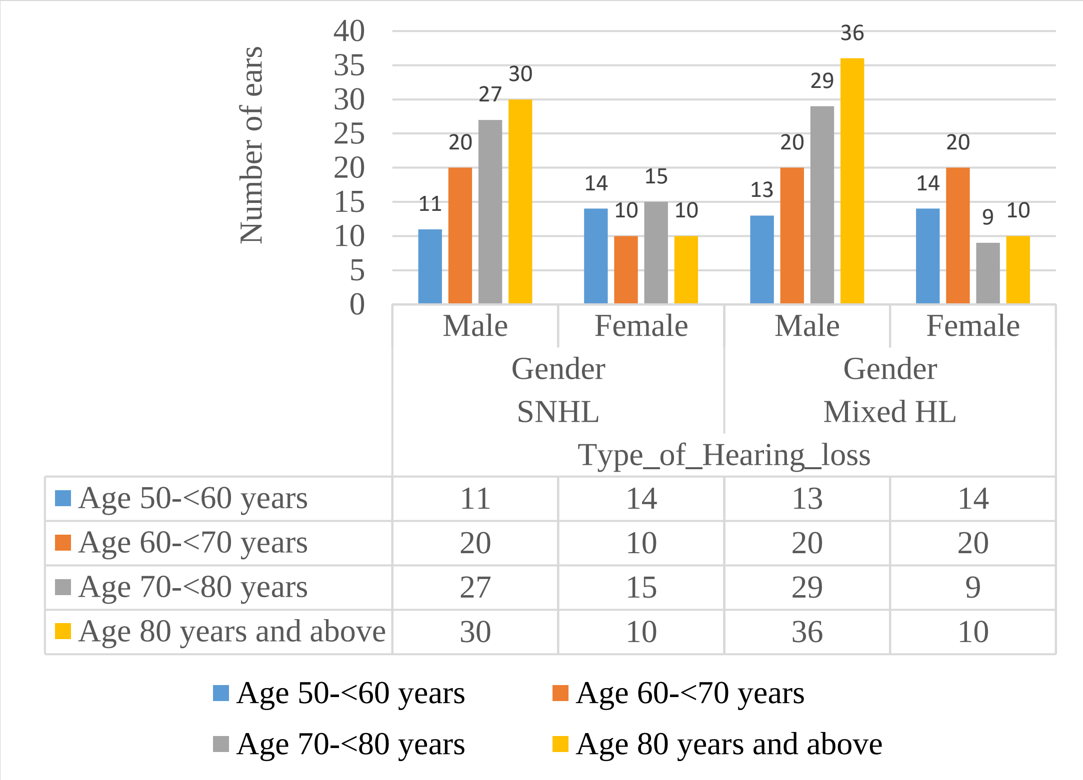
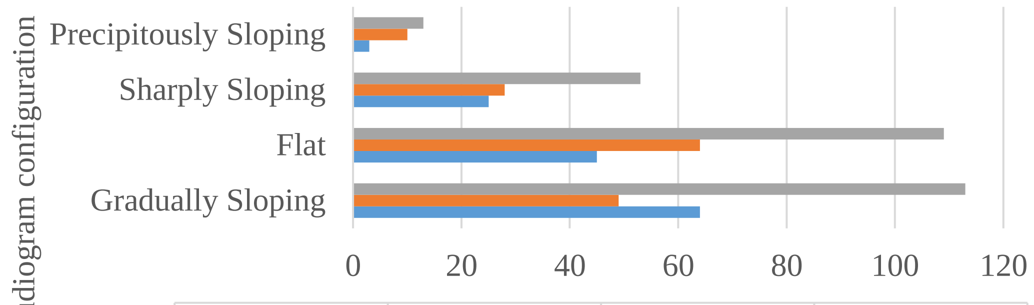


Figure 4.1: *Distribution of the number of ears of male and female participants considered in the study across different age groups and type of hearing loss.*

4.3 Configuration of hearing loss obtained in SNHL and mixed hearing loss group across age groups

The type of hearing loss was further divided based on the obtained AC audiogram configuration. It was observed that the total ears with a gradually sloping configuration were 133 (SNHL: 64 and MHL: 49), the flat configuration was 109 (SNHL: 45 and MHL: 64), sharply sloping configuration was 53 (SNHL: 25 and MHL: 28), and precipitously sloping configuration was 13 (SNHL: 3 and MHL: 10). It can be observed that gradually sloping (39.23%), and flat configuration (37.84%) are predominantly seen compared to sharply sloping (18.4%) and precipitously sloping (18.44%) configurations. Figure 4.2 shows the distribution of configuration of audiogram obtained in SNHL and mixed hearing loss.

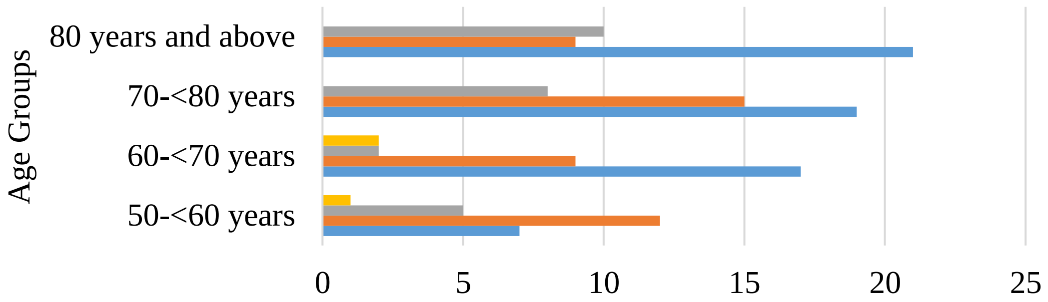


	Gradually Sloping	Flat	Sharply Sloping	Precipitously Sloping
Total	113	109	53	13
Mixed HL	49	64	28	10
SNHL	64	45	25	3

Figure 4.2: *Distribution of AC audiogram configuration in SNHL and mixed hearing loss.*

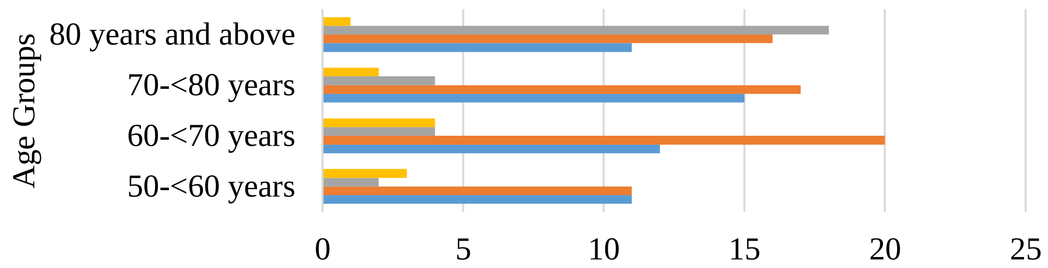
Further, the age wise distribution of configuration of hearing loss for ears with SNHL and mixed hearing loss was also obtained. Figure 4.3 represents the distribution of configuration of audiogram for ears with SNHL across various age groups. It was observed that with increase in age the number of ears with gradually sloping and sharply sloping also increase, on the other hand ears with flat or precipitously sloping configuration decrease or remained same with age.

Similarly, for ears with mixed hearing loss it was observed that frequency of sharply sloping configuration increase with age. Whereas, ears with other configuration pattern remained same across all the age groups. Figure 4.4 represents the distribution of configuration of audiogram for ears with mixed hearing loss across age various age groups.



	50-<60 years	60-<70 years	70-<80 years	80 years and above
Precipitously Sloping	1	2	0	0
Sharply Sloping	5	2	8	10
Flat	12	9	15	9
Gradually Sloping	7	17	19	21

Figure 4.3: *Distribution of audiogram configuration seen in ears with SNHL across age groups.*



	50-<60 years	60-<70 years	70-<80 years	80 years and above
Precipitously Sloping	3	4	2	1
Sharply Sloping	2	4	4	18
Flat	11	20	17	16
Gradually Sloping	11	12	15	11

Figure 4.4: *Distribution of audiogram configuration seen in ears with mixed hearing loss across age groups.*

4.4 Association between type and configuration of hearing loss

Audiogram configuration of ears with SNHL was dominated by gradually sloping configuration (46.7%) followed by flat configuration (32.8%). Only a few ears with SNHL demonstrated the presence of sharply sloping (18.2%) and precipitously sloping configurations (2.2%).

On the contrary, most ears with mixed hearing loss had a flat configuration (42.4%), followed by a gradually sloping configuration (32.5%). However, only a few ears had sharply (18.5%) and precipitously sloping configurations (6.6%). The distribution of configuration of audiogram patterns across different types of hearing loss is represented in figure 4.5.

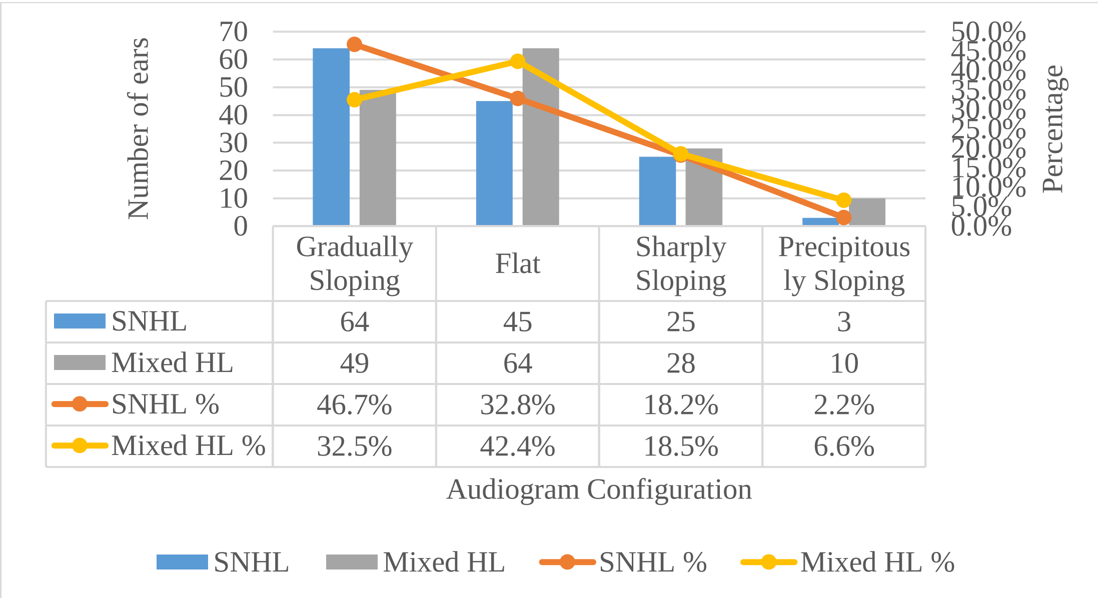


Figure 4.5: *Distribution of audiogram configuration in SNHL and mixed hearing loss.*

The Pearson Chi-square test was used to check whether there was a relationship between the type of hearing loss and the audiogram configuration. Results of the Pearson Chi-square test revealed an association between the type and the configuration of hearing loss [χ^2 (3) =8.582, p =0.035]. It was seen that ears with SNHL demonstrated predominant presence of gradually sloping hearing loss. Whereas, flat configuration was predominantly seen in ears with mixed hearing loss.

4.5 SIS findings

The SIS scores were taken for both, the SNHL and mixed hearing loss groups. SNHL group was further divided into 2 subgroups based on the configuration i.e., SNHL sloping and SNHL flat group, whereas the mixed was not classified further based on configurations. The total number of ears with SNHL sloping configuration, SNHL flat configuration, and mixed hearing loss was found to be 91, 46, and 151, respectively. Table 4.2 represent the mean, SD, and median of SIS across different type and configuration of hearing loss.

Table 4.2

Mean, SD, and median of SIS across different types and configurations of hearing loss.

Type of hearing loss	N	Mean	Std. Deviation	Median
SNHL sloping	91	73.2308	20.58644	76.0000
SNHL flat	46	72.1304	22.29660	72.0000
Mixed HL	151	75.1391	23.68066	80.0000
Total	288	74.0556	22.48027	80.0000

To compare SIS scores between males and females within SNHL sloping, SNHL flat and mixed hearing loss group, data was subjected to the normality check. The normality test was conducted for SIS for all the groups i.e., SNHL with sloping and flat configurations and mixed hearing loss to investigate whether the data was normally or non-normally distributed. Shapiro-Wilk test of normality was used, and data showed a non-normal distribution. Therefore, the Mann-Whitney U test was used to compare SIS between male and female ears in SNHL with sloping and flat configurations and mixed hearing loss groups irrespective of the age groups.

The Mann-Whitney U test results revealed no significant difference between males and females observed for any groups, i.e., SNHL sloping, SNHL flat, and mixed hearing loss group. Table 4.3 shows the Z and p values along with mean SIS scores for comparison of SIS between male and female ears in SNHL with sloping and flat configuration and mixed hearing loss groups.

Table 4.3

Mean, SD, median, Z, and p-value of SIS values for males and females across different types and configurations of hearing loss.

	N		Mean ± SD		Median		Mann Whitney U test value	
Type and configuration of HL	M	F	M	F	M	F	|Z|	p
SNHL sloping	61	30	73.01 ± 19.31	73.67 ± 23.31	76.00	76.00	0.551	0.582
SNHL flat	27	19	74.3 ± 23.81	69.05 ± 20.17	80.00	72.00	1.187	0.235
Mixed HL	98	53	76.39 ± 22.18	72.83 ± 26.29	80.00	80.00	0.634	0.526

4.5.1 Comparison of SIS for ears with SNHL with sloping configuration across age groups

Differences were observed in the SIS for SNHL sloping group across age groups. And hence, the Kruskal-Wallis test was conducted to check whether these differences are significant. Mean and SD values of SIS scores for ears with SNHL sloping configuration across various age groups are represented in table 4.4.

Table 4.4

Mean and SD of SIS obtained in ears with SNHL with sloping configuration across various age groups.

Age	N	Mean	Std. Deviation
50-<60 years	13.00	83.69	12.59
60-<70 years	20.00	76.40	17.08
70-<80 years	27.00	76.44	20.44
80 years and above	31.00	64.00	22.58

The results of the Kruskal-Wallis test suggest a significant difference at least between 1 age group (p = 0.009). Pairwise comparison of groups using Bonferroni post-hoc test revealed a significant decline in SIS for 80 years and above group when compared with 50 to <60years (p = 0.003), 60 to <70 years (p = 0.029) and 70 to <80 years groups (p = 0.013). Whereas there was no significant difference present between any other groups. Test statistics and p values for all the pairwise comparison between age groups is represented in table 4.5, and figure 4.6 represent SIS scores of ears with SNHL across various age groups.

Table 4.5

p values for pairwise comparison of SIS for ears with SNHL with sloping configuration between age groups.

Pairwise comparisons	Test Statistic	Significance (p-value)
≥80 years and 60-<70 years	16.51	0.029*
≥80 years and 70-<80 years	17.28	0.013*
≥80 years and 50-<60 years	25.74	0.003*
60-<70 years and 70-<80 years	-0.77	0.92
60-<70 years and 50-<60 years	9.23	0.32
70-<80 years and 50-<60 years	8.45	0.34

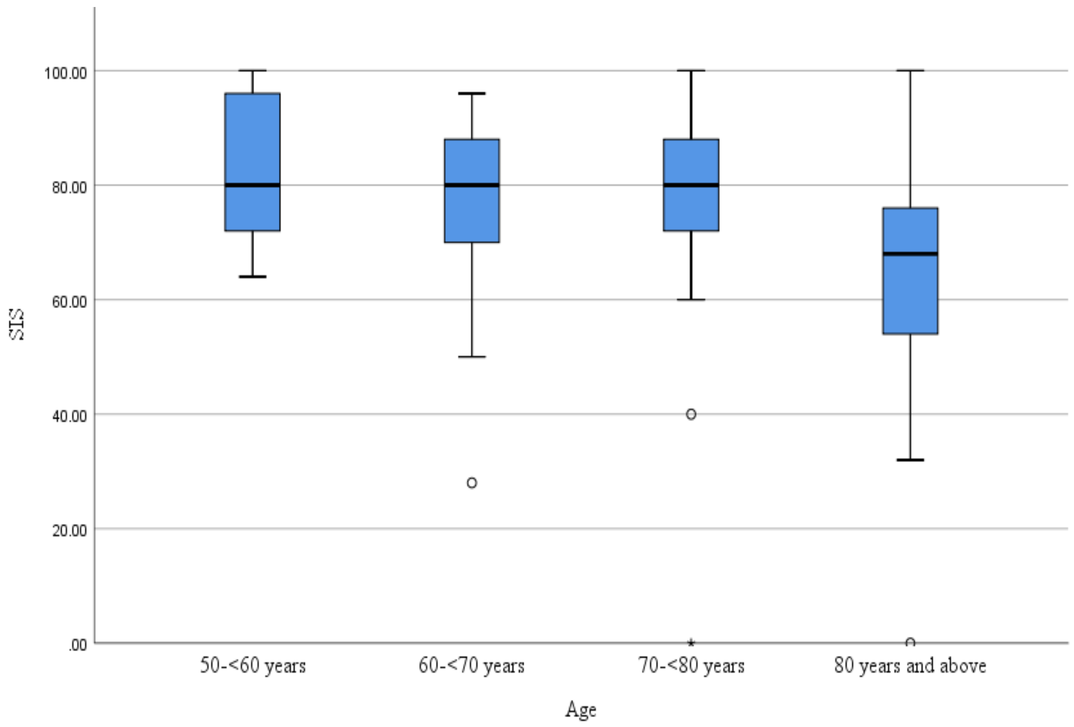


Figure 4.6: *SIS of ears having SNHL with sloping configuration across age groups.*

4.5.2 Comparison of SIS obtained in ears with SNHL with flat configuration across age groups

Differences were observed in the SIS for SNHL flat group across age groups. And hence, the Kruskal-Wallis test was conducted to check whether these differences are significant. Mean and SD values of SIS scores for ears with SNHL flat configuration across various age groups are represented in table 4.6.

Table 4.6

Mean and SD of SIS obtained in ears with SNHL with flat configuration group across various age groups.

Age	N	Mean	Std. Deviation
50-<60 years	12	85.67	12.59
60-<70 years	10	77.60	22.17
70-<80 years	15	62.67	28.35
80 years and above	9	63.78	7.77

The Kruskal-Wallis test results indicate a significant difference between at least one age group ($p = 0.017$). And hence, pairwise comparisons between all the age groups were carried out using Bonferroni post-hoc test. It was seen that SIS was significantly reduced for ≥80 years group when compared to 50-<60 years ($p = 0.005$) and 60-<70 years ($p = 0.046$). A significant decline in SIS score was also observed in the 70 to <80 years group compared to the 50 to <60 years age group ($p = 0.019$). In contrast, other age groups showed no significant difference ($p > 0.05$). Thus, statistical analysis showed significant change in SIS with change in age of two decades. p values for all the pairwise comparisons between age groups are shown in table 4.7, and figure 4.7 represents the SIS obtained across different age groups in ears with SNHL with flat configuration.

Table 4.7

p values for pairwise comparison of SIS for ears with SNHL with flat configuration between age groups.

Pairwise comparisons	Test Statistic	Significance (p-value)
≥80 years and 60-<70 years	12.23	0.046*
≥80 years and 70-<80 years	4.35	0.44
≥80 years and 50-<60 years	16.51	0.005*
60-<70 years and 70-<80 years	7.88	0.149
60-<70 years and 50-<60 years	4.27	0.455
70-<80 years and 50-<60 years	12.15	0.019*

* Indicates a significant difference between groups

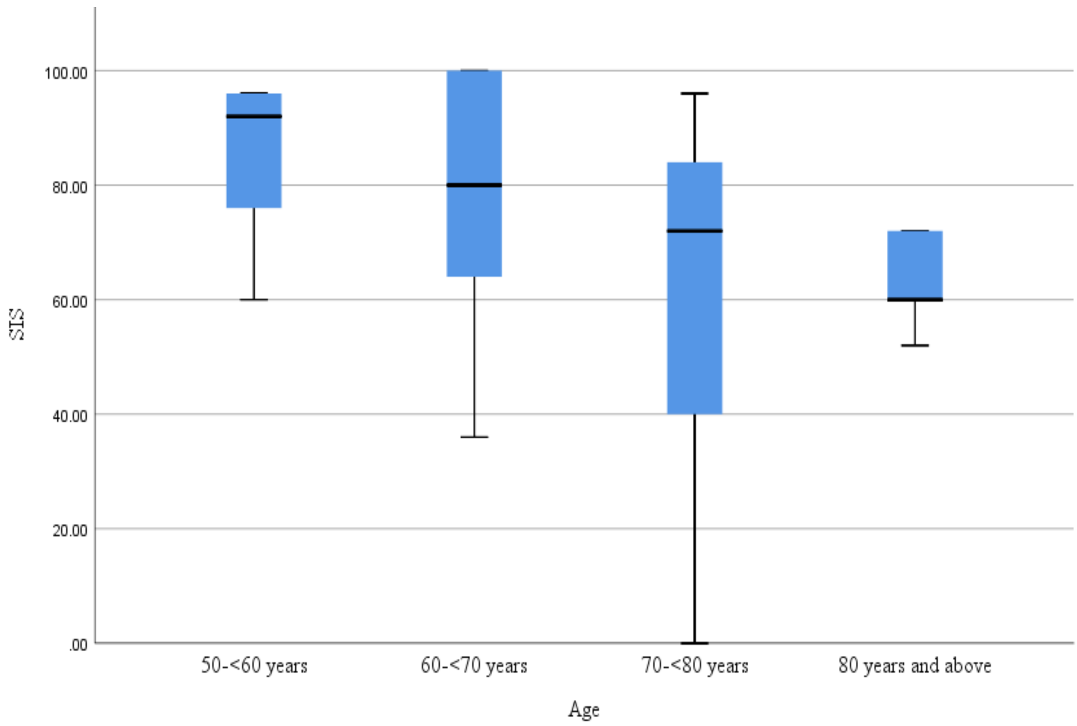


Figure 4.7: *SIS of ears having SNHL with flat configuration across age groups.*

4.5.3 Comparison of SIS obtained in ears with mixed hearing loss across age groups

Differences were evident in the SIS for ears with mixed hearing loss across various age groups. Therefore, the Kruskal-Wallis test was carried out to determine whether or not these differences are significant. Table 4.8 shows the mean and standard deviation (SD) values for SIS scores for ears with mixed hearing loss across different age groups.

Table 4.8

Mean and SD of SIS obtained in ears with mixed hearing loss across various age groups.

Age	N	Mean	Std. Deviation
50-<60 years	27	87.26	18.37
60-<70 years	40	72.40	27.64
70-<80 years	38	79.74	19.54
80 years and above	46	66.61	22.62

Kruskal-Wallis test revealed significant difference present between at least one of the groups (p = 0.000). Pairwise comparisons were carried out using Bonferroni post-hoc test to know which groups were significantly different from each other. It was observed that SIS for 80 years and above group was significantly lower compared to 50-<60 years (p = 0.000) and 70-<80 years group (p = 0.005). Similarly, SIS of 60-<70 years group was also significantly lower than 50-<60 years groups (p = 0.006). All the other pairwise comparison did not show any significant difference. p values for all the pairwise comparisons of SIS between age groups are shown in table 4.9 and figure 4.8 represents the SIS across different age groups of ears with mixed hearing loss.

Table 4.9

p values for pairwise comparison of SIS obtained in ears with mixed hearing loss between age groups.

Pairwise comparisons	Test Statistic	Significance (p value)
≥80 years and 60-<70 years	16.95	0.072
≥80 years and 70-<80 years	26.73	0.005*
≥80 years and 50-<60 years	46.74	0.000*
60-<70 years and 70-<80 years	-9.78	0.321
60-<70 years and 50-<60 years	29.79	0.006*
70-<80 years and 50-<60 years	20.01	0.068

* Indicates significant difference between groups.

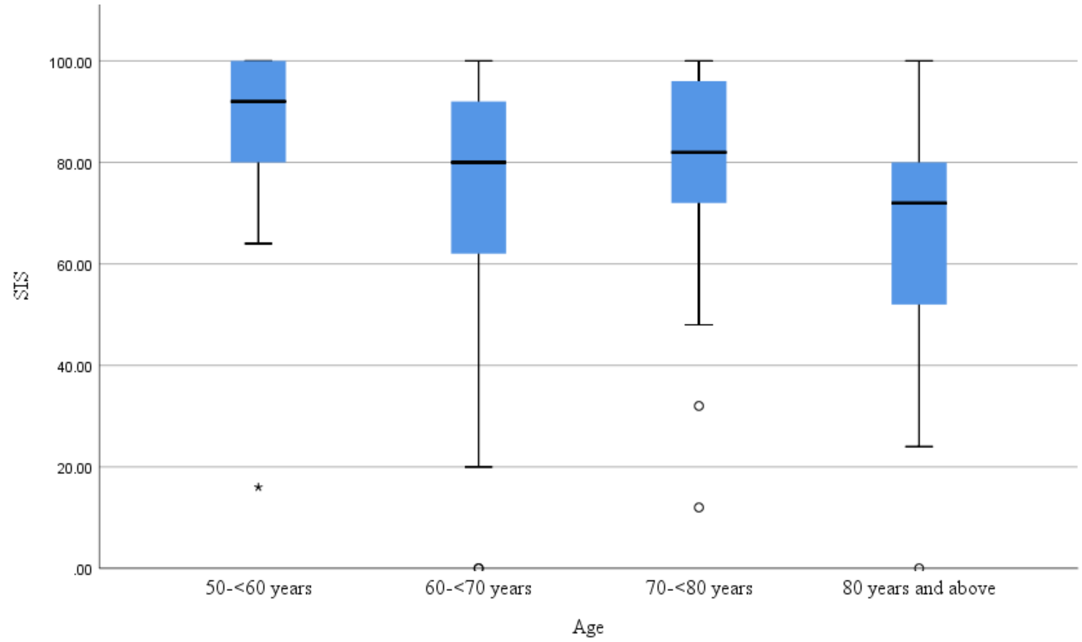


Figure 4.8: *SIS obtained in ears with mixed hearing loss across age groups.*

4.6 Comparison of SIS score obtained in different configuration of SNHL versus Mixed hearing loss in each age groups

The mean and standard deviation of SIS scores were calculated for each configuration of SNHL group and mixed hearing loss group. The mean score of SIS in the mixed group (M: 75.13 ± 23.68) was found to be greater compared to SNHL sloping (M: 73.23 ± 20.58) group and SNHL flat group (72.13 ± 22.29). The mean and standard deviation of SIS are shown in figure 4.9.

The normality test was conducted for SIS using Shapiro-Wilk test of normality, and data showed a non-normal distribution. Hence, for the comparison of SIS across 3 different groups, a non-parametric Kruskal-Wallis test was used. It was observed that the SIS was higher in mixed hearing loss compared to SNHL sloping and flat configuration (figure 4.9). However, the result of Kruskal-Wallis test ($p = 0.223$) revealed SIS scores between groups were not significantly different. As ears of all the age groups did not show any significant difference between any of the groups. Therefore, a comparison of SIS between SNHL with flat, SNHL with sloping and mixed hearing loss group was carried out in each age groups to check if these groups differ from each other in any of the age group.

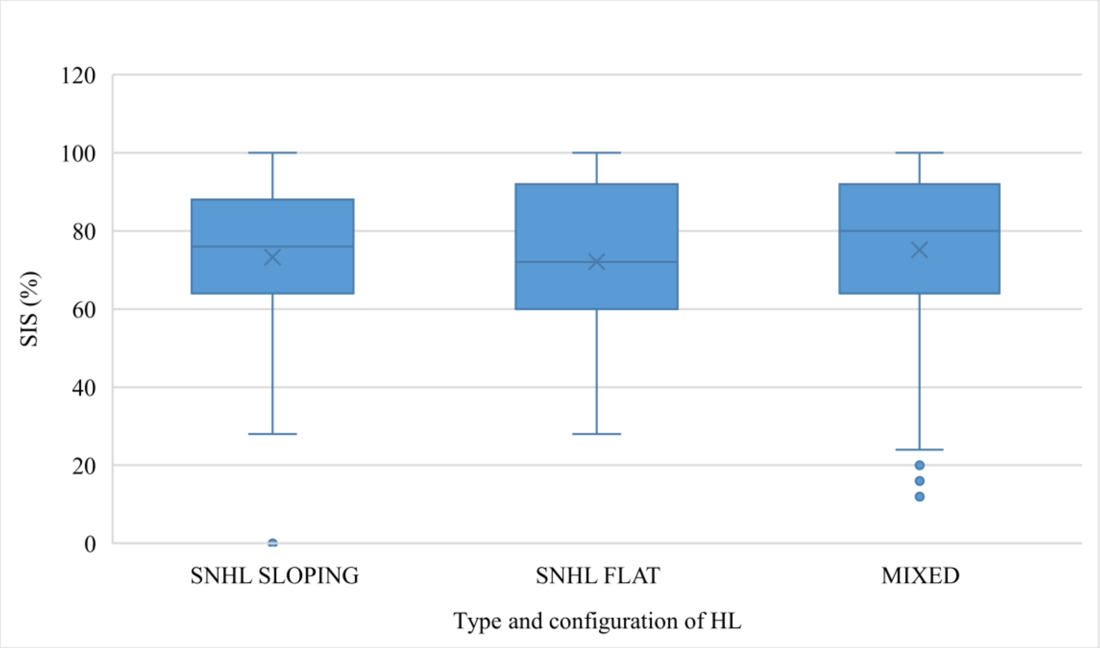


Figure 4.9: *Mean and SD of SIS obtained in different type and configuration of hearing loss.*

SIS scores were compared between SNHL with sloping and flat configuration and mixed hearing loss in each age groups using Kruskal-Wallis test. The result of Kruskal-Wallis test revealed that there was no significant difference between the groups for any age group ($p > 0.05$). Table 4.10 represents the mean and SD of SIS obtained for ears with different type and configuration of hearing loss in each age groups. And table 4.11 represents the test statistics and p value for comparison between SNHL with sloping and flat configuration and mixed hearing loss in each age groups.

Table 4.10

Mean and SD of SIS obtained for ears with different type and configuration of hearing loss in each age groups.

Age groups	Type and configurations	Mean	SD
	SNHL Sloping	83.69	12.59
	SNHL flat	85.66	12.58
50-<60 years	Mixed hearing loss	87.26	18.37
	SNHL Sloping	76.4	17.07
	SNHL flat	77.6	22.16
60-<70 years	Mixed hearing loss	72.4	27.63
	SNHL Sloping	76.44	20.44
	SNHL flat	62.66	28.35
70-<80 years	Mixed hearing loss	79.73	19.54
	SNHL Sloping	64	22.58
	SNHL flat	63.78	7.77
80 years and above	Mixed hearing loss	66.61	22.61

Table 4.11

Test statistics and p value for comparison between SNHL with sloping and flat configuration and mixed hearing loss in each age groups.

	Kruskal Wallis Test	
Age groups	Test statistics	p value
50-<60 years	2.679	0.262
60-<70 years	0.335	0.846
70-<80 years	4.907	0.086
80 years and above	1.558	0.459

4.7 Tympanometric findings

Various tympanometric parameters were assessed for both groups, i.e., SNHL and mixed hearing loss across different age groups. Tympanometric parameters considered were tympanometric peak pressure (TPP), static admittance (SA), and equivalent ear canal volume. The mean, standard deviation, and median for all the tympanometric parameters across age groups and gender for the SNHL group are shown in table 4.12 and for the mixed hearing loss group in table 4.13. Normality of the data was checked for each tympanometric parameter for all age groups, gender, and type of hearing loss using the Shapiro-Wilk test, and data was found to be non-normally distributed ($p < 0.05$).

It can be seen in table 4.12 that there is a drop in TPP observed with the increase in participant's age. Across all age groups, it was revealed that the mean TPP of female ears was lower compared to male ears. An increase in age was similarly associated with a decrease in SA. However, no trend was observed between male and female ears with respect to SA. For EECV, no clear trend across genders or ages was seen.

The mean, SD, and median of TPP, SA, and EECV values for males and females in the mixed hearing loss group across various age groups are shown in table 4.13. The findings clearly show that the TPP declines with an increase in age, regardless of gender. In a similar manner, a decline in SA was seen as age progressed in both males and females. However, it was revealed that EECV increased with age in males and females.

Table 4.12

Mean, SD, and median of TPP, SA, and EECV obtained in male and female ears across different age groups having SNHL.

Age	Gender		Mean			Std. Deviation			Median		
		N(ears)	TPP	SA	EECV	TPP	SA	EECV	TPP	SA	EECV
50-<60 years	Male	11	15.45	1.00	1.45	17.18	0.56	0.22	20.00	1.00	1.50
	Female	14	12.50	1.30	1.51	29.66	0.68	0.32	25.00	1.15	1.55
	Total	25	13.80	1.17	1.48	24.53	0.64	0.28	20.00	1.00	1.50
60-<70 years	Male	20	1.95	1.12	1.40	35.24	0.84	0.33	7.50	0.90	1.30
	Female	10	-0.10	0.79	1.42	20.20	0.70	0.29	6.00	0.50	1.45
	Total	30	1.26	1.01	1.41	30.68	0.80	0.31	7.50	0.72	1.30
70-<80 years	Male	27	0.44	0.88	1.52	32.83	0.55	0.37	15.00	0.77	1.50
	Female	15	-9.0	1.0	1.72	32.30	0.70	0.35	-10.0	0.60	1.80
	Total	42	-2.92	0.92	1.59	32.57	0.60	0.37	10.00	0.74	1.65
80 years and above	Male	30	8.3	1.05	1.45	27.34	0.89	0.31	15.00	0.82	1.50
	Female	10	-25.6	0.67	1.39	42.76	0.67	0.26	-22.5	0.30	1.35
	Total	40	-0.17	0.96	1.43	34.62	0.85	0.29	15.00	0.75	1.40
Total	Male	88	5.34	1.01	1.46	30.04	0.74	0.32	15.00	0.80	1.50
	Female	49	-4.42	0.97	1.53	33.90	0.71	0.33	5.00	0.60	1.50
	Total	137	1.84	0.99	1.48	31.71	0.73	0.33	15.00	0.80	1.50

Table 4.13

Mean, SD, and median of TPP, SA, and EECV obtained in male and female ears across different age groups having mixed hearing loss.

Age	Gender		Mean			Std. Deviation			Median		
		N (ears)	TPP	SA	EECV	TPP	SA	EECV	TPP	SA	EECV
50-<60 years	Male	13	-8.62	1.29	1.34	36.50	0.59	0.41	10	1.30	1.1
	Female	14	6.79	1.83	1.41	29.85	1.25	0.36	17.5	1.75	1.45
	Total	27	-0.63	1.57	1.37	33.49	1.01	0.38	15	1.30	1.3
60-<70 years	Male	20	-3.40	1.11	1.53	40.56	1.04	0.35	2.5	0.60	1.45
	Female	20	8.40	0.91	1.22	23.69	0.80	0.33	13.5	0.52	1.3
	Total	40	2.50	1.01	1.37	33.33	0.92	0.37	11	0.60	1.4
70-<80 years	Male	29	-15.41	1.64	1.60	42.57	1.67	0.37	-9	0.90	1.6
	Female	9	-34.22	0.85	1.60	35.85	0.25	0.34	-35	0.80	1.6
	Total	38	-19.87	1.45	1.60	41.42	1.50	0.36	-12.5	0.80	1.6
80 years and above	Male	36	-13.64	1.10	1.47	41.62	1.01	0.31	-5.5	0.70	1.45
	Female	10	-39.8	0.98	1.56	38.44	0.93	0.49	-38.5	0.45	1.55
	Total	46	-19.33	1.07	1.49	41.98	0.98	0.35	-14.5	0.70	1.5
Total	Male	98	-11.41	1.29	1.50	40.70	1.22	0.35	-5	0.83	1.5
	Female	53	-8.36	1.16	1.40	36.84	0.97	0.40	10	0.80	1.4
	Total	151	-10.34	1.24	1.47	39.29	1.14	0.37	0	0.80	1.4

4.7.1 Comparison of tympanometric parameters between males and females in SNHL group across different age groups

Differences were evident in the median of different tympanometric findings between males and females (Table 4.12) in SNHL group. To further check whether these differences are significant, the Mann-Whitney U test was used to compare the tympanometric parameter between males and females for each age group.

There was no significant difference observed between males and females for any tympanometric parameter (TPP, SA, and EECV) for any age groups: 50-<60 years, 60-<70 years, and 70-<80 years (p > 0.05) (Table 4.14). However, for the≥ 80 years age group, TPP for male ears was significantly higher than females (|Z| = 2.45; p = 0.014). Similarly, SA for males was also significantly higher than females (|Z| = 1.99; p = 0.047). Whereas, EECV did not show any significant gender difference in any age group (p > 0.05). A box plot for TPP of male and female ears with SNHL across age groups is represented in figure 4.10. Table 4.14 represents z and p values for the comparisons between males and females across all the age groups.

Table 4.14

Z and p values for the comparison of TPP, SA and EECV between male and female ears with SNHL across all the age groups.

	TPP		SA		EECV	
Age groups	|Z|	p	|Z|	p	|Z|	p
50-<60 years	0.250	0.803	0.823	0.411	0.831	0.406
60-<70 years	0.661	0.509	1.434	0.151	0.400	0.689
70-<80 years	1.043	0.297	0.053	0.958	1.648	0.099
80 years and above	2.450	0.014*	1.990	0.047*	0.613	0.540

* Indicates significant difference between group.

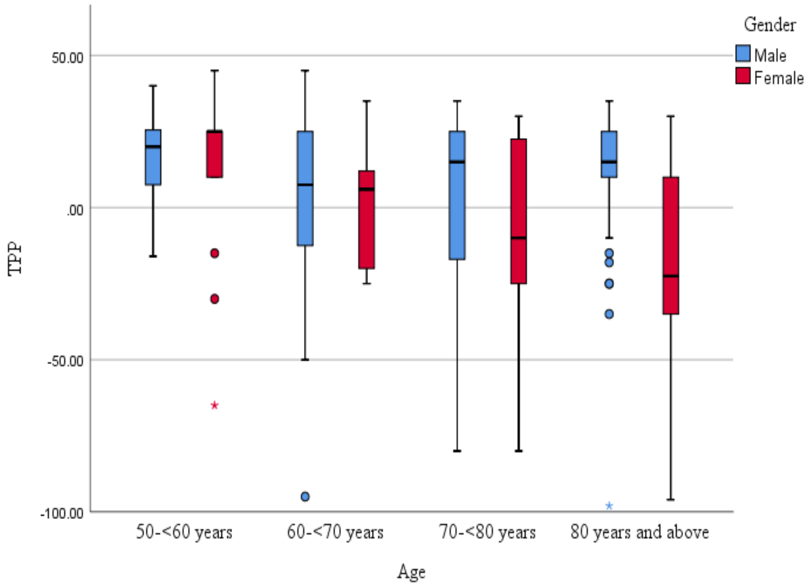


Figure 4.10: *TPP of male and female ears with SNHL across age groups.*

4.7.2 Comparison of tympanometric parameters between male and female ears in mixed hearing loss across different age groups

Tympanometric parameters were compared between males and females for each age groups using Mann-Whitney U Test. EECV of males was found to be significantly more when compared to females in the 60 to <70 years age group ($|Z| = 2.36$, $p = 0.018$), whereas in the same age group TPP and SA were not significantly different between both the genders. In the age group of 80 years and above, TPP for males was significantly higher than for females ($|Z| = 1.97$, $p = 0.049$) (Refer table 4.15). In contrast, other parameters did not significantly differ between males and females.

For the other 2 age groups, i.e., 50-<60 years and 70-<80 years, there was no significant difference observed between males and females for any tympanometric parameters ($p > 0.05$). Table 4.15 shows Z and p values for the comparisons between male and female ears for different tympanometric parameters with mixed hearing loss across all the age groups. Figure 4.11 and 4.12 represents the TPP and EECV of male and female ears with mixed hearing loss across age groups respectively.

Table 4.15

Z and p values for the comparison of TPP, SA and EECV between male and female ears with mixed hearing loss across all the age groups.

	TPP		SA		EECV	
Age groups	|Z|	p	|Z|	p	|Z|	p
50-<60 years	1.535	0.125	0.948	0.343	0.634	0.526
60-<70 years	0.691	0.490	0.638	0.524	2.366	0.018*
70-<80 years	1.220	0.222	0.345	0.730	0.034	0.973
80 years and above	1.975	0.048*	0.829	0.407	0.401	0.688

* Indicates a significant difference between groups.

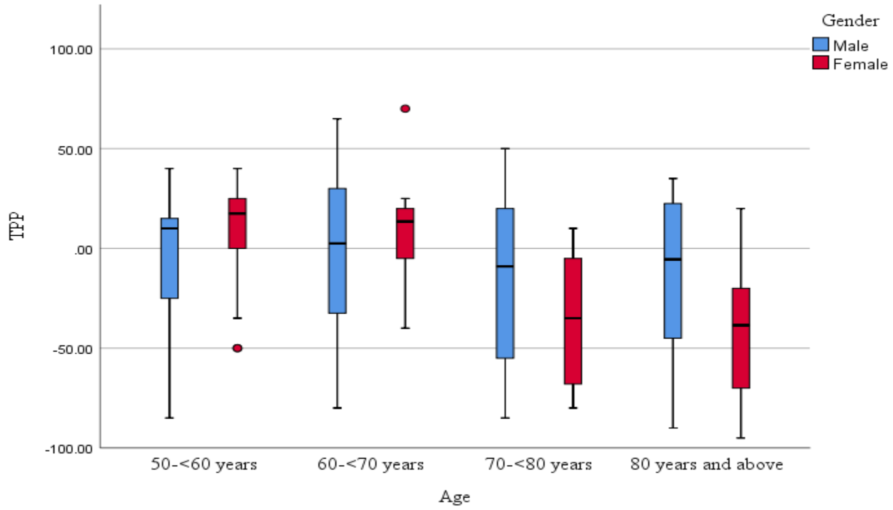


Figure 4.11: *TPP of male and female ears with Mixed hearing loss across age groups.*

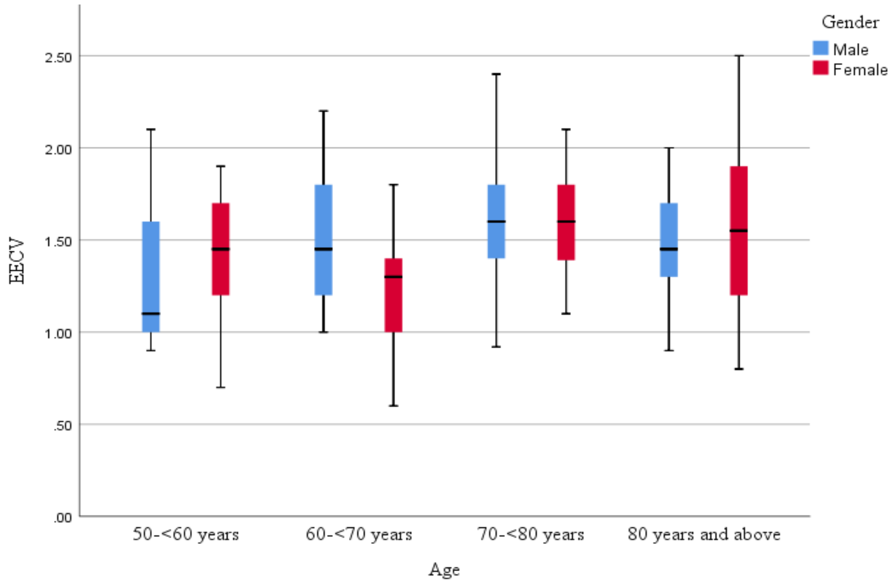


Figure 4.12: *EECV of male and female ears with Mixed hearing loss across age groups.*

4.7.3 Comparison of tympanometric findings in ears with SNHL across age groups

A comparison of tympanometric parameters for the SNHL group across age groups was conducted using the Kruskal-Wallis test as the data was non-normally distributed. The test results revealed no significant difference in any of the tympanometric parameters (TPP, SA, & EECV) across age groups. A decrease in SA was observed after 60 years of age (Figure 4.13), but the decrement was not significant ($p = 0.188$). Similarly, the EECV for age group 60 to <70 years and 80 years and above were found to be lower compared to other age groups (Figure 4.14), but this difference was also not significant ($p = 0.069$). Similarly, there was no significant difference in TPP observed across the age groups ($p = 0.146$). Figure 4.15 represents TPP for ears with SNHL across age. Table 4.16 represents the test statistics and p value for comparison of TPP, SA and EECV between age groups.

Table 4.16

Test statistics and p value for comparison of TPP, SA and EECV between age groups.

	Kruskal-Wallis Test	
Tympanometric parameter	Test statistics	p value
TPP	5.377	0.146
SA	4.784	0.188
EECV	7.084	0.069

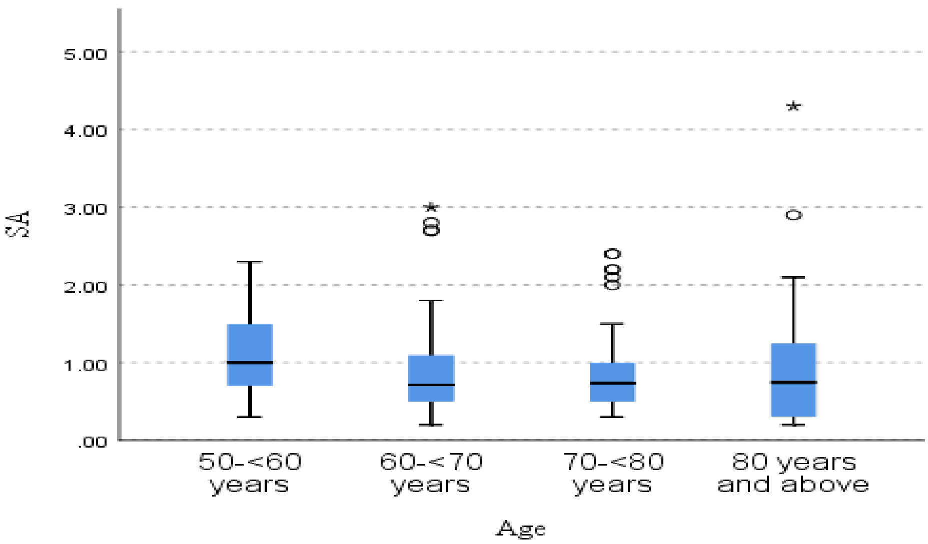


Figure 4.13: *Static admittance (SA) of ears with SNHL across age group.*

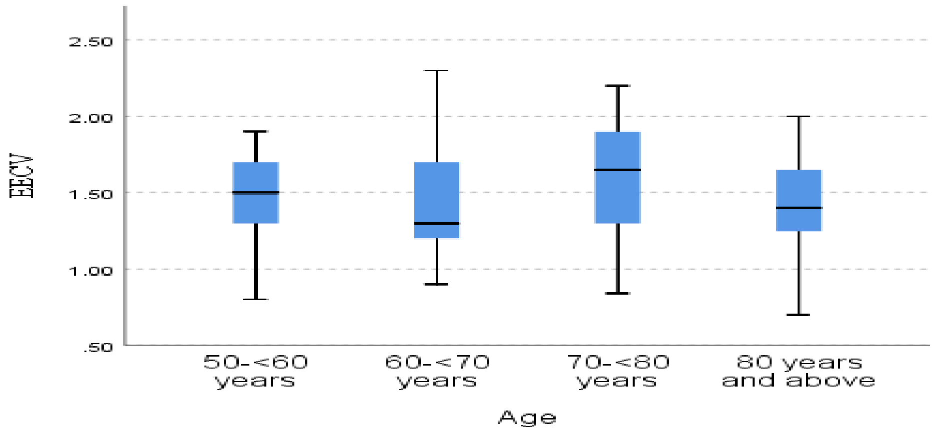


Figure 4.14: *EECV of ears with SNHL across age group.*

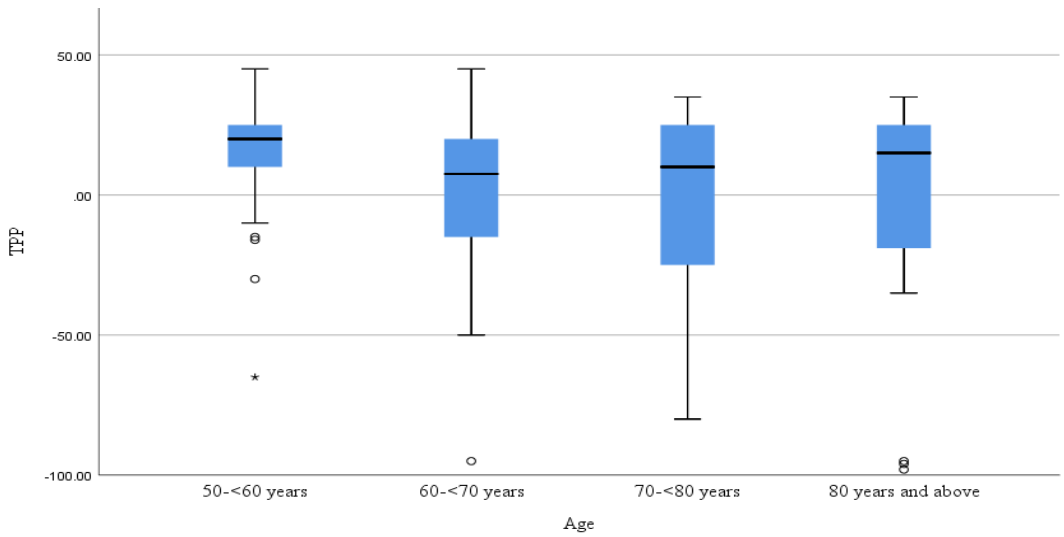


Figure 4.15: *TPP of ears with SNHL across age group.*

4.7.4 Comparison of tympanometric findings of ears with mixed hearing loss across age groups

Kruskal-Wallis test was used to compare different tympanometric parameters for mixed hearing loss groups across different age groups. A significant difference was observed in all the 3 tympanometric parametric, i.e., TPP (p = 0.041), SA (p = 0.019), and EECV (p = 0.040), between at least one of the age groups.

Pairwise comparison of SA using Bonferroni post-hoc test in different age groups revealed that SA was significantly reduced for 60 to <70 years age group (p = 0.003) and ≥ 80 years age group (p = 0.012) when compared to 50 to < 60 years age group. All the other age groups did not show any significant difference in SA in pairwise comparison. Table 4.17 shows test statistics and p values for all the pairwise comparison between age for SA. Figure 4.16 represents the box plot for SA across different age groups having mixed hearing loss.

Table 4.17

p value for pairwise comparison of SA between age groups obtained in ears with mixed hearing loss.

Pairwise Comparisons of SA between age groups	Test Statistic	Sig. (p value)
60-<70 years-80 years and above	-6.069	0.520
60-<70 years-70-<80 years	-14.705	0.137
60-<70 years-50-<60 years	32.511	0.003*
80 years and above-70-<80 years	8.636	0.367
80 years and above-50-<60 years	26.442	0.012*
70-<80 years-50-<60 years	17.806	0.105

* Indicates significant difference.

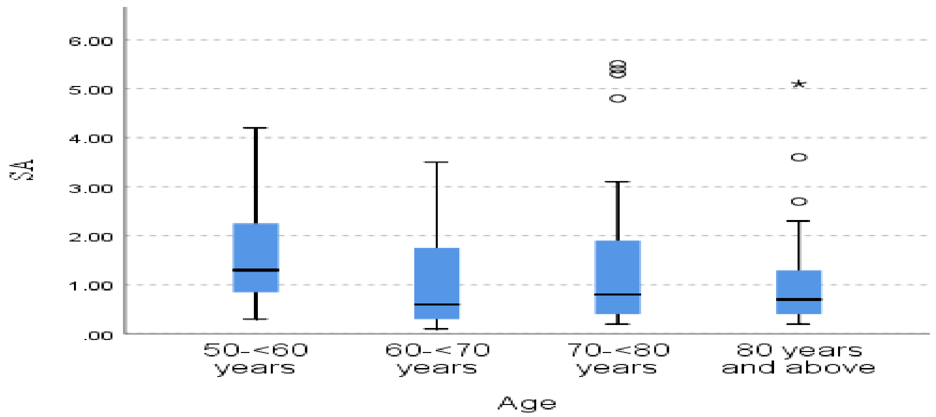


Figure 4.16: *Static admittance of ears with Mixed hearing loss across age group.*

Pairwise comparison of TPP using Bonferroni post-hoc test across age groups showed reduced TPP for 70 to <80 years ($p = 0.026$) and ≥ 80 years age group ($p = 0.032$), which was significant when compared to 60 to <70 years age group individuals. Reduced TPP was seen for 70 to <80 years and ≥ 80 years compared to the 50 to <60 years age group, but the reduction was not significant. Table 4.18 shows p values for all the pairwise comparison between age for TPP. Figure 4.17 represents a box plot for TPP across different age groups for the mixed hearing loss group.

Table 4.18

p value for pairwise comparison of TPP between age groups for ears with mixed hearing loss.

Pairwise Comparisons of TPP between age groups	Test Statistic	Sig. (p value)
70-<80 years-80 years and above	-1.829	0.849
70-<80 years-50-<60 years	20.616	0.061
70-<80 years-60-<70 years	22.029	0.026*
80 years and above-50-<60 years	18.787	0.076
80 years and above-60-<70 years	20.200	0.032*
50-<60 years-60-<70 years	-1.413	0.897

* Indicates a significant difference between groups.

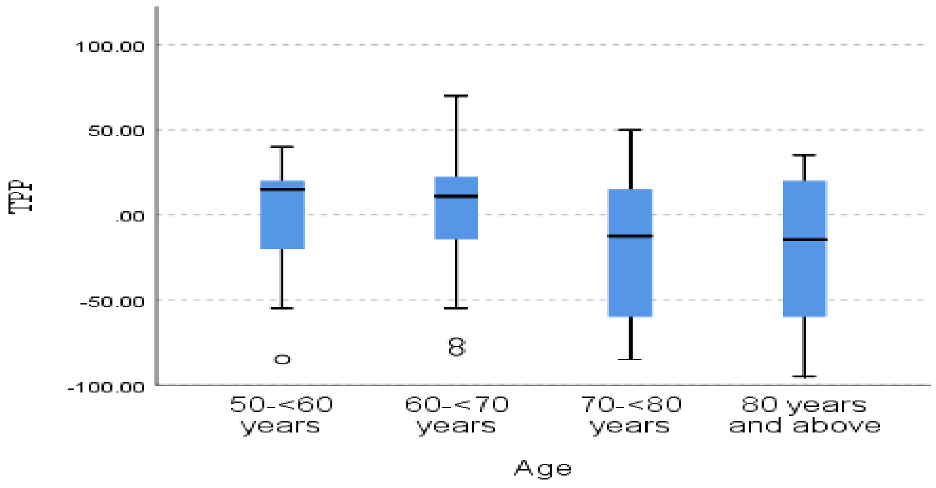


Figure 4.17: *TPP of ears with Mixed hearing loss across age group.*

Pairwise comparison of EECV showed that the EECV was significantly higher for the age group 70 to <80 years (p = 0.021) when compared to 50 to <60 years. EECV was also significantly lower for the 60 to <70 years group compared to the 70 to <80 years group (p = 0.011). All the other age groups did not show any significant difference for EECV. Table 4.19 shows p values for all the pairwise comparison between age for EECV. Figure 4.18 represents a box plot for EECV across different age groups for the mixed hearing loss group.

Table 4.19

p value for pairwise comparison of EECV between age groups for ears with mixed hearing loss.

Pairwise Comparisons of SA between age groups	Test Statistic	Sig. (p value)
50-<60 years-60-<70 years	-0.294	0.978
50-<60 years-80 years and above	-13.151	0.214
50-<60 years-70-<80 years	-25.273	0.021*
60-<70 years-80 years and above	-12.857	0.173
60-<70 years-70-<80 years	-24.979	0.011*
80 years and above-70-<80 years	12.122	0.205

* Indicates a significant difference between groups.

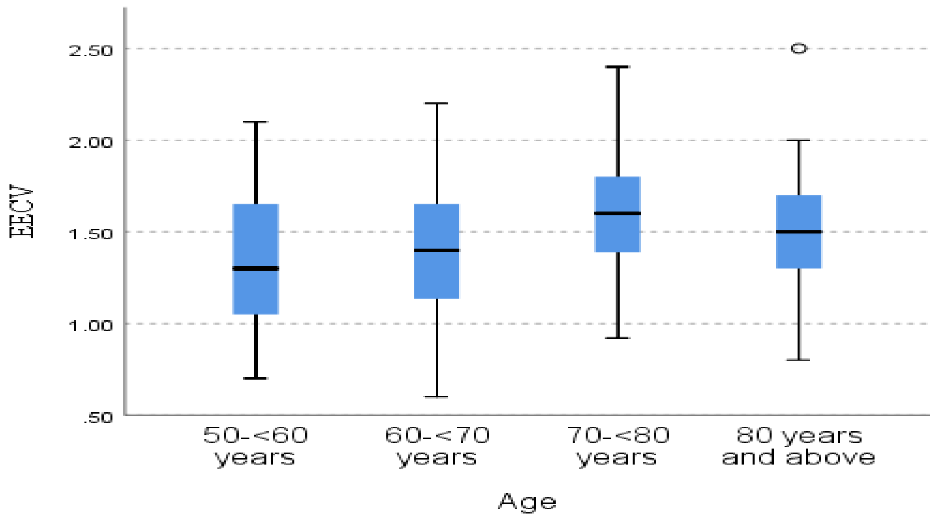


Figure 4.18: *EECV of ears with Mixed hearing loss across age group.*

4.7.5 Comparison of tympanometric findings between ears with SNHL and mixed hearing loss

Mann-Whitney U test was used to compare the tympanometric parameter between SNHL and mixed hearing loss for each age group. No significant difference was observed between SNHL and mixed hearing loss in any age groups for EECV and SA ($p > 0.05$). Whereas marginal difference was seen in TPP between SNHL and mixed hearing loss ears for 50 to <60 years, 70 to <80 years, and ≥ 80 years age groups (Table 4.20).

TPP of SNHL group was marginally higher compared to mixed hearing loss in age group of 50 to <60 years ($|Z| = 1.90$; $p = 0.056$), 70 to <80 years ($|Z| = 1.84$; $p = 0.065$) and ≥ 80 years age groups ($|Z| = 1.91$; $p = 0.055$). Table 4.20 shows |Z| and p values for comparison of tympanometric parameters between SNHL and mixed hearing loss for each age groups.

Table 4.20

|Z| and p values for comparison of tympanometric parameters between SNHL and mixed hearing loss for each age groups.

	TPP		SA		EECV	
Age group	|Z|	p	|Z|	p	|Z|	p
50-<60 years	1.907	0.056	1.421	0.155	1.159	0.246
60-<70 years	0.220	0.826	0.898	0.369	0.227	0.821
70-<80 years	1.845	0.065	0.909	0.364	0.150	0.881
80 years and above	1.918	0.055	0.648	0.517	0.657	0.511

4.8 Comparison of tympanometric findings of present study with that reported by Wiley (1996)

Mean SA and mean EECV of both the studies were compared using one sample t tests on a trial basis. Mean was used as a measure to compare as median was not available in Wiley (1996) study. Mean is not an appropriate measure to compare both the data using a one sample t-test as in the current study the sample was non- normally distributed, SD was high for few parameters, the number of individuals were quite different in both studies and also the age distribution criteria in the present study were also comparatively different from the Wiley (1996) study. But as median was not available in the Wiley (1996) study, the mean of both studies was compared using a one sample t test. Table 4.21 represents the mean and 90% range of SA and EECV for Wiley (1996) study and table 4.22 the mean and SD of SA and EECV of the present study.

Table 4.21

Mean and 90% range of SA and EECV as reported by Wiley (1996).

		SA		EECV	
	N	Mean	90% Range	Mean	90% Range
Both Ears and Both Genders	2147	0.66	0.2-1.5	1.36	0.9-2.0
48-59 years	788	0.67	0.2-1.5	1.4	0.9-2.1
60-69 years	636	0.67	0.2-1.5	1.34	0.9-1 .9
70-79 years	550	0.65	0.2-1.5	1.35	0.9-2.0
80-90 years	173	0.57	0.2-1.3	1.29	0.8-1.9

Table 4.22

Mean and SD of SA and EECV of the present study.

		SA		EECV	
Age	N	Mean	SD	Mean	SD
50-<60 years	52	1.3788	0.86621	1.4288	0.33859
60-<70 years	70	1.0113	0.86659	1.3897	0.34457
70-<80 years	80	1.1761	1.14437	1.5974	0.36401
80 years and above	86	1.0200	0.92104	1.4649	0.32802
Total	288	1.1260	0.97183	1.4769	0.35159

4.8.1 Comparison of SA between present and Wiley (1996) study

One sample t test was used and results revealed significant difference in the SA between the present study and Wiley (1996) study across all the age groups. Table 4.23 shows the p values for the comparison of SA between the 2 studies across all the age groups.

Table 4.23

Comparison of SA between the present and Wiley (1996) study across age groups.

Present study age group	Wiley. (1997) age group	p value
50-<60 years	48-59 years	0.000*
60-<70 years	60-69 years	0.002*
70-<80 years	70-79 years	0.000*
80 years and above	80-90 years	0.000*
Total		0.000*

* Indicates a significant difference between groups.

4.8.2 Comparison of EECV between the present and Wiley (1996) study

The result of one sample t test revealed no significant difference between EECV of both the studies in 2 age groups: 50-<60 years and 60-<70 years. Whereas, there was a significant difference observed in EECV for other 2 age groups between the studies. Table 4.24 shows the p value of comparison between studies for EECV in various age groups.

Table 4.24

Comparison of EECV between present and Wiley (1996) study across age groups.

Present study age group	Wiley. (1997) age group	p value
50-<60 years	48-59 years	0.542
60-<70 years	60-69 years	0.232
70-<80 years	70-79 years	0.000*
80 years and above	80-90 years	0.000*
Total		0.000*

* Indicates a significant difference between groups.

To summarize the results of the present study, gradually sloping configuration was predominantly observed in ears having SNHL. Whereas, ears with mixed hearing loss predominantly showed the presence of flat configuration. And it was also observed that as the age increased the presence of sharply sloping hearing loss also increased in both SNHL and mixed hearing loss groups.

For SIS there was drop in score that was observed for all the types and configuration of hearing loss groups with increase in age. For SNHL with flat configuration, there was drop in SIS which was evident in every 2 decades increase in age. Similarly, for SNHL with sloping configuration and mixed hearing loss it was observed that after the age of 80 years there is a significant drop in SIS.

In tympanometric findings for SNHL group, gender difference was evident only after the age of 80 years. TPP and SA for male ears was significantly greater than female ears for 80 years and above age group. Whereas, EECV in 80 years and above group also did not reveal any gender differences. Similarly, for mixed hearing loss group gender difference was evident in EECV and TPP for 60-<70 years and 80 years and above age groups respectively. Males were observed to have higher EECV and TPP compared to females for the respective age group mentioned above.

Age wise comparison of different tympanometric parameters for ears with SNHL did not reveal any significant difference for any tympanometric parameters (TPP, EECV & SA). On the other hand, significant differences were seen for ears with mixed hearing loss in all the tympanometric parameters in age wise comparison. TPP was seen to decrease significantly after the age of 70 years for ears with mixed hearing loss. Similarly, a decline in SA was also noted with increase in age which was significantly reduced for 60- <70 years, and 80 years and above age groups. EECV was observed to increase with increase in age which was remarkably seen for 70 - <80 years age group.

Comparison between SNHL and mixed hearing loss group did not reveal any significant difference for any of the age groups. But there were marginal differences observed for TPP in 50 to <60 years, 70 to <80 years and 80 years and above groups. TPP of mixed hearing loss groups was lower compared to SNHL group in all the stated age groups.

Chapter 5

Discussion

The current study, analysed and investigated various audiological tests like pure tone audiometry, speech audiometry and immittance audiometry in older individuals with age-related hearing loss. To achieve the objectives of the study data were obtained and analyzed from a total of 288 ears with both SNHL and mixed hearing loss. Results of the study and possible reason has been discussed below under several heading.

5.1 Configuration of hearing loss in SNHL and mixed hearing loss

In the present study, ears with SNHL majorly demonstrated gradually sloping hearing loss followed by flat hearing loss. These findings were seen up to the age of 80 years, whereas after the age of 80 years, gradually and sharply sloping configuration was more dominant. Similarly, for mixed hearing loss, the flat configuration was seen prominently followed by gradually sloping till 80 years of age. But after 80 years of age, there was a drastic increase in the number of ears with sharply sloping configurations.

The findings of the present study are consistent with that obtained by Saqulain et al. (2021), who observed a higher prevalence of gradually sloping configuration between 60 to 70 years, whereas steeply sloping was more commonly seen for individuals older than 70 years. Similar results were obtained by Hannula et al. (2011), who reported steeply sloping configuration to be more commonly seen in age-related hearing loss which was followed by gradually sloping. On the contrary, Demeester et al. (2009) reported flat configuration to be more common compared to sloping. The difference in the configuration pattern obtained among various studies can also possibly be due to different criteria adopted to classify configuration. In the present study, the predominance of sloping patterns can be explained by the degeneration of various inner ear structures due to aging (Fischer et al., 2020b). Further, degeneration of IHCs and OHCs is more evident in the cochlea's basal turn, which is responsible for higher frequency coding and leads to a sloping configuration (Gates & Mills, 2005).

Further, in the present study, the sharply sloping loss was predominantly seen in both mixed and SNHL groups after 80 years of age. This can possibly be due to the involvement of age-related changes happening in both the inner and middle ear (Roychowdhury et al., 2021; Gates & Mills, 2005). And hence can supplement the loss at a higher frequency leading to a sharply sloping loss for individuals older than 80 years. There are no studies to best of our knowledge which have explained the predominance of flat configuration in mixed hearing loss. The possible reason can be due to worsening of low frequency threshold due to stiffening changes evident in middle ear (Zhou et al., 2019) and increase in high frequency threshold due to degeneration of OHCs and IHCs in basal turn of cochlea hence leading to a flat audiogram configuration (Gates & Mills, 2005).

5.2 SIS findings

SIS across age groups in SNHL and mixed hearing loss group

There was a drop in SIS, which was noted as the age increased, and this drop in score was observed in both the groups, i.e., SNHL and the mixed hearing loss group. This decrease in SIS was evident for both flat and sloping configurations in the SNHL group. The findings of the present study are similar to those obtained by Dlouhá et al. (2017), wherein they observed poorer speech recognition scores with increased age in both quiet and noisy conditions. More recently, Hoppe et al. (2022) observed a decrease in word recognition scores on 19,801 ears with SNHL with an increase in age. Aimoni et al. (2015) also observed a drop in SIS with aging in noisy conditions. The current study results are also consistent with Wiley, (1998) who reported the word recognition scores to decrease in quiet and noisy conditions with aging. The reduction of scores in the presence of noise was more with aging compared to quiet conditions, irrespective of the degree of hearing loss. Similar results for a decline in SIS in a quiet situation were obtained in previous studies (Jerger., 1973; Gates et al., 1990a).

The decrease in SIS score, as reported in the previous and present study, is typically due to a decrease in the audibility of speech and the involvement of central and peripheral factors, which leads to a decrease in speech recognition with aging (Wiley, 1998). These findings can mainly be due to degeneration and changes occurring in various parts of the inner ear (Fischer et al., 2020b; Gates & Mills, 2005; K.-Y. Lee, 2013). Changes are also evident in the central auditory nervous system, which can further deteriorate the speech recognition scores in older individuals (Ouda et al., 2015; Schuknecht & Gacek, 1993). These degenerative changes in various structures with an increase in age would have been a possible reason for a reduction in SIS observed in all the groups in the current study. Other factors like mild cognitive impairment, which is common among older individuals, can further supplement the worsening of SIS scores (Aimoni et al., 2015). Additionally, dementia, depression, attention issues, and fatigue can also influence the SIS score in older individuals (Wiley, 1998).

Gender effect on SIS scores

No gender effect was established in the current study, and both males and females had similar SIS across all the three groups, i.e., SNHL with sloping configuration, SNHL with flat configuration, and mixed hearing loss. These study findings were consistent with the investigation performed by Decambron et al. (2022), in which no gender effect was found for SNR loss between males and females. However, (Gates et al., 1990a; Wiley, 1998) observed a gender effect in their study, with a rapid decline in speech recognition for males compared to females in quiet and noisy conditions with aging, which is predominantly due to more noise exposure in males. On the contrary, Dubno et al. (2008) did not notice any effect on noise exposure on SIS between the gender and reported females having a more rapid decline in SIS compared to males. No impact of gender on SIS across any group in the present study can perhaps be due to similar age-related changes for both males and females, or the difference in the changes taking place in both genders are not sufficient enough to alter the SIS findings.

SIS across configuration and type of hearing loss

SIS was found to be reduced for SNHL with both configurations when compared to mixed hearing loss, but this difference was not significant. The scores for SNHL with flat configuration and SNHL with sloping configuration were comparable. Prior studies have suggested that speech recognition is more affected in the sloping configuration when compared to the flat configuration. Present study results are consistent with Yonan and Sommers (2000) study, who found speech recognition scores are less affected in a quiet situation irrespective of audiogram configuration and performance degrades only when a competing noise is present. However, Gordon-Salant, (1987) obtained a contrary finding concluding more speech recognition problems in older individuals with sloping hearing loss, which was worst for sharply sloping configuration compared to gradually sloping. However, in Gordon-Salant, (1987) study, speech recognition was checked in the presence of noise which may be the contributing factor to reduced speech scores in sloping hearing loss.

Therefore, it can be concluded from the present study that age-related changes happening in the inner and middle ear can significantly reduce the speech recognition abilities in older individuals. And speech recognition deteriorates more with aging. However, the speech recognition performance was not found to be different for any of the 3 groups. The findings could be due to SIS obtained in the absence of noisy conditions. Hence, with sufficient intensity levels at higher frequencies, the performance of all the groups was comparable.

5.3 Tympanometric Findings

Various tympanometric parameters were analysed for gender effect and age effect in both SNHL and mixed hearing loss. The following section address the results obtained in the present study and possible reason for the findings.

Gender effects on tympanometric parameters

Overall, the current study's findings did not reveal significant effect of gender on various tympanometric parameters used in the study across the age groups for both SNHL and mixed hearing loss groups. A gender effect was observed for TPP for the age group 80 years and above for both the SNHL and mixed hearing loss groups. The TPP in this age group was found to be significantly higher for males compared to females. Majority of the studies in literatures have not found any gender effect with respect to TPP (Golding et al., 2007; Stenklev et al., 2004; Wiley, 1996; Sinha et al., 2021). No gender effect in TPP in other age groups reflects the minimal difference in the functioning of the eustachian tube across gender (Stenklev et al., 2004). The gender effect observed for subjects older than 80 years in the present study can mainly be due to fewer subjects in the present study compared to previous studies reporting no gender effect on TPP.

A gender effect was evident for SA for older individuals with SNHL above 80 years of age. The SA for males was observed to be higher compared to females. These findings regarding the gender effect for SA are consistent with other studies. Golding et al. (2007) also noted lower SA for females than males. Similarly, Wiley (1996) also observed a similar gender effect. Although the reason for the gender effect for SA is unclear, one possible explanation for lower SA for females can be the more stiffened middle ear leading to reduced SA. However, on the contrary, Gates et al. (1990) and Sinha et al. (2021) did not report any gender effect on SA in any age group.

In the mixed hearing loss group, gender effect was observed in EECV for 60 to <70 years. EECV for males was observed to be higher compared to females in the present study. These findings are consistent with the study of Wiley (1996) observed a smaller EECV for females, which was observed in a larger number of participants (N = 2147 ears). On the contrary, Sinha et al. (2021) did not observe any gender effect on EECV in ears with SNHL for any age group. Lower EECV in females is somewhat predictable, mainly due to differences in anatomical dimensions in auditory structures (Wiley, 1996).

Although there were gender effects in the current study, they did not apply equally to all age groups, types of hearing loss, and tympanometric parameters. This trend of gender effect can possibly be due to a smaller number of subjects in the present study compared to prior studies reporting gender effect mainly with respect to EECV and SA.

Tympanometric findings in ears with SNHL across age groups

In the present study, no difference was seen in TPP, SA, and EECV across age groups in ears with SNHL. There is an equivocal number of studies suggesting a change in tympanometric parameters and those not reporting a change in tympanometric parameters with age. The current study's findings are consistent with Sinha et al. (2021) findings wherein no difference was seen for TPP, SA, and EECV across age groups. Similar results for no change in TPP have been seen in various studies (Golding et al., 2007b; Nondahl et al., 2013; Sinha et al., 2021; Stenklev et al., 2004; Wiley, 1999). No change in TPP across age groups is possibly due to the negligible amount of changes happening in the Eustachian tube due to aging, which are not sufficient enough to alter TPP (Stenklev et al., 2004).

Statistical analysis has revealed no change in SA across age groups in our study. These findings are similar to that reported by Sinha et al. (2021). On the contrary, Golding et al. (2007) reported a decrease in SA as the age increased. Similar findings on a decline of SA with aging have been reported by various authors (Nondahl et al., 2013; Stenklev et al., 2004; Wiley, 1999). The changes not present in SA can be due lesser sample size in the present study, due to which no significant difference was observed.

The current study showed no change in ear canal volume, which was observed for the SNHL group across age groups. EECV has been shown to decrease, remain the same or increase with age across various studies. For example, Hall. (1979) reported an increase in the ear canal volume with age, which was more evident for males. Whereas, Nondahl et al. (2013) and Wiley (1996) have found that EECV declines with age mainly due to atrophic changes to the canal's walls, a collapsed ear canal, and increased hair growth. On the other hand, Sinha et al. (2021) did not find any change in EECV as age progressed. Therefore, the explanation for the change in EECV is unclear due to the disparate outcomes from different studies.

Tympanometric findings in ears with mixed hearing loss across age groups

Although the SNHL group did not show any age effects, the mixed hearing loss group did show age effects for all tympanometric measures in the present study. Mixed hearing loss groups showed a decrease in SA with an increase in age. These findings are consistent with that reported by Wiley (1996), Nondahl et al. (2013), and Golding et al. (2007), which were conducted on a larger number of subjects and have also reported a decrease in SA with an increase in age. The possible reason for the reduction in SA with aging can be stiffening changes within the middle ear. According to Ruah et al. (1991), the tympanic membrane becomes less vascular, less cellular, more rigid, and less elastic with age, which may account for the stiffening of the middle ear. More recently, Zhou et al. (2019) also suggested osteoporosis (OP) in the middle ear can contribute to the stiffening of ossicles, incudomalleolar and incudostapedial joints, leading to a decrease in the admittance which is more evident with aging. However, in the present study, no significant changes in SA are associated with SNHL and significant changes in SA are associated with mixed hearing loss suggested significant change in middle ear structure, thus resulting in some amount of conductive loss.

In the present study, an increase in EECV was noted with aging for the mixed hearing loss group, which was significant. However, as stated before, regarding ear canal volume, several studies have contradicting findings. Few studies suggest a decrease in EECV with aging observed due to atrophic changes to the canal's walls, a collapsed ear canal, and increased hair growth (Nondahl et al., 2013; Wiley, 1996). At the same time, an equal number of studies suggest no change in EECV with aging (Sinha et al., 2021). On the other hand, Hall. (1979) reported an increase in ear canal volume, which is in line with the present study. An increase in EECV can also result in a decrease in SA, which was observed in the present study, as admittance and EECV are inversely related to each other (Hall, 1979). However, more research with bigger sample size is required before drawing any conclusions about the reasons behind the disparate results of ear canal volume with aging.

The current investigation showed that TPP decreased dramatically after the age of 70 years, which was significant. On the contrary, a lot of studies have not reported any changes in TPP with aging (Golding et al., 2007b; Nondahl et al., 2013; Stenklev et al., 2004; Wiley, 1999) concluding that changes happening in Eustachian tube or middle ear are not sufficient enough to alter the peak pressure of middle ear. However, all the prior studies reporting no change in TPP were conducted on older individuals with normal hearing or SNHL, due to which possible changes concerning the middle ear were not taken into account. But more recent findings by Sogebi (2015) suggest the 'C' type to be the most common tympanogram after the 'As' type, which is observed in older individuals and hence offers the possible influence of aging on the Eustachian tube as well. Histopathological studies on Eustachian tube and tensor veli palatini muscle suggest atrophy and calcification of cells, which is prominently seen in older individuals (Takasaki et al., 1999). Therefore, due to changes observed with aging in the above studies, we can conclude that aging can cause Eustachian tube dysfunction leading to a decrease in TPP.

Therefore, from the present study, we can conclude that though changes may not be evident in SNHL older individuals concerning tympanometry. Still, older individuals with mixed hearing loss have shown significant changes in all the tympanometric parameters. Hence, the type of hearing loss in older individuals should also be considered when assessing middle ear using tympanometry.

5.4 Comparison of EECV and SA of the present study with Wiley (1996)

The present study's comparison with Wiley's (1996) was just made on a trial basis. It was observed that the SA was significantly different for both the study. SA in the present study was comparatively higher in all the age groups when compared to Wiley (1996). The EECV was found not found to be significantly different for both the studies for 2 age groups, i.e., 50 to <60 years and 60 to <70 years. In contrast, EECV was significantly higher in the present study for other age groups.

The possible reason for the difference in SA and EECV among both the studies can be due to the difference in the number of participants in both studies. The present study was only conducted on 288 ears, whereas Wiley (1996) performed measurements on 2147 ears. Another possible reason can also be due to the inclusion of mixed hearing loss individuals in the current study, which Wiley (1996) did not take into account. Also, the mean is not entirely an accurate measurement to compare the two groups in current conditions due to the high SD observed in both the studies for SA. Other factor that could have possibly caused a difference in both tympanometric findings between study can be due to racial differences between the population (Robinson & Allen, 1984; Shahnaz & Bork, 2006; Shahnaz & Davies, 2006) Age distribution criteria were also a little different for both the studies, which could have also caused a difference in the findings.

Hence, from the present study we can conclude that changes happening in various ear structures have a direct effect on audiological tests. Changes due to aging like stiffening of middle ear and degenerative changes in cochlea have a impact on configuration of audiogram. Similarly, these changes along with changes in CANS can cause a decline in SIS with aging. Also, changes are evident in mixed hearing loss groups with increase in age for all the tympanometric parameters suggesting more influence of aging on middle ear for older individuals with mixed hearing loss.

Chapter 6

Summary and Conclusion

The present study was conducted to profile the audiological finding in older individuals who reported to All India Institute of Speech and Hearing (AIISH) for having hearing loss between January 2019 and December 2020. It is a retrospective standard group comparison study. A total of 288 ears (M: 186; F: 102) data were collected from the AIISH clinical database, and accordingly, the audiological profiling was carried out for ears with SNHL and mixed hearing loss. Various audiological tests (pure tone audiometry, speech audiometry, and immittance audiometry) were analyzed to compare the changes happening in these audiological tests as the age of the person increased from 50 years to 80 years and above.

The type and configuration of hearing loss were among the pure tone audiometry data considered for the analysis. And based on the current investigation results, it is clear that, compared to other configurations, ears with SNHL mostly exhibited gradually sloping configuration due to degeneration of OHC and IHC in basal turn of cochlea. On the other hand, the majority of the ears with mixed hearing loss showed the existence of a flat configuration which is mainly due to stiffening of middle ear along with degenerative changes in cochlea which would have affected all the frequencies. Additionally, mixed hearing loss and SNHL showed a rise in the prevalence of sharply sloping loss due to increase in degeneration of OHC and IHC at basal turn of cochlea as age increased.

According to the findings of the SIS scores, it can be concluded that as individual's age increased, the SIS became worse for all different types and configurations of hearing loss which can be explained due to degenerative changes in cochlea and CANS. But the current study did not find any effect of gender, type, and configuration of hearing loss on SIS, which could be due to a smaller number of participants in the present study or because the speech audiometry was conducted in the absence of noise.

In tympanometric findings, comparison within the SNHL group revealed no difference in tympanometric parameters with an increase in age, probably due to changes in middle ear are not sufficient enough to alter tympanometric parameters in SNHL group. Similarly, gender differences in ears with SNHL was only evident in the 80 years and above age group for static admittance (SA) and tympanometric peak pressure (TPP), with both SA and TPP greater for male than female ears. Significant differences were seen in mixed hearing loss groups with an increase in age. It was observed that TPP and SA decreased with an increase in age, and this decline increased drastically after 80 years of age which possibly due to significant changes in eustachian tube leading to change in TPP and stiffening changing of middle ear causing a reduction in SA. On the other hand, EECV showed an increase with aging. Even for ears with mixed hearing loss, the gender difference was only evident for EECV and TPP for 60 to <70 years and 80 years and above age groups, respectively. Tympanometric findings between SNHL and mixed hearing loss showed marginal differences for TPP, whereas other parameters did not differ between SNHL and mixed hearing loss groups no difference could be due to a smaller number of subjects in the present study.

Therefore, from the present study, it can be **concluded** that aging can cause considerable changes in various structures of the ear, which can lead to a substantial change in audiogram configuration. The results of the study also suggests that a significant age-related structural change can be observed even in the middle ear, as significant number of individuals had mixed hearing loss. Not only that middle ear changes due to altered middle ear structure likely affect almost all frequencies equally than SNHL only showing for loss at high frequencies. Also, tympanometric findings are likely get altered with the increase in age if middle ear changes are notice and no such changes can be expected if there is SNHL.

6.1 Limitations:

The present study has a few limitations. Firstly, the present study was conducted in a small number of the ear (N = 288), which would have altered the results. Hence a more significant number of subjects can be used to carry out similar research. Secondly, the severity of the hearing loss was not controlled which could have possibly altered the study findings. And lastly, association tests of statistics could not be applied for assessing configuration across age groups in both mixed hearing loss and SNHL as the number of participants in each configuration was not uniformly distributed.

6.2 Clinical Implications:

The present study has a lot of clinical implications. First, the current study provides an idea about the configuration of audiogram patterns that can be observed for both SNHL and mixed hearing loss across age groups in elderly individuals. Second, the study gives a conception of how the SIS varies with age, type, and configuration of hearing loss in older adults. Third, it provides insight into how tympanometric parameters can change across age for SNHL and mixed hearing loss. Hence, all these clinical implications of the current study will help to identify how different audiological test results should be looked at when dealing with individuals with age-related hearing loss of the different types of hearing loss.

6.3 Future directions:

1. The study can be carried out with larger sample size.

2. A uniform number of samples can be taken in each category to check the further association between age and configuration using appropriate statistical tests.
3. As there were differences in all the tympanometric parameters across age groups for mixed hearing loss, normative values can be found for mixed hearing loss groups for different age groups in older individuals.

References

Aazh, H., & Moore, B. C. J. (2007). Dead regions in the cochlea at 4 kHz in elderly adults: Relation to absolute threshold, steepness of audiogram, and pure-tone average. *Journal of the American Academy of Audiology*, *18*(2), 97–106. https://doi.org/10.3766/JAAA.18.2.2/BIB

Aimoni, C., Prosser, S., Ciorba, A., Sant'anna, A., Soavi, C., Prosser, S., Menozzi, L., Soavi, C., & Zuliani, G. (2015). Speech Audiometry Tests in Noise Are Impaired in Older Patients with Mild Cognitive Impairment: A Pilot Study Human inner ear development View project Speech Audiometry Tests in Noise Are Impaired in Older Patients with Mild Cognitive Impairment: A Pilot Study. *Article in The Journal of International Advanced Otology*, *10*(3), 228–261. https://doi.org/10.5152/iao.2014.349

Audiological findings in aging - PubMed. (n.d.). Retrieved July 30, 2022, from https://pubmed.ncbi.nlm.nih.gov/4710504/

Carhart, C. R. (1945). An improved method for classifying audiograms. *Laryngoscope*, *55*(11), 640–662. https://doi.org/10.1288/00005537-194511000-00002

Cruickshanks, K. J., Wiley, T. L., Tweed, T. S., Klein, B. E. K., Klein, R., Mares-Perlman, J. A., & Nondahl, D. M. (1998). *Prevalence of Hearing Loss in Older Adults in Beaver Dam, Wisconsin The Epidemiology of Hearing Loss Study*. *148*(9). https://academic.oup.com/aje/article/148/9/879/125560

D, C., S, C., & Veeraiah, S. (2020). Gender variation in age-related hearing loss using pure tone audiometry in city of Bengaluru. *National Journal of Physiology,* *Pharmacy and Pharmacology*, *0*, 1. https://doi.org/10.5455/NJPPP.2021.11.12354202012122020

Dalton, D. S., Cruickshanks, K. J., Klein, B. E. K., Klein, R., Wiley, T. L., & Nondahl, D. M. (2003). The Impact of Hearing Loss on Quality of Life in Older Adults. *The Gerontologist*, *43*(5), 661–668. https://doi.org/10.1093/GERONT/43.5.661

De Sousa, C. S., De Castro, N., Larsson, E. J., & Ting, H. C. (2009). Risk factors for presbycusis in a socio-economic middle-class sample. *Brazilian Journal of Otorhinolaryngology*, *75*(4), 530–536. https://doi.org/10.1590/S1808-86942009000400011

Decambron, M., Leclercq, F., Renard, C., & Vincent, C. (2022). Speech audiometry in noise: SNR Loss per age-group in normal hearing subjects. *European Annals of Otorhinolaryngology, Head and Neck Diseases*, *139*(2), 61–64. https://doi.org/10.1016/J.ANORL.2021.05.001

Demeester, K., Van Wieringen, A., Hendrickx, J. J., Topsakal, V., Fransen, E., Van Laer, L., Van Camp, G., & Van De Heyning, P. (2009). Audiometric shape and presbycusis. *Https://Doi.Org/10.1080/14992020802441799*, *48*(4), 222–232. https://doi.org/10.1080/14992020802441799

Dlouhá, O., Vokřál, J., & Černý, L. (2017). [Speech intelligibility in noise at presbycusis]. *Casopis Lekaru Ceskych*, *156*(4), 183–186. https://europepmc.org/article/med/28862007

Dubno, J. R., Lee, F.-S., Matthews, L. J., Ahlstrom, J. B., Horwitz, A. R., & Mills, J. H. (2008). Longitudinal changes in speech recognition in older persons. *The*

Journal of the Acoustical Society of America, *123*(1), 462. https://doi.org/10.1121/1.2817362

Etholm, B., & Belal, A. (1974). Senile changes in the middle ear joints. *Annals of Otology, Rhinology & Laryngology*, *83*(1), 49–54. https://doi.org/10.1177/000348947408300109

Fischer, N., Johnson Chacko, L., Glueckert, R., & Schrott-Fischer, A. (2020a). Age-Dependent Changes in the Cochlea. *Gerontology*, *66*(1), 33–39. https://doi.org/10.1159/000499582

Fischer, N., Johnson Chacko, L., Glueckert, R., & Schrott-Fischer, A. (2020b). Age-Dependent Changes in the Cochlea. *Gerontology*, *66*(1), 33–39. https://doi.org/10.1159/000499582

Fischer, N., Weber, B., & Riechelmann, H. (2016). [Presbycusis - Age Related Hearing Loss]. *Laryngo- Rhino- Otologie*, *95*(7), 497–510. https://doi.org/10.1055/S-0042-106918

Gates, G. A., Cooper, J. C., Kannel, W. B., & Miller, N. J. (1990a). Hearing in the elderly: the Framingham cohort, 1983-1985. Part I. Basic audiometric test results. *Ear and Hearing*, *11*(4), 247–256. https://doi.org/10.1097/00003446-199008000-00001

Gates, G. A., Cooper, J. C., Kannel, W. B., & Miller, N. J. (1990b). Hearing in the elderly: the Framingham cohort, 1983-1985. Part I. Basic audiometric test results. *Ear and Hearing*, *11*(4), 247–256. https://doi.org/10.1097/00003446-199008000-00001

Gates, G. A., & Mills, J. H. (2005). Presbycusis. *The Lancet*, *366*(9491), 1111–1120.

https://doi.org/10.1016/S0140-6736(05)67423-5

Giri, P. (2010). Otorhinolaryngological disorders in a geriatric population: A study from a rural tertiary care hospital in India Knowledge about epidemiological determinants of rabies and its prevention amongst medical interns of Marathwada region of Maharashtra, India View project Communication skills View project. *Article in Australasian Medical Journal*, *3*, 291–294. https://doi.org/10.4066/AMJ.2010.277

Golding, M., Doyle, K., Sindhusake, D., Mitchell, P., Newall, P., & Hartley, D. (2007a). Tympanometric and acoustic stapedius reflex measures in older adults: The blue mountains hearing study. *Journal of the American Academy of Audiology*, *18*(5), 391–403. https://doi.org/10.3766/JAAA.18.5.4/BIB

Golding, M., Doyle, K., Sindhusake, D., Mitchell, P., Newall, P., & Hartley, D. (2007b). Tympanometric and acoustic stapedius reflex measures in older adults: The blue mountains hearing study. *Journal of the American Academy of Audiology*, *18*(5), 391–403. https://doi.org/10.3766/JAAA.18.5.4/BIB

Gordon-Salant, S. (1987). Consonant recognition and confusion patterns among elderly hearing-impaired subjects. *Ear and Hearing*, *8*(5), 270–276. https://doi.org/10.1097/00003446-198710000-00003

Hall, J. W. (1979a). Effects of Age and Sex on Static Compliance. *Archives of Otolaryngology*, *105*(3), 153–156. https://doi.org/10.1001/ARCHOTOL.1979.00790150043011

Hall, J. W. (1979b). Effects of Age and Sex on Static Compliance. *Archives of Otolaryngology*, *105*(3), 153–156.

https://doi.org/10.1001/ARCHOTOL.1979.00790150043011

Hannula, S., Bloigu, R., Majamaa, K., Sorri, M., & Mki-Torkko, E. (2011). Audiogram configurations among older adults: Prevalence and relation to self-reported hearing problems. *Http://Dx.Doi.Org/10.3109/14992027.2011.593562*, *50*(11), 793–801. https://doi.org/10.3109/14992027.2011.593562

Homans, N. C., Metselaar, R. M., Dingemanse, J. G., van der Schroeff, M. P., Brocaar, M. P., Wieringa, M. H., Baatenburg de Jong, R. J., Hofman, A., & Goedegebure, A. (2017). Prevalence of age-related hearing loss, including sex differences, in older adults in a large cohort study. *The Laryngoscope*, *127*(3), 725–730. https://doi.org/10.1002/LARY.26150

Hoppe, U., Hocke, T., & Iro, H. (2022). Age-Related Decline of Speech Perception. *Frontiers in Aging Neuroscience*, *14*. https://doi.org/10.3389/FNAGI.2022.891202

Hyams, A. V., Hay-McCutcheon, M., & Scogin, F. (2018). Hearing and quality of life in older adults. *Journal of Clinical Psychology*, *74*(10), 1874–1883. https://doi.org/10.1002/JCLP.22648

Ito, I., Imada, M., Ikeda, M., Sueno, K., Arikuni, T., & Kida, A. (2001). A Morphological Study of Age Changes in Adult Human Auricular Cartilage With Special Emphasis on Elastic Fibers. *The Laryngoscope*, *111*(5), 881–886. https://doi.org/10.1097/00005537-200105000-00023

Lee, F. S., Matthews, L. J., Dubno, J. R., & Mills, J. H. (2005). Longitudinal study of pure-tone thresholds in older persons. *Ear and Hearing*, *26*(1), 1–11. https://doi.org/10.1097/00003446-200502000-00001

Lee, K.-Y. (2013). Pathophysiology of Age-Related Hearing Loss (Peripheral and Central). *Korean Journal of Audiology*, *17*(2), 45. https://doi.org/10.7874/KJA.2013.17.2.45

Lin, F. R., & Ferrucci, L. (2012). Hearing Loss and Falls Among Older Adults in the United States. *Archives of Internal Medicine*, *172*(4), 369–371. https://doi.org/10.1001/ARCHINTERNMED.2011.728

Lo, Y. C. (2020). Standard and multiple-frequency tympanometric norms in Chinese young and older adults. *Https://Doi.Org/10.1080/2050571X.2020.1846838*, *25*(2), 204–210. https://doi.org/10.1080/2050571X.2020.1846838

Löhler, J., Cebulla, M., Shehata-Dieler, W., Volkenstein, S., Völter, C., & Erik Walther, L. (2019). Hearing Impairment in Old Age: Detection, Treatment, and Associated Risks. *Deutsches Ärzteblatt International*, *116*(17), 301. https://doi.org/10.3238/ARZTEBL.2019.0301

Makary, C. A., Shin, J., Kujawa, S. G., Liberman, M. C., & Merchant, S. N. (2011). Age-related primary cochlear neuronal degeneration in human temporal bones. *JARO - Journal of the Association for Research in Otolaryngology*, *12*(6), 711–717. https://doi.org/10.1007/S10162-011-0283-2/FIGURES/6

Milne, J. S., & Lauder, I. J. (1975). Pure tone audiometry in older people. *British Journal of Audiology*, *9*(2), 50–58. https://doi.org/10.3109/03005367509079109

Moore, B. C. J., Glasberg, B. R., & Stone, M. A. (2004). New version of the TEN test with calibrations in dB HL. *Ear and Hearing*, *25*(5), 478–487. https://doi.org/10.1097/01.AUD.0000145992.31135.89

Nondahl, D. M., Cruickshanks, K. J., Wiley, T. L., Tweed, T. S., & Dalton, D. S.

(2013). Sixteen-Year Change in Acoustic-Admittance Measures Among Older Adults: Data From a Population-Based Study. *Journal of Speech, Language, and Hearing Research*, *56*(6), 1745–1750. https://doi.org/10.1044/1092-4388(2013/12-0381)

Ouda, L., Profant, O., & Syka, J. (2015). Age-related changes in the central auditory system. *Cell and Tissue Research 2015 361:1*, *361*(1), 337–358. https://doi.org/10.1007/S00441-014-2107-2

Robinson, D. O., & Allen, D. V. (1984). RACIAL DIFFERENCES IN TYMPANOMETRIC RESULTS. *Journal of Speech and Hearing Disorders*, *49*, 140–144. https://doi.org/10.1044/jshd.4902.140

Rodríguez-Valiente, A., Álvarez-Montero, Ó., Górriz-Gil, C., & García-Berrocal, J. R. (2020). Prevalence of presbycusis in an otologically normal population. *Acta Otorrinolaringológica Española*, *71*(3), 175–180. https://doi.org/10.1016/J.OTORRI.2019.05.002

Roychowdhury, P., Castillo-Bustamante, M., Polanik, M., Kozin, E. D., & Remenschneider, A. K. (2021a). Histopathology of the Incudomalleolar Joint in Cases of “Indeterminate” Presbycusis: *Https://Doi.Org/10.1177/0194599821993813*. https://doi.org/10.1177/0194599821993813

Roychowdhury, P., Castillo-Bustamante, M., Polanik, M., Kozin, E. D., & Remenschneider, A. K. (2021b). Histopathology of the Incudomalleolar Joint in Cases of “Indeterminate” Presbycusis. *Otolaryngology - Head and Neck Surgery (United States)*, *165*(5), 701–704. https://doi.org/10.1177/0194599821993813

Ruah, C. B., Schachern, P. A., Zelterman, D., Paparella, M. M., & Yoon, T. H. (1991). Age-Related Morphologic Changes in the Human Tympanic Membrane: A Light and Electron Microscopic Study. *Archives of Otolaryngology–Head & Neck Surgery*, *117*(6), 627–634. https://doi.org/10.1001/ARCHOTOL.1991.01870180063013

Saqulain, G., Zahra, G., & Mumtaz, N. (2021). Audiometric Characteristics of Presbycusis: A Hospital-Based Study. *Journal of Islamabad Medical & Dental College*, *10*(3), 169–175. https://doi.org/10.35787/JIMDC.V10I3.543

Schuknecht, H. F., & Gacek, M. R. (1993). Cochlear pathology in presbycusis. *Annals of Otology, Rhinology and Laryngology*, *102*(1 II), 1–16. https://doi.org/10.1177/00034894931020s101

Shahnaz, N., & Bork, K. (2006). Wideband reflectance norms for Caucasian and Chinese young adults. *Ear and Hearing*, *27*(6), 774–788. https://doi.org/10.1097/01.AUD.0000240568.00816.4A

Shahnaz, N., & Davies, D. (2006). Standard and multifrequency tympanometric norms for caucasian and chinese young adults. *Ear and Hearing*, *27*(1), 75–90. https://doi.org/10.1097/01.AUD.0000194516.18632.D2

Sinha, S. K., Neupane, A. K., & Gururaj, K. (2021). Effect of Aging on Tympanometric Findings in Indian Population. *Annals of Otology and Neurotology*. https://doi.org/10.1055/S-0041-1731921

Sogebi, O. A. (2015). Middle ear impedance studies in elderly patients implications on age-related hearing loss. *Brazilian Journal of Otorhinolaryngology*, *81*(2), 133–140. https://doi.org/10.1016/J.BJORL.2014.09.007

Stenklev, N. C., Vik, O., & Laukli, E. (2004). The Aging Ear: An Otomicroscopic and Tympanometric Study. *Acta Oto-Laryngologica*, *124*(1), 69–76. https://doi.org/10.1080/00016480310002212

Stenklev, N. C., Vik, O., & Laukli, E. (2014). The aging ear: an otomicroscopic and tympanometric study. *Http://Dx.Doi.Org/10.1080/00016480310002212*, *124*(1), 69–76. https://doi.org/10.1080/00016480310002212

Takasaki, K., Sando, I., Balaban, C. D., Haginomori, S. I., Ishijima, K., & Kitagawa, M. (1999). Histopathological Changes of the Eustachian Tube Cartilage and the Tensor Veli Palatini Muscle With Aging. *The Laryngoscope*, *109*(10), 1679–1683. https://doi.org/10.1097/00005537-199910000-00024

Tereza de Matos Magalhães, A., Valéria Schmidt Goffi Gómez, M., & Fonoaudióloga, A. (n.d.). *Índice de Reconhecimento de Fala na Presbiacusia Speech Discrimination Index in Presbycusis*.

Van Laer, L., & Van Eyken Van Camp L Van Laer, E. G. (2007). The Complexity of Age-Related Hearing Impairment: Contributing Environmental and Genetic Factors. *Article in Audiology and Neurotology*, *12*, 345–358. https://doi.org/10.1159/000106478

Wiley, T. (1996a). Tympanometric measures in older adults Speech Recognition View project Hearing and Aging View project. *Article in Journal of the American Academy of Audiology*. https://www.researchgate.net/publication/14377292

Wiley, T. (1996b). Tympanometric measures in older adults Speech Recognition View project Hearing and Aging View project. *Article in Journal of the*

American Academy of Audiology. https://www.researchgate.net/publication/14377292

Wiley, T. (1998). Aging and word recognition in competing message Speech Recognition View project Speech Recognition View project. *Article in Journal of the American Academy of Audiology*. https://www.researchgate.net/publication/13639377

Wiley, T. (1999). Aging and middle ear resonance Hearing and Aging View project Speech Recognition View project. *Article in Journal of the American Academy of Audiology*. https://www.researchgate.net/publication/12378463

Wu, P.-Z., O'malley, J. T., De Gruttola, V., & Liberman, M. C. (2020). *Age-Related Hearing Loss Is Dominated by Damage to Inner Ear Sensory Cells, Not the Cellular Battery That Powers Them*. https://doi.org/10.1523/JNEUROSCI.0937-20.2020

Yonan, C. A., & Sommers, M. S. (2000). The effects of talker familiarity on spoken word identification in younger and older listeners. *Psychology and Aging*, *15*(1), 88–99. https://doi.org/10.1037/0882-7974.15.1.88

Zhou, L., Shen, N., Feng, M., Liu, H., Duan, M., & Huang, X. (2019). Study of age-related changes in Middle ear transfer function. *Https://Doi.Org/10.1080/10255842.2019.1632297*, *22*(13), 1093–1102. https://doi.org/10.1080/10255842.2019.1632297