RELATIONSHIP AMONG PSYCHOPHYSICAL ABILITIES, SPEECH PERCEPTION IN NOISE AND WORKING MEMORY ON INDIVIDUALS WITH NORMAL HEARING SENSITIVITY ACROSS DIFFERENT AGE GROUPS

A DOCTORAL THESIS

Submitted to the University of Mysore,
for the award of degree of
Doctor of Philosophy (Ph.D) in Audiology

by

Chandni Jain

Under the guidance of

Dr. Ajith Kumar U

All India Institute of Speech and Hearing
Manasagangothri, Mysore

August, 2016

DECLARATION

I declare that this thesis entitled **"Relationship among Psychophysical abilities, Speech Perception in Noise and Working memory in Individuals with Normal hearing sensitivity across different age groups"** which is submitted herewith for the award of the degree of Doctor of Philosophy in Audiology to the University of Mysore, Mysore is the result of work carried out by me at the All India Institute of Speech and Hearing, Mysore, under the guidance of Dr. Ajith Kumar U, Reader in Audiology, All India Institute of Speech and Hearing, Mysore. I further declare that the results of this work have not been previously submitted for any other degree.

Place: Mysore   Chandni Jain

Date:

CERTIFICATE

This is to certify that the thesis entitled **"Relationship among Psychophysical abilities, Speech Perception in Noise and Working memory in Individuals with Normal hearing sensitivity across different age groups"** submitted by Ms. Chandni Jain for the degree of Doctor of Philosophy in Audiology to the University of Mysore, Mysore was carried out at the All India Institute of Speech and Hearing, Mysore, under my guidance. I further declare that the results of this work have not been previously submitted for any other degree.

Place: Mysore

Date:

Dr. Ajith Kumar U

Reader in Audiology

All India Institute of Speech and Hearing

Mysore

CERTIFICATE

This is to certify that the thesis entitled **"Relationship among Psychophysical abilities, Speech Perception in Noise and Working memory in Individuals with Normal hearing sensitivity across different age groups"** submitted by Ms. Chandni Jain for the degree of Doctor of Philosophy in Audiology to the University of Mysore, Mysore was carried out at the All India Institute of Speech and Hearing, Mysore.

Place: Mysore
Date:

Dr. S. R. Savithri
Director
All India Institute of Speech and Hearing
Mysore

DEDICATED TO

SARANSH

AND

AVI, AADYA

Acknowledgements

My sincere gratitude to my mentor Dr. Ajith Kumar U, for his guidance, support, patience and effort provided throughout this journey of Ph.D. More than me, this thesis is an outcome of his efforts and knowledge. I fall short of words to express my gratitude for you. Thank you again…

I thank Dr. S.R. Savithri, Director, AIISH, Mysore, for permitting me to carry out this research work.

I thank Doctoral committee members, Dr S R Savithri, Dr Asha Yathiraj, Dr Animesh Barman, for offering their valuable suggestions regarding the work.

My sincere thanks to all the participants of this study for their participation and cooperation.

I thank Dr. Vijaya Kumar Narne and Nike for all help with MATLAB software and my sincere thanks to Dr. Vasanthalakshmi for teaching and helping with statistics.

My sincere thanks to all the staff, Department of Audiology, for their valuable support throughout this work.

I sincerely thank Mrs Chudamani and Mr Ravi for providing all the technical help needed during the study.

Sandeep…. it has been 18 years!!! I will cherish all the moments that we had spent together in these many years and the years to come. Priya…..how will I miss to thank you, spending time with you and listening to your talks is always refreshing…..

My classmates Jayashree, Gopi and Mamtha, moment spent with you will always be relishing.

My PhD companions Usha, Niraj, Sreeraj, Megha, Jithin, discussions and talks with you was always comforting, relaxing and refreshing.

Devi and Geetha, would like to thank you guys for helping me whenever needed….you are special…

Amrutha, Tina and Latika…….thank you for helping me in finding participants and helping in data collection…..

I am greatly indebited to my parents, though not with me physically, have always believed in me and my decisions. You have supported and stood beside me at each and every step that I have taken. Suraj bhaiji, Vaishali bhabhi, Akash bhaiji, Veenu bhabhi and all kiddus…….thanx a lot for everything

Mother-in-law and Father-in-law, thank you for supporting me to work for thesis every moment. I couldn't have had better in-laws than you. Simpy bhaiya , I appreciate your support, care and enthusiasm.

Saransh, you are just perfect for me. No words to explain what you mean to me and having you around me makes my life brighter……Avi and Aaadya, you are world to me and thank you for all the cooperation and allowing me to do my work. I know you are too small to understand this….

Throughout this journey there are numerous people who have helped me………this list is a never ending and I apologize if I have missed anyone.

TABLE OF CONTENTS

List of Tables

List of Figures

Abstract

The present study investigated the age related changes in psychophysical abilities, speech perception in noise and working memory. The relationship among age, psychophysical abilities, speech perception in noise and working memory was also assessed. A cross-sectional research design was used and a total of 210 participants were selected for the study. Participants in the age range of 10-85 years were equally divided into seven cross-sectional age groups. The effect of age was studied on processing of all three main domains of sound: frequency, intensity and duration. Frequency and intensity processing was investigated through frequency difference limen and intensity difference limen. Temporal processing skills were assessed through duration discrimination thresholds, gap detection thresholds, backward masking, modulation detection thresholds and duration pattern scores. Speech perception in noise was assessed through quick speech perception in noise test in Kannada. Working memory assessment involved operation span test, reading span test and auditory sequencing and digit span measures (forward, backward, ascending and descending digit span). The results showed that the younger participants performed significantly better in most of the psychophysical measures, speech perception in noise and working memory. Working memory measures had significant relationship with the psychophysical measures and speech perception in noise. Structural equation modeling revealed that direct effect of age on speech perception in noise was negligible. However, age had significant indirect effect on speech perception through its effect on temporal and frequency processing skills. Direct effect of age on working memory skills was also small and negligible. However, age had significant indirect effect on working memory skills through temporal and frequency processing. Temporal processing, frequency processing and intensity processing skills significantly affected working memory skills and speech perception in noise.

Key words: Frequency processing, intensity processing, temporal processing, operation span, reading span

Chapter 1

Introduction

Ageing in adults is associated with decline in sensory functioning including hearing (Pinto et al., 2014). It is well known that older individuals have higher absolute hearing thresholds compared to young adults (Corso, 1963). It's also been shown that older individuals perform poorly compared to their younger counterparts on many supra threshold auditory abilities (Marshall, 1981).

Age related declines are reported in terms of frequency discrimination (He, Dubno, & Mills, 1998; König, 1957), intensity discrimination (Harris, Mills, & Dubno, 2007), duration discrimination (Abel, Krever, & Alberti, 1990; Fitzgibbons & Gordon-Salant, 1994), gap detection (Fitzgibbons & Gordon-Salant, 1995; Phillips, Gordon-Salant, Fitzgibbons, & Yeni-Komshian, 1994), modulation detection (He, Mills, Ahlstrom, & Dubno, 2008), and temporal ordering skills (Humes & Christopherson, 1991; Trainor & Trehub, 1989). Age related decline in these abilities could be attributed to the anatomical and physiological changes taking place in the auditory system. Ageing leads to degenerative changes in the peripheral and central auditory system and results in functional and structural changes throughout the auditory system. Changes in the cochlea associated with ageing is summarized in the Table 1.1.

Table 1.1

Changes in cochlea with ageing (from Howarth & Shone, 2006).

Cochlea lesion	**Pathology**	**Result**
Sensory	Loss of sensory cells in basal turn of cochlea	Sloping high frequency loss above the speech frequency range
Neural	Loss of cochlear neurons	Progressive loss of speech discrimination in the presence of stable pure tone thresholds
Strial	Metabolic and vascular changes within cochlea	Slowly progressive hearing loss with flat audiogram and good speech discrimination
Conductive	Changes in the conduction or resonance of the cochlear duct	Linear descending type of audiogram
Indeterminate	No pathological correlate identified. Possibly impaired cellular function	Flat and/or sudden high tone hearing loss
Mixed	Combination of above	Mild to moderate high frequency loss

Similarly, age related degenerative changes are also often observed in cochlear nucleus, superior olivery complex, and in the other parts of the central auditory pathway (Willott, 1991). With the advancing age, number of neurons in the cochlear nuclei and auditory centres of the brain decreases (Chisolm, Willott, & Lister, 2003; Johnsson & Hawkins, 1972). Decline in the size of cells and alterations in the neurochemical make up of the cells can lead to the reduced capability of the central auditory system to process sound (Pichora-Fuller & Souza, 2003). These changes may result in attenuation of the neural input from an damaged peripheral auditory system (Chisolm et al., 2003) and can affect hearing sensitivity itself or affect supra threshold auditory abilities.

1.1. Effect of age on psychophysical abilities

Ageing affects frequency discrimination and resolution skills (He et al., 1998; König, 1957). He, Mills, and Dubno (2007) observed that older listeners performed poorly on frequency modulation detection task compared to younger listeners especially at low carrier frequencies. On a similar line, it's also been shown that older participants have larger intensity difference limen compared to young adults (Harris et al., 2007). Moreover, elderly participant's exhibits larger inter subject variability than young participants on both frequency and intensity discrimination tasks (He et al., 1998). In addition, adverse effects of ageing are also observed on temporal processing skills. Fitzgibbons and Gordon-Salant (1994) reported that differential limen for time was larger in older listeners compared to young listeners. Harris, Eckert, Ahlstrom, and Dubno (2010) measured gap detection thresholds (GDT) on young and old individuals with normal hearing sensitivity. GDT was calculated in two conditions - gap location was kept fixed at 5%, 50% or 90% of the total noise duration and gap location varied randomly from trial to trial. Results suggested that random positioning of the gap affected the GDT more in older listeners compared to young listeners. Authors attributed increased GDT in random gap location condition to increased cognitive load while performing the task. Modulation detection thresholds, especially for high modulation frequencies, were also poorer in older adults compared to young adults (Kumar & Sangamanatha, 2011).

Temporal patterning is another measure to assess temporal perception and can be measured through tasks such as duration pattern test and pitch pattern test. Studies have shown that older listeners have difficulty in discrimination and identification of temporal pattern judgments (Fitzgibbons & Gordon-Salant, 1998; Humes & Christopherson, 1991; Trainor & Trehub, 1989). Furthermore, the task difficulty and processing time needed for temporal order discrimination and identification is more for older adults. Temporal masking measures the ability of a listener to determine the timing differences between masking noise and the target sound. Studies have reported poorer temporal masked thresholds in older listeners (Dubno, Horwitz, & Ahlstrom, 2002; Gehr & Sommers, 1999a; Gifford, Bacon, & Williams, 2007). In summary, ageing has shown to have deleterious effects on almost all psychophysical measures. These basic supra threshold auditory or psychophysical skills play a vital role in speech perception. Ageing also has negative effect on speech perception, especially, in adverse listening conditions (CHABA, 1988).

1.2. Effect of age on speech perception

Speech perception is a complex phenomenon involving both auditory and language processing (Kalikow, Stevens, & Elliott, 1977). Research evidence indicates that speech perception abilities also deteriorate with ageing. Effect of age on speech perception is influenced by various other factors such as redundancy in the stimulus, rate of speech, background noise, signal to noise ratio, knowledge of the language and cognitive abilities (CHABA, 1988).

Previous research has indicated that individuals above the age of 60 years start exhibiting speech perception problems in the presence of noise. They require at least 2 to 3 dB better signal-to-noise ratio compared to younger listeners (Duquesnoy & Plomp, 1980; Plomp, 1977; Plomp, 1986; Plomp & Mimpen, 1979). In a longitudinal study Divenyi, Stark, and Haupt (2005), reported that speech-recognition skills declined rapidly with age in older participants than their pure-tone thresholds. Humes and Coughlin (2009) studied the effects of increased processing load on the closed-set speech-identification task among young and old adults in a one-talker background. Results revealed that older adults performed poorer than young adults and they also showed less relative improvement as the processing load was decreased. These results indicate that there could be interplay among ageing, cognition and speech perception skills.

1.3. Effect of age on cognition

With advancing age, cognitive abilities, specifically those related to working memory skills show a decline. Working memory is a cognitive system that helps an individual to sustain and manipulate information in brain for short duration of time and it plays a significant role in various cognitive tasks like learning, reasoning, problem solving and language comprehension (Vuontela et al., 2003). Morris, Gick, and Craik (1988) assessed the effect of age on working memory using operation span task and results indicated that geriatric participants responded more slowly and that increase in the memory load and sentence complexity was associated with longer verification latencies. Hester, Kinsella and Ong (2004) studied auditory working memory using forward and backward digit tasks in adults and geriatrics. Results showed an age related decline in both digit forward and digit backward tasks and both the abilities deteriorated to the same extent. Thus, it is apparent that the age related decline is seen in working memory.

1.4. Relationship among age, working memory, psychophysical abilities and speech perception in noise

Although, the relationship of psychophysical abilities with speech perception skills are well studied (Dreschler & Plomp, 1985; Fitzgibbons & Gordon-Salant, 1995), the relationship among age, psychophysical abilities, speech perception skills and cognitive abilities are poorly understood. Over a past decade, there is an increased interest among researchers in studying the association between cognitive functions and sensory skills (Gatehouse, Naylor, & Elberling, 2003; van Rooij, 1989). Humes and his colleagues in series of studies investigated the relationship among peripheral, central auditory processing skills and cognitive skills, specifically working memory (Humes, 2002; Humes, Burk, Coughlin, Busey, & Strauser, 2007; Humes & Coughlin, 2009; Humes & Christopherson, 1991). Collectively their results indicated that cognitive factors contributed substantially to speech understanding. This association between cognition and speech understanding was stronger in adverse listening conditions and for amplified speech. Furthermore, their observation also supported the hypothesis that age related changes in cognitive functions might be mediated through age related changes in sensory functioning. Grassi and Borella (2013) showed that some of the auditory abilities (i.e., frequency discrimination, duration discrimination, timbre discrimination, and amplitude modulation detection) could explain a significant amount of varience observed in the processing speed of older adults. Similar, association between sensory and cognitive functions is reported by other investigators too. Akeroyd (2008) did meta-analysis on 20 scientific studies that examined relationship between speech perception and cognitive skills. He noted that in acoustically demanding situations, listener's use previous knowledge to understand speech. Hence, when speech signals are degraded, missing, or ambiguous top-down skills are used to understand. Schneider and Pichora- Fuller (2000) summarized the association between cognitive and sensory decline with ageing as - a) the sensory deprivation hypothesis b) information degradation hypothesis c) cognitive load on perception hypothesis and d) common cause hypothesis. First two hypotheses predict that cognitive decline is preceded by sensory decline, while the third hypothesis predicts the reverse. The common cause hypothesis suggests that there is a common underlying factor responsible for decline in cognition and sensory skills with the advancing age. Although, the relationship between cognition and audition is studied in a few investigations, strength of this relationship is still not clear. Furthermore, complex interplay among age, cognition, suprathreshold auditory skills (psychophysical skills) and speech perception in noise is not clearly understood.

1.5. Need for the study

1.5.1. Need to study the effect of age on psychophysical abilities, speech perception in noise and working memory. From the literature reviewed above, it is clear that psychophysical abilities, working memory and speech perception skills deteriorate with age. Most of the studies cited above have investigated the effect of age on some of the psychophysical skills such as gap detection thresholds, duration discrimination thresholds, temporal ordering. However, there are only a few studies that have investigated the effect of age on psychophysical skills along all three main dimensions of sound: frequency, intensity and duration. In the present study, we investigated the effect of age on frequency, intensity and temporal processing in same group of participants. This will help us to determine whether all psychophysical skills deteriorate to the same extent or whether some are more resistant to the effects of ageing than others. Frequency and intensity processing skills were assessed by measuring just noticeable differences. Just noticeable differences in intensity and frequency were measured at four frequencies: 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. Just noticeable differences assess the minimum differences in intensity or frequency that the individual can discriminate and provides a good estimate of frequency and intensity resolution (Houtsma, 1995; Plack & Carlyon, 1995). Hence, these measures were used in the study.

Temporal processing was assessed using multiple measures – duration discrimination thresholds, modulation detection thresholds, gap detection thresholds, backward masking and temporal ordering (duration pattern). These measures were chosen as previous investigations have indicated that these abilities assess temporal processing skills (Eddins & Green, 1995). Furthermore, these psychophysical abilities were chosen, as they are important for the perception of speech in noise (Moore & Glasberg, 1987). In addition, previous studies have used only discrete age groups such as 'young vs. old'. Studying speech perception and psychophysical abilities in continuum of age groups, would help in understanding the pattern of decline in psychophysical abilities with age and its relationship with speech perception.

With ageing many cognitive abilities, specifically working memory skills also show a decline. Working memory has a limited ability and the components of working memory are rather independent of each other. The predictions of the working memory model (Baddeley & Hitch, 1974) states that if two abilities use related component of the working memory, they cannot be executed effectively, simultaneously. However, if two abilities use different components of the working memory, it is possible to execute them simultaneously as well as separately. This process can be evaluated through various tests such as operation span task and reading span task (Kane et al., 2004) as well as auditory working memory tests such as digit span and auditory number sequencing tasks. In the present study multiple measures of working memory skills (operation span, reading span, auditory digit span and auditory number sequencing) was used in order to get a good estimate of working memory capacity and its pattern of decline with age. Multiple measures of working memory capacity drastically improves the validity of measuring working memory capacity (Wilhelm, Hildebrandt, & Oberauer, 2013) and hence were used.

1.5.2. Need to study the relationship among age, working memory, speech perception in noise and psychophysical abilities. As noted earlier, working memory, speech perception in noise and basic psychophysical skills deteriorate with ageing. Some of the paradigms used to tap psychophysical skills may depend on attention and memory. For example, sequences used in temporal ordering might involve more cognitive resources than just discrimination task. Given the known age related decline in cognitive processes, poor performance of older adults on such psychophysical task may not necessarily be because of poor auditory processing skills alone. Therefore, since past two decade or so, researchers have started to investigate the association among age related decline in these skills (Harris, Wilson, Eckert, & Dubno, 2012; Mukari, Umat, & Othman, 2010; van Rooij, 1989). For example, Humes, Busey, Craig, and Kewley-Port (2013) reported that age related changes in global cognitive abilities may be mediated by age related changes in global sensory abilities. Grassi and Borella (2013) showed a strong association between cognitive and psychophysical tasks. When the sensory performance deteriorated with ageing, cognitive performance, specifically working memory skills also worsened. However, baring a few exceptions majority of the studies exploring the relationship between cognitive and sensory functions have used small sample sizes. Moreover, these studies have been typically carried out on young and old age groups and have not explored the relationship using continuous cross-sectional age groups across adult lifespan. Furthermore, most of the studies have often used Wechsler's adult intelligent scale to assess cognitive skills. However, this test is not dedicated to assess working memory skills, which is an important cognitive factor influencing speech perception (Francis & Nusbaum, 2009; Ingvalson, Dhar, Wong, & Liu, 2015). Hence, in the present study relationship among auditory and working memory skills were assessed using a large number of participants (across all age groups) divided across adults' lifespan. In addition multiple measures of auditory and working memory skills were also obtained.

1.6. Aim of the Study

The aim of the present study was to assess the effect of age on psychophysical abilities, speech perception in noise and working memory skills. Furthermore, this study also investigated the relationship among age, psychophysical abilities, speech perception in noise, and working memory in individuals with normal hearing sensitivity.

1.7. Objectives of the Study

1. To compare frequency and intensity discrimination through frequency difference limen and intensity difference limen at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz between different age groups.
2. To compare temporal processing abilities through duration discrimination at 1000 Hz, gap detection in white noise, modulation detection thresholds, backward masking and duration pattern scores between different age groups.
3. To compare speech perception in noise between different age groups.
4. To compare working memory abilities (operation span, reading span task, auditory digit span and auditory digit sequencing) between different age groups.

5. To assess the relationship among age, working memory, speech perception in noise and psychophysical abilities.

1.8. Hypotheses

The null hypothesis was assumed for the present study indicating:

1. There is no significant difference among age groups on frequency discrimination and intensity discrimination.
2. There is no significant difference among age groups on temporal processing skills (duration discrimination, gap detection, modulation detection, backward masking and duration pattern).
3. There is no significant difference among age groups on speech perception in noise.
4. There is no significant difference among age groups in working memory.
5. There is no significant relationship among age, working memory, speech perception in noise and psychophysical abilities.

Chapter 2

Review of Literature

The psychophysical abilities involve the perception of frequency, intensity and the temporal parameters of sound. Frequency analysis refers to the ability of the auditory system to resolve the acoustic components of a complex sound which can be measured through tasks such as masking and frequency discrimination (Moore, 1995). Intensity discrimination refers to the ability of the auditory system to detect differences in the intensity of sound. This ability can be evaluated using modulation detection and increment detection function (Plack & Carlyon, 1995). Temporal parameters may be conceptualized in terms of temporal processing abilities. Temporal processing ability is an umbrella term involving sub processes such as temporal resolution, temporal patterning, temporal integration and temporal masking (Shinn, 2007).

2.1. Factors affecting psychophysical abilities

There are various factors which can affect the perception of psychophysical abilities. These include age, hearing loss, background noise, cognition, etc. These factors have been studied in individuals with normal hearing sensitivity across age groups and have been compared with those having hearing problems. Psychophysical studies have indicated age related changes on various auditory abilities. The common complaint of elderly individuals with normal hearing sensitivity and those with hearing loss is difficulty in speech perception, especially in difficult listening environments (Dubno, Lee, Matthews, & Mills, 1997). Psychophysical experiments have shown age related declines in frequency discrimination (König, 1957), intensity discrimination (Harris et al., 2007), duration discrimination (Abel et al., 1990), gap detection (Fitzgibbons & Gordon-Salant, 1995; Phillips et al., 1994), and temporal order determination (Humes & Christopherson, 1991; Trainor & Trehub, 1989).

2.1.1. Frequency discrimination. It is the ability of an individual to identify changes in frequency over time. There are several studies on frequency discrimination in individuals with normal hearing sensitivity (Harris, 1952; Moore, 1973; Nordmark, 1968; Shower, 1931; Wier, 1977). All the studies are in agreement that the difference limen (DL) increases with the increase in frequency in individuals with normal hearing sensitivity.

Frequency discrimination can be measured through various ways, such as two interval forced choice method, three interval forced choice method, and so on. Studies have shown that as the number of alternatives is increased from 2 to 4, the variability of repeated threshold estimates decreases or remains constant, and the accuracy of the estimator, in most cases, improves (Schlauch, 1990). The physiology behind frequency discrimination has been explained by Moore (1973); Sek and Moore (1995). For pure tone stimuli of 1000 Hz and above, frequency discrimination is primarily due to place mechanisms based on spatial changes in the basilar membrane excitation pattern. However, for stimuli less than 1000 Hz, frequency discrimination depends on temporal information (Moore, 1973; Sek & Moore, 1995). It has been assumed that the perception of low frequency discrimination abilities is due to the neural phase locking and for high frequencies, limitations in neural refractory period prevents a phase related response (Rance, 2005). This has been substantiated by Sek and Moore (1995), who gave explanation for frequency discrimination based on the excitation pattern information and not taking into account the phase locking.

Effect of Age. Effect of age on frequency discrimination is well studied. Konig (1957) studied 70 participants with normal hearing sensitivity in the age range of 20-89 years. 10 participants were taken from each and frequency difference limen (FDL) was measured for 125, 250, 500, 1000, 2000, 3000 and 4000 Hz at 40 dB SL. Results indicated that the pitch discrimination deteriorated in a linear manner between the ages of 25 to 55 years, and after 55 years the size of difference limen increases more abruptly. Abel et al. (1990) measured FDL among participants with normal hearing sensitivity at 500 and 4000 Hz to compare the age effect. Results showed that older adults had higher FDL by a factor of 1.8 at 500 Hz and 2.3 at 4000 Hz, compared to younger adults.

He et al. (1998) measured frequency discrimination on 13 participants (7 young & 6 elderly) with normal hearing sensitivity. They measured FDL at 500, 1000, 2000 and 4000 Hz using the maximum likelihood procedure starting at 40 dB SPL followed by 80 dB SPL. Frequency discrimination was poorer for aged participants compared to younger participants with maximum difference at 500Hz. Aged participants also showed larger intersubject variability than young participants and age related difference was greater at low than at high frequency. Clinard, Tremblay, and Krishnan (2010) measured FDL on 32 participants (22-77 years) with normal hearing sensitivity at 500 and 1000 Hz using a two-interval forced choice procedure. Results demonstrated a significant decline in FDLs for both 500 and 1000 Hz, with increase in age. Thus, it can be concluded that frequency discrimination ability declines with age and there is large intersubject variability among them.

Effect of frequency. Frequency discrimination would also depend upon the frequency for which it is obtained. Henning (1966) measured FDL from 250 Hz to 12500 Hz using 250 ms tone bursts. Results indicated that discrimination was poorer at high frequencies mainly above 5000 Hz and frequency discrimination varied with loudness level. He reported that at higher frequencies participants may use intensity fluctuations as cues to discriminate frequency changes.

Wier, Jesteadt and Green (1977) measured FDL from 200 Hz to 4000 Hz. They reported that the DL was approximately 1 to 1.5 Hz at 200 Hz to 800 Hz and approximately 2 to 3 Hz at 1000 Hz to 2000 Hz. The DL increased to around 18 Hz for the frequency region of 4000 Hz. They also reported that the effect of sensation level on frequency discrimination was more for low then for high frequencies. Similar results were reported by other investigators as well (Freyman & Nelson, 1991; Sek & Moore, 1995).

Effect of sensation level. Frequency discrimination has also been studied at various sensation levels. In a study by Freyman and Nelson (1991) on five participants with normal hearing sensitivity and seven participants with hearing impairment, DL was obtained at ten different intensity levels, for short (5 ms) and long (300 ms) duration pure tones of 500, 1000 and 2000 Hz. The short duration pure tone did not show an increase in DL with the increase in intensity. However, for long duration pure tones, there was an increase in DL with increase in intensity. Kamath (1989) also measured DL of frequency on 40 adults at various sensation levels (20 dB SL, 40 dB SL, 60 dB SL & 80 dB SL) for octaves between 250 to 4000 Hz. She concluded that FDL obtained across the frequencies and sensation levels did not differ significantly.

Effect of hearing loss. Frequency discrimination has been studied in individuals with normal hearing sensitivity across age groups and has also been compared with those having hearing loss. Hall and Wood (1984) measured frequency discrimination on 10 participants with normal hearing sensitivity and 10 participants with cochlear hearing loss for pure tones of 500 Hz and 2000 Hz at durations of 200, 50, 20, 10 and 5 ms at 90 dB SPL. Results indicated that FDL was 1.9 Hz at 500 Hz and 4.4 Hz at 2000 Hz for 200 ms duration stimuli. DL value increased with decrease in stimulus duration and DL function of hearing impaired listeners were parallel to that of normal hearing, showing poorer discrimination overall.

Moore and Peters (1992) measured FDLs on four groups of participants including young and elderly participants with normal hearing sensitivity and those with hearing loss. Results showed that FDL of both hearing impaired groups were higher than the FDL of younger group with normal hearing sensitivity. Simon and Yund (1993) measured FDL for each ear on 34 participants with bilateral cochlear hearing loss. They reported that FDLs could be different for the two ears when the absolute thresholds were same and FDLs could be same when the thresholds of the two ears were different. Thus, it is evident across studies that frequency discrimination depends on various factors such as age, frequency, hearing loss, sensation level, etc. Studies comparing frequency discrimination ability across age have shown that FDL is poorer in the elderly population and effect was more prominent for low frequencies.

2.1.2. Intensity discrimination. It is the ability of a person to detect small changes in intensity. Gelfand (2009) reported that DLs for intensity becomes smaller as the sensation level increases for mid frequency stimuli. Intensity discrimination can be measured through two interval forced choice method, four interval forced choice method in a similar manner as frequency discrimination. Loudness sensations evoked by sounds are usually thought to detect the changes in intensity or to compare the intensity of two separate sounds. Loudness growth is reported to be usually more in individuals with cochlear damage than normal hearing individuals for given changes in intensity. Studies have been done to determine the effect of age, frequencies, hearing loss, and sensation level on intensity discrimination.

Effect of age. Florentine et al. (1993) measured intensity difference limen (IDL) on two older listeners and they reported that IDL was larger in older adults compared to those of young listeners with comparable hearing sensitivity. He et al. (1998) compared IDL for 13 participants with normal hearing sensitivity (7 young & 6 elderly). DL was measured at 500, 1000, 2000 and 4000 Hz using the maximum likelihood procedure starting at 40 dB SPL followed by 80 dB SPL. DL was uniform across participants and frequency with an overall mean of 2.98 dB. Aged subject showed larger intersubject variability than young subject and age related difference was greater at lower than at high frequency.

In an another study, Harris et al. (2007) compared DL of intensity for younger and older subject using P1N2 complex of late latency responses at 500 Hz and 3000 Hz where the intensity increment was varied randomly from +0 dB to +5 dB and +0 dB to +8 dB for 500 Hz and 3000 Hz respectively. Results indicated that at low frequencies DL decreased with enhanced amplitudes; however latencies were delayed in some older participants. This could be due to the reduced inhibitory control of the central auditory nervous system with ageing.

Fostick, Ben-Artzi and Babkoff (2013) measured IDL on 89 participants (21-82 years) with normal hearing sensitivity at 40 dB SL. Results showed that intensity discrimination did not decline with age. Thus, it is evident from the above studies that intensity discrimination varies with age, but the results are not conclusive and needs further study.

***Effect of frequency*.** Jesteadt, Weir and Green (1977) measured DL of intensity in three participants with normal hearing sensitivity at 5, 10, 20, 40 and 80 dB SL for frequencies of 400, 600, 800, 1000, 2000, 4000 and 8000 Hz. They did not find any frequency effect on DL at any given SLs. However, Florentine, Buus, and Mason (1987) reported that DL of intensity was poorer at higher frequencies than the low and middle frequencies. The difference in the results of two studies can be attributed to the difference in methodology.

Effect of sensation level. Gelfand (2009) reported that the DLs for intensity reduce as the sensation level increases for mid-frequency stimuli. Miller (1947) measured DL for white noise in participants with normal hearing sensitivity and he reported that DL in level was constant regardless of the absolute level. The value was about 0.5-1 dB for white noise, presented at 20 dB to 100 dB above absolute threshold in normal hearing individuals. Another study by Jesteadt at al. (1977) also supports the same results. It has also been reported that with increase in intensity the change in DL was less for pulsed tone than modulated tone (Moore, 1995).

Iyanger (2000) measured intensity DL for 1000 Hz tone at 10 and 40 dB SL using a 'yes-no' procedure on 21 adults with normal hearing sensitivity. She reported that the mean DL was 3.84 dB and 2.87 dB at 10 and 40 dB SL respectively. It was concluded there was no significant difference in DLs at two sensation levels.

Effect of hearing loss. Buus, Florentine and Ridden (1982a, 1982b), measured intensity DL in hearing impaired individuals. They reported that the DL was better in individuals with cochlear damage compared to normal hearing individuals when testing was done at equal sensation levels. Similarly, Turner, Zwislocki and Filion (1989) measured the DL for pure tones with gated and continuous-pedestal paradigms in individuals with normal hearing sensitivity and individuals with cochlear hearing loss. The experiments were performed at 500, 2000 and 6000 Hz, and at a wide range of SLs by means of an adaptive two alternative forced-choice procedure. Results revealed that the individuals with hearing loss had smaller DL values than the individuals with normal hearing for both pedestal paradigms at equal SLs. However, when the comparisons were made on the basis of equal SPLs both groups showed similar values for moderate and high SPLs. At relatively low SPLs, the group with hearing loss had a higher DL value. Thus, it is evident from the above study that DL of intensity reduces at equal sensation level in individuals with cochlear hearing loss compared to individuals with normal hearing sensitivity. Humes (1996) reported in his study that older participants had poorer IDL compared to younger participants and when the hearing levels between the two groups were minimized by adding a high pass masker for younger subjects, IDL difference became negligible.

Thus, from the above studies, it can be concluded that intensity discrimination ability depends on various factors such as ageing, hearing loss, frequency, etc. Studies comparing intensity discrimination ability in young and elderly individuals have shown that DL of intensity in older participants decreases at low frequencies which can be due to the decreased inhibitory control of the central auditory nervous system. Studies comparing the effect frequency and intensity on IDL have shown that DL does not vary across frequency and intensity. However, whether cognition plays a role in intensity discrimination has not been studied till date.

2.1.3. Auditory temporal processing. It is defined as the perception of the temporal envelope or the variation in the durational characteristics of a sound in a defined time interval (Musiek et al., 2005).

Duration discrimination. It is the skill of the auditory system to detect minute changes in the duration of acoustic stimuli. Creelman (1962) reported that the smallest detectable change in duration of a stimulus (ΔT) increases with increase in baseline duration (T) of a stimulus. Shylaja (2005) measured duration discrimination on normal hearing adults using 1000 Hz anchor tone having duration of 50 ms at 40 dB SL using a gated method. The results indicated that the participants could differentiate 15 to 25 ms difference in duration between the two stimuli.

Effect of age. Duration discrimination has been studied to examine whether there is any age related difference. Fitzgibbons and Gordon-Salant (1994) studied duration discrimination on 40 participants in four groups consisting of elderly listeners and young listeners with normal hearing sensitivity and with mild to moderate sloping sensorineural hearing loss. Duration discrimination was measured for a tone burst of 500 Hz and 4000 Hz using reference duration of 250 ms at 85 dB SPL. Results indicated that average discrimination for elderly listeners was larger than for younger listeners. However, there was no effect of hearing loss on discrimination ability.

In another study, Phillips et al. (1994) compared duration discrimination in young and elderly participants with normal hearing sensitivity. DL for duration was measured between a standard 1000 Hz tone of 40 ms and a comparison tone of longer duration. The duration discrimination paradigm was presented with a tonal masker following the tonal stimulus at three delay times: 80 ms, 240 ms, and 720 ms and complex stimulus. Age effects were observed on the duration discrimination task with interference, but not on the initial duration discrimination task without interference. These results suggest that the time required to process the duration characteristics of acoustic stimuli is prolonged in elderly listeners.

Kumar and Sangamanatha (2011) measured duration discrimination on 176 participants (20 to 85 years) with normal hearing sensitivity using an anchor stimulus of 250 ms white noise. Scores were similar for individuals in the age range of 20-30 years and 31-40 years. Individuals above 70 years had poorer scores compared to all other age groups. Thus, from the above studies, it is clear that duration discrimination ability deteriorates with age and elderly individual above 70 years showed poorest discrimination ability.

Effect of duration. Abel (1972) measured duration discrimination using stimuli with baseline durations of 10, 100 and 1000 ms and ΔT was found to be around 4, 15 and 60 ms respectively. The results were relatively independent of the overall level of the stimuli and were also similar for noise bursts of various widths and 1000 Hz tone burst. Thus, it is evident from the above studies that duration discrimination deteriorates with age and the time required to process the duration characteristics of acoustic stimuli is prolonged in elderly listeners. However, there is no effect of overall duration on discrimination ability.

There is growing evidence that cognitive factors such as attention, memory, etc. play an important role in listening ability. From the literature discussed above, it can be concluded that the psychophysical abilities have been studied to compare age, hearing loss, etc. However, these will also depend on the cognitive abilities of the listener which needs to be studied.

Temporal resolution. It is the ability of an individual to detect changes in acoustic stimuli over time. Temporal resolution is important for resolving brief dips in the intensity of the interfering noise and, therefore, is critical for understanding speech in these situations (Dubno, Horwitz, & Ahlstrom, 2003; Oxenham & Bacon, 2003; Peters, Moore, & Baer, 1998). The temporal resolution is typically evaluated through a psychophysical measurement known as gap detection (Shinn, Chermak, & Musiek, 2009). Amplitude modulation detection is also a measure to assess temporal resolution.

Gap detection thresholds. Gap detection reflects the shortest interval of silence a listener can detect, whereas amplitude detection reflects an individual's ability to detect slow overall changes in the amplitude of a sound (Gelfand, 2009). Gap detection has been compared across age groups, hearing loss, etc. by various authors.

Effect of age. Gap detection has been studied by various authors across age. Lutman (1990) studied gap detection thresholds (GDT) in 229 participants with normal hearing (50- 75 years) and 1764 participants with sensorineural hearing loss (17-80 years). It was measured with shortest detectable silent interval in a 1sec noise burst centered at 2000 Hz with a 400 Hz bandwidth presented at 85 dB SPL. Results indicated that temporal resolution did not deteriorate with age.

In another study, Snell (1997) measured GDT on 20 young and 20 older participants with normal hearing sensitivity who were matched in audiometric configuration for frequencies between 250 Hz to 4000 Hz. Stimulus used was 150 ms low pass noise bursts digitized with cutoff frequencies of 1000 or 6000 Hz with an inter stimulus interval of 600 ms. GDT was estimated in quiet, in the presence of white noise and high frequency masker at two intensity levels (70 & 80 dB SPL) and at two levels of modulation (0% & 12.6 %). Results indicated that mean gap of older participants was larger than younger participants and they were more sensitive to noise. Mean GDT scores was higher in both groups for high frequency masker.

In a similar study, Strouse, Ashmead, Ohde and Grantham (1998) measured GDT on 12 young adults and 12 elderly adults with normal hearing sensitivity. The GDT was measured through computer generated 1000 Hz, 200 ms, sinusoidal signal in the presence of a continuous noise with a spectral notch at 1000 Hz. The mean GDT for younger and older participants was 4.8 dB and 16 dB. Results indicated larger GDT in elderly listeners the gap between young and elderly participants increased at low sound levels.

Snell and Frisina (2000) measured GDT on 40 young and 40 older participants with 150 ms modulated noise burst which had a cutoff frequency of 1000 or 6000 Hz. The gaps were measured at 80 dB SPL in three background conditions (quiet, continuous noise floor and continuous noise floor with a high frequency masker). Results showed that the mean gap thresholds ranged between 2.6 and 7.8 ms for younger participants and between 3.4 and 10.0 ms for older participants. It was also noted that the mean GDT were significantly higher in older participants for all six conditions.

In an Indian study, Shivprakash (2003) estimated GDT on 60 participants with normal hearing sensitivity. The participants were divided into six cross-sectional age groups of 7 to 12.11 years and 30 normal hearing adults using noise bursts of 300 ms duration with a silence of different durations at 40 dB SL. The results indicated that normal hearing adults could detect a mean gap of 3.3 ms and children aged 7 years could detect a gap of 4.05 ms. However, GDT did not differ significantly between children and adults.

Harris et al. (2010) measured GDT on 10 young and 10 older participants with normal hearing sensitivity. GDT was assessed in two conditions: (1) when the gap was fixed at 5%, 50% or 90% of the total noise duration of 500 ms and (2) when the gap was varied from trial to trial which was randomly presented from the same three values with a maximum gap set to 12 ms. Results suggested that GDT was more for older participants and it increased with random gap detection suggesting that the cognitive load increases during random task compared to fixed task.

Schneider, Pichora-Fuller and Daneman (2010) compared GDT among young and old participants with normal hearing sensitivity. The results showed that the GDT was highly variable in older listeners and it was two times greater than that of young listeners. Kumar and Sangamanatha (2011) measured GDT in176 participants with normal hearing sensitivity in the age range from 20 to 85 years divided into six cross-sectional age groups. GDT was measured with a 750 ms broadband noise and temporal gap was presented in the center of the noise. GDT in individuals >70 years of age was almost eight folds greater than those for young adults (20–30 years of age).

John, Hall and Kreisman (2012) studied the effect of age and sensorineural hearing loss on temporal resolution using Gaps-in-Noise test in 154 participants. Results showed that the thresholds were poorer in older listeners' with hearing loss compared to both younger and older listeners with normal hearing sensitivity. This was attributed to the changes taking place in the central nervous system and central auditory processing with ageing. Similar results were reported by Palmer and Musiek (2014), where gap detection was assessed using electrophysiological and behavioral procedure on older adults and younger adults. Results indicated that GDT was significantly poorer in older adults compared to the younger adults and there was no significant difference between the GDT using either procedure for both the groups.

However, in contrary to above studies Moore, Peters and Glasberg (1992) reported that ageing does not have an impact on temporal resolution. They measured

GDT in elderly participants with normal hearing sensitivity and with hearing loss using sinusoidal signals from frequencies between 100 to 2000 Hz. Results showed that for the older listener's, GDT did not differ significantly from that of younger listeners. Thus, across majority of studies, it is evident that gap detection ability becomes poorer with age and it also deteriorates with increase in cognitive load.

Effect of frequency. Shailer and Moore (1987) measured temporal gaps in sinusoidal signals for center frequencies between 200 and 2000 Hz**.** GDT was about 5 ms for center frequencies of 400, 1000 and 2000 Hz. Psychometric functions for gap detection using sinusoidal signals depend on the phase at which the signals are turned on and off. For some phase conditions, the psychometric functions are distinctly non-monotonic showing oscillations at the period of the signal frequency. Non-monotonicities are not observed when the signal following the gap starts at the phase it would have had if the gap were not present. The non-monotonicities decreased with increasing center frequency.

Moore, Peters and Glasberg (1993) measured GDT on 11 female participants with normal hearing sensitivity for 100, 200, 400, 800, 1000 and 2000 Hz at 25, 40, 55, 70 and 85 dB SPL. Results indicated that thresholds varied slightly for frequencies at 400-2000 Hz (6-8 ms), but increased markedly at 100 and 200 Hz (17 ms). Thus, it is evident across studies that GDT does not vary much with frequency, however, threshold increases at very low frequency.

Effect of sensation level. GDT has also been studied at various sensation levels. Penner (1977) reported that gap threshold was around 2-3 ms for broadband noise at high SLs which was almost constant for moderate and low levels. However, Moore et al. (1993) reported that gap threshold increased at low levels. GDT for narrow band and broad band noise reduced with increase in stimulus level till 30 dB SL and it remained constant for higher stimulus levels (Buus & Florentine, 1985).

Effect of hearing loss. Fitzgibbons and Wightman (1982) compared GDT in individuals with normal hearing sensitivity and hearing loss. Results showed that the temporal resolution was significantly poorer in individuals with hearing loss compared to individuals with normal hearing. This was seen regardless of whether the comparison was made at the equal SPL or at the equal SL.

Roberts and Lister (2004) measured GDT on eight young listeners with normal hearing sensitivity, eight older listeners with normal hearing sensitivity and eight older listeners with high frequency sensorineural hearing loss. GDT was measured within channel (monotic and diotic) and across the ear. Results for the gap detection task indicated the following: (a) scores in the across ear condition was poorer than in either of the within-channel conditions, and there was no difference in performance between the within-channel conditions; (b) older listeners with normal hearing sensitivity demonstrated the poorest performance for the across-ear condition; and (c) the pattern of gap detection performance remained the same for an equal presentation level control condition.

Thus, from the above studies discussed, it can be concluded that GDT depends on various factors. It is evident that GDT reaches adult like values by around 7 years of age and it deteriorates in an elderly population. Gap detection values increases at very low frequencies and at low sensation level. GDT was poorer in hearing impaired participants compared to normal hearing participants. However, effect of cognition on gap detection still needs to be probed upon.

Temporal modulation transfer function. Another measure to assess temporal resolution is through temporal modulation transfer function (TMTF). Amplitude modulation detection assesses the capability to hear the sinusoidal amplitude modulation of a continuous sound (Moore & Jorasz, 1992; Yost, Sheft, & Opie, 1989). Several authors have reported the attenuation slope of TMTF in normal hearing individuals. Attenuation slope of -6dB per octave (Rodenburg ,1977) and about -3dB per octave is reported in individuals with normal hearing sensitivity (Bacon & Viemeister, 1985; Eddins, 1993; Formby & Muir, 1988; Forrest & Green, 1987; Viemeister, 1979). The modulation detection thresholds obtained as a function of frequencies can be characterized in terms of peak sensitivity and bandwidth (Viemeister, 1979).

Effect of age. Hall and Grose (1994) measured TMTF in listeners aged 4 years to adult in order to characterize the maturation of temporal resolution abilities in children. Sensitivity to the sinusoidal modulation of a noise carrier of a band pass noise from 200-1200 Hz was determined for modulation frequencies of 5, 20, 100, 150, and 200 Hz. The data from all the listeners indicated a decreased sensitivity to modulations with increasing frequency of modulation. Sensitivity to modulation was found to be reduced in the children of 4-5 and 6-7 years of age, as compared to adults, and in the children of 4-5 years of age as compared to children of 9-10 years of age.

He et al. (2008) measured amplitude modulation (AM) detection for 500 and 4000 Hz tonal carriers in younger and older participants with normal hearing sensitivity. Results indicated that AM detection increased with increasing modulation frequency in older participants. This shows that age related decline in temporal resolution is more for faster envelope fluctuations. Results also showed that age related changes were more for the lower frequency carrier when the modulation frequency was above the transition frequency. This could be because, for low frequency carrier, both temporal and spectral cues are available, however, for the higher frequency carrier, only spectral cues are available. These changes could be attributed to the diminished synchronization of neural responses for the carrier waveform as well as the envelope fluctuation with ageing.

Kumar and Sangamanatha (2011) measured TMTF in176 participants with normal hearing sensitivity in the age range from 20 to 85 years using a 500 ms Gaussian noise which was sinusoidally amplitude modulated at 8, 20, 60, and 200 Hz modulation frequencies. Results indicated that AM detection thresholds for the higher modulation frequencies (60 & 200 Hz) deteriorated faster when compared to the lower modulation frequencies (8 & 20 Hz). For lower modulation frequencies, deterioration began at 60 years whereas, for higher modulation frequencies, deterioration began by 40 years of age.

Similarly, Jin, Liu and Sladen (2014) investigated the effects of ageing on temporal processing and speech perception in noise among participants with normal hearing sensitivity and with cochlear implant. Temporal processing was assessed using amplitude modulation detection thresholds at 2, 4 and 8 Hz. Results showed significant effect of ageing on amplitude modulation detection for all three modulating frequencies. Thus, it can be concluded that AM detection deteriorates with age and the deterioration is faster for the higher modulation frequencies compared to lower modulation frequencies.

Effect of hearing loss. Modulation detection ability also deteriorates with hearing loss. Bacon and Gleitman (1992) measured modulation detection in five normal hearing participants and in eight participants with flat, slight-to-moderate hearing loss. The broadband noise was sinusoidally amplitude modulated from 2 to 1024 Hz. The carrier intensity ranged from -10 to 50 dB SPL. Results indicated that the TMTFs from the normal hearing participants were independent of carrier level. However, TMTFs from seven of the eight hearing impaired participants were similar to those of normal hearing participants when the carriers were presented at equal SPLs, except that the derived time constants were larger in the participants with hearing impairment.

Bacon and Opie (2002) measured AM detection of a target carrier presented in isolation and in the presence of an additional (masker) carrier in participants with normal hearing sensitivity, bilateral hearing loss, and unilateral hearing loss. The modulated rate of 10 Hz was used for signal and the masker was unmodulated or was modulated at a rate of 2, 10, or 40 Hz. Results showed that AM detection was not affected with hearing loss signifying that mild cochlear hearing loss does not have an effect on the ability to process AM in one frequency region when the competing AM was present in another region.

Thus, it is evident across studies that amplitude modulation detection ability deteriorates with age and age related decline was more for faster envelope fluctuations. Although, mild cochlear hearing loss does not show an effect in the ability to identify amplitude modulation. However, whether cognition will affect the ability to process the amplitude modulation has not been studied.

Temporal patterning. It is the skill of the auditory system to perceive and recall the order of sounds presented in a sequence. Temporal patterning can be measured through various tests such as duration pattern test, pitch pattern test. Studies have been done to see the effect of age and hearing loss on patterning task.

Effect of age. Trainor and Trehub (1989) measured temporal order recognition and discrimination tasks on younger and older adults. Participants were asked to discriminate among two different component orders in four-tone sequences with alternating higher and lower frequencies presented below 1000 Hz. The study was designed to measure the effect of perceptual organization (Bregman & Campbell, 1971), on temporal ordering. Results showed that the temporal ordering was significantly poorer in the older adults compared to the younger adults. However, differences related to ageing were independent of the type of task (discrimination vs. identification), amount of practice and the stimulus presentation rate.

Humes and Christopherson (1991) compared different auditory processing abilities among younger and older participants with normal hearing sensitivity and hearing loss by means of the Test of Basic Auditory Capabilities (TBAC) (Johnson, Watson, & Jensen, 1987). TBAC has two tests which measures temporal order, one test had four-tone sequences, and other test consist of one four-syllable sequences with different consonant-vowel combinations. Results indicated that older participants performed significantly poorer on temporal ordering task compared to younger participants and there was no effect of hearing loss.

In a similar study, Fitzgibbons and Gordon-Salant (1998) investigated the effect of age on the ability to discriminate and identify the temporal order of tonal sequences. Temporal ordering was done on temporally adjacent three-tone patterns with a 1/3 octave frequency range centered at 4000 Hz. The result indicated that the discrimination and the identification task were poorer in older participants compared to the younger participants for faster stimulus presentation rates. It was furthermore reported that the order discrimination was easier than the order identification for all participants. However, hearing loss had minimal effect on the ordering task.

Kolodziejczyk and Szelag (2008) measured temporal order judgment across the life span of approx. 80 years, i.e. in young, elderly and very old participants. Results showed an age related decline in temporal ordering performance, with slight changes in elderly participants and significant decline in centenarians which was more in women than in men. This age related decline in temporal ordering may be attributed to slowing of information processing.

Kumar and Sangamanatha (2011) measured duration pattern perception ability in 176 participants (20 to 85 years) with normal hearing sensitivity. Results showed that there was no significant difference in mean duration pattern scores till 60 years of age. However, participants of 61–70 years and participants above 70 years had significantly poorer duration pattern scores.

Effect of hearing loss. Studies have shown that hearing loss has minimum effect on pattern discrimination (Fitzgibbons & Gordon-Salant, 1998; Humes & Christopherson, 1991). The performance of the older listeners and younger listeners were compared on ordering task where older listeners had a high frequency hearing loss. Results indicated no obvious influence of audibility factors on temporal ordering.

Thus, it is evident from the above studies that hearing loss has minimal effect on temporal pattern perception ability. However, it deteriorates with age and order discrimination is easier than order identification for listeners of all age groups. The age related decrease in temporal ordering can be explained by slowing of information processing which can also be studied by evaluating working memory.

Temporal masking. The temporal masking (forward and the backward masking) have been reported to depend on the stimulus intensity, duration of the masker and the interval between the two stimuli. Moore and Glasberg (1987) reported that the effect of backward masking is higher than the effect of forward masking, keeping all the other factors constant. They also reported that the maximum effect could be approximately 30 dB in individuals with normal hearing sensitivity and this maximum effect was seen when the duration between the stimuli or masker duration or intensity of the masker was reduced. However whether ageing has any effect on backward masking still needs to be studied.

2.2. Factors affecting speech perception in noise

Speech perception is a complex phenomenon involving auditory processing and language processing of the information (Kalikow et al., 1977). It is affected by various factors such as redundancy in the stimulus, rate of speech, background noise, signal to noise ratio, age, knowledge of the language and cognitive abilities.

2.2.1. Effect of age. It is a well-documented fact that the proportion of the population, which experience difficulties in the perception of speech increases progressively with age. This difficulty does not increase in a linear manner with age, but it rather accelerates with older age (Pronk et al., 2013). These difficulties manifest themselves primarily in the presence of ambient noise and reverberation. Previous studies have indicated that individuals above the age of 60 years start exhibiting speech perception problems in the presence of noise. They require at least 2 to 3 dB larger signal-to-noise (S/N) ratio than the minimum S/N ratio normal listeners need to understand speech correctly (Plomp, 1977, 1986; Plomp & Mimpen, 1979).

Studies have also shown that hearing in noise depends on both sensation and cognition (Frisina & Frisina, 1997; Humes, 2002). There are age related changes in cognitive process which have a significant role in the comprehension of language spoken in everyday life. Studies have shown that cognitive ageing leads to slowing of perceptual and cognitive operations which can be associated with decline in working memory and attention (Salthouse, 1996).

Humes and Coughlin (2009) assessed the effects of higher processing load on the speech identification ability among young and older adults. The speech from target talker and the speech of a competing talker, speaking a similar sentence, were presented simultaneously to the same ear. The processing load of speech identification was manipulated by using three combinations: talker uncertainty, gender match among target and competing talkers, and meaningfulness of the speech. Results revealed that older adults performed poorer than young adults and they also showed lesser improvement in speech identification as the processing load was decreased.

In another study, Jin et al. (2014) examined the effects of ageing on temporal processing and speech perception in noise among participants with normal hearing sensitivity and with cochlear implant. Results showed that older individuals with normal hearing sensitivity and cochlear implant listeners performed poorly in speech recognition in noise. However, there was no age effect seen for speech recognition in quiet performance.

2.2.2. Effect of hearing loss. Studies have shown that speech perception in noise deteriorates with hearing loss. Humes, Burk, Coughlin, Busey and Strauser (2007) measured speech perception ability to elderly hearing impaired listeners. They concluded that hearing loss affects speech recognition abilities. In another study, Best, Gallun, Mason, Kidd and Shinn (2010) measured the effect of hearing loss on an individual's ability to understand messages spoken simultaneously on young hearing impaired listeners. The test stimuli consisted of two messages presented at equal level to the two ears separately which were degraded by adding speech-shaped noise. Participants were asked to either perform a single task of reporting one message and a dual task of reporting both the messages. Results revealed that the participant's ability to understand a secondary message was sensitive to noise and hearing loss. It was concluded that the task which involves the processing of two simultaneous messages would help in assessing hearing handicap and the benefits of rehabilitation.

2.2.3. Effect of cognition. Studies have shown a link between cognition and speech perception in noise. However, in most cases cognition plays only a minor role and hearing loss plays the major role in speech perception in noise. Gatehouse et al. (2003) assessed speech perception on 50 hearing impaired individuals in aided and unaided conditions. Assessment was done using words, (FAAF: Foster & Haggard, 1987) static and modulated noise (ICRA 2-talker), modulated noise (ICRA 6-talker). Cognitive abilities were assessed through visual digit test (Knutson et al., 1991) and visual letter test. Other tests included were spectral degradation, temporal degradation and upward spread of masking. Results indicated that the cognitive abilities are influential in speech understanding and interact strongly both with the benefits delivered by different hearing aid regimes and with the temporal characteristics of test environment. Other investigators have also reported similar findings (Humes, 2002; Humes et al., 2007; van Rooij, 1989).

Meister et al. (2013) investigated the association between working memory and speech recognition with different background maskers in older individuals. Results showed that older individuals performed poorly compared to the younger individuals in the presence of all background maskers. The scores of speech recognition correlated well with working memory task and it was also observed that working memory was the only significant predictor variable. Thus, they concluded that an individual's working memory ability should be taken into account for aural diagnosis and rehabilitation.

Moore et al. (2014) investigated the link between speech perception in noise and cognition (processing speed, memory, and reasoning) on about half a million participants of 40 to 60 years of age. Regression analysis showed an exponential decline in speech perception in noise for both sexes by around 50 years of age. They also reported that this decline in speech perception in noise was significant in participants with poorer cognitive abilities. It was concluded that both old age and reduced cognitive ability are independently associated to poor speech perception in noise.

Besser et al. (2015) evaluated age effect on listening performance with the Spatialized Noise Sentences (LISN – S) test on older group and younger group with normal hearing sensitivity. All the participants completed four auditory temporal processing tests, a cognitive screening test, a vocabulary test, and tests of linguistic closure for high- and low-context sentences. Results showed that the older group performed poorer on the LISN-S test compared to the younger group. It was reported that older listeners find it difficult to ignore the interfering talker's speech.

In a similar study, Souza and Arehart (2015) investigated the relationship between working memory capacity and speech recognition among 94 older adults with different degree of hearing loss and 30 younger adults with normal hearing sensitivity. Results revealed that working memory had a good correlation with speech recognition, wherein listeners with poorer working memory had more difficulty understanding speech in noise after accounting for both age and degree of hearing loss. Similar results have been reported by Rönnberg, Rudner, Lunner and Stenfelt (2014), wherein they concluded that participants with higher working memory had better speech recognition at various signal to noise ratios compared to people with lower working memory capacity. However, a study by Supernant and Watson (2001) is an exception where they concluded that there was a weak correlation between cognition and speech perception in noise. This could be because speech signal is quite redundant and there are multiple cues to each phonemic distinction.

Thus, it is evident from the above studies that speech perception in noise gets affected by various factors. However, in normal hearing individuals ageing and cognition plays an important role. Studies have shown that cognitive ageing leads to slowing of perceptual and cognitive operations which can be associated with decline in working memory and attention.

2.3. Working Memory

Working memory is an ability to sustain and manipulate information in mind for short duration of time. It plays a significant role in various cognitive tasks such as learning, analytical thinking, problem solving, and language comprehension. It consists of a central executive control system which monitors two subsystems including visuospatial sketchpad (VSS) and phonological loop (PL). VSS is responsible for a spatial processing and PL is responsible for nonspatial, primarily verbal information processing (Baddeley 1986, 1992). The working memory function depends on the frontal lobe and it controls and manages the functioning of two subsystems: the PL and the VSS (Baddeley 1986).

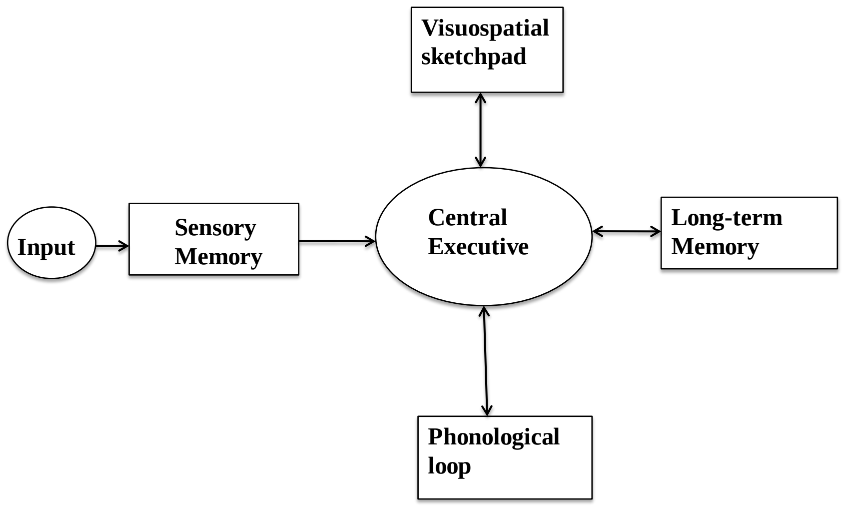


*Figure 2.1.*The Working Memory Model Components (Baddeley and Hitch, 1974).

In Figure 2.1, central executive manages the entire working memory system (e.g. the boss of working memory) and assigns function to the subsystems (VSS & PL). Further, it deals with other cognitive tasks like maths and problem solving. The PL assist in remembering spoken and written material. It has two parts:

- Phonological Store – It is associated with speech perception and maintains speech-based information (i.e. spoken words) for about 1-2 seconds.
- Articulatory control process – It is associated with speech production and is used to practice and store the verbal information from the phonological store.

The above model recommends that each component of working memory has a restricted ability, and each component is rather independent of each other. It formulates two predictions: 1) if two tasks use same component (of working memory), then they cannot be executed simultaneously and 2) if two tasks use different components, it is possible to execute them simultaneously as well as separately.

2.3.1. Evaluation of working memory. Working memory involves variety of tasks such as, verbal reasoning, comprehension, reading, and problem solving and visual and spatial processing. It can be evaluated through various tests such as operation span task and reading span task (Kane et al., 2004) and auditory working memory test.

Operation span task. In the operation span task, each part consists of a math problem which is followed by a word (e.g., Is [8*5] -25 = 20? FISH). The participant is asked to read the math problem loudly and indicate whether the problem is right or wrong and then say the word loudly. When all the elements in an item are presented, the participant is asked to write or repeat the words in the correct sequence.

Reading span task. In the reading span task, each part consists of a sentence which is followed by a syllable (e.g., The policeman stopped him because he did not use a helmet? Ra). The participant is asked to say the sentence aloud and indicate whether the sentence is correct or not and then say the syllable. Similar to operation span task, when all the elements in an item are presented the participant is asked to write/repeat the syllables in correct sequence.

Sequencing and span. Working memory can also be assessed through auditory number sequencing and auditory digit span. In the auditory number sequencing participants are presented with cluster of numbers increasing in length and they have to arrange the numbers in lowest to highest order for ascending span or highest to lowest order in descending span. The auditory digit span test is divided into forward and backward digit span. In this cluster of digits are presented in random order with the increasing levels of difficulty and participants are asked to repeat the numbers in same or reverse order. Working memory capacity can be calculated as the total number of digits that the person can successfully recall in auditory number sequencing and digit span test.

2.3.2. Effect of age. Studies have indicated age related decline in working memory (Spilich, 1983; Wright, 1981). Morris et al. (1988) assessed the effect of ageing on working memory using operation span task. Results indicated that older participants responded slowly and, increase in the memory load and in sentence complexity was associated with longer verification latencies. Hester et al. (2004) compared auditory working memory using digit forward and digit backward tasks among adults and older individuals. Results showed an age related decline in both digit forward and digit backward tasks and both the abilities deteriorated to the same extent. Thus, it is evident that working memory abilities decline with ageing.

2.4. Psychophysical abilities, speech perception in noise and cognition

The relationship between psychophysical abilities, speech perception in noise and cognition has been compared in the past by few authors. vanRooij, Plomp and Orlebeke (1989) measured speech perception, temporal resolution and frequency selectivity among young and elderly listeners. The cognitive abilities of the participants were assessed through digit span test, reaction time and memory scanning. The results were heterogeneous for elderly listeners and cognitive factors seem to have relatively less effect on auditory factors.

Humes et al. (1994) measured the speech recognition ability on 50 elderly participants. The participants underwent audiological evaluations, measures of auditory processing (TBAC) and cognitive function (Wechsler Adult Intelligence Scale-Revised [WAIS-R], and the Wechsler Memory Scale-Revised [WMS-R], Wechsler, 1981, 1987). Results revealed that hearing loss had an effect on speech recognition performance among the elderly participants and the auditory processing abilities and cognitive function showed no significant effect on speech recognition.

Suprenant and Watson (2001) compared speech perception and psychophysical abilities on 45 normal hearing adults. Speech measures included recognition of syllables, words and sentences and non-speech tasks included frequency, intensity and duration discrimination and temporal order identification. The cognitive abilities of participants were also assessed through intellectual and cognitive function (SAT-V, SAT-M) and academic performance (GPA). Results revealed that there was a weak correlation between speech and non-speech task. This could be because speech signal is quite redundant and there are multiple cues to each phonemic distinction which is not present for non-speech task.

In a similar study, Humes (2002) measured aided and unaided speech recognition scores on 171 elderly participants using hearing aid. Auditory discrimination ability of participants was assessed using TBAC at 30 dB SL. Cognitive assessment was done through WAIS-R (Wechsler, 1981). It was found that there was an age related difference in scores which could be attributed to cognitive factors.

Akeroyd (2008) did a metanalysis on 20 articles related to speech perception in noise and cognition and he observed a link between hearing and cognition. He noted that in complex and acoustically challenging situations, listeners use previous knowledge to understand speech. Hence, when speech signals are degraded, missing, or ambiguous top-down skills are used to resolve the acoustic input. It has been hypothesized that higher level factors like cognition plays a significant role in speech understanding when speech is made audible through amplification (Humes 2007).

Mukari et al. (2010) measured the effect of ageing and working memory on dichotic listening ability and temporal patterning on 20 young and 20 older adults with normal hearing sensitivity. Results revealed that the older adults had significantly poorer scores on all measures of dichotic listening and temporal sequencing compared to the young adults. Working memory correlated well with pitch pattern task but not with dichotic digit test.

Harris et al. (2012) assessed the effect of age, attention, and cortical processing speed on gap detection using cortical event related potentials on 25 younger and 25 older normal hearing participants. Results showed that GDT was significantly poorer in older adults and they also had slower processing speed. It was also noted that for older adults, P2 latencies prolonged and N2 amplitude decreased with attention. It was concluded that decline in gap detection with ageing could be contributed to the differences in cognitive abilities or attention related processing deficits with ageing.

Grassi and Borella (2013) assessed age related differences in auditory abilities and also tried to establish the effect of audition on cognitive abilities. Results showed that some of the auditory abilities (i.e., frequency, duration and timbre discrimination, and amplitude modulation detection) could explain a significant variation noted in the processing speed of older adults. This suggests that auditory abilities also do have an effect on cognition.

In contrary, Kidd, Watson, and Gygi (2007a) measured individual differences in auditory abilities, through identification of nonsense syllables, words, and sentences and from 16 psychophysical tests (expanded TBAC) in 340 normal hearing adults. These auditory abilities were correlated with the common intellectual ability of the participants using scholastic aptitude test. Results showed that there was little or no relationship among general or specific auditory abilities and general intellectual ability.

From the above studies, it is evident that the age related difference is seen on various psychophysical tasks which can be attributed to cognitive factors. However, the results are not consistent and studies are done mostly on elderly listeners. Thus, whether cognition plays a role in the perception of psychophysical aspects or vice versa still needs to be probed across various age groups.

Chapter 3

Methods

The aim of the present investigation was to study the effect of age on psychophysical abilities, speech perception in noise and working memory in individuals with normal hearing sensitivity. Furthermore, this study also investigated the relationship among age, basic psychophysical abilities, speech perception in noise, and working memory.

3.1. Research Design

A cross-sectional descriptive research design (Schiavetti, Orlikoff, & Metz, 2015) was employed to achieve the aims. A between subject design was used to compare the psychophysical abilities, speech perception in noise and working memory among different age groups. Within subjects design was used to assess the relationship among age, psychophysical abilities, speech perception in noise and working memory.

Participants were selected using purposive convenient sampling technique. The purpose and nature of the study was explained to each participant and written informed consent was taken before the commencement of the study. Study adhered to the 'Ethical guidelines for bio-behavioural research involving human subjects' of All India Institute of Speech and Hearing (Basavraj & Venkatsan, 2009) and ethical committee approval was obtained prior to the commencement of the study. Copy of the Ethical committee approval is enclosed in Appendix I.

3.2. Participants

A total of 210 participants participated in the current study. Participants were divided into seven cross-sectional age groups. Table 3.1 provides the demographic details of the participants in each group.

Table 3.1

Demographic details of the participants

Age (Years)	No.of Participants	Gender	Mean Age (years)	One Standard Deviation (years)
10-19.11	30	16 M, 14 F	15.11	2.85
20-29.11	30	9 M, 21 F	24.47	3.00
30-39.11	30	11 M, 19 F	34.27	2.79
40-49.11	30	13 M, 17 F	44.4	2.77
50-59.11	30	14 M, 16 F	54.87	3.12
60-69.11	30	18 M, 12 F	63.09	3.42
70-84.11	30	14 M, 16 F	74.03	3.52

Note: M- male, F-female

None of the participants had history of hearing loss, ear disease, head trauma, ototoxic drug intake, ear surgery or speech language problems. In addition, none of them reported any illness on the day of testing. These details were noted through a structured interview with the participant. Furthermore, participants of all the age groups met the following inclusion criteria:

- Speech recognition thresholds (SRT) within $\pm$12 dB of pure tone average (average threshold of 500, 1000, 2000 and 4000 Hz).
- Speech identification scores greater than 80% at 40 dB SL (ref SRT). Speech identification scores were assessed through phonetically balanced word list in Kannada (Mayadevi, 1974).
- Normal functioning of middle ear as indicated by bilateral 'A' type of tympanogram and with acoustic reflex (ipsilateral and contralateral) present at normal sensation levels at 500 Hz and 1000 Hz.
- Participants above 60 years passed the Screening checklist for auditory processing in adults (Vidyanath & Yathiraj, 2014) and Minnesota mental status examination (Folstein, Folstein, & McHugh, 1975).
- Had formal education for at least 10 years.
- Individuals residing in Mysuru for more than ten years and were fluent in speaking and reading Kannada and English.

Furthermore, all the participants in age groups up to 50-59.11 years had air conduction pure tone thresholds of less than 15 dB HL at octave frequencies between 250 Hz to 8000 Hz in both ears. Participants above 60 years of age (60-69.11 years & 70-84.11 years) had hearing thresholds less than 15 dB HL from 250 Hz-2000 Hz and within 30 dB HL at 4000 Hz and 8000 Hz frequencies. Hearing thresholds were measured using modified Hughson and Westlake procedure (Carhart & Jerger, 1959).

3.3. Testing Environment

Pure tone audiometry was conducted in an acoustically treated room with noise levels as per ANSI S 3.1 (1999) standards. All the other experiments were done in a quiet room with good illumination, ventilation and minimum distraction.

3.4. Instrumentation

This study used following instruments:

1. A calibrated two channel diagnostic audiometer, MA-53 (MAICO Diagnostics, Germany) equipped with TDH-39 headphones to estimate the air conduction pure tone thresholds, speech recognition thresholds and speech identification scores.
2. A calibrated immittance meter, GSI- TympStar (Grason-Stadler, MN, USA), to assess tympanometry and acoustic reflex.
3. A computer (Asus N570 Eee PC) with MATLAB version 7.9 (The Math Works, Inc., MA, USA, 2009) and Audacity software version 1.3.13 (The Audacity Team, MA, USA, 2011) to record and present stimuli for psychophysical and working memory tests.
4. A Sennhieser 449 high fidelity headphone (Wedenmark, Germany) to present the stimulus for psychophysical measures, speech perception in noise and working memory measures.

3.5. Materials

1. Psychophysical testing: The stimuli for all the psychophysical tests except for duration pattern test were generated through maximum likelihood procedure toolbox (mlp toolbox, Grassi & Soranzo, 2009) implemented in Matlab. The details of the specific stimuli are provided under each test in the section 3.6. The stimulus for duration pattern test was generated using Audacity software.
2. Working memory assessment: The stimuli for operation span and reading span task were developed as a part of the study. Auditory digit span and sequencing (forward, backward, ascending and descending digit span) measures were done using auditory cognitive training module (Kumar & Sandeep, 2013) software.
3. Speech perception in noise: The quick speech perception in noise test in Kannada (Methi, Avinash, & Kumar, 2009) was used for speech perception in noise assessment.

3.6. Stimulus and Procedure

Written informed consent was taken from all the participants for willingly participating in the investigation. All psychophysical tests except duration pattern test were carried out using mlp toolbox, which implements maximum likelihood procedure for threshold estimation in Matlab (Grassi & Soranzo, 2009). The mlp makes use of a large number of participant's psychometric functions and following every trial, it estimates the likelihood of arriving at the listener's response for all the stimuli that has been presented. Further, the psychometric function that gives the highest likelihood is used to decide the stimulus to be presented in the next trial. It is reported that within 12 trials, the mlp generally meets the fairly stable approximation of the most probable psychometric function, which can be used to approximate thresholds (Grassi & Soranzo, 2009; Green, 1990, 1993). This procedure has been widely used to assess psychophysical abilities and found to have good reliability and validity (Kumar & Sangamanatha, 2011).

Stimuli for all psychophysical tests were generated at 44,100 Hz sampling rate. All the tests were performed using a three-interval alternate forced-choice technique to track a 79.4% correct response criterion. Each trial consisted of three blocks, wherein, two blocks had the standard stimulus and the other block chosen randomly had the variable stimulus. The participant's task was to identify the block containing the variable stimulus. All the psychophysical tests were performed as per the procedure stated above and the presentation of the stimulus and acquisition of the response was controlled by the mlp toolbox. Before the beginning of the each test 5 -6 practice items were given. The tests were performed in a randomized order across participants to avoid potential order effect. The stimulus for all psychophysical and working memory tests was presented at 85 dB SPL binaurally. Headphone was calibrated to produce desired output using Bruel and Kjaer 2270 sound level meter in a 6 cc coupler. Previous investigators have recommended this presentation level (Fitzgibbons & Gordon-Salant, 1994; Snell, 1997) and therefore, using the same levels helps us in comparing the results of the present study with that of previous studies. Stimulus duration was kept at 250 ms for most of the tests as it avoids temporal integration. Details of the stimuli and procedure used for individual tests are provided below.

3.6.1. Frequency difference limen. In this, the minimum frequency difference necessary to discriminate two closely spaced frequencies was assessed. Frequency difference limen (FDL) was measured at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. Both the standard and variable stimuli were of 250 ms long pure tones with the onset and offsets of 10 ms raised cosine ramp (Grassi & Soranzo, 2009; Jain, Mohamed, & Kumar, 2014). On each trial of three blocks, two blocks had pure tones at a standard frequency and other block contained a pure tone of variable frequency, which was always higher than the standard frequency. The minimum and maximum frequency deviation of the variable stimulus was 0.1 Hz and 200 Hz respectively. The participant's task was to identify the variable block. Frequency difference corresponding to the 79.4% point of the psychometric function was calculated using mlp.

3.6.2. Intensity difference limen. In this, the minimum intensity difference necessary to discriminate two otherwise same sounds was assessed. Intensity difference limen (IDL) was measured at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. Both the standard and variable stimuli were of 250 ms long pure tones with 10 ms raised cosine ramps at onset and offsets (Grassi & Soranzo, 2009; Jain et al., 2014). The minimum and maximum intensity deviation used was 0.99 dB and 10 dB. On each trial of three blocks, two blocks had pure tones at a standard intensity and other block selected at random contained a pure tone of variable intensity, which was always higher than the standard intensity. The participant's task was to identify the variable block. Intensity difference corresponding to the 79.4% point of the psychometric function was calculated using mlp.

3.6.3. Duration discrimination test. In this, the minimum difference in duration which a participant can discriminate was assessed. Duration discrimination thresholds (DDT) were measured for a 1000 Hz (Abel, 1972; Phillips et al., 1994) tone at anchor duration of 250 ms (Kumar & Sangamanatha, 2011). The tone had raised cosine onset and offset gates of 10 ms. The minimum and maximum value of duration deviation used was 0.1 ms and 200.1 ms. On each trial of three blocks, two blocks had pure tones at a standard duration and other block selected at random contained a pure tone of variable duration, which was always longer than the standard duration. The participant's task was to identify the variable block. Duration difference corresponding to the 79.4% point of the psychometric function was calculated using mlp

3.6.4. Gap detection thresholds. The participant's ability to identify a temporal gap in the centre of a 500 ms broadband noise was measured (Harris et al., 2010). Noise was used for the gap detection task (GDT), as its magnitude spectrum does not change when the gap is inserted into it, unlike tones. Tones also might produce audible clicks when gaps are inserted in between (Moore, 2003). Noise had 0.5 ms cosine ramps present at the beginning and the end of the gap. This avoided the abrupt changes in the frequency spectrum of noise which may aid the listeners in gap detection. The minimum and maximum duration of gap used was 0.1 ms and 64 ms. On each trial of three blocks, two blocks consisted of a 500 ms broadband noise with no gap and the other block had a variable stimulus with the gap in it. Figure 3.1 shows the graphical representation of waveforms of the stimuli used in gap detection test. In the Figure 3.1, block 1 and 2 contains no gap whereas block 3 is the variable block which has a gap present in it.

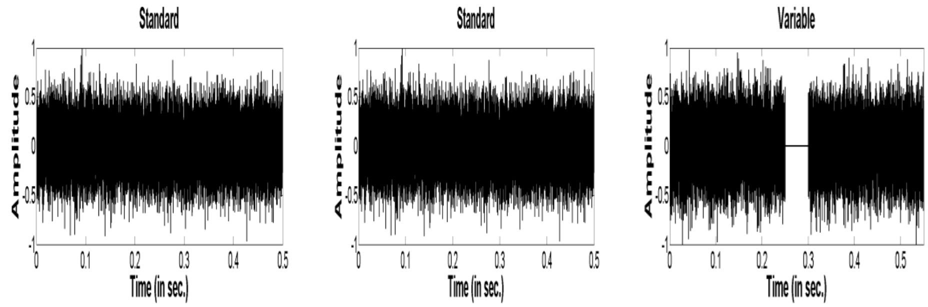


*Figure 3.1.*Graphical representation of the stimuli used in gap detection test.

3.6.5. Modulation detection thresholds. In this, the minimum amplitude modulation necessary to identify amplitude-modulated noise from an un-modulated white noise was assessed. A 1000 ms Gaussian noise was sinusoidally amplitude modulated at 4 Hz, 8 Hz, 16 Hz, 32 Hz, 64 Hz and 128 Hz modulation frequencies. Noise carrier eliminates the spectral cues and hence broadband noise was used to estimate the modulation detection thresholds (MDT) instead of tones (Viemeister, 1979). These modulation frequencies were selected as it covers both high and low modulation frequencies and temporal modulation transfer function can reliably be constructed with these frequencies to calculate peak sensitivity and bandwidth (Bacon & Viemeister, 1985; Desloge, Reed, Braida, Perez, & Delhorne, 2011; Viemeister, 1979). Furthermore, low frequency modulations were used, as speech is characterized by low modulations (Singh & Theunissen, 2003). On each trial of three blocks, two blocks had standard un-modulated stimuli and one selected at random contained modulated stimuli. The participants were asked to identify the modulation and determine which block had the modulated noise. Modulated and un-modulated stimuli were equated to total root mean square (rms) power. The depth of the modulated signal was changed based on the participant's response to obtain 79.4% criterion level. The minimum and maximum value of amplitude modulation used was -30 dB and 0 dB. The MDT was measured in dB by using the following relationship:

$$\boxed{\text{Modulation detection thresholds in dB} = 20 \log10\ m}$$

where, m= modulation detection threshold in percentage.

Peak sensitivity and bandwidth of temporal modulation transfer functions were estimated for all the age groups. This was obtained by fitting a first order low pass Butterworth filter using the following equation adapted from Zeng, Kong, Michalewski, and Starr (2005):

$$\boxed{Y = -10*\log10\ [xo/1+ (f/fc)^{2}]}$$

Where, 'Y' is the modulation index (m) in dB (-10 log m), 'f' is the modulation frequency in Hz, '-10 log (xo)' is the peak sensitivity or gain in dB, 'fc' is the 3 dB cutoff frequency or bandwidth in Hz. Figure 3.2 shows the graphical representation of waveforms of the stimuli used in MDT. In the Figure 3.2, block 1 and 2 is the standard block with no modulation in it and block 3 is the variable block with modulation present.

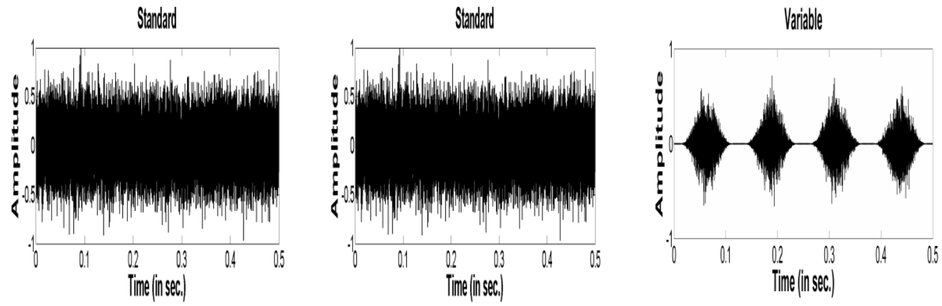


*Figure 3.2.*Graphical representation of the stimuli used in modulation detection test.

3.6.6. Backward masking. In this, the participant's ability to detect a short duration tone presented just before the onset of a noise was assessed. A 20 ms pure tone signal (1000 Hz) was given just before a band pass noise of 300 ms (400-1600 Hz) (Buss, Hall, Grose, & Dev, 1999; Roth, Kishon-Rabin, & Hildesheimer, 2001; Wright et al., 1997). All sounds were onset and offset gated by means of two raised cosine onset and offset ramps of 10 ms (Rosen & Manganari, 2001; Rosen, Adlard, & van der Lely, 2009; Wright et al., 1997). The task of the participant was to detect the interval that contained tone. The level of the signal was varied adaptively according to the maximum likelihood procedure (Green, 1990, 1993) to obtain the threshold for the tone. Figure 3.3 shows the graphical representation of waveforms of the stimuli used in backward masking along with the zoomed version to represent raised cosine onset ramp of 10 ms. In the Figure 3.3, block 1 and 2 is the standard block with no tone present and block 3 is the variable block with tone present before the noise.

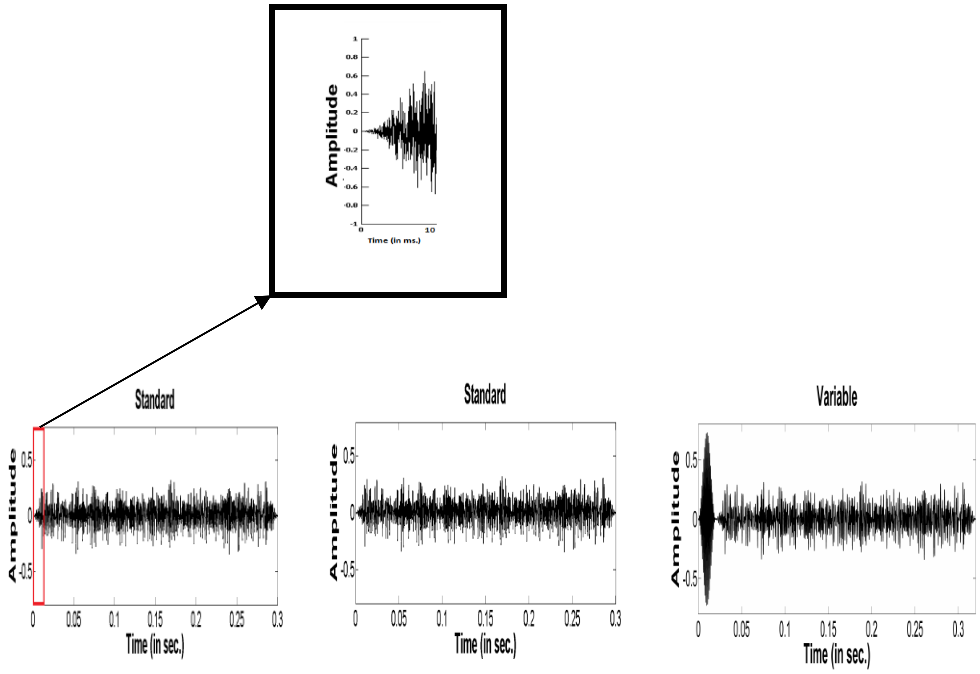


*Figure 3.3.*Graphical representation of the stimuli used in backward masking. Zoomed section of the figure depicts the ramp used.

3.6.7. Duration pattern test. In this, the participant's ability to sequence the three tones varied in duration was assessed. The duration pattern test (DPT) was performed in the similar way as given by Musiek (1994) and test stimuli was adapted from Kumar and Sangamanatha (2011). A 1000 Hz pure tone was generated using Audacity software with two different durations (i.e. short 250 ms and long 500 ms). These two durations were combined in three tone pattern and thus six different patterns were generated (Short Short Long, Short Long Short, Long Long Short, Long Short Short, Short Long Long, Long Short Long). Test consisted of practice trails and 30 test trials. The participant task was to verbally repeat the sequence. Each correctly repeated sequence was awarded a score of one and thus maximum score possible was 30.

3.6.8. Speech perception in noise. In this, the signal to noise ratio (SNR) required to understand 50% of the words in a sentence was measured (SNR-50) using quick speech perception in noise test in Kannada (Methi et al., 2009). Testing was done in the presence of four talker babble under the earphones. Test had 7 equivalent lists and every list consists of seven sentences with five key words each. The SNR reduced from +8 dB SNR to -10 dB SNR in 3 dB steps from sentence 1 to 7 in each list. Two lists (list 1 and 2) were used in the current investigation. The participants were instructed to write down or verbally repeat the target sentences. Score of one was given to each correctly identified key word. The number of correct key words recognized at each SNR was counted. The SNR-50 was calculated using the Spearman-Karber equation (Finney, 1978) as:

$$\boxed{\text{SNR-50} = I + \tfrac{1}{2}(d) - (d)(\#\ \text{correct}) / (w)}$$

where:

I = the initial presentation level (dB S/B);

d = the attenuation step size (decrement);

w = the number of key words per decrement;

correct = total number of correct key words.

3.6.9. Working memory assessment. The procedures used to measure working memory capacity included operation span task, reading span task, ascending, descending, forward and backward digit span. Measures of operation span task and reading span task was adapted from the versions of Kane et al. (2004) and Conway et al. (2005).

Participants were asked to sit comfortably and were instructed about the procedure of the test.

Operation span task. The stimuli, procedure and the scoring of the test are provided below.

Stimuli. In operation span task, participant's ability to remember the target stimuli which was presented along with a secondary task was assessed. The secondary task here was to solve the mathematical problem. Stimuli were prepared following the guidelines of Kane et al. (2004). In the operation span task each element consisted of a mathematical operation and a word to be remembered (e.g., Is [8*5] -25 = 21 yes or no? /mara/). The words used in the test were bisyllabic and were selected from various sources such as school books, magazines and newspaper. The words were then rated for familiarity in a three point rating scale by three judges and then the most familiar and less familiar words were eliminated from the list. The secondary task, - the mathematical problem - had either multiplication or division for the first mathematical operation within the parenthesis and either addition or subtraction outside the parenthesis. Mathematical problem was true in half of the trials and it was false in the other half of the trials which were presented randomly. The size of each trial varied from two to five mathematical problem-word items. Three trials of each length were presented for a total of 12 trials. Figure 3.4 shows the sample representation of the stimuli used in operation span task.

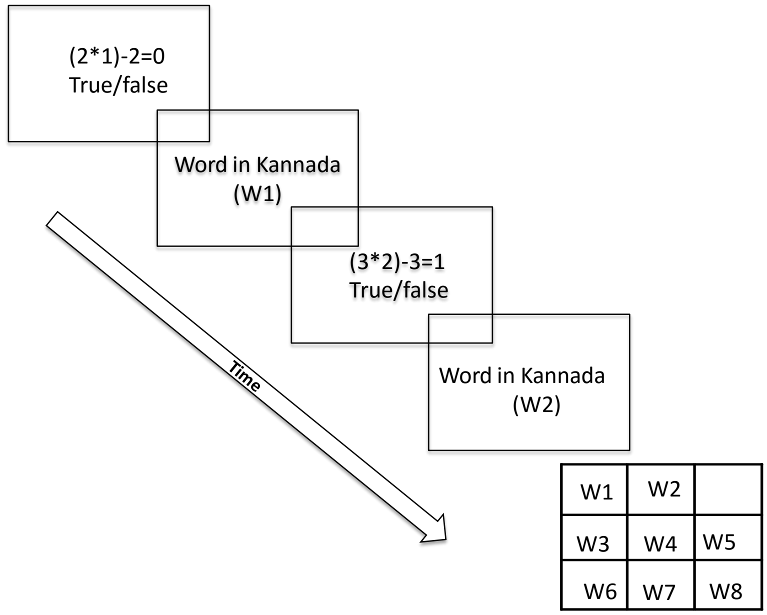


*Figure 3.4.*Sample representation of stimuli used for operation span task

Procedure. During testing, mathematical problem was shown on the computer screen which was followed by a word to be remembered. The participant had to read the math problem loudy, say “yes” or “no” to signify whether the given answer is right or wrong and subsequently say the word. After all the elements in the trial are presented, the participant was asked to repeat the words in the same sequence. The difficulty level of the test was randomized in such a way that the number of elements was not predictable at the onset of a trial. The size of each trial varied from two to five mathematical problem-word items. Accuracy of solving the mathematical problem as well as recalling the words in correct serial order were noted down.

The guidelines recommended by Kane et al. (2004) and Conway et al. (2005) were followed during the scoring. A score of '1' was assigned when all the words were correctly recalled and a score of zero was given if the words were either not recalled or if recalled in the wrong serial order. Furthermore, proportion correct score for each trial was calculated (e.g., if one element was recalled correctly in a trial of two elements, a proportion correct score of 0.5 was obtained). These scores were averaged across all the 12 trials and therefore, maximum possible score was 12. During scoring it was also ensured that the correctness on the mathematical problem was not less than 85% (Sanchez et al., 2010).

Reading span task. The stimuli, procedure and the scoring of the test are given below.

Stimuli. In the reading span task, participant's ability to remember the target stimuli (syllable) which was presented along with a secondary task was evaluated. The secondary task was to identify the correctness of a Kannada sentence. The stimuli for reading span task were developed following the guidelines of Kane et al. (2004). In reading span task, each element contained a sentence which was followed by a syllable. The sentences were selected from magazines, children's textbook and day to day conversation. After the selection of sentences, half of the sentences were modified to make it semantically wrong. These sentences were given to three native speakers of Kannada to judge the correctness of the sentence and intended modifications. Only those sentences in which all three judges agreed upon were considered for the final test. Each display in reading span task thus had a sentence which either makes sense or no sense followed by a CV syllable (e.g., /surɛʃənœňu/ /pɔli:sœru/ /hɛlmɛt/ /d̪œrɪsɪl̂œvɛnd̪u/ /nɪl̂ɪsɪd̪œru/ followed by /ra/). Half of the sentences in the test made sense and other half of the sentences did not make sense. These sentences were presented randomly. The number of elements in each trial varied from two to five sentence-letter items. Three trials of each length were presented for a total of 12 trials. Figure 3.5 shows the sample representation of the stimuli used in reading span task.

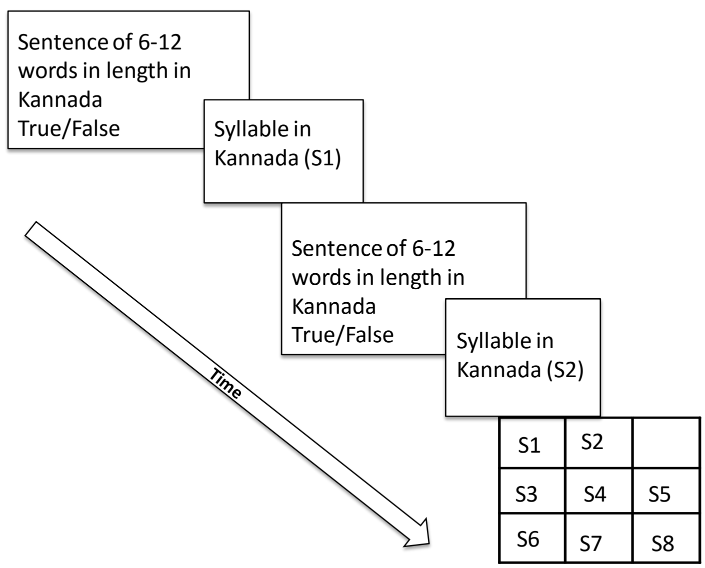


*Figure 3.5.*Sample representation of stimuli used for reading span task

Procedure. The test procedure was similar to that of operation span task. In reading span test, a sentence was displayed on the computer screen followed by a syllable to be remembered. The participant task was to read the sentence aloud and indicate whether it makes sense or not and then read the syllable aloud. Soon after, the next sentence-syllable combination was presented. After all the elements in a trial were presented, the participant had to recall each syllable from the preceding set of sentences, in the order they appeared. The number of elements in each trial varied randomly so that the difficulty level could not be predicted at the beginning of the trial. The accuracy of judging the sentence and also recalling the syllables in the same order were noted. The scoring was done in a similar way as that of operation span task. A score of one was given if all the items in a trial were recalled correctly and a score of zero was given if all the items was not recalled or recalled in a wrong serial order. Also, proportion correct score was calculated for each trial in the similar way as that of operation span scoring. The correctness of the secondary task was also noted down and it was ensured that the accuracy was not less than 85% (Sanchez et al., 2010).

Auditory number sequencing and digit span. These tests were administered using "*Auditory cognitive training module"* software. Detail description of software, stimulus and procedure is provided in Kumar & Sandeep (2013). Stimuli consisted of English digits from one to nine except seven. Stimuli were presented binaurally at 85 dB SPL. In all the tests minimum number of digits that could be recalled was assessed using staircase procedure.

Auditory number sequencing. Auditory number sequencing included ascending and descending digit sequencing task. Participants were presented with cluster of numbers and asked to repeat them in an increasing or decreasing order depending on the task. For ascending task the participants were asked to rearrange the numbers in an increasing order. For e.g.: if the test stimulus is ‘four, nine, six, eight’, the response expected was ‘four, six, eight, and nine’. For every correct response, number of digits in next presentation was increased by one and for incorrect response number of digits in next presentation was decreased by one. Using this stair case procedure, minimum number of digits that the person can identify was noted down. Similarly, in the descending task they had to arrange the numbers in decreasing order. Thus, for the same stimulus the expected response would be ‘nine, eight, six, and four’. The test item started with four digits and went up to ten digits.

Auditory digit span. Auditory digit span was tested by measuring forward and backward spans. Procedure used was similar to auditory sequencing measures. Cluster of digits were presented and participants were asked to repeat it in same or reverse order as the case may be. In forward span the participants were expected to repeat the digit in the same order. For e.g.: if the stimuli were ‘four, nine, six, eight’, the response expected was ‘four, nine, six, and eight’. For every correct response, number of digits in next presentation was increased by one and for incorrect response number of digits in next presentation was decreased by one. In backward digit span they were expected to repeat the digits in reverse order. Thus, for the same stimuli the expected response would be ‘eight, six, nine, and four’.

3.7. Statistical Analyses

The data obtained from the study was subjected to statistical analyses using the Statistical Package for the Social Sciences (Version 17) and AMOS (Analysis of Moment Structures, version 18, SPSS Inc, Chicago). Descriptive statistics was carried out to estimate the mean and standard deviation for all the parameters. Following this, normality and other assumptions of parametric tests were assessed. Repeated measures ANOVA was carried out to analyze the effect of age on FDL and IDL. One way ANOVA was done to analyze the effect of age on GDT, DDT, MDT (peak sensitivity and band width), SPIN, operation span and reading span tasks. Kruskal-Wallis test was carried out to analyze the effect of age on backward masking, duration pattern and auditory sequencing and digit spans. Pearson's product moment correlation was used to assess the relationship among working memory measures, psychophysical abilities, speech perception in noise and age. Structural equation modeling was used to model the effect of working memory measures, age and psychophysical abilities on speech perception in noise.

Chapter 4

Results

The present study investigated the effect of age on psychophysical abilities, speech perception in noise and working memory. The study also investigated the relationship among psychophysical abilities, speech perception in noise, working memory measures and age. Prior to statistical analysis data was screened for outliers and missing values. We examined the box plots for outliers and found few participants having exceptionally low or high scores on various measures. These participants were removed from the analysis. Table 4.1 shows the number of participants in each age group after removing the outliers. It was noted that except backward masking, duration pattern test, forward digit, backward digit, ascending digit and descending digit span all the other tests fulfilled the assumptions of normality ($p>0.05$), and hence parametric tests were used.

Table 4.1.

Number of subjects in each group after removing outliers.

Age Groups (years)	Number of participants
10-19.11	27
20-29.11	30
30-39.11	30
40-49.11	29
50-59.11	29
60-69.11	28
70-84.11	28

4.1. Effect of age on different psychophysical abilities and speech perception in noise.

This section addresses the objectives 1 to 3 of the study. The results for the effect of age on frequency discrimination, intensity discrimination, temporal processing and speech perception in noise is discussed below.

4.1.1. Frequency difference limen. The mean and one standard deviation (SD) of frequency difference limen (FDL) across age groups for all the four frequencies are shown in Table 4.2 and Figure 4.1. From the Table 4.2 and Figure 4.1 it can be inferred that FDLs increased with age and frequency. Figure 4.2 shows relative FDL ($\Delta f/f$). From Figure 4.2 it can be seen that effect of age on FDL was more at 500 Hz. Repeated measures of ANOVA was done to assess the statistical significance of these differences in FDL across different age. Results showed a significant main effect of age [$F(6,194) = 20.505$, $p<0.01$, $\eta^2=0.388$] and frequencies [$F(3,194) = 224.909$, $p<0.01$, $\eta^2=0.537$] on FDLs. The interaction between frequency and age was not significant [$F(18,582) = 1.459$, $p>0.05$, $\eta^2=0.043$]. Further one way ANOVA was done to assess the significance of difference in FDLs for each frequency between age groups. Results showed that age had a significant effect on FDLs at 500 Hz [$F(6,194) = 17.972$, $p<0.01$, $\eta^2=0.357$], 1000 Hz [$F(6,194) = 11.504$, $p<0.01$, $\eta^2=0.262$], 2000 Hz [$F(6,194) = 17.158$, $p<0.01$, $\eta^2=0.347$] and 4000 Hz [$F(6,194) = 8.298$, $p<0.01$, $\eta^2=0.204$]. Table 4.3 (a-d) shows the results of pair-wise comparisons at different frequencies using Bonferroni's corrections for multiple comparisons. From the Table 4.3 it can be noted that the age related decline in FDL for 1000 Hz and 4000 Hz begins at 40 years of age. For 500 Hz age related changes appeared only after 50 years of age. FDL of 2000 Hz showed that participants of 20-29.11 years age had significantly better thresholds compared to all other age groups. Pair-wise comparisons were not carried out between frequencies, as this was not the objective of the study.

Table 4.2.

Mean frequency difference limen and one SD across all the age groups at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

Age in years	500 Hz		1000 Hz		2000 Hz		4000 Hz	
	Mean (Hz)	SD	Mean (Hz)	SD	Mean (Hz)	SD	Mean (Hz)	SD
10-19.11	26.15	11.14	39.92	22.34	56.63	29.68	82.24	28.63
20-29.11	18.73	12.23	25.01	13.44	35.47	22.66	60.95	28.62
30-39.11	37.07	24.56	44.95	31.71	60.54	33.06	79.01	34.14
40-49.11	33.06	22.41	50.24	30.01	61.07	27.43	90.11	26.69
50-59.11	45.20	22.43	60.84	26.99	77.76	18.01	94.37	32.88
60-69.11	66.22	28.09	67.66	27.42	85.77	20.53	98.91	27.25
70-84.11	63.40	30.59	71.94	27.41	97.40	32.49	112.71	35.48

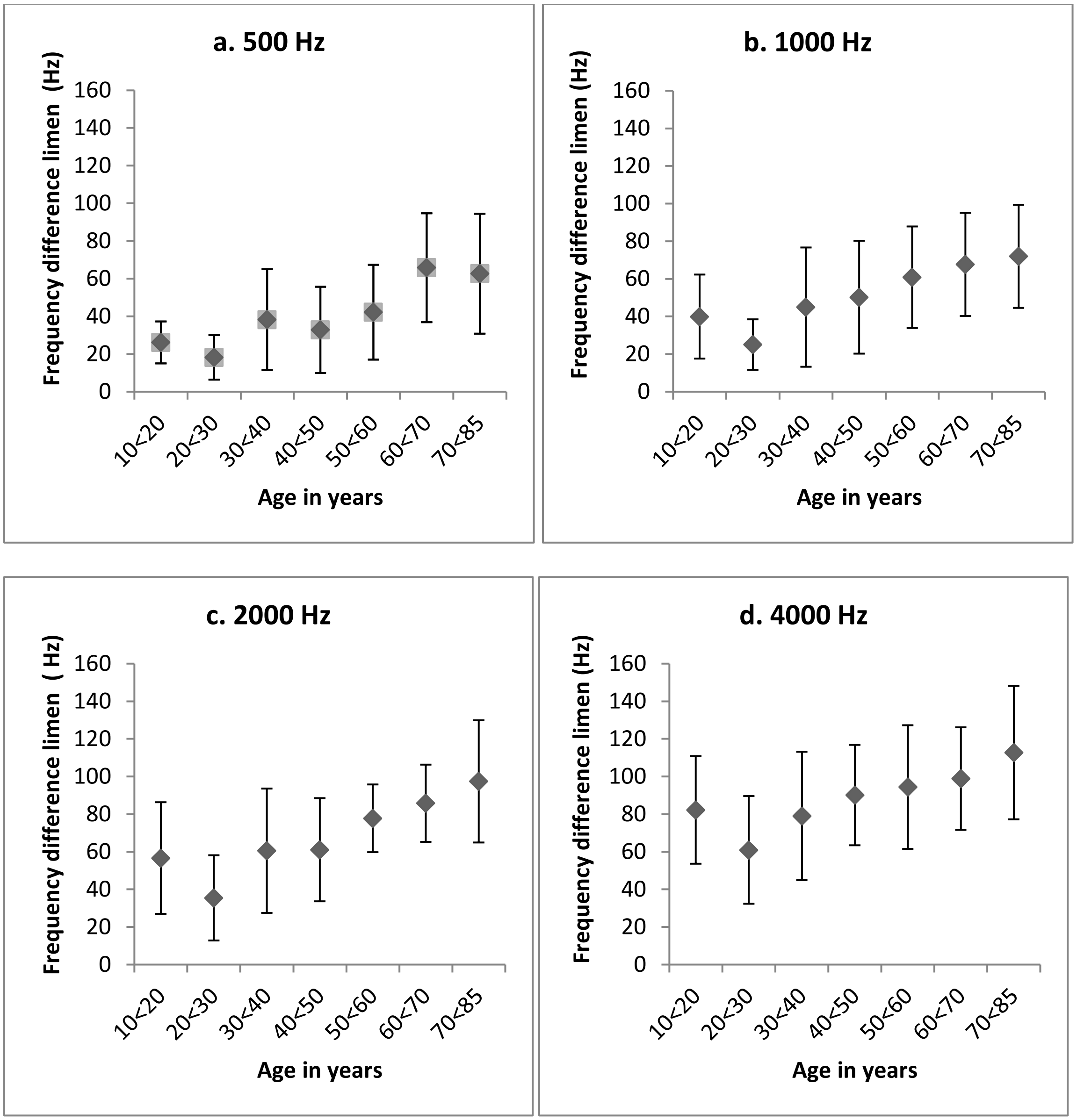


*Figure 4.1.*Mean frequency difference limen with one SD across all the age groups at 500 Hz (a), 1000 Hz (b), 2000 Hz (c) and 4000 Hz (d).

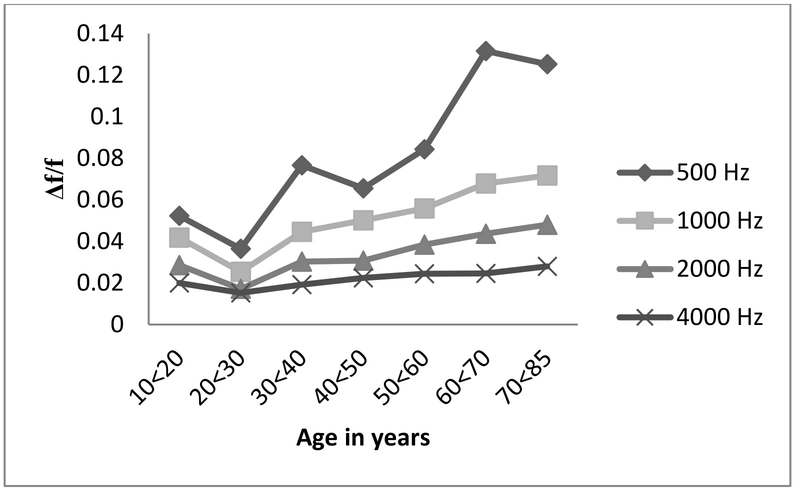


Figure 4.2. Δf/f across all the age groups at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

Table 4.3.

a. Results of pair-wise comparison across age for FDL at 500 Hz

Age in years	10-19.11	20-29.11	30-39.11	40-49.11	50-59.11	60-69.11	70-84.11
10-19.11							
20-29.11	NS						
30-39.11	NS	NS					
40-49.11	NS	NS	NS				
50-59.11	NS	S	NS	NS			
60-69.11	S	S	S	S	NS		
70-84.11	S	S	S	S	NS	NS	

Note: S-Significant, NS-Not significant at 0.05level (adjusted for Bonferroni's multiple comparison)

b. Results of pair-wise comparison across age for FDL at 1000 Hz

Age in years	10-19.11	20-29.11	30-39.11	40-49.11	50-59.11	60-69.11	70-84.11
10-19.11							
20-29.11	NS						
30-39.11	NS	NS					
40-49.11	NS	S	NS				
50-59.11	NS	S	NS	NS			
60-69.11	S	S	S	NS	NS		
70-84.11	S	S	S	NS	NS	NS	

Note: S-Significant, NS-Not significant at 0.05 level (adjusted for Bonferroni's multiple comparison)

c. Results of pair-wise comparison across age for FDL at 2000 Hz

Age in years	10-19.11	20-29.11	30-39.11	40-49.11	50-59.11	60-69.11	70-84.11
10-19.11							
20-29.11	S						
30-39.11	NS	S					
40-49.11	NS	S	NS				
50-59.11	NS	S	NS	NS			
60-69.11	S	S	S	S	NS		
70-84.11	S	S	S	S	NS	NS	

Note: S-Significant, NS-Not significant at 0.05 level (adjusted for Bonferroni's multiple comparison)

d. Results of pair-wise comparison across age for FDL at 4000 Hz

Age in years	10-19.11	20-29.11	30-39.11	40-49.11	50-59.11	60-69.11	70-84.11
10-19.11							
20-29.11	NS						
30-39.11	NS	NS					
40-49.11	NS	S	NS				
50-59.11	NS	S	NS	NS			
60-69.11	NS	S	NS	NS	NS		
70-84.11	S	S	S	NS	NS	NS	

Note: S-Significant, NS-Not significant at 0.05 level (adjusted for Bonferroni's multiple comparison)

Relationship between FDLs and age was assessed using Pearson's product-moment correlation. The Table 4.4 shows the correlation coefficients between FDL and age for different frequencies. The scatter plots for the significant correlations along with linear regression line are shown in Figure 4.3. From the Table 4.4 and Figure 4.3 it can be inferred that correlation was stronger between age and FDL for low and mid frequencies compared to high frequency. As age advanced frequency discrimination abilities reduced significantly.

Table 4.4.

Result of Pearson product moment correlation between FDL and age

Test	FDL (500 Hz)	FDL (1000 Hz)	FDL (2000 Hz)	FDL (4000 Hz)
Age	.542**	.469**	.525**	.394**

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

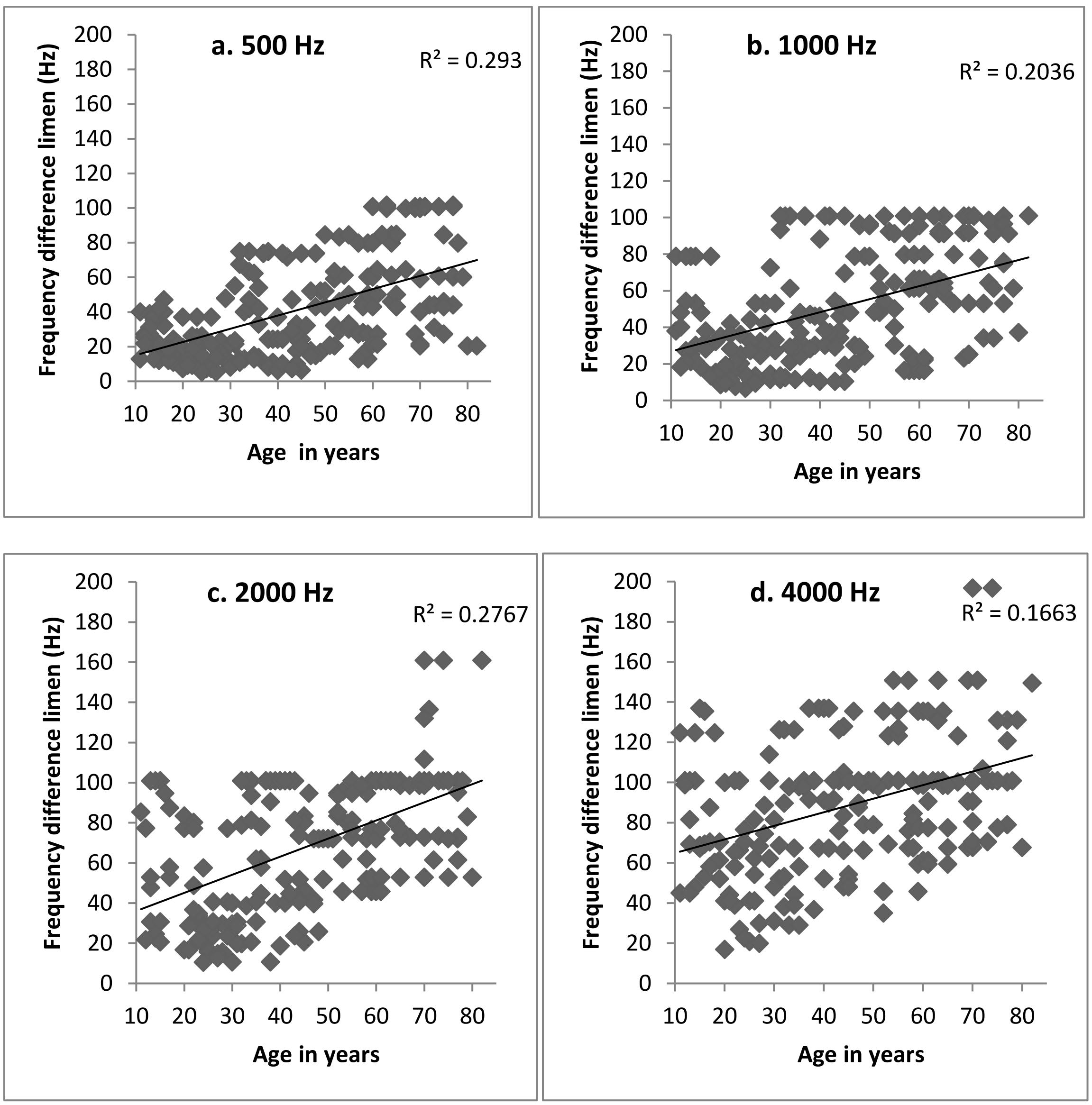


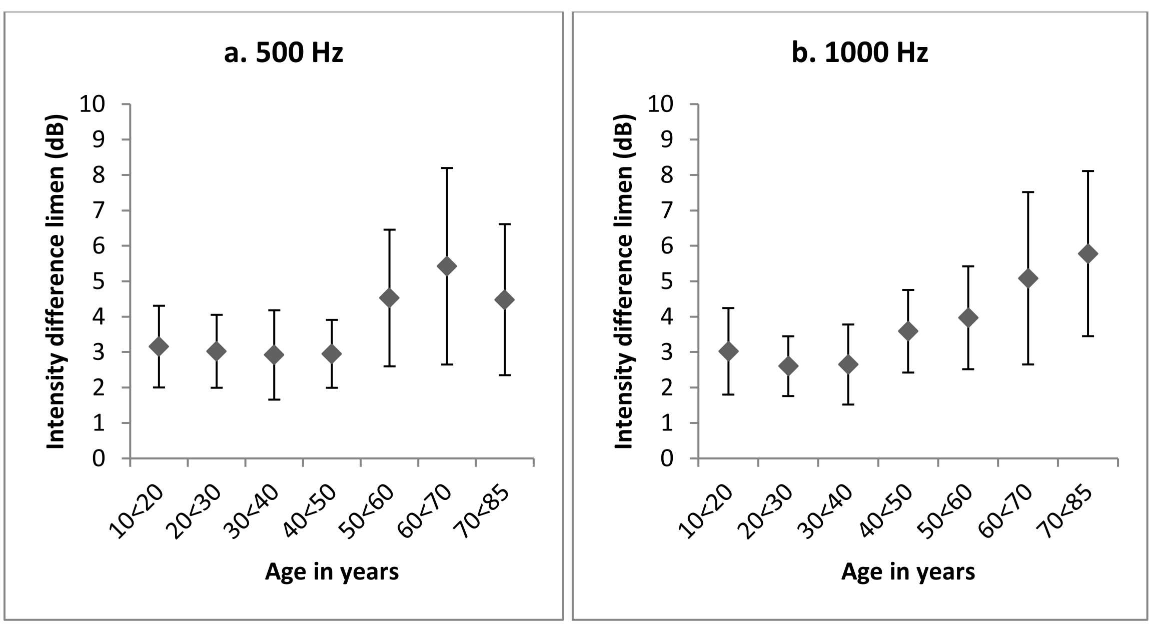
*Figure 4.3.*Scatter plot of FDL as a function of age at 500 Hz (a), 1000 Hz (b), 2000 Hz (c) and 4000 Hz (d). R^2 values are represented on the top right corner of the scatter plot.

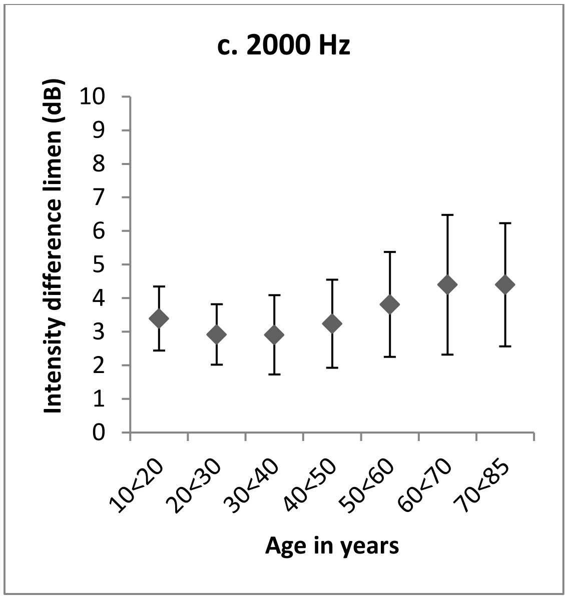
4.1.2. Intensity difference limen. Intensity difference limen (IDL) was assessed at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. The mean and one SD of IDL across age groups for all the four frequencies are depicted in Table 4.5 and Figure 4.4. From the Table 4.5 and Figure 4.4 it can be noted that older adults had poor IDL compared to young adults. A repeated measure of ANOVA was done to assess the statistical significance of these differences in IDL across different age groups. Results showed a significant main effect of age ($F(6,194) = 14.524$, $p<0.01$, $\eta^2=0.310$) and frequencies [$F(3,194) = 9.437$, $p<0.01$, $\eta^2=0.08$] on IDL. The interaction between frequency and age was not significant [$F(18,582) = 1.567$, $p>0.05$, $\eta^2=0.046$]. One way ANOVA was done to assess the significance of difference in IDLs for each frequency between age groups. Results showed that age had a significant effect on IDLs at 500 Hz [$F(6,194) = 9.904$, $p<0.01$, $\eta^2=0.234$], 1000 Hz [$F(6,194) = 10.968$, $p<0.01$, $\eta^2=0.253$], 2000 Hz [$F(6,194) = 5.527$, $p<0.01$, $\eta^2=0.146$] and 4000 Hz [$F(6,194) = 8.954$, $p<0.01$, $\eta^2=0.217$]. Table 4.6(a-d) shows pair-wise comparisons with Bonferroni's corrections for multiple comparisons between IDL of different age groups. It can be noted that the deterioration in IDL begins at 50 years of age for 500 Hz, 1000 Hz and 4000 Hz. At 2000 Hz IDL deteriorated after 6th decade of life. Pair-wise comparisons were not carried out between frequencies as this was not the objective of the study.

Table 4.5.

Mean intensity difference limen and one SD across all the age groups at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

Age in years	500 Hz		1000 Hz		2000 Hz		4000 Hz	
	Mean (dB)	SD	Mean (dB)	SD	Mean (dB)	SD	Mean (dB)	SD
10-19.11	3.15	1.15	3.02	1.22	3.39	.95	3.43	.66
20-29.11	3.02	1.02	2.60	.84	2.92	.91	3.03	.97
30-39.11	2.92	1.26	2.65	1.14	2.91	1.18	3.25	1.66
40-49.11	2.95	.95	3.58	1.16	3.24	1.31	4.04	2.17
50-59.11	4.52	1.92	3.97	1.45	3.86	1.56	4.82	1.79
60-69.11	5.42	2.77	5.08	2.43	4.40	2.08	5.31	2.43
70-84.11	4.48	2.13	4.78	2.33	4.4	1.83	5.48	2.21





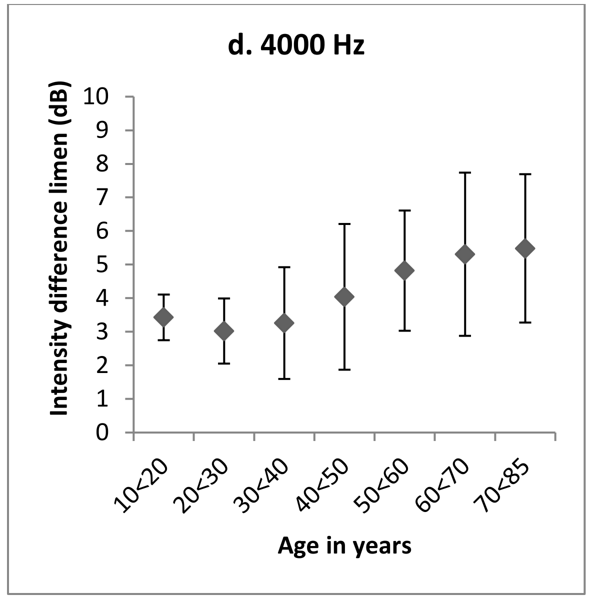


*Figure 4.4.*Mean intensity difference limen of with one SD across all the age groups at 500 Hz (a), 1000 Hz (b), 2000 Hz (c) and 4000 Hz (d).

Table 4.6.

a. Results of pair-wise comparison across age for IDL at 500 Hz

Age in years	10-19.11	20-29.11	30-39.11	40-49.11	50-59.11	60-69.11	70-84.11
10-19.11							
20-29.11	NS						
30-39.11	NS	NS					
40-49.11	NS	NS	NS				
50-59.11	NS	S	S	S			
60-69.11	S	S	S	S	NS		
70-84.11	S	S	S	NS	NS	NS	

Note: S-Significant, NS-Not significant at 0.05 level (adjusted for Bonferroni's multiple comparison)

b. Results of pair-wise comparison across age for IDL at 1000 Hz

Age in years	10-19.11	20-29.11	30-39.11	40-49.11	50-59.11	60-69.11	70-84.11
10-19.11							
20-29.11	NS						
30-39.11	NS	NS					
40-49.11	NS	NS	NS				
50-59.11	NS	S	NS	NS			
60-69.11	S	S	S	S	NS		
70-84.11	S	S	S	NS	NS	NS	

Note: S-Significant, NS-Not significant at 0.05 level (adjusted for Bonferroni's multiple comparison)

c. Results of pair-wise comparison across age for IDL at 2000 Hz

Age in years	10-19.11	20-29.11	30-39.11	40-49.11	50-59.11	60-69.11	70-84.11
10-19.11							
20-29.11	NS						
30-39.11	NS	NS					
40-49.11	NS	NS	NS				
50-59.11	NS	NS	NS	NS			
60-69.11	NS	S	S	S	NS		
70-84.11	NS	S	S	NS	NS	NS	

Note: S-Significant, NS-Not significant at 0.05 level (adjusted for Bonferroni's multiple comparison)

d. Results of pair-wise comparison across age for IDL at 4000 Hz

Age in years	10-19.11	20-29.11	30-39.11	40-49.11	50-59.11	60-69.11	70-84.11
10-19.11							
20-29.11	NS						
30-39.11	NS	NS					
40-49.11	NS	NS	NS				
50-59.11	NS	S	S	NS			
60-69.11	S	S	S	NS	NS		
70-84.11	S	S	S	S	NS	NS	

Note: S-Significant, NS-Not significant at 0.05 level (adjusted for Bonferroni's multiple comparison)

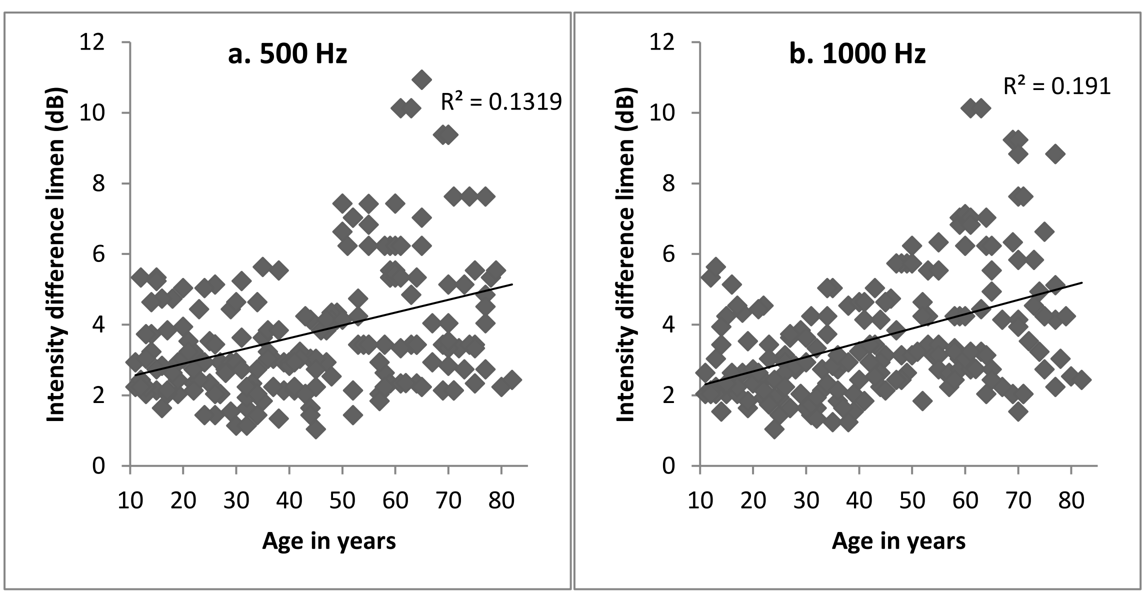
The Pearson's product moment correlation was done to assess the relationship between the IDL and age. The Table 4.7 shows the correlation coefficients between IDL and age across different frequencies. The scatter plots for the significant correlations are shown in Figure 4.5. From the Table 4.7 and Figure 4.5 it can be inferred that there was a significant positive correlation between IDL and age, indicating that as the age increases IDL deteriorates. This relationship was strongest for 1000 Hz followed by 4000 Hz, 500 Hz and 2000 Hz.

Table 4.7.

Result of Pearson product moment correlation between IDL and age

Test	IDL (500 Hz)	IDL (1000 Hz)	IDL (2000 Hz)	IDL (4000 Hz)
Age	.370**	.437**	.307**	.431**

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



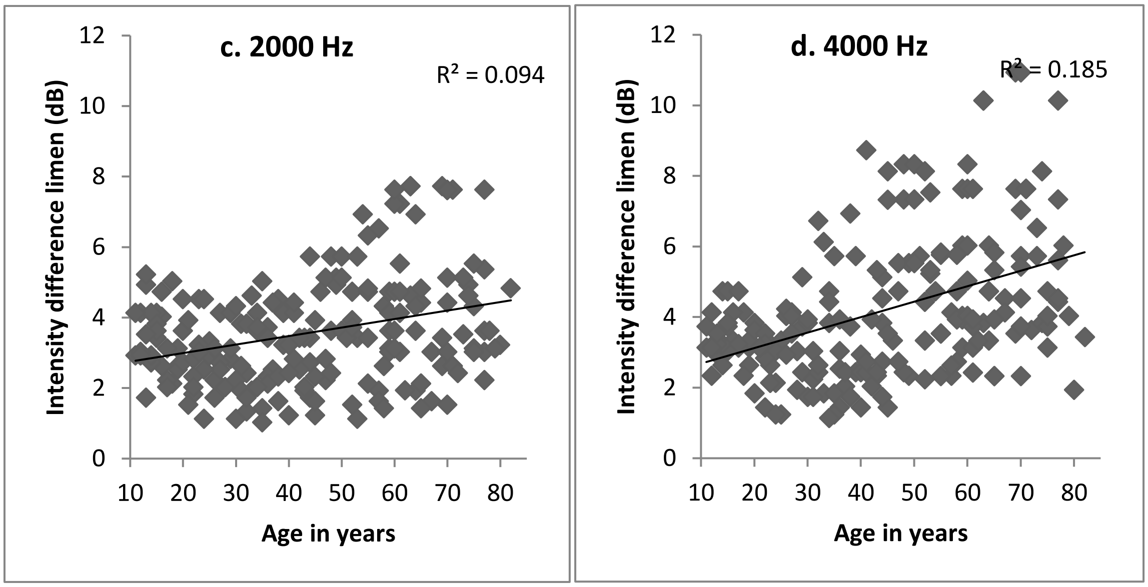


*Figure 4.5.*Scatter plot of IDL as a function of age at 500 Hz (a), 1000 Hz (b), 2000 Hz (c) and 4000 Hz (d). R^2 values are represented on the top right corner of the scatter plot.

4.1.3. Temporal processing abilities across different age groups.

Duration discrimination thresholds. Table 4.8 and Figure 4.6 depict the mean and one SD of duration discrimination thresholds (DDT) across different age groups. 20-29.11 years group had lowest DDT followed by 30<40 years. One way ANOVA showed a significant main effect of age on DDT [$F(6,194) = 4.103$, $p<0.01$, $\eta^2=0.113$]. Pair-wise comparison with Bonferroni's corrections for multiple comparison revealed that DDT were scattered and no clear trend was visible. DDT of 20-29.11 years age group significantly differed from 50-59.11 years and 60-69.11 years age group. Also, DDT of 30-39.11 years group differed significantly from 50-59.11 years age group. No other comparisons were significantly different (Table 4.9).

Table 4.8.

Mean duration discrimination thresholds and one SD across all the age groups

Age in years	Mean (ms)	SD
10-19.11	63.32	18.89
20-29.11	48.51	16.71
30-39.11	49.43	16.87
40-49.11	54.77	22.81
50-59.11	67.35	26.94
60-69.11	66.14	22.73
70-84.11	63.22	21.33

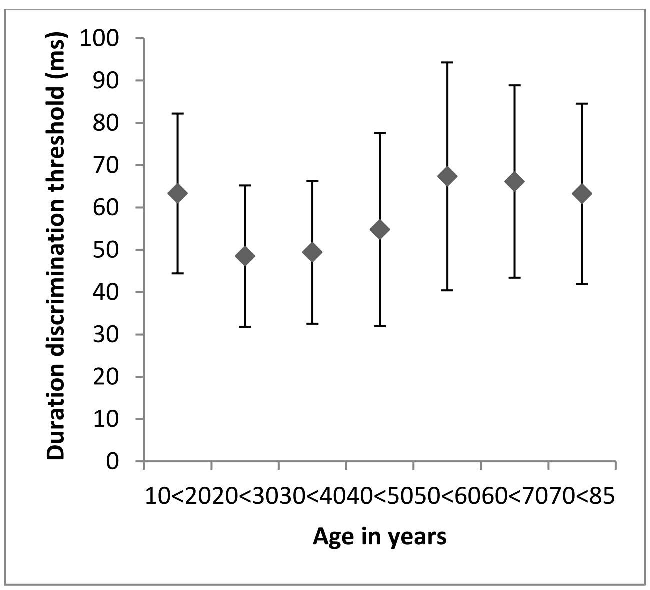


*Figure 4.6.*Mean duration discrimination thresholds with one SD across all the age groups.

Table 4.9.

Results of pair-wise comparison across age for DDT

Age in years	10-19.11	20-29.11	30-39.11	40-49.11	50-59.11	60-69.11	70-84.11
10-19.11							
20-29.11	NS						
30-39.11	NS	NS					
40-49.11	NS	NS	NS				
50-59.11	NS	S	S	NS			
60-69.11	NS	S	NS	NS	NS		
70-84.11	NS	NS	NS	NS	NS	NS	

Note: S-Significant, NS-Not significant at 0.05 level (adjusted for Bonferroni's multiple comparison)

The relationship between DDT and age was assessed through Pearson's product moment correlation. There was a weak but significant correlation between age and DDT (r=.177, p<0.05). However, scatter plot (Figure 4.7) failed to reveal any trend and R squared value was only 0.03.

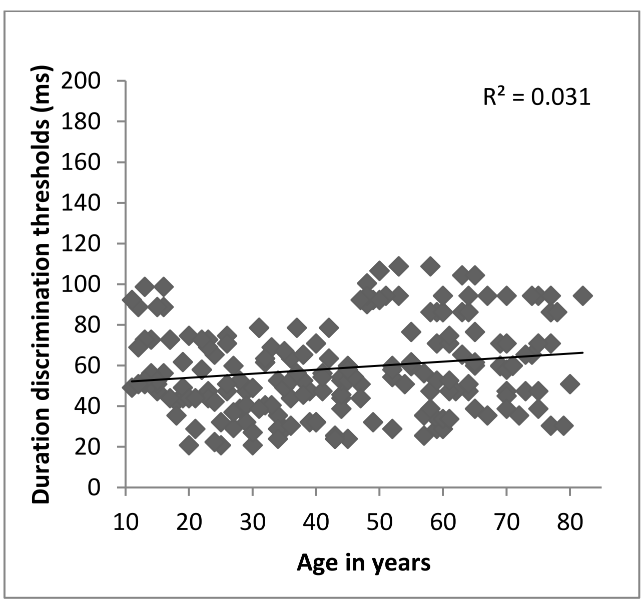


*Figure 4.7.*Scatter plot of DDT as a function of age. R^2 values are represented on the top right corner of the scatter plot.

Gap detection thresholds. Table 4.10 and Figure 4.8 depict the mean and one SD of gap detection thresholds (GDT) across age groups. It can be inferred from the Figure 4.8 that the GDT deteriorated more rapidly with advancing age especially after 60 years. The oldest age group had largest standard deviation indicating increased variability of GDT in 70-79.11 years age group. One way ANOVA showed a significant main effect of age on GDT [F (6,194) = 12.448, p<0.01, $ŋ^2$=0.277]. Pair-wise comparison with Bonferroni's corrections for multiple comparisons showed that only 70-84.11 years age group had significantly poorer GDT compared to other age groups. GDT of 70-84.11 years of age was almost eight fold poorer than the younger age groups.

Table 4.10.

Mean gap detection thresholds and one SD across all the age groups

Age in years	Mean (ms)	SD
10-19.11	2.68	.64
20-29.11	2.42	.46
30-39.11	2.57	.61
40-49.11	3.33	1.14
50-59.11	4.50	1.26
60-69.11	6.22	3.06
70-84.11	17.81	22.01

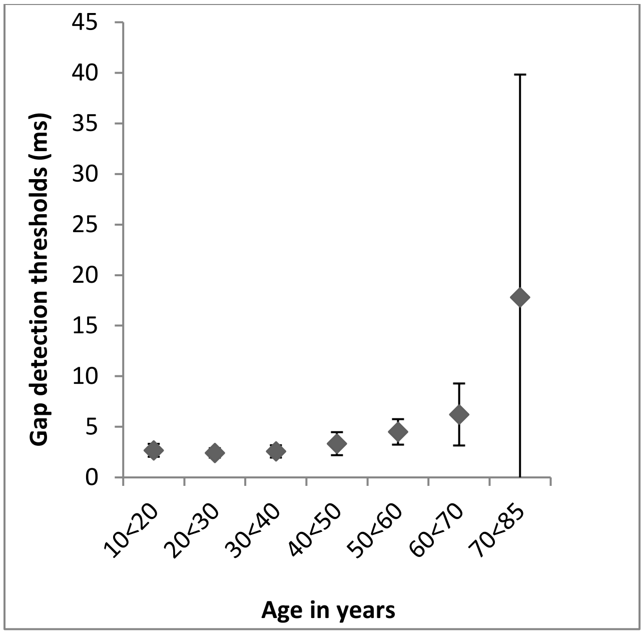


*Figure 4.8.*Mean gap detection thresholds with one SD across all the age groups.

Pearson' product moment correlation between age and gap detection thresholds showed a significant positive correlation ($r=0.416$, $p<0.01$) indicating that as the age increases GDT also increases. The scatter plot of GDT as a function of age is shown in Figure 4.9.From the Figure 4.9 it can be seen that in older age groups there were some individuals with GDT of more than 40 ms. They were not considered as outliers as initial box plot did not group them into outliers.

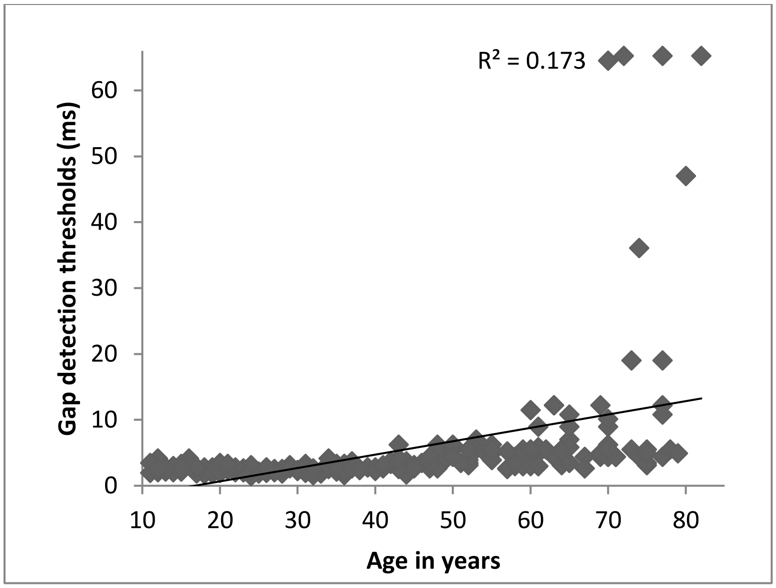


*Figure 4.9.*Scatter plot of GDT as a function of age. R^2 values are represented on the top right corner of the scatter plot.

Modulation detection thresholds. Peak sensitivity (PS) and bandwidth (BW) of modulation transfer function were estimated using a curve-fitting tool in Matlab. The mean and one SD of the PS and BW across different age groups are shown in Table 4.11 and Figure 4.10. One way ANOVA showed a significant main effect of age on both PS [F (6,194) = 19.851, p<0.01, η^2=0.380] and BW [F (6,194) = 8.396, p<0.01, η^2=0.206]. Both PS and BW deteriorated with the age. PS of modulation detection thresholds in participants above 50 years age group were significantly poorer compared to younger age groups (20<30 years age group). BW of modulation transfer function also deteriorated significantly after 50 years of age. Table 4.12 shows the results of pair-wise comparisons with Bonferroni's corrections of multiple comparisons.

Table 4.11.

Mean peak sensitivity and band width with one SD across all the age groups

	PS		BW	
Age in years	Mean (dB)	SD	Mean (Hz)	SD
10-19.11	-21.41	1.86	182.79	82.82
20-29.11	-23.41	2.64	165.00	67.06
30-39.11	-22.92	1.91	171.13	88.73
40-49.11	-21.82	2.08	124.63	30.48
50-59.11	-20.12	2.01	110.14	30.83
60-69.11	-18.83	3.02	118.95	37.13
70-84.11	-18.05	3.16	109.94	26.34

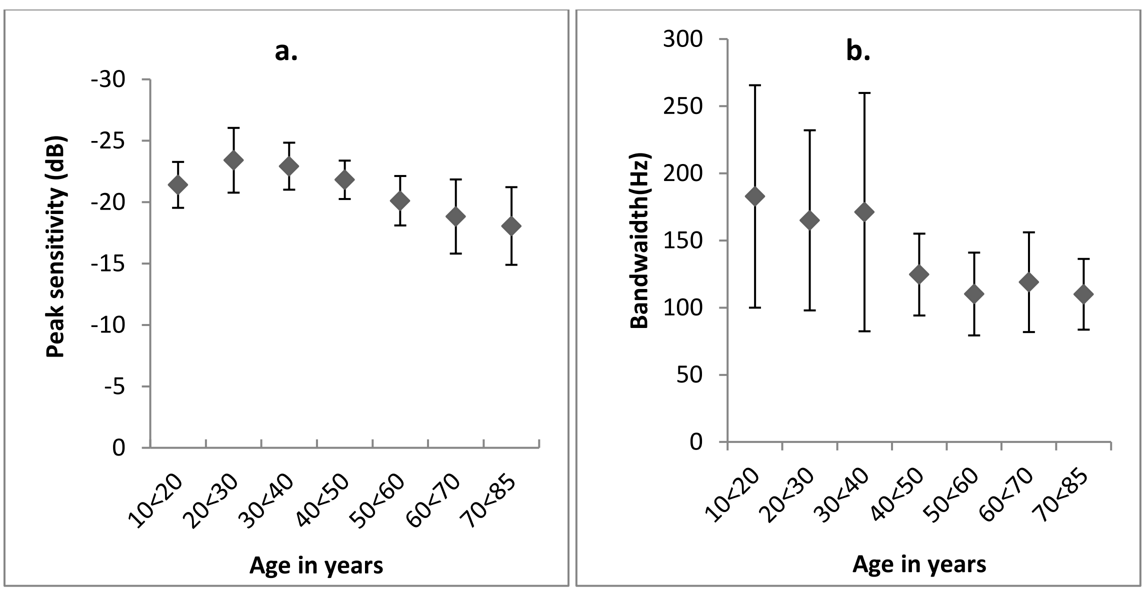


*Figure 4.10.*Mean peak sensitivity (a) and bandwidth (b) with one SD across all the age groups.

Table 4.12.

Results of pair-wise comparison across age for peak sensitivity and bandwidth

	Age in years	10-19.11	20-29.11	30-39.11	40-49.11	50-59.11	60-69.11	70-84.11
Peak sensitivity	10-19.11							
	20-29.11	S						
	30-39.11	NS	NS					
	40-49.11	NS	NS	NS				
	50-59.11	NS	S	S	NS			
	60-69.11	S	S	S	S	NS		
	70-84.11	S	S	S	S	S	NS	
Bandwidth	10-19.11							
	20-29.11	NS						
	30-39.11	NS	NS					
	40-49.11	S	NS	S				
	50-59.11	S	S	S	NS			
	60-69.11	S	NS	S	NS	NS		
	70-84.11	S	S	S	NS	NS	NS	

Note: S-Significant, NS-Not significant at 0.05 level (adjusted for Bonferroni's multiple comparison)

PS ($r= 0.513$, $p<0.01$) had a significant positive correlation with age and BW ($r= -0.443$, $p<0.01$) had a significant negative correlation with age. This means that younger age group had higher PS of modulation detection thresholds and wider BW of temporal modulation transfer function compared to older age group. The scatter plots of PS and BW as a function of age are shown in Figure 4.11. From the Figure 4.11 it can be inferred that as the age increases PS and BW decreases.

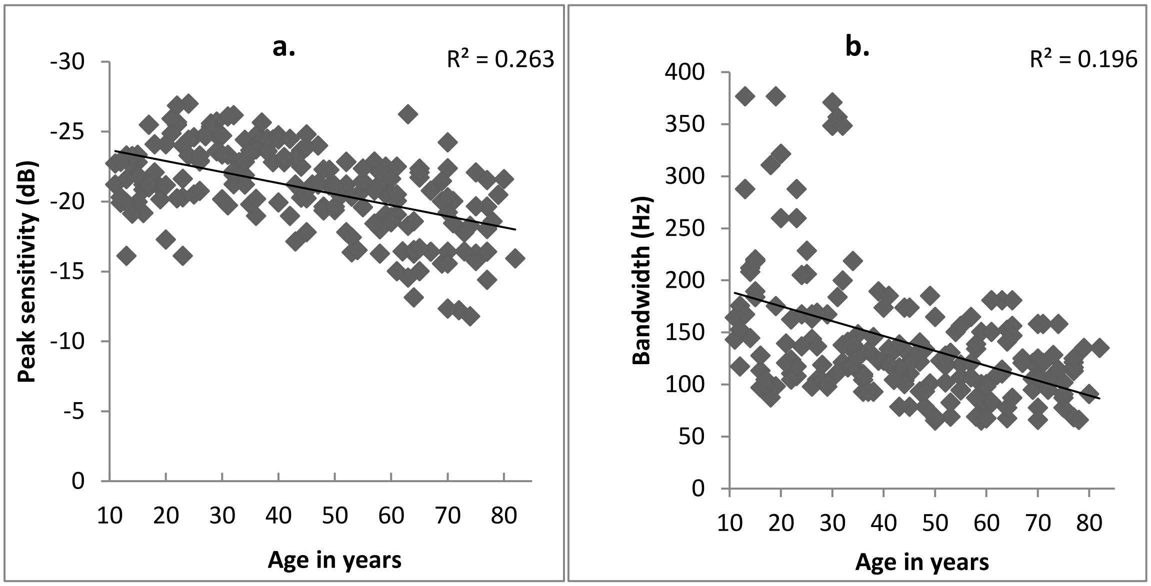


*Figure 4.11.*Scatter plot of PS (a) and BW (b) as a function of age. R^2 values are represented on the top right corner of the scatter plot.

Backward masking. Table 4.13 and Figure 4.12 depict the median of backward masking thresholds across age groups. Thresholds are expressed in relative to noise levels and hence are in negative values. More negative thresholds indicate better responses. From the Figure 4.12 it is evident that the thresholds deteriorated with the advancing age and participants in the 20<30 years age group had best thresholds. As mentioned earlier since data was not normally distributed non-parametric statistics were used to evaluate the significance of differences in backward masking thresholds across different age groups. The Kruskal Wallis test revealed that backward masking thresholds significantly differed across age groups [$\chi^2(6) = 67.572$, $p < 0.01$]. Mann Whitney U test showed that backward masking thresholds deteriorated significantly after 50 years of life.

Table 4.13.

Median and range of backward masking thresholds across all the age groups

Age in years	Median (dB)	Range
10-19.11	-29.12	-59.6230 to -9.6230
20-29.11	-34.37	-58.1230 to -9.6230
30-39.11	-25.62	-51.6230 to -9.6230
40-49.11	-22.62	-52.1230 to -9.6230
50-59.11	-11.12	-38.1230 to -9.6230
60-69.11	-9.62	-31.6230 to -9.6230
70-84.11	-9.62	-31.6230 to -9.6230

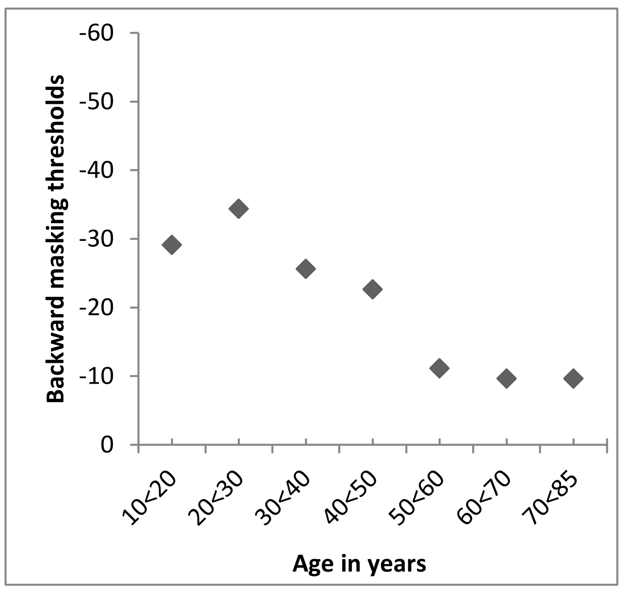


*Figure 4.12.*Median of backward masking thresholds across all the age groups.

Spearman's rank correlation revealed a significant positive correlation (ρ=0.536, p<0.01) between age and backward masked thresholds. Younger age group had better thresholds compared to older age group. Scatter plot of backward masked thresholds as a function of age is shown in Figure 4.13.

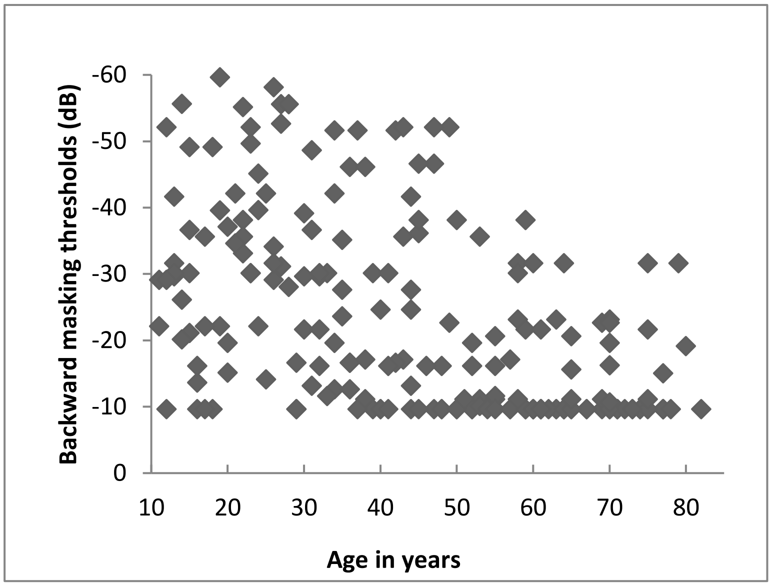


*Figure 4.13.*Scatter plot of backward masking as a function of age.

Duration pattern scores across different age groups. Table 4.14 and Figure 4.14 depict the median of duration pattern scores across age groups. From the Table 4.14 and Figure 4.14 it is evident that the scores were poorer in older individuals compared to young adults. Similar to backward masking thresholds, duration pattern scores were also non normally distributed. Therefore, non-parametric tests were used for statistical analysis. Kruskal-Wallis test showed that duration pattern scores significantly deteriorated with the age [$\chi^2(6) = 71.285$, $p < 0.01$]. Mann Whitney U test revealed that duration pattern scores of 10-19.11 years age group was similar to that of older participants (50-59.11 years age group and above). Participants above 50-59.11 years age group had significantly poorer duration pattern scores compared to 20-29.11 and 30-39.11 years age group.

Table 4.14.

Median and range of duration pattern scores across all the age groups

Age in years	Median	Range
10-19.11	28	21 to 30
20-29.11	29	27 to 30
30-39.11	28	24 to 30
40-49.11	27	20 to 30
50-59.11	24	15 to 30
60-69.11	23	11 to 29
70-84.11	21.5	15 to 29

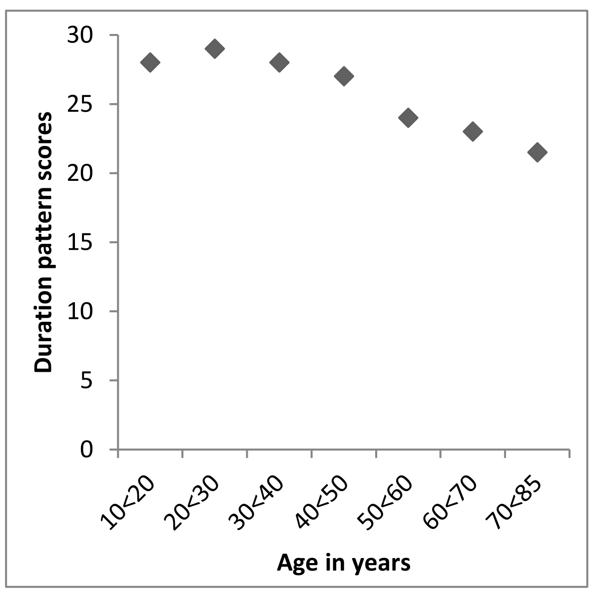


*Figure 4.14.*Median of duration pattern scores across all the age groups.

There was significant negative correlation between age and duration pattern scores (Spearman's rank correlation $\rho = -0.5$, $p<0.01$). Figure 4.15 shows the scatter plot of duration pattern scores as a function of age. From correlation coefficient and scatter plot it can be concluded that as the age advanced duration pattern scores steadily deteriorated.

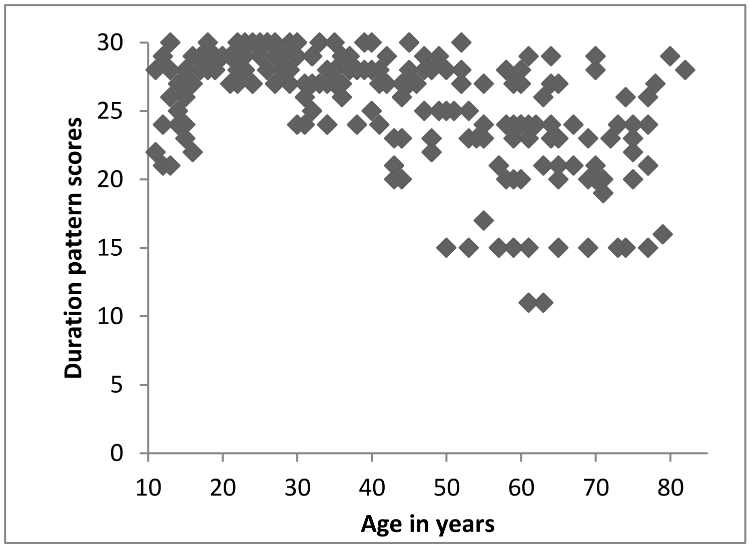


*Figure 4.15.*Scatter plot of duration pattern test as a function of age.

4.1.4. Speech perception in noise across different age groups. The mean and one SD of raw SPIN scores and SNR-50 values across different age groups are shown in Table 4.15 and Figures 4.16 (a & b). From Table 4.15 and Figure 4.16 it is evident that speech perception in noise deteriorated with increase in age with best scores seen in the age range of 20-29.11 years. One way ANOVA showed a significant main effect of age on SNR-50 [$F(6,194)= 39.233$, $p<0.01$, $\eta^2=0.548$]. Pair-wise comparisons with Bonferroni's corrections for multiple comparisons are depicted in Table 4.16. From the Table 4.16 it can be noted that SNR-50 deteriorates significantly after 40 years of age.

Table 4.15.

Mean SPIN and SNR-50 with SD across all the age groups

	SPIN		SNR-50	
Age in years	Mean	SD	Mean	SD
10-19.11	26.78	3.389	-6.56	2.03
20-29.11	28.93	2.545	-7.86	1.52
30-39.11	26.83	3.206	-6.60	1.92
40-49.11	24.76	3.356	-5.35	2.01
50-59.11	23.00	3.251	-4.30	1.95
60-69.11	21.89	3.814	-3.63	2.28
70-84.11	17.68	2.907	-1.10	1.74

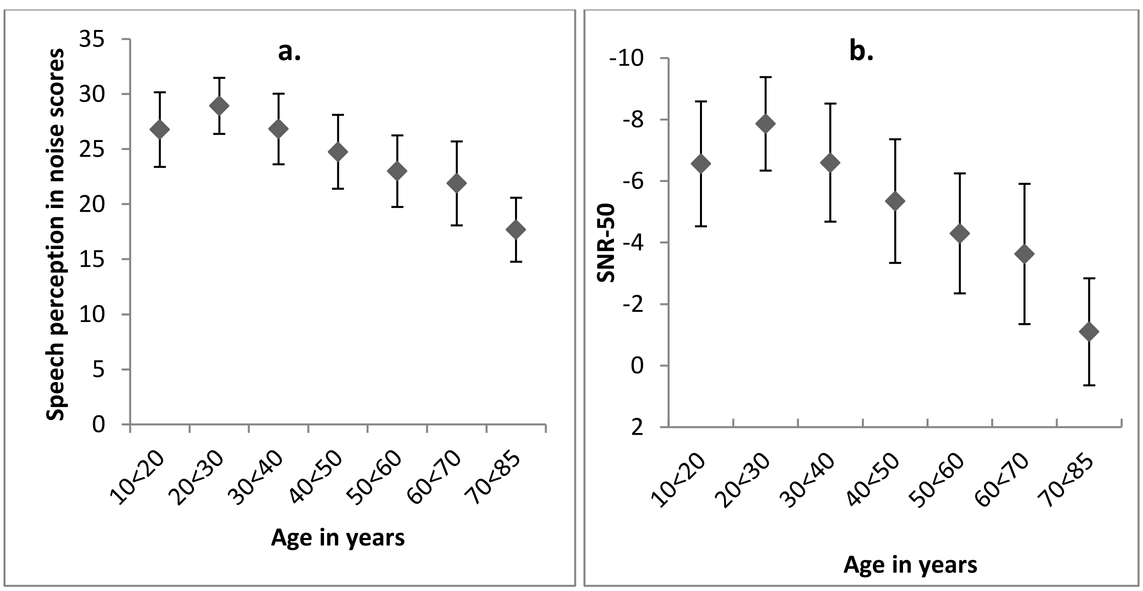


*Figure 4.16.*Mean raw speech perception in noise scores (a) and SNR-50 (b) with one SD across all the age groups.

Table 4.16.

Results of pair-wise comparison across age for SNR-50

Age in years	10-19.11	20-29.11	30-39.11	40-49.11	50-59.11	60-69.11	70-84.11
10-19.11							
20-29.11	NS						
30-39.11	NS	NS					
40-49.11	NS	S	NS				
50-59.11	S	S	S	NS			
60-69.11	S	S	S	S	NS		
70-84.11	S	S	S	S	S	S	

Note: S-Significant, NS-Not significant at 0.05 level (adjusted for Bonferroni's multiple comparison)

Pearson's product moment correlation between SNR-50 and age showed a significant positive correlation (r= 0.68, p<0.01). The scatter plot of SNR-50 as a function of age is shown in Figure 4.17.

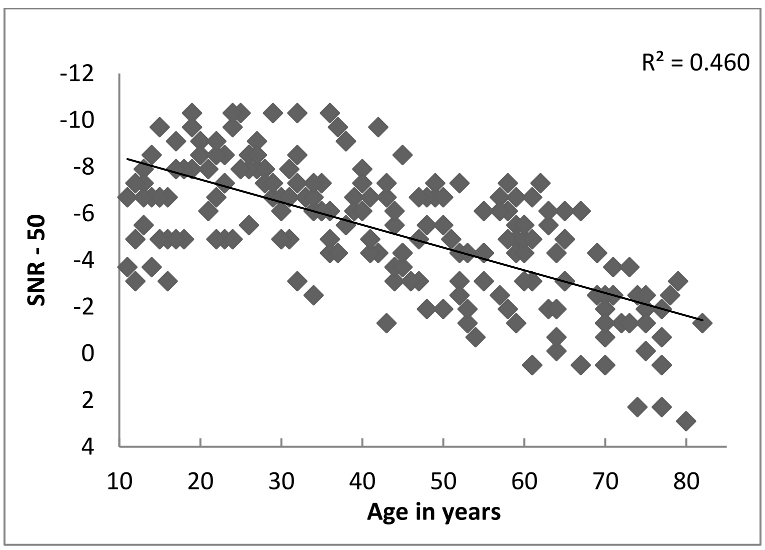


*Figure 4.17.*Scatter plot of SNR-50 as a function of age. R^2 values are represented on the top right corner of the scatter plot.

To summarize, it can be noted that frequency discrimination, intensity discrimination, temporal processing abilities and speech perception in noise declined with age. The summary table depicting the age at which decline in psychophysical abilities and speech perception in noise begins is shown in Table 4.17.

Table 4.17.

Effect of age on different auditory abilities.

Tests		Age of decline (in years)
FDL	500 Hz	50
	1000 Hz	40
	2000 Hz	30
	4000 Hz	40
IDL	500 Hz	50
	1000 Hz	50
	2000 Hz	60
	4000 Hz	50
DDT		No clear trend
GDT		70
MDT	PS	50
	BW	50
BM		50
DPT		50
SPIN		40

4.2. Working memory across different age groups.

This section addresses the objective 4 of the study. The effect of age on operation span, reading span, forward, backward, ascending and descending digit span is discussed below.

4.2.1. Operation span and reading span task. Table 4.18 and Figure 4.18 depict the mean and one SD of operation span (OS) and reading span (RS) scores. From the Table 4.18 and Figure 4.18 it can be seen that both OS and RS scores deteriorated with age. One way ANOVA showed significant main effect of age on OS [$F(6,194)=17.691$, $p<0.01$, $\eta^2=0.354$] and RS [$F(6,194)=18.747$, $p<0.01$, $\eta^2=0.367$]. Pair-wise comparisons with Bonferroni's correction for multiple comparisons (Table 4.19) showed that OS scores deteriorated significantly after 50 years of age and RS scores reduced after 60 years of age. There were no significant differences in OS scores in age groups beyond 50 years of age and RS scores in age groups beyond 60 years age. Pearson's product moment correlation revealed a significant negative correlation between age and OS ($r=-0.505$, $p<0.05$) and RS ($r=-0.521$, $p<0.05$). Figure 4.19 shows the scatter plot between OS and RS as a function of age.

Table 4.18.

Mean operation and reading span scores with SD across all the age groups

	OS		RS	
Age in years	Mean	SD	Mean	SD
10-19.11	9.20	.86	8.61	.74
20-29.11	9.53	1.18	8.93	1.04
30-39.11	9.46	1.19	8.52	1.44
40-49.11	9.72	1.26	8.61	1.17
50-59.11	8.54	1.42	8.04	1.18
60-69.11	7.82	1.23	7.36	.91
70-84.11	7.29	1.07	6.29	1.33

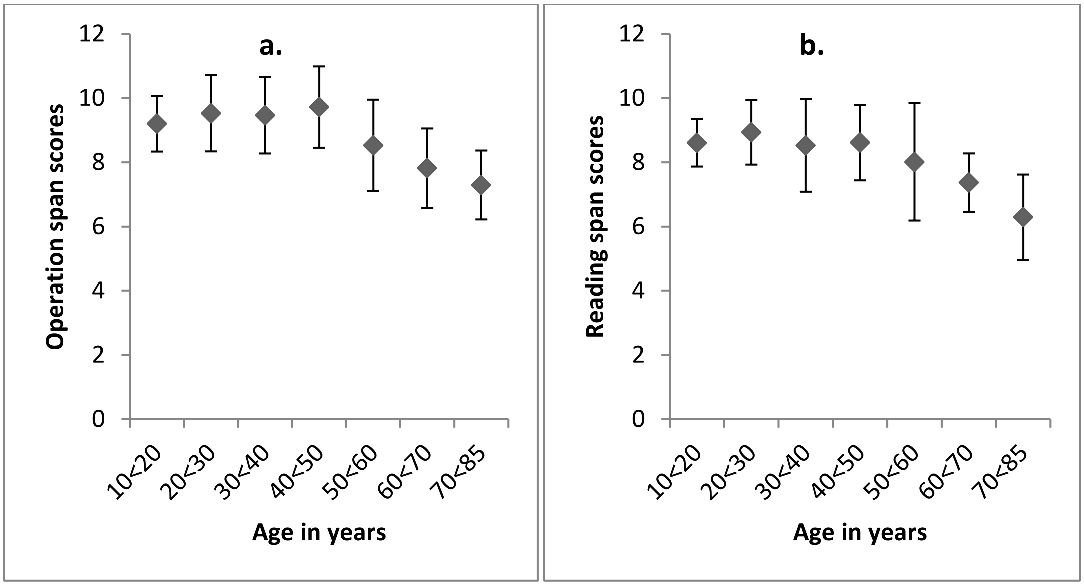


*Figure 4.18.*Mean operation span scores (a) and reading span scores (b) with one SD across all the age groups.

Table 4.19.

Results of pair-wise comparison across age for operation span task and reading span task

	Age in years	10-19.11	20-29.11	30-39.11	40-49.11	50-59.11	60-69.11	70-84.11
OS	10-19.11							
	20-29.11	NS						
	30-39.11	NS	NS					
	40-49.11	NS	NS	NS				
	50-59.11	NS	S	NS	S			
	60-69.11	S	S	S	S	NS		
	70-84.11	S	S	S	S	S	NS	
RS	10-19.11							
	20-29.11	NS						
	30-39.11	NS	NS					
	40-49.11	NS	NS	NS				
	50-59.11	NS	NS	NS	NS			
	60-69.11	S	S	S	S	NS		
	70-84.11	S	S	S	S	S	S	

Note: S-Significant, NS-Not significant at 0.05 level (adjusted for Bonferroni's multiple comparison)

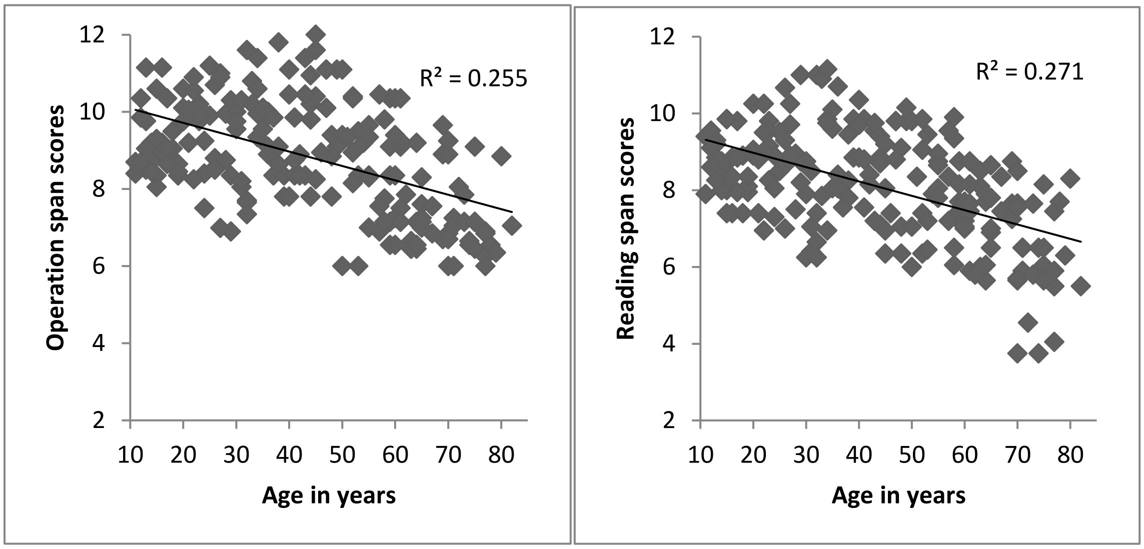


*Figure 4.19.*Scatter plot of OS and RS as a function of age. R^2 values are represented on the top right corner of the scatter plot.

4.2.2. Forward, Backward, Ascending and Descending digit span. Table 4.20 and Figure 4.20 shows the median of forward, backward, ascending and descending digit span across age groups. From the Figure 4.20 it can be noted that all the auditory working memory spans reduced with age. 20-29.11 years age group had better working memory capacity compared to older participants. Since data was non- normally distributed non-parametric tests were used to assess the statistical significance of differences in working memory capacity across different age groups. Kruskal Wallis test revealed that age significantly affected forward digit span [χ^2 (6) = 43.363, $p < 0.01$], backward digit span [χ^2 (6) = 65.619, $p < 0.01$], ascending digit span [χ^2 (6) = 71.833, $p < 0.01$] and descending digit span [χ^2 (6) = 58.518, $p < 0.01$]. Mann Whitney U test showed that forward digit span reduced significantly after 50 years of age. Forward digit span scores were similar in all age groups more than 50 years. In backward digit span and ascending digit span 20-29.11 years group had significantly better thresholds compared to all other age groups. However, descending digit span showed deterioration by 40 years of age.

Spearman rank correlation revealed significant negative correlation between age and all working memory span tasks. Table 4.21 shows the correlation coefficients between age and different working memory tasks and it can be noted that the relationship was stronger for sequencing tasks i.e. ascending and descending digit task. Figure 4.21 shows the scatter plots between age and different working memory spans.

Table 4.20.

Median and range of forward, backward, ascending and descending scores across all the age groups

Age in years	FD		BD		ASC		DSC	
	Median	Range	Median	Range	Median	Range	Median	Range
10-19.11	6	4 to 8	5	3 to8	6	4 to10	6	4 to 8
20-29.11	6	4 to 8	6	4 to 8	7	5 to10	6	4 to10
30-39.11	5	4 to 9	4	3 to 7	6	4 to 9	6	3 to 9
40-49.11	5	4 to 8	4	3 to 5	6	4 to 8	5	4 to 8
50-59.11	5	3 to 7	4	2 to 5	5	2 to 7	5	3 to 7
60-69.11	5	3 to 7	4	2 to 5	5	3 to 7	4.5	2 to7
70-84.11	5	3 to 6	4	2 to 5	5	3 to 8	5	2 to 8

Note: FD- Forward, BD- Backward, ASC- Ascending, DSC- Descending

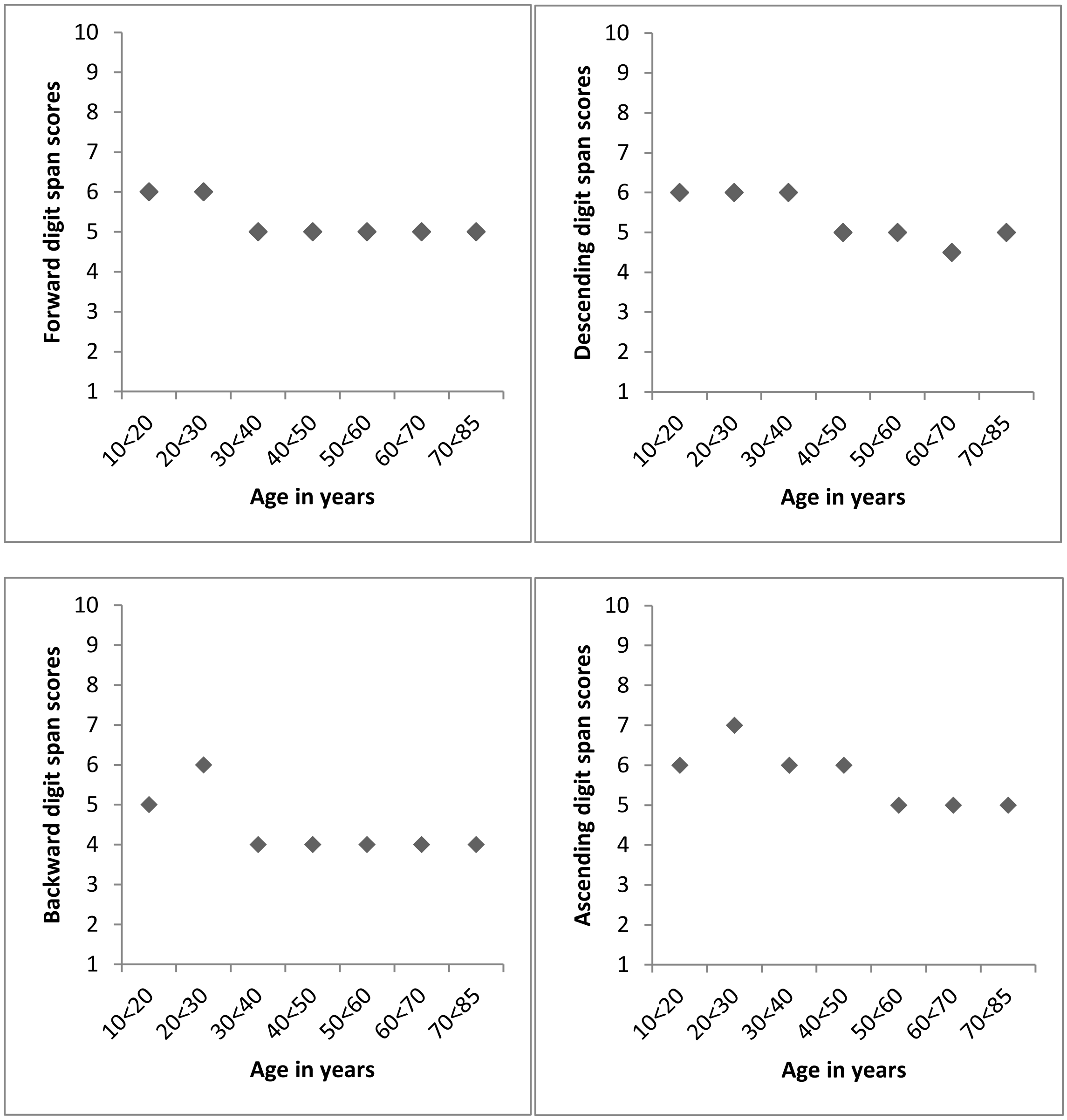


*Figure 4.20.*Median of forward, backward, ascending and descending digit span across age groups.

Table 4.21.

Result of Spearman rank correlation between auditory working memory measures and age

Test	Forward digit test	Backward digit test	Ascending digit test	Descending digit test
Age	-.446**	-.497**	-.546**	-.528**

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

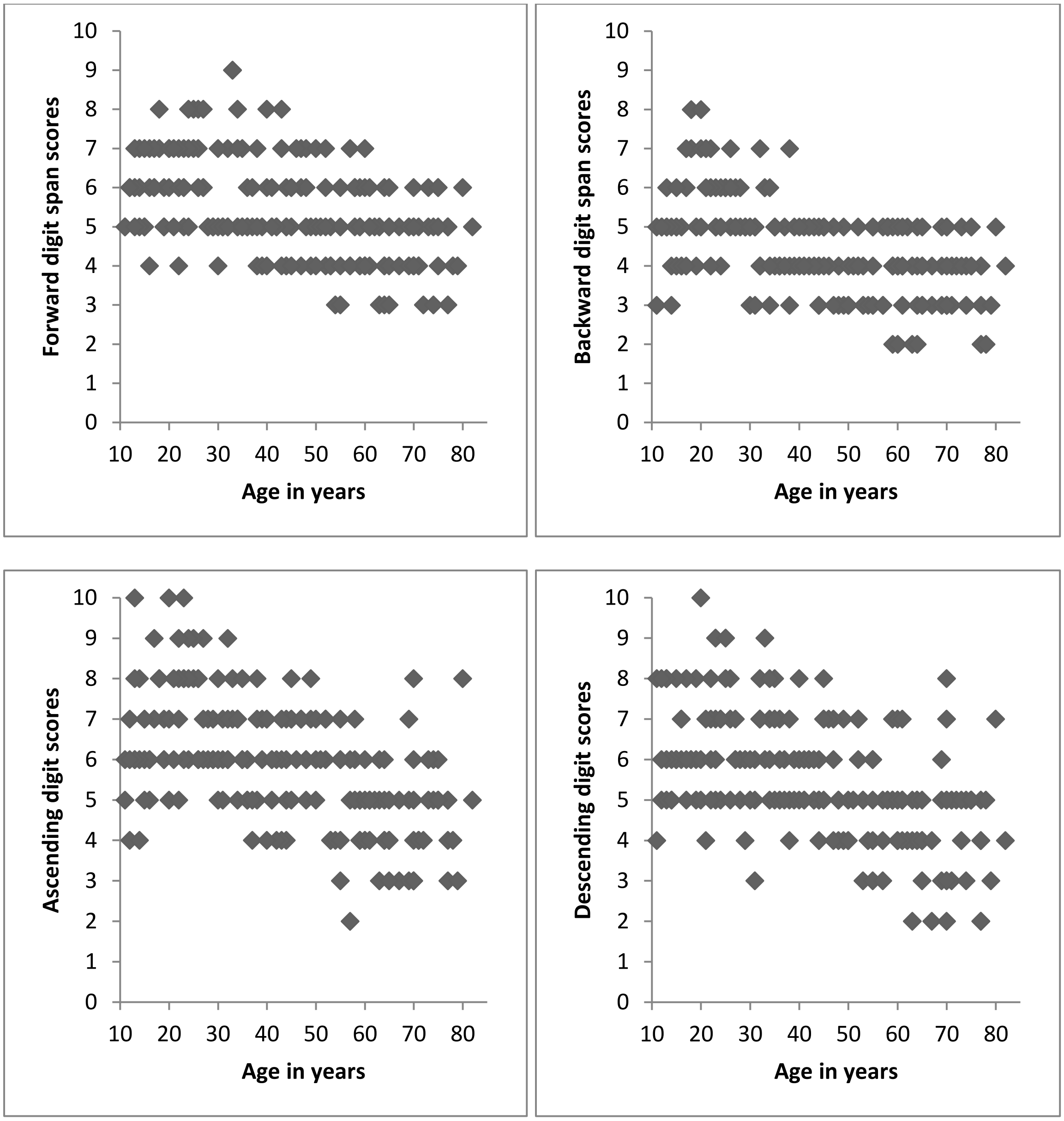


*Figure 4.21.*Scatter plot of forward, backward, ascending, descending digit span as a function of age.

4.3. The relationship among age, working memory, speech perception in noise and psychophysical abilities.

This section addresses objective 5 of the study. The Pearson's product moment correlation was performed to assess the relationship among psychophysical abilities, speech perception and working memory capacity. For this purpose data from all the age groups were combined. Many other investigators have used similar approaches (Fostick et al., 2013; Füllgrabe, Moore, & Stone, 2014). Table 4.22 shows the correlation coefficients between psychophysical abilities, speech perception in noise and working measures. From the Table 4.22 it can be seen that working memory measures had significant association with most of the psychophysical measures and speech perception in noise. Strength of the association ranged from moderate to good. Relationship among these measures was further evaluated using structural equation modeling.

Table 4.22.

Result of Pearson product moment correlation between psychophysical abilities, speech perception in noise with various working memory measures

	OS	RS	FD	BD	ASC	DSC	SPIN
FDL (500 Hz)	-.544**	-.496**	-.488**	-.580**	-.546**	-.492**	.433**
FDL (1000 Hz)	-.482**	-.515**	-.388**	-.506**	-.526**	-.466**	.413**
FDL (2000 Hz)	-.417**	-.459**	-.395**	-.494**	-.440**	-.362**	.410**
FDL (4000 Hz)	-.383**	-.334**	-.378**	-.462**	-.460**	-.501**	.358**
IDL (500 Hz)	-.335**	-.350**	-.249**	-.349**	-.397**	-.365**	.296
IDL (1000 Hz)	-.255**	-.324**	-.259**	-.301**	-.341**	-.357**	.368**
IDL (2000Hz)	-.294**	-.268**	-.270**	-.312**	-.315**	-.333**	.359**
IDL (4000 Hz)	-.379**	-.373**	-.270**	-.351**	-.395**	-.349**	.374**
DDT	-.325**	-.246**	-.235**	-.293**	-.307**	-.282**	.232**
GDT	-.283**	-.337**	-.297**	-.269**	-.261**	-.321**	.431*
PS	-.256**	-.363**	-.234**	-.253**	-.321**	-.201**	.490**
BW	.112	.109	.100	.127	.152*	.182**	-.345*
Backward masking	-.350**	-.371**	-.265**	-.344**	-.347**	-.277**	.481**
DPT	.485**	.392**	.371**	.458**	.509**	.463**	-.450**
SPIN	.444**	.523**	.394**	.427**	.444**	.433**	-

Note: *WM- Working Memory, OS- Operation span, RS- Reading span, FD- Forward digit, BD- Backward digit, ASC- Ascending digit, DSC- Descending digit

4.3.1. Structural equation modeling

Relationship among age, working memory measures, psychophysical abilities and speech perception in noise was further assessed through structural equation modeling (SEM). SEM can be viewed as an extension of multiple regression, but it allows us to study the mediation effects among the variables which is not possible in regression. Before performing SEM *a priory* model of relationship among working memory, psychophysical abilities and speech perception in noise was developed. Model shown in Figure 4.22 was based on previous studies and existing theoretical knowledge (Akeroyd, 2008; Grassi &Borella, 2013; Humes et al., 2013). Deleterious effects of age on psychophysical measures (temporal, frequency and intensity) (Abel et al., 1990; Fitzgibbons & Gordon-Salant, 1995; Harris et al., 2007; Humes & Christopherson, 1991; König, 1957; Trainor & Trehub, 1989), working memory capacity (Bopp & Verhaeghen, 2005; Bowles & Salthouse, 2003) and speech perception in noise (Plomp, 1977, 1986; Plomp & Mimpen, 1979; Pronk et al., 2013) are reported by previous investigations. Therefore, it was hypothesized that age will have direct effect on working memory, psychophysical abilities and speech perception in noise. Age can also have indirect effect on working memory and SPIN through psychophysical abilities (Harris et al., 2012; Mukari et al., 2010). A few studies have examined the effect of working memory on speech perception in noise (Gatehouse et al., 2003; Meister et al., 2013; Moore et al., 2014). Based on the results of these studies it was hypothesized that working memory capacity can have a direct influence on speech perception in noise. Furthermore, it was also posited that psychophysical abilities could exert a direct effect on speech perception in noise (Fostick et al., 2013; Henry & Turner, 2003; Summers, Makashay, Theodoroff, & Leek, 2013).

Before conducting SEM it was ensured that data had multivariate normality and met the assumptions homoscedasticity. Multicolinearity was tested by measuring variable inflation factor for all exogenous variables simultaneously. The variable inflation factors were less than 3 for all the variables indicating that predictor variables were highly correlated. Linear relationship between the independent and dependent variables were tested using the test of linearity. Results showed that relationship between predicator variable age and FDL at 500 Hz, DDT, and GDT deviated significantly from linearity. In addition, relationship between SPIN and FDL at 500 Hz, IDL at 4000 Hz, GDT, and reading span scores deviated significantly from linearity. Therefore, these variables were dropped from the measurement model. Kaiser-Mayer-Olkin test for sampling adequacy was sufficiently high (0.9) suggesting that sample size was sufficiently large. Communalities for most of the variables were high (more than 0.5), indicating that variables were correlated for factor analysis. Exploratory factor analysis with maximum likelihood procedure and varimax rotation confirmed our selections of latent variables, in that measured variables grouped together in four factors as factor 1, 2, 3 and 4. It was noted that all FDLs had higher loading in factor 1, IDLs in factor 2, DDT, GDT, PS, BW, backward masking in factor 3 and all working memory measures in factor 4. Thus, based on these loadings, these four factors were further named as frequency, intensity, temporal and working memory to depict in Figure 4.22. Duration pattern scores which were initially treated as temporal processing measure (method section) had higher factor loading to working memory. Hence, duration pattern was considered as one of the measured variable for latent factor working memory. Proposed model also demonstrated excellent convergent validity, as most of the factor loadings were above 0.5 and good discriminate validity, as none of the factor loading exceeded 0.7. All Chronbach's alphas were sufficiently high (more than 0.8) indicating that all latent factors are reflective because their measured variables were highly correlated.

After identifying latent variables we examined their relative contribution to speech perception in noise performance. Figure 4.22 shows the final structural equation model that was evaluated. This model had good convergent validity (tested by calculating average variance explained, which was more than 0.5 for all factors) and discriminant validity (square root of average variance explained was greater than all inter factor correlations). Modification indices as suggested by Amos were consulted to improve the model fit. Several measures of goodness of fit of the final SEM were selected to evaluate the model. Table 4.23 shows the various measures of model fit along with the recommended values for good fit (Hooper, Coughlan, & Mullen, 2008). From Table 4.24 it can be inferred that the final model represented a good fit to the model.

Table 4.23

Model fit indices along with the recommended values.

Measure	Observed value	Recommended value
CMIN/DF	1.8	Between 1 and 3
CFI	0.95	More than 0.9
RMSEA	0.05	Less than 0.06
SRMR	0.05	Less than 0.09

Note: CMIN- Chi^2, CFI – Comparative Fit Index, RMSEA – Root mean square error of approximation, SRMR-Standardized root mean square residual

Figure 4.22 shows final model along with factor loadings that were significant (at 0.05 level). Constructed model accounted for 65% of the variance in speech perception in noise scores and working memory. In Figure 4.22, path coefficients between observed variable and latent factor was removed to avoid cluttering. In Figure 4.22, latent valuables are represented with the oval, observed or measured variables are represented with the rectangle and error terms are represented with the circle. Direction of the arrows in Figure 4.22 represents the flow of causal effects and influence of one variable on another. Standardized path coefficients are represented on the unidirectional arrows. These standardized regression weights indicate the amount of standard deviation that a dependent variable will change, per one standard deviation change in predictor variable. For example, when the age goes up by one standard deviation temporal processing goes down by 0.82 standard deviation. Standardized regression weights less than 0.1 indicates small effects, 0.1 to 0.3 indicate medium effects and more than 0.3 indicates strong effects (Cohen, 1988). Table 4.24 shows standardized regression weights. Table 4.25 and 4.26 shows standardized direct, indirect and total effects of variables on SPIN and working memory capacity respectively.

Table 4.24

Standardized regression weights

			Estimate
Working memory	<---	Age	-0.2
Temporal processing	<---	Age	0.81***
Frequency processing	<---	Age	0.56***
Intensity processing	<---	Age	0.50***
SPIN	<---	Age	-0.01
Working memory	<---	Temporal processing	0.22*
Working memory	<---	Intensity processing	-0.15*
Working memory	<---	Frequency processing	-0.40*
SPIN	<---	Working memory	0.1
SPIN	<---	Temporal	.94***
SPIN	<---	Intensity	-.07
SPIN	<---	Frequency	0.4**

Note: *** p<0.001, *p<0.05

Table 4.25

Standardized direct, indirect and total effects of variables on SPIN

Variable	Direct effect	Indirect effect	Total effect
Age	-0.01	-0.67	-0.68
Working memory	0.1	#	0.1
Temporal processing	0.94	0.02	0.96
Frequency processing	0.36	-0.04	0.32
Intensity processing	0.07	-0.01	-0.09

Note: # indirect effects are not available as influence of these variables on SPIN as assessed only directly and there was no mediation

Table 4.26

Standardized direct, indirect and total effects of variables on working memory

Variable	Direct effect	Indirect effect	Total effect
Age	-0.19	-0.48	-0.67
Temporal processing	0.224	#	0.22
Frequency processing	-0.4	#	-0.4
Intensity processing	0.15	#	-0.15

Note: # indirect effects are not available as influence of these variables on working memory as assessed only directly and there was no mediation

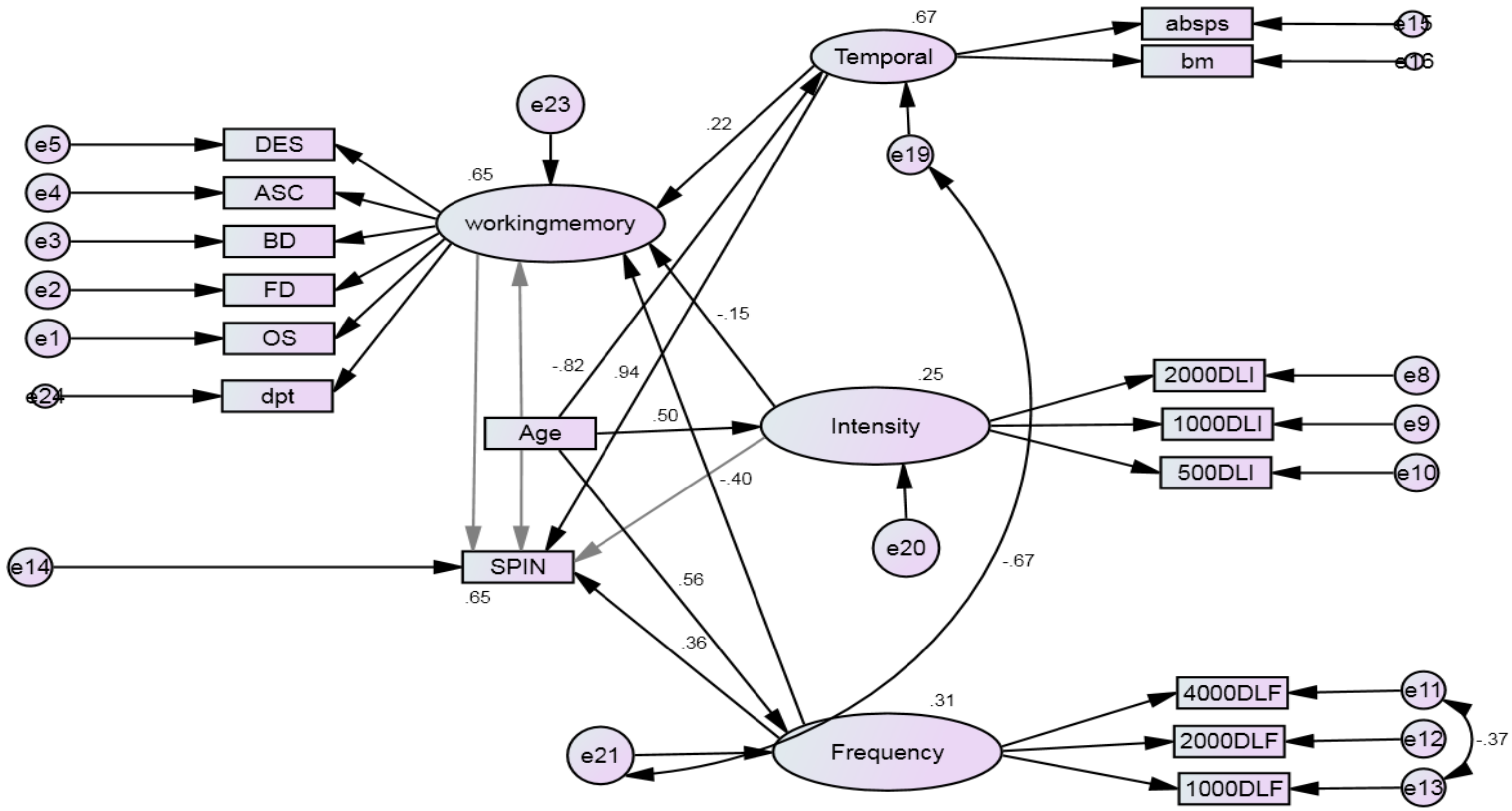


*Figure 4.22.*Final SEM representing the relationship between age, working memory, psychophysical abilities and speech perception in noise. Path coefficients are represented on the unidirectional arrow. Values shown next to endogenous variables represent the total variance accounted for. Non-significant paths are shown in gray arrows and significant paths are depicted in black arrows.
(DES=Descending Digit Span; ASC=Ascending Digit Span; BD=Backward Digit Span; FD: Forward Digit Span; OS=Operation Span; DPT=Duration Pattern Test; ABSPS=Absolute Peak Sensitivity; BM=Backward Masking; DLI=Intensity Difference Limen; DLF=Frequency Difference Limen; SPIN=Speech Perception in Noise)

From Tables 4.24, 4.25 and 4.26 and Figure 4.22 following observations can be made:

- Age is a significant predictor of frequency processing and temporal processing skills. Direct effect of age on speech perception in noise was negligible. However, age had significant indirect effect on speech processing through its effect on temporal and frequency processing skills.
- Direct effect of age on working memory skills was small and negligible. However, age had significant indirect effect on working memory skills through temporal and frequency processing.
- Temporal processing, frequency processing and intensity processing skills significantly affected working memory skills. Relationship was such that better sensory processing skills predicted better working memory capacity. Direct effect of working memory capacity on speech perception in noise was small.
- Among the psychophysical abilities frequency and temporal processing had significant direct effect on speech perception in noise.

Chapter 5

Discussion

The aim of the present study was to assess the effect of age on psychophysical abilities, speech perception in noise and working memory skills across adults' lifespan. The relationship among age, psychophysical abilities, speech perception in noise, and working memory was also studied. The results of the study are discussed below:

5.1. Effect of age on different psychophysical abilities and speech perception in noise.

5.1.1. Frequency and Intensity difference limen. Present study investigated the effect of age on processing of all main three domains of sound: frequency, intensity and duration. Frequency and intensity processing was investigated by measuring just noticeable differences. Results indicated that frequency and intensity resolution as measured by difference limens declined with advancing age. Frequency difference limens (FDLs) measured at all frequencies (500 Hz, 1000 Hz, 2000 Hz and 4000 Hz) declined linearly with age. FDLs for high frequencies deteriorated by 40 years of age while that of low frequencies declined by 50 years of age. However, effect of age on FDL (as measured by $\Delta f/f$) was more pronounced at low frequencies compared to high frequencies (Figure 4.2). Age related decline in intensity difference limen (IDL) of all frequencies started by 50 years of age. Pearson's product moment correlation revealed a significant positive correlation between IDL, FDL and age. Based on these observations null hypothesis 1 stating "there is no significant difference among age groups on frequency discrimination and intensity discrimination" was rejected.

Our results are consistent with previous research (Abel et al., 1990; Grassi & Borella, 2013; He et al., 1998; König, 1957; Moore, Peters, & Glasberg, 1992). Konig (1957) reported that the pitch discrimination deteriorates in a linear manner between the ages of 25 to 55 years, and after 55 years discrimination ability reduces abruptly. This kind of two-legged function between age and FDLs were not evidenced in present study. However, many subjects of Konig (1957) had concomitant age related hearing loss and it is difficult to determine whether the poor FDL are due to hearing loss or ageing. On contrary, Humes (1996) reviewed series of studies wherein he examined the effects of age and hearing loss on intensity discrimination. Older adults performed poorer on intensity discrimination task compared to younger adults with normal hearing sensitivity. However, when the two groups were matched in hearing levels, intensity discrimination did not differ significantly between younger and older subjects (Humes, 1996; Humes & Christopherson, 1991). He et al., (1998) investigated the effect of age on frequency and intensity difference limens at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. Their results showed that older listeners had larger FDL and IDL compared to younger listeners at all frequencies. These age related changes in difference limens were more obvious at 500 Hz compared to high frequencies.

The physiological mechanism responsible for decline in difference limen with ageing is still uncertain. Age related decline in frequency discrimination could be attributed to the changes taking place in the auditory system which could lead to a decline in the neural representation of frequency. Ageing can affect neural synchrony (Mills, Schmiedt, Schulte, & Dubno, 2006), inhibitory neurotransmitters (Caspary, Ling, Turner, & Hughes, 2008), or can also lead to decreased neurons in auditory nuclei (Frisina & Walton, 2006). All these physiological changes might have resulted in poor FDL and IDL in aged individuals. Another interesting observation of the present study was differential effect of frequency on age related decline in FDL. Difference between young and old listeners was always largest at 500 Hz and decreased as frequency increased. It is known that temporal coding which depends on phase locking and neural synchrony is important for pitch processing at low frequency(Moore, 2008). Age related changes in auditory nervous system may cause reduced phase locking and neural synchrony which in turn may lead to poorer FDLs, especially at low frequencies.

5.1.2. Temporal processing abilities across different age groups. In the present study temporal processing skills were assessed using multiple measures. These included duration discrimination thresholds (DDT), gap detection thresholds (GDT), backward masking, modulation detection thresholds (MDT) (at 4, 8, 16, 32, 64, 128 Hz modulation frequencies) and duration pattern scores (DPT). Though duration pattern scores were originally grouped under temporal processing test, factor analysis showed that it had more loading towards working memory and hence the results of duration pattern are discussed under working memory. On all the temporal processing measures age had negative effect and older listeners performed poorly compared to young adults. Age related decline in majority of the temporal processing skills begun by 50 years of age. Only exceptions were GDT and DDT. GDT deteriorated by 70 years of age whereas no clear trend between age and DDT was evident. Based on these observations null hypothesis 2 stating “there is no significant difference among age groups on temporal processing skills” was rejected.

By and large, trend and data obtained in current investigation is consistent with previous studies on effect of age on temporal processing (Fitzgibbons & Gordon-Salant, 1994; Gehr & Sommers, 1999; Harris et al., 2010; He et al., 2008; Humes & Coughlin, 2009; Jin, Liu, & Sladen, 2014; John, Hall, & Kreisman, 2012; Kumar & Sangamanatha, 2011; Palmer & Musiek, 2014; Schneider, & Pichora-

Fuller, 2000; Snell, 1997; Snell & Frisina, 2000; Strouse, 1998). Grassi and Borella (2013) assessed various temporal processing skills in young adults, young-old (64-75 years) and old-old (more than 75 years) participants. Temporal processing measures assessed were, GDT, MDT and DDT. Results indicated that two groups of older adults performed worse than young adults. Humes and colleagues in series of studies have assessed the impact of age on variety of temporal processing skills (Humes, 2002; Humes et al., 2007; Humes & Coughlin, 2009; Humes & Christopherson, 1991). Collectively their results indicated that age had significant negative impact on GDT, monoaural and binaural temporal order identification, MDT and modulation detection interference tasks. He et al. (2008) assessed the effect of age on MDT as a function of modulation frequency in young and old listeners for pure tone carriers. Older listeners MDT were significantly poorer compared to younger listeners especially at high modulation frequencies. On a similar line even in the current study, we observed narrower bandwidth of temporal modulation transfer functions (TMTF) in older individuals. Narrower bandwidth of TMTF indicates the age related decline in sensitivity to faster envelope fluctuations. Even though previous literature has shown strong effect of ageing on different psychophysical tasks, none of the previous studies have assessed the same participant with multiple temporal measures. Moreover, barring a few, most of the previous studies have evaluated temporal processing abilities in old and young participants and not across the continuum of ages (Fitzgibbons & Gordon-Salant, 1994; Gehr & Sommers, 1999; Harris et al., 2010; He et al., 2008; Humes & Coughlin, 2009; Jin et al., 2014; John et al., 2012; Palmer & Musiek, 2014; Schneider, & Pichora-Fuller, 2000; Snell, 1997; Snell & Frisina, 2000; Strouse, 1998). Kumar and Sangamanatha (2011) assessed MDT, GDT, DDT and DPT in individuals ranging from 20 years to 85 years. Except for duration pattern all other temporal processing skills showed age related decline by 4th decade. Whereas, duration pattern scores declined by 6th decade.

Although there is an apparent age related changes on all measure of temporal processing tested, underlying physiological basis for these remains unclear and it could be due to both peripheral and central auditory mechanism. For example, theories of temporal processing presume that central timing mechanisms code duration by summing the neural firings which are extracted through stimulation. These models have successfully explained the empirical data available on duration discrimination of young trained participants (Abel, 1972; Creelman, 1962; Divenyi et al., 2005). According to this theory, the precision of counting would depend also on the accuracy of sensory coding the stimulus onsets and offsets. Thus, the observed decline in DDT and/or GDT for older participants could be a due to the diminished central processing components or due to poorer peripheral coding of stimulus onsets and offsets. This could be a consequence of decline in synchronous response of auditory nerve fibers. These peripheral auditory effects can explain the age related deficits in DDT and GDT.

Walton and colleagues (Walton, Simon, & Frisina, 2002; Walton, Frisina, & O'Neill, 1998) measured the neural correlates of age related decline in the temporal processing. They measured recordings of inferior colliculus neurons from central auditory pathway in young and old cytometric bead array mice. Three types of age related effects in neural processing of gaps were mainly observed – reduction in number of gap sensitive neurons, longer and less efficient recovery after stimulation and alteration of neuronal maps representing best frequency. Walton et al. (2002) recorded single unit responses from inferior colliculus for sinusoidally amplitude modulated noise carriers at 10 to 800 Hz modulation frequencies in young and aged mice. They observed significant age related decline in the synchrony to fast rate envelope modulations which is consistent with the trend observed in the current study.

Overton and Recanzone (2016) studied the age related changes in the firing rate and phase locking of neurons in primary auditory cortex of macaque monkeys using amplitude modulated noise. They observed that in young monkeys both firing rate and temporal code (phase locking) constructively coded amplitude modulation while in older monkeys there was a disassociation between these two codes. In addition, old monkeys had fewer neurons that synchronized with the amplitude modulated stimulus. Poor modulation detection thresholds as indicated by peak sensitivity and bandwidth of temporal modulation transfer function may be attributed to decline in the synchronization of neural responses with ageing for both the carrier waveform and envelope fluctuation. Furthermore, Mendelson and Ricketts (2001) reported that the most of the auditory cortex neurons in young rats respond robustly to the faster frequency modulation. However, in older rats most of the neurons respond robustly to slower modulation frequencies. Thus, it can be concluded that decline in temporal processing abilities with ageing could be due to the changes in the neurons of midbrain and auditory cortex.

5.1.3. Speech perception in noise across different age groups. Speech perception in noise (SPIN) scores deteriorated with increase in age with best scores seen in the age range of 20-29.11 years. Statistically significant deterioration in SPIN performance was evident by 4^{th}decade. Based on these observations null hypothesis 3 stating "there is no significant difference among age groups on speech perception in noise" was rejected.

Pattern of age related decline in SPIN observed in present investigation is in consensus with the previous literature (E.g.: CHABA, 1988; Plomp, 1977; Plomp, 1986; Plomp & Mimpen, 1979). SPIN is a complex behavior and is influenced by multiple factors. CHABA (1988) proposed three main factors explaining the poor SPIN in older adults: (1) peripheral, which focused on cochlear damage resulting in impaired audibility and suprathreshold processing skills, (2) central auditory, which included damage to auditory brainstem and cortical structures and (3) cognitive, which involved age related degeneration in non auditory areas responsible for linguistic and cognitive process. Furthermore, these three factors are not mutually exclusive. Any or all of them may be present in a given individual and interact in a complex fashion. Complex interplay among speech in noise, psychophysical abilities (peripheral and central) and cognitive factors were assessed using correlations and structural equation modeling and results of these analyses are discussed in section 5.3.

5.2. Working memory across different age groups.

Results of the present study showed that both operation span (OS) and reading span (RS) scores deteriorated with age. OS scores deteriorated significantly after 50 years of age and RS scores reduced after 60 years of age. Also, auditory sequencing and digit span measures (forward, backward, ascending and descending digit span) and duration pattern scores reduced with age and 20-29.11 years age group performed significantly better than other age groups in majority of the measures. Based on these observations null hypothesis 4 stating “there is no significant difference among age groups in working memory” was rejected.

Similar results have been reported in the past, wherein reading span task show a robust age-difference (Babcock & Salthouse, 1990; Bopp & Verhaeghen, 2005). Age related deterioration in working memory skills are explained by many theories of cognitive ageing. In fact, age related decline in working memory is thought to be primary factor responsible for age related declines observed in wide variety of tasks involving fluid cognition (Baddeley, 1986; Engle, Kane, & Tuholski, 1999; Kane, Bleckley, Conway, & Engle, 2001; Miyake et al., 2000). Many cognitive ageing theories predict that ageing reduces the cognitive resources available for processing. As working memory demands processing of stored information, it will be adversely affected by ageing (e.g., Belleville, Rouleau, & Caza, 1998; Craik, Morris, & Gick, 1990; Dobbs & Rule, 1989; Foos, 1989; Light, Zelinski, & Moore, 1982; Salthouse, Babcock, & Shaw, 1991). Thus, age deficits in complex working memory tasks such as operation and reading span tasks mainly reveal a decline in executive control abilities of the subject and not due to the decline in storage capacity.

Brain imaging studies have shown that there is a decline in grey matter volume in prefrontal cortex of older subjects, changes in neuronal concentration, metabolic activity, and neurochemical modulation, mainly by the neurotransmitter dopamine (Raz, 2000) is associated with cognitive impairments (Gunning-Dixon & Raz, 2003; Raz, Gunning-Dixon, Head, Dupuis, & Acker, 1998). Studies on neurochemical markers have shown that dopamine receptor binding can explain the age related decline in cognitive tasks (Backman, & Farde, 2004).

5.3. Relationship among age, working memory, speech perception in noise and psychophysical abilities.

Relationship among age, working memory, psychophysical abilities and speech perception in noise was assessed using correlations and structural equation modeling. Correlation analysis revealed (i) significant association between age and all the variables (psychophysical, speech perception in noise and working memory) tested. In general, older individuals exhibited poorer scores on all tests compared to young adults. (ii) significant association between psychophysical and speech perception tests with the working memory measures. Individuals with higher working memory capacity showed better performance on psychophysical and speech perception tests. But correlation analyses cannot reveal cause and effect relationship and also mediating effects of independent variables. Therefore, structural equation modeling was employed to further probe into the relationship between dependent and independent variables. Model proposed in Figure 4.22 is simplified and depicted in Figure 5.1.

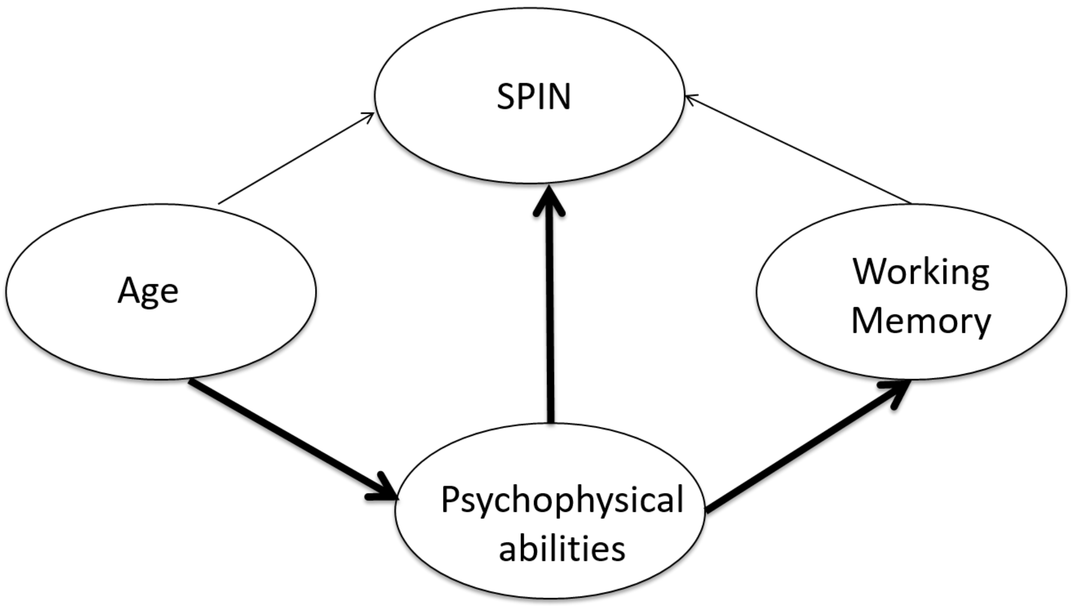


*Figure 5.1.*Relationship between different variables tested. Thickness of the line indicates the strength of the relationship between variables.

Important observations from this analysis were:

(i) Effect of age on working memory capacity was mediated through temporal and frequency processing.

(ii) Direct effect of age on speech perception in noise was negligible. However, age had significant indirect effect on speech processing through its effect on temporal and frequency processing skills.

(iii) Temporal processing, frequency processing and intensity processing skills significantly affected working memory skills. Relationship was such that better sensory processing skills predicted better working memory capacity. Direct effect of working memory capacity on speech perception in noise was small.

(iv) Among the psychophysical abilities frequency and temporal processing had significant direct effect on speech perception in noise.

Correlational analyses showed that age had significant negative correlation with working memory measures. But as noted above, this effect was primarily mediated through temporal and frequency processing skills. Regression weights for psychophysical measures were higher (0.4 and 0.22) compared to that of age (0.1) in predicting working memory. Based on these observations null hypothesis 5 stating "there is no significant relationship among age, working memory, speech perception in noise and psychophysical abilities" was rejected.

Other investigators report similar results too (Akeroyd, 2008; Grassi & Borella, 2013; Humes et al., 2013). Humes et al. (2013) investigated the relationship between sensory functions and cognitive functions in 245 (18-80 years) individuals. Sensory functions were assessed across hearing, vision and touch by measuring threshold sensitivity, gap detection thresholds, temporal order identification and temporal masking. Cognitive measures were assessed using Wechsler's adult intelligent scale. Results indicated that age, sensory processing and cognitive functions were significantly correlated. However, partial correlations and structural equation modeling revealed that relationship between age and cognitive processing reduced and became insignificant when effect of sensory processing was controlled. Garssi and Borella (2013) investigated the auditory and cognitive abilities in young and old participants. Auditory abilities were investigated using gap detection thresholds, modulation detection thresholds, intensity discrimination, frequency discrimination and duration discrimination. Cognitive abilities were assessed using reading span task. Results showed that both cognitive and auditory abilities deteriorated with old age. Auditory abilities specifically, frequency, intensity, duration, modulation and spectral shape discrimination abilities had significant impact on cognitive processing.

Schneider and Pichora- Fuller (2000) summarized the association between cognitive and sensory decline with ageing as a) the sensory deprivation hypothesis b) information degradation hypothesis c) cognitive load on perception hypothesis and d) common cause hypothesis. First two hypotheses predict that cognitive decline is preceded by sensory decline, while the third hypothesis predicts the reverse. Common cause hypothesis suggests that there is a common underlying factor responsible for decline in cognition and sensory skills with the advancing age. Data from this research suggest that auditory abilities have significant impact on cognitive functions. This link is consistent with the sensory deprivation and information degradation hypothesis. According to this poor sensory input or degraded information is responsible for cognitive ageing. With ageing all psychophysical abilities deteriorated resulting in sensory deprivation as well as information degradation which in turn had a negative impact on cognitive performance.

Another important observation in the current study was significant association between psychophysical abilities and SPIN. Strength and the direction of association seen were comparable to previous investigations (Fostick et al., 2013; Henry & Turner, 2003; Summers, Makashay, Theodoroff, & Leek, 2013). Surprisingly, in structural equation modeling psychophysical abilities emerged as single largest factor predicting SPIN. Working memory measures failed to show any significant impact on SPIN when psychophysical measures were included in the model. These results are consistent with the some of the earlier findings (Humes et al., 1994; Kidd, Watson, & Gygi, 2007; Sheft, Shafiro, Wang, Barnes, & Shah, 2015; van Rooij, Plomp, & Orlebeke, 1989). Sheft et al.(2015) assessed the relationship between SPIN, cognitive functions and psychophysical measures in older adults. SPIN was assessed using QuickSIN, cognitive functions were assessed using a battery of 12 tests and psychophysical measures were assessed using spectral pattern discrimination. Their results failed to show any significant association between working memory and SPIN. In contrast, other studies have reported a significant impact of working memory on SPIN (Akeroyd, 2008; Desjardins & Doherty, 2013; Gatehouse et al., 2003; Zekveld, Rudner, Johnsrude, & Rönnberg, 2013). These differences between results of current study and others at least in part may be attributable to methodological differences such as type of speech material used, working memory measures assessed, and use of amplification devices. A common finding among the many of the studies cited above and ours is strong association between auditory measures and SPIN. Psychophysical skills were significant predictor of SPIN.

In conclusion, results of the present study indicated that SPIN, working memory skills and psychophysical abilities deteriorated with age. However, psychophysical skills mediated the effect of age on working memory and SPIN. Significant proportion of age related variance in working memory could be explained by psychophysical abilities.

Chapter 6

Summary and Conclusions

The present study investigated the effect of age on psychophysical abilities, speech perception in noise and working memory skills across adult lifespan. The study also assessed the relationship among age, psychophysical abilities, speech perception in noise, and working memory.

A total of 210 participants participated in the study and they were divided into seven cross-sectional age groups from 10 years to 85 years. Each group consisted of 30 participants. Psychophysical abilities, speech perception in noise and working memory were assessed on each participant. Psychophysical abilities were assessed through frequency difference limen (FDL), intensity difference limen (IDL), duration discrimination test (DDT), gap detection test (GDT), peak sensitivity (PS) and bandwidth (BW) of modulation detection thresholds (MDT), duration pattern test (DPT) and backward masking. Speech perception in noise (SPIN) was assessed through quick speech perception in noise test in Kannada. Working memory assessment was done through operation span test, reading span test and various auditory working measures (forward, backward, ascending and descending digit span).

The results showed that the younger participants performed significantly better in psychophysical measures, speech perception in noise and working memory measures. The decline in processing abilities started by 4^{th} decade for FDL (1000, 2000 & 4000 Hz) and SPIN. FDL (500 Hz), IDL (500, 1000 & 4000 Hz), MDT, DPT, backward masking abilities and operation span started to deteriorate by 5^{th} decade of life. Decline in GDT started only by 7^{th} decade. The Pearson's product moment correlation showed that working memory measures had significant relationship with most of the psychophysical measures and speech perception in noise. Individuals with higher working memory capacity showed better performance on psychophysical and speech perception tests. Relationship between different working memory measures, psychophysical abilities and speech perception in noise was also assessed through structural equation modeling (SEM). SEM revealed that direct effect of age on speech perception in noise was negligible. However, age had significant indirect effect on speech processing through its effect on temporal and frequency processing skills. Significant proportion of age related variance in working memory could be explained by psychophysical abilities.

6.1. Implications of the Study

- The study contributed to identify age related changes in psychophysical abilities, speech perception in noise and working memory. It helped to determine that all psychophysical skills do not decline to the same degree with age. GDT was more resistant to the effects of ageing than others.
- The present study also helped in determining normative for each test of psychophysical ability, speech perception in noise and working memory measures across age groups.
- Study helped to un-entangle the complex relationship between age, cognition and auditory abilities. Most important finding from the study was that of revealing the influence of supra threshold auditory abilities on working memory and speech perception skills. Age related decline in psychophysical skills seems to mediate the age related decline in working memory and speech perception in noise abilities. This can open-up a wide range of applications including change of rehabilitation strategies in older adults.

6.2. Future Directions

- Older individuals had slightly higher hearing thresholds at 4000 Hz and 8000 Hz. Possible effects of these elevated thresholds on psychophysical and SPIN are not tested.
- It would be interesting to replicate this study using a longitudinal design. This will help in delineating the possible sequential effects and interactions between auditory and cognitive factors.
- Study could be extended to other senses such as touch and vision in order to get more holistic relationship between global sensory and cognitive factors. On the similar lines influence of sensory processing on other cognitive measures such as processing speed, inhibition and general intelligence could also be investigated.

References

Abel, S. M. (1972). Duration Discrimination of Noise and Tone Bursts.*The Journal of the Acoustical Society of America*, *51*(4B), 1219. http://doi.org/10.1121/1.1912963

Abel, S. M., Krever, E. M., & Alberti, P. W. (1990). Auditory detection, discrimination and speech processing in ageing, noise-sensitive and hearing-impaired listeners.*Scandinavian Audiology*, *19*(1), 43–54.

Akeroyd, M. A. (2008). Are individual differences in speech reception related to individual differences in cognitive ability? A survey of twenty experimental studies with normal and hearing-impaired adults.*International Journal of Audiology*, *47 Suppl 2*, S53–71. http://doi.org/10.1080/14992020802301142

ANSI, S. . (1999). *Maximum permissiable ambient noise levels for audiometric test rooms. American National Standards Institute, S3.1*. New York: American National Standards Institute.

Babcock, R. L., & Salthouse, T. A. (1990). Effects of increased processing demands on age differences in working memory. *Psychology and Aging*, *5*(3), 421–428.

Backman, L., & Farde, L. (2004). The role of dopamine systems in cognitive aging. In *Cognitive Neuroscience of Aging: Linking Cognitive and Cerebral Aging*. New York: Oxford University Press.

Bacon, S. P., & Gleitman, R. M. (1992). Modulation detection in subjects with relatively flat hearing losses. *Journal of Speech and Hearing Research*, *35*(3), 642–653.

Bacon, S. P., & Opie, J. M. (2002). Modulation detection interference in listeners with normal and impaired hearing.*Journal of Speech, Language, and Hearing Research: JSLHR*, *45*(2), 392–402.

Bacon, S. P., & Viemeister, N. F. (1985). Temporal modulation transfer functions in normal-hearing and hearing-impaired listeners. *Audiology: Official Organ of the International Society of Audiology*, *24*(2), 117–134.

Baddeley, A. (1986). *Working memory*. Oxford [Oxfordshire] : New York: Clarendon Press ; Oxford University Press.

Baddeley, A., & Hitch, G. (1974). Working memory. In *The psychology of learning and motivation: Advances in research and theory* (Vol. 8, pp. 47–89). New York: Academic Press.

Basavraj, V., & Venkatsan, S. (2009).Ethical guidelines for bio-behavioral research involving human subjects. All Insia Institute of Speech and Hearing, Mysore. Retrieved from http://www.aiishmysore.in/en/pdf/ethical_guidelines.pdf

Belleville, S., Rouleau, N., & Caza, N. (1998).Effect of normal aging on the manipulation of information in working memory.*Memory & Cognition*, *26*(3), 572–583. http://doi.org/10.3758/BF03201163

Besser, J., Festen, J. M., Goverts, S. T., Kramer, S. E., & Pichora-Fuller, M. K. (2015). Speech-in-speech listening on the LiSN-S test by older adults with good audiograms depends on cognition and hearing acuity at high frequencies. *Ear and Hearing*, *36*(1), 24–41. http://doi.org/10.1097/AUD.0000000000000096

Best, V., Gallun, F. J., Mason, C. R., Kidd, G., & Shinn-Cunningham, B. G. (2010). The impact of noise and hearing loss on the processing of simultaneous sentences.*Ear and Hearing*, *31*(2), 213–220. http://doi.org/10.1097/AUD.0b013e3181c34ba6

Bopp, K. L., & Verhaeghen, P. (2005). Aging and verbal memory span: a meta-analysis. *The Journals of Gerontology.Series B, Psychological Sciences and Social Sciences*, *60*(5), P223–233.

Bowles, R. P., & Salthouse, T. A. (2003). Assessing the age-related effects of proactive interference on working memory tasks using the Rasch model. *Psychology and Aging*, *18*(3), 608–615. http://doi.org/10.1037/0882-7974.18.3.608

Bregman, A. S., & Campbell, J. (1971).Primary auditory stream segregation and perception of order in rapid sequences of tones.*Journal of Experimental Psychology*, *89*(2), 244–249.

Buss, E., Hall, J. W., Grose, J. H., & Dev, M. B. (1999). Development of adult-like performance in backward, simultaneous, and forward masking.*Journal of Speech, Language, and Hearing Research: JSLHR*, *42*(4), 844–849.

Buus, S., Florentine, M., & Redden, R. B. (1982a). Review·Revue: The SISI Test: A Review Part I. *International Journal of Audiology*, *21*(4), 273–293. http://doi.org/10.3109/00206098209072744

Buus, S., Florentine, M., & Redden, R. B. (1982b). The SISI test: a review. Part II. *Audiology: Official Organ of the International Society of Audiology*, *21*(5), 365–385.

Carhart, R., & Jerger, J. F. (1959). Preferred Method For Clinical Determination Of Pure-Tone Thresholds. *Journal of Speech and Hearing Disorders*, *24*(4), 330. http://doi.org/10.1044/jshd.2404.330

Caspary, D. M., Ling, L., Turner, J. G., & Hughes, L. F. (2008). Inhibitory neurotransmission, plasticity and aging in the mammalian central auditory system.*Journal of Experimental Biology*, *211*(11), 1781–1791. http://doi.org/10.1242/jeb.013581

CHABA. (1988). Speech understanding and aging. Working Group on Speech Understanding and Aging. Committee on Hearing, Bioacoustics, and Biomechanics, Commission on Behavioral and Social Sciences and Education, National Research Council.*The Journal of the Acoustical Society of America*, *83*(3), 859–895.

Chisolm, T. H., Willott, J. F., & Lister, J. J. (2003). The aging auditory system: anatomic and physiologic changes and implications for rehabilitation. *International Journal of Audiology, 42 Suppl 2,* 2S3–10.

Clinard, C. G., Tremblay, K. L., & Krishnan, A. R. (2010). Aging alters the perception and physiological representation of frequency: evidence from human frequency-following response recordings. *Hearing Research*, *264*(1-2), 48–55. http://doi.org/10.1016/j.heares.2009.11.010

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review*, *12*(5), 769–786.

Corso, J. F. (1963). Age and sex differences in pure-tone thresholds.Survey of hearing levels from 18 to 65 years.*Archives of Otolaryngology (Chicago, Ill.: 1960)*, *77*, 385–405.

Craik, F. I. M., Morris, R. G., & Gick, M. L. (1990). Adult age differences in working memory.In *Neuropsychological impairments of short-term memory* (pp. 247–267). Cambridge, UK: Cambridge University Press.

Creelman, C. D. (1962). Human Discrimination of Auditory Duration.*The Journal of the Acoustical Society of America*, *34*(5), 582. http://doi.org/10.1121/1.1918172

Desjardins, J. L., & Doherty, K. A. (2013). Age-related changes in listening effort for various types of masker noises.*Ear and Hearing*, *34*(3), 261–272. http://doi.org/10.1097/AUD.0b013e31826d0ba4

Desloge, J. G., Reed, C. M., Braida, L. D., Perez, Z. D., & Delhorne, L. A. (2011). Temporal modulation transfer functions for listeners with real and simulated hearing loss. *The Journal of the Acoustical Society of America*, *129*(6), 3884–3896. http://doi.org/10.1121/1.3583550

Divenyi, P. L., Stark, P. B., & Haupt, K. M. (2005). Decline of speech understanding and auditory thresholds in the elderly.*The Journal of the Acoustical Society of America*, *118*(2), 1089–1100.

Dobbs, A. R., & Rule, B. G. (1989). Adult age differences in working memory.*Psychology and Aging*, *4*(4), 500–503. http://doi.org/10.1037/0882-7974.4.4.500

Dreschler, W. A., & Plomp, R. (1985).Relations between psychophysical data and speech perception for hearing-impaired subjects. II. *The Journal of the Acoustical Society of America*, *78*(4), 1261. http://doi.org/10.1121/1.392895

Dubno, J. R., Horwitz, A. R., & Ahlstrom, J. B. (2002). Benefit of modulated maskers for speech recognition by younger and older adults with normal hearing. *The Journal of the Acoustical Society of America*, *111*(6), 2897. http://doi.org/10.1121/1.1480421

Dubno, J. R., Horwitz, A. R., & Ahlstrom, J. B. (2003). Recovery from prior stimulation: Masking of speech by interrupted noise for younger and older adults with normal hearing. *The Journal of the Acoustical Society of America*, *113*(4), 2084. http://doi.org/10.1121/1.1555611

Dubno, J. R., Lee, F.-S., Matthews, L. J., & Mills, J. H. (1997). Age-Related and Gender-Related Changes in Monaural Speech Recognition.*Journal of Speech Language and Hearing Research*, *40*(2), 444. http://doi.org/10.1044/jslhr.4002.444

Duquesnoy, A. J., & Plomp, R. (1980). Effect of reverberation and noise on the intelligibility of sentences in cases of presbyacusis.*The Journal of the Acoustical Society of America*, *68*(2), 537–544.

Eddins, D. A. (1993). Amplitude modulation detection of narrow-band noise: Effects of absolute bandwidth and frequency region. *The Journal of the Acoustical Society of America*, *93*(1), 470. http://doi.org/10.1121/1.405627

Eddins, D. A., & Green, D. M. (1995). Temporal integration and temporal resolution.In *Hearing* (pp. 207–242). San Diego: Academic Press.

Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 102–134). New York: Cambridge University Press.

Finney, D. J. (1978).*Statistical method in biological assay* (3. ed). London: Griffin.

Fitzgibbons, P. J., & Gordon-Salant, S. (1994). Age effects on measures of auditory duration discrimination. *Journal of Speech and Hearing Research*, *37*(3), 662–670.

Fitzgibbons, P. J., & Gordon-Salant, S. (1995). Age effects on duration discrimination with simple and complex stimuli. *The Journal of the Acoustical Society of America*, *98*(6), 3140–3145.

Fitzgibbons, P. J., & Gordon-Salant, S. (1998). Auditory temporal order perception in younger and older adults.*Journal of Speech, Language, and Hearing Research: JSLHR*, *41*(5), 1052–1060.

Fitzgibbons, P. J., & Wightman, F. L. (1982). Gap detection in normal and hearing-impaired listeners.*The Journal of the Acoustical Society of America*, *72*(3), 761–765.

Florentine, M., Buus, S., & Mason, C. R. (1987). Level discrimination as a function of level for tones from 0.25 to 16 kHz.*The Journal of the Acoustical Society of America*, *81*(5), 1528–1541.

Florentine, M., Reed, C. M., Rabinowitz, W. M., Braida, L. D., Durlach, N. I., & Buus, S. (1993). Intensity perception. XIV. Intensity discrimination in listeners with sensorineural hearing loss. *The Journal of the Acoustical Society of America*, *94*(5), 2575–2586.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). “Mini-mental state”.A practical method for grading the cognitive state of patients for the clinician.*Journal of Psychiatric Research*, *12*(3), 189–198.

Foos, P. W. (1989). Adult age differences in working memory.*Psychology and Aging*, *4*(3), 269–275. http://doi.org/10.1037/0882-7974.4.3.269

Formby, C., & Muir, K. (1988). Modulation and gap detection for broadband and filtered noise signals.*The Journal of the Acoustical Society of America*, *84*(2), 545–550.

Forrest, T. G., & Green, D. M. (1987). Detection of partially filled gaps in noise and the temporal modulation transfer function. *The Journal of the Acoustical Society of America*, *82*(6), 1933–1943.

Foster, J. R., & Haggard, M. P. (1987). The four alternative auditory feature test (FAAF)--linguistic and psychometric properties of the material with normative data in noise.*British Journal of Audiology*, *21*(3), 165–174.

Fostick, L., Ben-Artzi, E., & Babkoff, H. (2013). Aging and speech perception: beyond hearing threshold and cognitive ability. *Journal of Basic and Clinical Physiology and Pharmacology*, *24*(3), 175–183. http://doi.org/10.1515/jbcpp-2013-0048

Francis, A. L., & Nusbaum, H. C. (2009). Effects of intelligibility on working memory demand for speech perception.*Attention, Perception & Psychophysics*, *71*(6), 1360–1374. http://doi.org/10.3758/APP.71.6.1360

Freyman, R. L., & Nelson, D. A. (1991). Frequency discrimination as a function of signal frequency and level in normal-hearing and hearing-impaired listeners.*Journal of Speech and Hearing Research*, *34*(6), 1371–1386.

Frisina, D. R., & Frisina, R. D. (1997). Speech recognition in noise and presbycusis: relations to possible neural mechanisms. *Hearing Research*, *106*(1-2), 95–104.

Frisina, R. D., & Walton, J. P. (2006). Age-related structural and functional changes in the cochlear nucleus.*Hearing Research*, *216-217*, 216–223. http://doi.org/10.1016/j.heares.2006.02.003

Füllgrabe, C., Moore, B. C. J., & Stone, M. A. (2014). Age-group differences in speech identification despite matched audiometrically normal hearing: contributions from auditory temporal processing and cognition. *Frontiers in Aging Neuroscience*, *6*, 347. http://doi.org/10.3389/fnagi.2014.00347

Gatehouse, S., Naylor, G., & Elberling, C. (2003). Benefits from hearing aids in relation to the interaction between the user and the environment. *International Journal of Audiology*, *42 Suppl 1*, S77–85.

Gehr, S. E., & Sommers, M. S. (1999a). Age differences in backward masking. *The Journal of the Acoustical Society of America*, *106*(5), 2793. http://doi.org/10.1121/1.428104

Gehr, S. E., & Sommers, M. S. (1999b). Age differences in backward masking. *The Journal of the Acoustical Society of America*, *106*(5), 2793–2799.

Gelfand, S. A. (2009).*Hearing: an introduction to psychological and physiological acoustics* (5. ed). New York: Informa Healthcare.

Gifford, R. H., Bacon, S. P., & Williams, E. J. (2007). An examination of speech recognition in a modulated background and of forward masking in younger and older listeners.*Journal of Speech, Language, and Hearing Research: JSLHR*, *50*(4), 857–864. http://doi.org/10.1044/1092-4388(2007/060)

Grassi, M., & Borella, E. (2013).The role of auditory abilities in basic mechanisms of cognition in older adults.*Frontiers in Aging Neuroscience*, *5*. http://doi.org/10.3389/fnagi.2013.00059

Grassi, M., & Soranzo, A. (2009). MLP: a MATLAB toolbox for rapid and reliable auditory threshold estimation. *Behavior Research Methods*, *41*(1), 20–28. http://doi.org/10.3758/BRM.41.1.20

Green, D. M. (1990).Stimulus selection in adaptive psychophysical procedures.*The Journal of the Acoustical Society of America*, *87*(6), 2662–2674.

Green, D. M. (1993).A maximum-likelihood method for estimating thresholds in a yes-no task.*The Journal of the Acoustical Society of America*, *93*(4 Pt 1), 2096–2105.

Gunning-Dixon, F. M., & Raz, N. (2003). Neuroanatomical correlates of selected executive functions in middle-aged and older adults: a prospective MRI study. *Neuropsychologia*, *41*(14), 1929–1941.

Hall, J. W., & Grose, J. H. (1994). Development of temporal resolution in children as measured by the temporal modulation transfer function. *The Journal of the Acoustical Society of America*, *96*(1), 150–154.

Hall, J. W., & Wood, E. J. (1984). Stimulus duration and frequency discrimination for normal-hearing and hearing-impaired subjects.*Journal of Speech and Hearing Research*, *27*(2), 252–256.

Harris, J. D. (1952). Pitch Discrimination. *The Journal of the Acoustical Society of America*, *24*(6), 750. http://doi.org/10.1121/1.1906970

Harris, K. C., Eckert, M. A., Ahlstrom, J. B., & Dubno, J. R. (2010). Age-related differences in gap detection: effects of task difficulty and cognitive ability. *Hearing Research*, *264*(1-2), 21–29. http://doi.org/10.1016/j.heares.2009.09.017

Harris, K. C., Mills, J. H., & Dubno, J. R. (2007). Electrophysiologic correlates of intensity discrimination in cortical evoked potentials of younger and older adults. *Hearing Research*, *228*(1-2), 58–68. http://doi.org/10.1016/j.heares.2007.01.021

Harris, K. C., Wilson, S., Eckert, M. A., & Dubno, J. R. (2012). Human evoked cortical activity to silent gaps in noise: effects of age, attention, and cortical processing speed. *Ear and Hearing*, *33*(3), 330–339. http://doi.org/10.1097/AUD.0b013e31823fb585

He, N., Dubno, J. R., & Mills, J. H. (1998). Frequency and intensity discrimination measured in a maximum-likelihood procedure from young and aged normal-hearing subjects. *The Journal of the Acoustical Society of America*, *103*(1), 553–565.

He, N., Mills, J. H., Ahlstrom, J. B., & Dubno, J. R. (2008). Age-related differences in the temporal modulation transfer function with pure-tone carriers. *The Journal of the Acoustical Society of America*, *124*(6), 3841–3849. http://doi.org/10.1121/1.2998779

He, N., Mills, J. H., & Dubno, J. R. (2007). Frequency modulation detection: effects of age, psychophysical method, and modulation waveform. *The Journal of the Acoustical Society of America*, *122*(1), 467–477. http://doi.org/10.1121/1.2741208

Henning, G. B. (1966). Frequency Discrimination of Random-Amplitude Tones.*The Journal of the Acoustical Society of America*, *39*(2), 336. http://doi.org/10.1121/1.1909894

Henry, B. A., & Turner, C. W. (2003). The resolution of complex spectral patterns by cochlear implant and normal-hearing listeners.*The Journal of the Acoustical Society of America*, *113*(5), 2861–2873.

Hester, R. L., Kinsella, G. J., & Ong, B. (2004). Effect of age on forward and backward span tasks.*Journal of the International Neuropsychological Society*, *10*(4), 475–481. http://doi.org/10.1017/S1355617704104037

Hooper, D., Coughlan, J., & Mullen, M. R. (2008). Structural Equation Modelling: Guidelines for Determining Model Fit. *The Electronic Journal of Business Research Methods*, *6*(1), 53–60. Retrieved from www.ejbrm.com

Houtsma, A. J. M. (1995). Pitch perception in hearing. In *Handbook of Perception and Cognition* (2nd Edition, pp. 267–295). San Diego, CA: Academic Press.

Howarth, A., & Shone, G. R. (2006). Ageing and the auditory system.*Postgraduate Medical Journal*, *82*(965), 166–171. http://doi.org/10.1136/pgmj.2005.039388

Humes, L. E. (1996). Speech understanding in the elderly.*Journal of the American Academy of Audiology*, *7*(3), 161–167.

Humes, L. E. (2002). Factors underlying the speech-recognition performance of elderly hearing-aid wearers.*The Journal of the Acoustical Society of America*, *112*(3), 1112. http://doi.org/10.1121/1.1499132

Humes, L. E., Burk, M. H., Coughlin, M. P., Busey, T. A., & Strauser, L. E. (2007). Auditory speech recognition and visual text recognition in younger and older adults: similarities and differences between modalities and the effects of presentation rate. *Journal of Speech, Language, and Hearing Research: JSLHR*, *50*(2), 283–303. http://doi.org/10.1044/1092-4388(2007/021)

Humes, L. E., Busey, T. A., Craig, J., & Kewley-Port, D. (2013). Are age-related changes in cognitive function driven by age-related changes in sensory processing? *Attention, Perception & Psychophysics*, *75*(3), 508–524. http://doi.org/10.3758/s13414-012-0406-9

Humes, L. E., & Christopherson, L. (1991). Speech identification difficulties of hearing-impaired elderly persons: the contributions of auditory processing deficits. *Journal of Speech and Hearing Research*, *34*(3), 686–693.

Humes, L. E., & Coughlin, M. (2009). Aided speech-identification performance in single-talker competition by older adults with impaired hearing. *Scandinavian Journal of Psychology*, *50*(5), 485–494. http://doi.org/10.1111/j.1467-9450.2009.00740.x

Humes, L. E., Watson, B. U., Christensen, L. A., Cokely, C. G., Halling, D. C., & Lee, L. (1994). Factors associated with individual differences in clinical measures of speech recognition among the elderly. *Journal of Speech and Hearing Research*, *37*(2), 465–474.

Ingvalson, E. M., Dhar, S., Wong, P. C. M., & Liu, H. (2015). Working memory training to improve speech perception in noise across languages. *The Journal of the Acoustical Society of America*, *137*(6), 3477–3486. http://doi.org/10.1121/1.4921601

Iyenger, K. (2000). *MMN-An objective correlates of DLI* (Unpublished Master's Dissertation). University of Mysore, Mysore, India.

Jain, C., Mohamed, H., & Kumar U., A. (2014). Short-term musical training and pyschoacoustical abilities.*Audiology Research*, *4*(1). http://doi.org/10.4081/audiores.2014.102

Jesteadt, W., Wier, C. C., & Green, D. M. (1977). Intensity discrimination as a function of frequency and sensation level.*The Journal of the Acoustical Society of America*, *61*(1), 169–177.

Jin, S.-H., Liu, C., & Sladen, D. P. (2014). The effects of aging on speech perception in noise: comparison between normal-hearing and cochlear-implant listeners. *Journal of the American Academy of Audiology*, *25*(7), 656–665. http://doi.org/10.3766/jaaa.25.7.4

John, A. B., Hall, J. W., & Kreisman, B. M. (2012). Effects of advancing age and hearing loss on gaps-in-noise test performance.*American Journal of Audiology*, *21*(2), 242–250. http://doi.org/10.1044/1059-0889(2012/11-0023)

Johnsson, L. G., & Hawkins, J. E. (1972). Sensory and Neural Degeneration with Aging, as Seen in Microdissections of the Human Inner Ear.*Annals of Otology, Rhinology & Laryngology*, *81*(2), 179–193. http://doi.org/10.1177/000348947208100203

Kalikow, D. N., Stevens, K. N., & Elliott, L. L. (1977). Development of a test of speech intelligibility in noise using sentence materials with controlled word predictability. *The Journal of the Acoustical Society of America*, *61*(5), 1337. http://doi.org/10.1121/1.381436

Kamath, S. (1989).*Frequency DL in normals – effects of frequency, sensation level, ear differences, sex and interaction effect.*(Unpublished Master's Dissertation). University of Mysore, Mysore, India.

Kane, M. J., Bleckley, M. K., Conway, A. R., & Engle, R. W. (2001). A controlled-attention view of working-memory capacity.*Journal of Experimental Psychology. General*, *130*(2), 169–183.

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: a latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology. General*, *133*(2), 189–217. http://doi.org/10.1037/0096-3445.133.2.189

Kidd, G. R., Watson, C. S., & Gygi, B. (2007a). Individual differences in auditory abilities.*The Journal of the Acoustical Society of America*, *122*(1), 418–435. http://doi.org/10.1121/1.2743154

Kidd, G. R., Watson, C. S., & Gygi, B. (2007b). Individual differences in auditory abilities.*The Journal of the Acoustical Society of America*, *122*(1), 418–435. http://doi.org/10.1121/1.2743154

Knutson, J. F., Hinrichs, J. V., Tyler, R. S., Gantz, B. J., Schartz, H. A., & Woodworth, G. (1991). Psychological predictors of audiological outcomes of multichannel cochlear implants: preliminary findings. *The Annals of Otology, Rhinology, and Laryngology*, *100*(10), 817–822.

Kołodziejczyk, I., & Szelsg, E. (2008). Auditory perception of temporal order in centenarians in comparison with young and elderly subjects.*Acta Neurobiologiae Experimentalis*, *68*(3), 373–381.

König, E. (1957). Pitch Discrimination and Age. *Acta Oto-Laryngologica*, *48*(5-6), 475–489. http://doi.org/10.3109/00016485709126909

Kumar, A. U., & Sandeep, M. (2013). Auditory cognitive training module. ARF funded departmental project submitted to All India Institute of Speech and Hearing, Mysore.

Kumar, A. U., & Sangamanatha, A. V. (2011). Temporal processing abilities across different age groups.*Journal of the American Academy of Audiology*, *22*(1), 5–12. http://doi.org/10.3766/jaaa.22.1.2

Light, L. L., Zelinski, E. M., & Moore, M. (1982). Adult age differences in reasoning from new information.*Journal of Experimental Psychology: Learning, Memory, and Cognition*, *8*(5), 435–447. http://doi.org/10.1037/0278-7393.8.5.435

Lutman, M. E. (1990).Degradations in frequency and temporal resolution with age and their impact on speech identification.*Acta Oto-Laryngologica. Supplementum*, *476*, 120–125; discussion 126.

Marshall, L. (1981). Auditory processing in aging listeners.*The Journal of Speech and Hearing Disorders*, *46*(3), 226–240.

Mayadevi. (1974). *The development and standardization of a comon speech discrimination test for Indians* (Unpublished Master's Dissertation). University of Mysore, Mysore, India.

Meister, H., Schreitmüller, S., Grugel, L., Beutner, D., Walger, M., & Meister, I. (2013). Examining speech perception in noise and cognitive functions in the elderly. *American Journal of Audiology*, *22*(2), 310–312. http://doi.org/10.1044/1059-0889(2012/12-0067)

Mendelson, J. R., & Ricketts, C. (2001). Age-related temporal processing speed deterioration in auditory cortex. *Hearing Research*, *158*(1-2), 84–94.

Methi, R., Avinash, A., & Kumar, U. A. (2009). Development of sentence material for Quick Speech in Noise test (Quick SIN) in Kannada.*Journal of Indian Speech and Hearing Association*, *23*(1), 59–65.

Miller, G. A. (1947). Sensitivity to Changes in the Intensity of White Noise and Its Relation to Masking and Loudness.*The Journal of the Acoustical Society of America*, *19*(4), 609. http://doi.org/10.1121/1.1916528

Mills, J. H., Schmiedt, R. A., Schulte, B. A., & Dubno, J. R. (2006). Age-related hearing loss: A loss of voltage, not hair cells. *Seminars in Hearing*, *27*(4), 228–236.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “Frontal Lobe” tasks: a latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100. http://doi.org/10.1006/cogp.1999.0734

Moore, B. C. (1973). Frequency difference limens for short-duration tones.*The Journal of the Acoustical Society of America*, *54*(3), 610. http://doi.org/10.1121/1.1913640

Moore, B. C. (2003). *An introduction to the psychology of hearing* (5th ed). Amsterdam ; Boston: Academic Press.

Moore, B. C., & Glasberg, B. R. (1987).Factors affecting thresholds for sinusoidal signals in narrow-band maskers with fluctuating envelopes.*The Journal of the Acoustical Society of America*, *82*(1), 69–79.

Moore, B. C. J. (1973). Frequency difference limens for narrow bands of noise.*The Journal of the Acoustical Society of America*, *54*(4), 888. http://doi.org/10.1121/1.1914343

Moore, B. C. J. (1995). Frequency analysis and masking.In *Hearing* (pp. 161–205). Orlando, Florida: Academic Press.

Moore, B. C. J. (2008). The Role of Temporal Fine Structure Processing in Pitch Perception, Masking, and Speech Perception for Normal-Hearing and

Hearing-Impaired People.*Journal of the Association for Research in Otolaryngology*, *9*(4), 399–406. http://doi.org/10.1007/s10162-008-0143-x

Moore, B. C. J., & Jorasz, U. (1992). Detection of changes in modulation depth of a target sound in the presence of other modulated sounds. *The Journal of the Acoustical Society of America*, *91*(2), 1051. http://doi.org/10.1121/1.402631

Moore, B. C. J., Peters, R. W., & Glasberg, B. R. (1992). Detection of temporal gaps in sinusoids by elderly subjects with and without hearing loss.*The Journal of the Acoustical Society of America*, *92*(4), 1923. http://doi.org/10.1121/1.405240

Moore, B. C. J., Peters, R. W., & Glasberg, B. R. (1992). Detection of temporal gaps in sinusoids by elderly subjects with and without hearing loss.*The Journal of the Acoustical Society of America*, *92*(4), 1923. http://doi.org/10.1121/1.405240

Moore, B. C., & Peters, R. W. (1992). Pitch discrimination and phase sensitivity in young and elderly subjects and its relationship to frequency selectivity. *The Journal of the Acoustical Society of America*, *91*(5), 2881–2893.

Moore, B. C., Peters, R. W., & Glasberg, B. R. (1993). Detection of temporal gaps in sinusoids: effects of frequency and level. *The Journal of the Acoustical Society of America*, *93*(3), 1563–1570.

Moore, D. R., Edmondson-Jones, M., Dawes, P., Fortnum, H., McCormack, A., Pierzycki, R. H., & Munro, K. J. (2014).Relation between speech-in-noise threshold, hearing loss and cognition from 40-69 years of age.*PloS One*, *9*(9), e107720. http://doi.org/10.1371/journal.pone.0107720

Morris, R. G., Gick, M. L., & Craik, F. I. M. (1988). Processing resources and age differences in working memory. *Memory & Cognition*, *16*(4), 362–366. http://doi.org/10.3758/BF03197047

Mukari, S. Z., Umat, C., & Othman, N. I. (2010). Effects of age and working memory capacity on pitch pattern sequence test and dichotic listening. *Audiology & Neuro-Otology*, *15*(5), 303–310. http://doi.org/10.1159/000283007

Musiek, F. E. (1994). Frequency (pitch) and duration pattern tests. *Journal of the American Academy of Audiology*, *5*(4), 265–268.

Musiek, F. E., Shinn, J. B., Jirsa, R., Bamiou, D.-E., Baran, J. A., & Zaida, E. (2005). GIN (Gaps-In-Noise) test performance in subjects with confirmed central auditory nervous system involvement. *Ear and Hearing*, *26*(6), 608–618.

Nordmark, J. O. (1968). Mechanisms of Frequency Discrimination.*The Journal of the Acoustical Society of America*, *44*(6), 1533. http://doi.org/10.1121/1.1911293

Overton, J. A., & Recanzone, G. H. (2016). Effects of aging on the response of single neurons to amplitude-modulated noise in primary auditory cortex of rhesus macaque.*Journal of Neurophysiology, 115*(6), 2911–2923. http://doi.org/10.1152/jn.01098.2015

Oxenham, A. J., & Bacon, S. P. (2003). Cochlear compression: perceptual measures and implications for normal and impaired hearing. *Ear and Hearing*, *24*(5), 352–366. http://doi.org/10.1097/01.AUD.0000090470.73934.78

Palmer, S. B., & Musiek, F. E. (2014). Electrophysiological gap detection thresholds: effects of age and comparison with a behavioral measure. *Journal of the American Academy of Audiology*, *25*(10), 999–1007. http://doi.org/10.3766/jaaa.25.10.8

Penner, M. J. (1977).Detection of temporal gaps in noise as a measure of the decay of auditory sensation.*The Journal of the Acoustical Society of America*, *61*(2), 552. http://doi.org/10.1121/1.381297

Peters, R. W., Moore, B. C., & Baer, T. (1998).Speech reception thresholds in noise with and without spectral and temporal dips for hearing-impaired and normally hearing people.*The Journal of the Acoustical Society of America*, *103*(1), 577–587.

Phillips, S. L., Gordon-Salant, S., Fitzgibbons, P. J., & Yeni-Komshian, G. H. (1994).Auditory duration discrimination in young and elderly listeners with normal hearing.*Journal of the American Academy of Audiology*, *5*(3), 210–215.

Pichora-Fuller, M. K., & Souza, P. E. (2003).Effects of aging on auditory processing of speech.*International Journal of Audiology*, *42*(sup2), 11–16. http://doi.org/10.3109/14992020309074638

Pinto, J. M., Kern, D. W., Wroblewski, K. E., Chen, R. C., Schumm, L. P., & McClintock, M. K. (2014). Sensory Function: Insights From Wave 2 of the National Social Life, Health, and Aging Project. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *69*(Suppl 2), S144–S153. http://doi.org/10.1093/geronb/gbu102

Plack, C. J., & Carlyon, R. P. (1995). Loudness perception and intensity coding.In *Hearing* (pp. 123–160). New York: Academic Press.

Plomp, R. (1977). Auditory handicap of hearing impairment and the limited benefit of hearing aids.*The Journal of the Acoustical Society of America*, *61*(S1), S5. http://doi.org/10.1121/1.2015802

Plomp, R. (1986). A Signal-to-Noise Ratio Model for the Speech-Reception Threshold of the Hearing Impaired.*Journal of Speech Language and Hearing Research*, *29*(2), 146. http://doi.org/10.1044/jshr.2902.146

Plomp, R., & Mimpen, A. M. (1979). Improving the reliability of testing the speech reception threshold for sentences. *Audiology: Official Organ of the International Society of Audiology*, *18*(1), 43–52.

Pronk, M., Deeg, D. J. H., Festen, J. M., Twisk, J. W., Smits, C., Comijs, H. C., & Kramer, S. E. (2013). Decline in older persons' ability to recognize speech in noise: the influence of demographic, health-related, environmental, and cognitive factors. *Ear and Hearing*, *34*(6), 722–732. http://doi.org/10.1097/AUD.0b013e3182994eee

Rance, G. (2005). Auditory neuropathy/dys-synchrony and its perceptual consequences.*Trends in Amplification*, *9*(1), 1–43.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: integration of structural and functional findings. In *Handbook of Aging and Cognition* (Vols. 1–2, pp. 1–90). New Jersy: Erlbaum, Mahwah.

Raz, N., Gunning-Dixon, F. M., Head, D., Dupuis, J. H., & Acker, J. D. (1998). Neuroanatomical correlates of cognitive aging: evidence from structural magnetic resonance imaging. *Neuropsychology*, *12*(1), 95–114.

Roberts, R. A., & Lister, J. J. (2004). Effects of age and hearing loss on gap detection and the precedence effect: broadband stimuli. *Journal of Speech, Language, and Hearing Research: JSLHR*, *47*(5), 965–978.

Rodenburg, M. (1977). Investigation of temporal effects with amplitude modulated signals. In *Psychophysics and Physiology of Hearing* (pp. 429–437). London: Academic Press. Retrieved from http://mechanicsofhearing.org/mohdl/pdfs/AN/Yost-Sheft-AudNeurosci-1997.pdf

Rönnberg, N., Rudner, M., Lunner, T., & Stenfelt, S. (2014). Assessing listening effort by measuring short-term memory storage and processing of speech in noise. *Speech, Language and Hearing, 17*(3), 123–132. http://doi.org/10.1179/2050572813Y.0000000033

Rosen, S., Adlard, A., & van der Lely, H. K. J. (2009). Backward and Simultaneous Masking in Children With Grammatical Specific Language Impairment: No Simple Link Between Auditory and Language Abilities. *Journal of Speech Language and Hearing Research*, *52*(2), 396. http://doi.org/10.1044/1092-4388(2009/08-0114)

Rosen, S., & Manganari, E. (2001). Is there a relationship between speech and nonspeech auditory processing in children with dyslexia? *Journal of Speech, Language, and Hearing Research: JSLHR*, *44*(4), 720–736.

Roth, D. A., Kishon-Rabin, L., & Hildesheimer, M. (2001). Auditory backward masking and the effect of training in normal hearing adults.*Journal of Basic and Clinical Physiology and Pharmacology*, *12*(2 Suppl), 145–159.

Sanchez C. A., Wiley J., Miura T. K., Colflesh G. J. H., Jensen M. S., Ricks T. R., et al. (2010). Assessing working memory capacity in a non-native language. *Learning Individual Differences. 20,* 488–493 10.1016/ j.lindif.2010.04.001

Salthouse, T. A. (1996).The processing-speed theory of adult age differences in cognition.*Psychological Review*, *103*(3), 403–428.

Salthouse, T. A., Babcock, R. L., & Shaw, R. J. (1991). Effects of adult age on structural and operational capacities in working memory.*Psychology and Aging*, *6*(1), 118–127. http://doi.org/10.1037/0882-7974.6.1.118

Schiavetti, N., Orlikoff, R. F., & Metz, D. E. (2015). *Evaluating research in communication disorders* (Seventh edition). Boston: Pearson.

Schlauch, R. S. (1990). Two-, three-, and four-interval forced-choice staircase procedures: Estimator bias and efficiency. *The Journal of the Acoustical Society of America*, *88*(2), 732. http://doi.org/10.1121/1.399776

Schneider, B. A., Pichora-Fuller, K., & Daneman, M. (2010). Effects of Senescent Changes in Audition and Cognition on Spoken Language Comprehension.In *The Aging Auditory System* (pp. 167–210). New York: Springer.

Schneider, B. A., & Pichora-Fuller, M. K. (2000). Implications of perceptual processing for cognitive aging research.In *The handbook of aging and cognition* (2nd Edition, pp. 155–219). New York: Lawrence Erlbaum Associates, Publishers.

Sek, A., & Moore, B. C. J. (1995). Frequency discrimination as a function of frequency, measured in several ways. *The Journal of the Acoustical Society of America*, *97*(4), 2479. http://doi.org/10.1121/1.411968

Shailer, M. J., & Moore, B. C. (1987). Gap detection and the auditory filter: phase effects using sinusoidal stimuli. *The Journal of the Acoustical Society of America*, *81*(4), 1110–1117.

Sheft, S., Shafiro, V., Wang, E., Barnes, L. L., & Shah, R. C. (2015).Relationship between Auditory and Cognitive Abilities in Older Adults.*PloS One*, *10*(8), e0134330. http://doi.org/10.1371/journal.pone.0134330

Shinn, J. B. (2007). Temporal processing and temporal patterning tests. In *Handbook of (central) auditory processing disorder: Auditory neuroscience and diagnosis* (Vol. 1, pp. 231–256). San Diego: Plural Publishing.

Shinn, J. B., Chermak, G. D., & Musiek, F. E. (2009). GIN (Gaps-In-Noise) performance in the pediatric population. *Journal of the American Academy of Audiology*, *20*(4), 229–238.

Shivprakash, K. (2003). *Gap detection test – Development of normative data.*(Unpublished Independent Project). University of Mysore, Mysore, India.

Shower, E. G. (1931).Differential Pitch Sensitivity of the Ear.*The Journal of the Acoustical Society of America*, *3*(1A), 7. http://doi.org/10.1121/1.1901921

Shylaja, T. (2005). *Evaluation of some aspects of auditory temporal processing deficits in subjects with conductive hearing loss* (Unpublished Master's Dissertation). University of Mysore, Mysore, India.

Simon, H. J., & Yund, E. W. (1993). Frequency discrimination in listeners with sensorineural hearing loss.*Ear and Hearing*, *14*(3), 190–201.

Singh, N. C., & Theunissen, F. E. (2003). Modulation spectra of natural sounds and ethological theories of auditory processing.*The Journal of the Acoustical Society of America*, *114*(6), 3394. http://doi.org/10.1121/1.1624067

Snell, K. B. (1997). Age-related changes in temporal gap detection.*The Journal of the Acoustical Society of America*, *101*(4), 2214. http://doi.org/10.1121/1.418205

Snell, K. B., & Frisina, D. R. (2000). Relationships among age-related differences in gap detection and word recognition.*The Journal of the Acoustical Society of America*, *107*(3), 1615. http://doi.org/10.1121/1.428446

Souza, P., & Arehart, K. (2015). Robust relationship between reading span and speech recognition in noise.*International Journal of Audiology*, *54*(10), 705–713. http://doi.org/10.3109/14992027.2015.1043062

Spilich, G. J. (1983). Life-span components of text processing: structural and procedural differences. *Journal of Verbal Learning and Verbal Behavior*, *22*(2), 231–244. http://doi.org/10.1016/S0022-5371(83)90178-0

Stelmachowicz, P. G., & Seewald, R. C. (1977). Threshold and suprathreshold temporal integration function in normal and cochlear-impaired subjects.*Audiology: Official Organ of the International Society of Audiology*, *16*(2), 94–101.

Strouse, A. (1998). Temporal processing in the aging auditory system.*The Journal of the Acoustical Society of America*, *104*(4), 2385. http://doi.org/10.1121/1.423748

Strouse, A., Ashmead, D. H., Ohde, R. N., & Grantham, D. W. (1998). Temporal processing in the aging auditory system.*The Journal of the Acoustical Society of America*, *104*(4), 2385–2399.

Summers, V., Makashay, M. J., Theodoroff, S. M., & Leek, M. R. (2013). Suprathreshold Auditory Processing and Speech Perception in Noise: Hearing-Impaired and Normal-Hearing Listeners. *Journal of the American Academy of Audiology*, *24*(4), 274–292. http://doi.org/10.3766/jaaa.24.4.4

Surprenant, A. M., & Watson, C. S. (2001). Individual differences in the processing of speech and nonspeech sounds by normal-hearing listeners. *The Journal of the Acoustical Society of America*, *110*(4), 2085. http://doi.org/10.1121/1.1404973

Trainor, L. J., & Trehub, S. E. (1989). Aging and auditory temporal sequencing: ordering the elements of repeating tone patterns. *Perception & Psychophysics*, *45*(5), 417–426.

Turner, C. W., Zwislocki, J. J., & Filion, P. R. (1989). Intensity discrimination determined with two paradigms in normal and hearing-impaired subjects. *The Journal of the Acoustical Society of America*, *86*(1), 109–115.

van Rooij, J. C. (1989). Auditive and cognitive factors in speech perception by elderly listeners. I: Development of test battery. *The Journal of the Acoustical Society of America*, *86*(4), 1294. http://doi.org/10.1121/1.398744

van Rooij, J. C., Plomp, R., & Orlebeke, J. F. (1989). Auditive and cognitive factors in speech perception by elderly listeners. I: Development of test battery. *The Journal of the Acoustical Society of America*, *86*(4), 1294–1309.

Vidyanath, R., & Yathiraj, A. (2014). Screening Checklist for Auditory Processing in Adults (SCAP-A): Development and preliminary findings. *Journal of Hearing Science*, (1), 27–37. http://doi.org/10.17430/890788

Viemeister, N. F. (1979). Temporal modulation transfer functions based upon modulation thresholds. *The Journal of the Acoustical Society of America*, *66*(5), 1364. http://doi.org/10.1121/1.383531

Vuontela, V., Steenari, M.-R., Carlson, S., Koivisto, J., Fjällberg, M., & Aronen, E. T. (2003). Audiospatial and visuospatial working memory in 6-13 year old school children.*Learning & Memory (Cold Spring Harbor, N.Y.)*, *10*(1), 74–81. http://doi.org/10.1101/lm.53503

Walton, J. P., Frisina, R. D., & O'Neill, W. E. (1998). Age-related alteration in processing of temporal sound features in the auditory midbrain of the CBA mouse. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *18*(7), 2764–2776.

Walton, J. P., Simon, H., & Frisina, R. D. (2002). Age-related alterations in the neural coding of envelope periodicities.*Journal of Neurophysiology*, *88*(2), 565–578.

Wechsler, D. (1981). *The Wechsler Adult Intelligence Scale-Revised.* New York: The Psychological Corporation.

Wechsler, D. (1987). *Wechsler Memory Scale-Revised.* New York: The Psychological Corporation.

Wier, C. C. (1977).Frequency discrimination as a function of frequency and sensation level.*The Journal of the Acoustical Society of America*, *61*(1), 178. http://doi.org/10.1121/1.381251

Wilhelm, O., Hildebrandt, A., & Oberauer, K. (2013). What is working memory capacity, and how can we measure it? *Frontiers in Psychology*, *4*. http://doi.org/10.3389/fpsyg.2013.00433

Willott, J. F. (1991). *Aging and the auditory system: anatomy, physiology, and psychophysics*. San Diego, Calif: Singular Pub. Group.

Wright, B. A., Lombardino, L. J., King, W. M., Puranik, C. S., Leonard, C. M., & Merzenich, M. M. (1997). Deficits in auditory temporal and spectral resolution in language-impaired children.*Nature*, *387*(6629), 176–178. http://doi.org/10.1038/387176a0

Wright, R. E. (1981). Aging, Divided Attention, and Processing Capacity.*Journal of Gerontology*, *36*(5), 605–614. http://doi.org/10.1093/geronj/36.5.605

Yost, W. A., Sheft, S., & Opie, J. (1989). Modulation interference in detection and discrimination of amplitude modulation.*The Journal of the Acoustical Society of America*, *86*(6), 2138–2147.

Zekveld, A. A., Rudner, M., Johnsrude, I. S., & Rönnberg, J. (2013).The effects of working memory capacity and semantic cues on the intelligibility of speech in noise.*The Journal of the Acoustical Society of America*, *134*(3), 2225–2234. http://doi.org/10.1121/1.4817926

Zeng, F.-G., Kong, Y.-Y., Michalewski, H. J., & Starr, A. (2005). Perceptual consequences of disrupted auditory nerve activity.*Journal of Neurophysiology*, *93*(6), 3050–3063. http://doi.org/10.1152/jn.00985.2004

Appendix I

All India Institute of Speech and Hearing

(An autonomous Institute under the
Ministry of Health and Family Welfare, Govt. of India)
Manasagangothri, Mysore - 570 006.

ಅಖಿಲ ಭಾರತ ವಾಕ್ ಶ್ರವಣ ಸಂಸ್ಥೆ
ಮಾನಸಗಂಗೋತ್ರಿ, ಮೈಸೂರು -570 006.

अखिल भारतीय वाक् श्रवण संस्थान
मानसगंगोत्री, मैसूर - 570 006.

ETHICS APPROVAL FOR BIO-BEHAVIORAL RESEARCH PROJECTS INVOLVING HUMAN SUBJECTS AT AIISH

AIISH ETHICS COMMITTEE (AEC)

Title of Ph.D Proposal:	Relationship between psychophysical abilities, speech perception in Nose and working memory in individuals with normal hearing sensitivity across different age groups
Candidate:	Ms. Chandini Jain
Guide:	Dr. Ajith Kumar U
Proposed Duration of the Ph.D program:	3 years
Estimated Budget Requirements:	Not applicable
Source of Funding:	Not applicable

Reference number of the proposal:	Not applicable
Date on which AEC meeting was held:	9.5.2013
Clear statement of decision reached at AEC meeting (in the event of a proposal being not approved, a statement of reasons for the same must be indicated):	**Approved**
Advice & Suggestions (If any):	Nil

DATE: 16.05.2013

Shyamala K.C.
Signature & Name of Member Secretary
Dr. Shyamala K.C.
Prof. & HOD - SLP

Phone : 0821-2514449 / 2515410 / 2515805. Fax : 0821-2510515, e-mail : aiish_dir@yahoo.com Web : www.aiishmysore.in

Appendix II

ALL INDIA INSTITUTE OF SPEECH AND HEARING, MYSURU-6

Proceedings of doctoral committee meeting in respect of pre-thesis submission colloquium

Name of the candidate	:	*Chandni Jain*
Date of pre-thesis submission colloquium	:	*18/07/16*
Venue: Mini Seminar Hall	:	*AIISH*
Whether the performance of the candidate was satisfactory	:	*Satisfactory*
1st or 2nd appearance	:	*1st appearance*

Recommendations of the Doctoral Committee:

The candidate presented the synopsis of the doctoral thesis titled "Relationship among psychophysical abilities, speech perception in noise and working memory on individuals with normal hearing sensitivity across different age groups". The doctoral committee recommended the following modifications:

Introduction

- To modify hypotheses according to the objectives by combining the first two objectives.
- To use 'between age' groups instead of 'across age groups' in objectives and hypotheses.
- To remove across age groups from last objective.

Method

- To remove the introduction paragraph of aims from the method in the synopsis.
- To mention Bio behavioural ethical committee in ethical principles.
- To remove Appendix 1 from synopsis.
- To mention the correct reference for the phonetically balanced test.
- To specify the education level of the participants and mention that they all resided in Mysuru for more than ten years and were fluent in reading and speaking Kannada. They also had knowledge of English and did not have any history of speech and language problems.
- To mention the reference for Audacity software and should be capitalise throughout the document.
- To superimpose intensity contour showing rise and fall times of the stimuli on the waveforms.
- To mention the reference/rational for using 250 ms stimuli in the test procedures and to mention about temporal integration.
- To mention the minimum and maximum value available in mlp for all the test procedures.
- To move the general instruction of operation and reading span task to general instructions for all working memory measures.

18-7-16 18/7/16

- To use use 'word and sentence in Kannada' instead of Kannada script in the graphical representation of operation and reading span and use sample representation in the figure legends instead of graphical representation.
- To include reference in operation and reading span for using 85% criterion.
- To change the sentence 'detail description of software, stimulus and procedure is provided elsewhere'.
- To change the description of auditory digit and sequencing from figures to words.

Results& Discussion

- To mention one way ANOVA was done to assess the pair-wise comparison in FDL ad IDL.
- To change the age groups to 10<20 years, 20<30 years and so on.
- To change the figure titles scatter plot'---- as a function of age'.
- To correct the typographical errors in statistics (eg: - sign for negative correlations).
- To change the figures to represent minimum and maximum values.
- To change the titles heading for the Table 3.9.
- To use Factor 1, 2, 3 and 4 instead of frequency, intensity, temporal and working memory in the table 3.13.
- To expand the abbreviations in all tables and figures.
- To write correct references.

Others

- To replace singular terms with plurals wherever necessary (eg: Analysis to analyses, hypothesis to hypotheses, Method to Methods).
- To remove the summary and conclusion from synopsis.
- To mention future directions after implications.
- To check the spelling and grammatical errors throughout the document.
- To add a brief description between two conservative headings throughout the document.
- To avoid single sentence paragraphs.

Ms Chandni Jain may prepare the synopsis with the above mentioned modifications and submit the same with the thesis.

Doctoral committee:

Dr. Nith Kumar U
Chairperson, Doctoral committee, AIISH, Mysore

Dr. Asha Yathiraj Member, Doctoral committee, AIISH, Mysore

Dr.Animesh Barman Member, Doctoral committee, AIISH, Mysore
18/7/16

डॉ. अनिमेश बर्मन
Dr. ANIMESH BARMAN
All India Institute of Speech and Hearing
मैसूरु / MYSURU-570 006

Savithri. SR 18-7-16
Dr. S.R. Savithri
Chairperson BoS and Director, AIISH, Mysore

Director
AIISH, Mysore-6

Copy to Ms. Chandini Jain through the Guide

List of Publications

1. Jain,C., Mohamad, H., & Kumar, A.U. (2015). The effect of short-term musical training on speech perception in noise. *Audiology Research, 5*(1), 5-8.

2. Jain,C., Mohamad, H., & Kumar, A.U. (2014). Short-term musical training and pyschoacoustical abilities. *Audiology Research, 4*(1), 40-45.

Short-term musical training and pyschoacoustical abilities

Chandni Jain,[1] Hijas Mohamed,[2] Ajith Kumar U.[1]

[1]Department of Audiology, All India Institute of Speech and Hearing, Manasagangothri, Mysore; [2]Hero Electronic-Siemens Best Sound Centre, Coimbatore, Tamil Nadu, India

Abstract

The aim of the study was to assess the effect of short-term perceptual training of music on some psycho-acoustical measures. The study was carried out in three phases. In first the phase pre-training evaluation was done which included raga identification and various psycho acoustical tests. Psycho-acoustical tests included measurement of differential limen of frequency and intensity, duration discrimination, gap detection, modulation detection, backward masking and duration pattern test. In the second phase, auditory perceptual training was given for raga identification and in the third phase post- training evaluation was done though same tests as mentioned in pre-training phase. A total of 10 normal hearing adults (7 males, 3 females) in the age range of 18-25 years participated in the study. The results revealed that all the subjects performed significantly better on raga identification after training. However; there was no significant difference in psycho-acoustical measures in pre and post-training.

Introduction

A multitude of evidences suggests that long term musical training has benefits on sensory and cognitive processing.[1,2] Music involves fine modulations of amplitude, frequency, and temporal aspects and musicians are trained to recognize these fine variations due to their extensive training. As a result of this practice a well-trained musician will have rich auditory experience. Due to their auditory experience musicians are considered as auditory experts and they are thought to have better auditory skills than non-musicians.[3] Musicians perform better than non-musicians, both on music specific as well as general auditory skills.[4]

Psychoacoustic research on musicians using behavioral measures suggests an enhancement of various psycho-acoustical skills. It has been reported that musicians perform better than non-musicians on tasks involving pitch discrimination, backward masking, forward masking and random gap detection.[5-9] Micheyl *et al*.[10] reported that musicians had pitch discrimination thresholds that were six times smaller than non-musicians. Similarly, Ishii *et al*.[6] reported that gap detection thresholds of trained musicians were better when compared to non-musicians. Furthermore, significant enhanced performance on the backward masking and backward masking with a gap were also reported in musicians compared to non-musicians.[11] It was also observed that there was a correlation between years of musical practice and performance on backward masking, which suggests that musical training influences temporal resolution.[12] Furthermore, it has also been shown that long-term musical training induces both structural and functional plasticity in the auditory system.[13,14] Schlaug[14] reported differences in auditory, motor and visual-spatial brain regions in trained adult musicians compared to amateur musicians or non musicians. More specifically, professional musicians had a larger gray matter density in the pre-central gyrus, Heschl's gyrus and right superior parietal cortex. Gaab and Schlaug[15] reported increased activations in auditory association areas of professional musicians compared to non-musicians. Music induced structural and functional plasticity changes have also been reported in the auditory brainstem.

Taken together, from the above studies, it can be concluded that long-term formal music training results in structural, functional and behavioral changes in the auditory system. It has also been shown that, positive effects of music can be transferred on auditory processing as well as speech and language.[16] However, the positive effects of music have been demonstrated only on those musicians who have undergone long term formal training in music.[5-10] It would be interesting to see whether these advantages would extend for short-term perceptual musical exposure also. Therefore, the present study was taken up to evaluate the perceptual changes in the auditory system, if any, due to short-term perceptual music training. Short-term musical training was operationally defined as non-formal perceptual listening to music for 8-10 sessions. This study measured the effect of short-term auditory perceptual training of two Carnatic Ragas on auditory system using various psycho-acoustical abilities (frequency, intensity and temporal abilities).

Correspondence: Chandni Jain, All India Institute of Speech and Hearing, Mysore - 570006, India.
E-mail: chandni_j_2002@yahoo.co.in

Key words: short-term music training, psychoacoustical abilities.

Acknowledgements: we would like to express gratitude to the Director, AIISH and HOD-Audiology for permitting us to carry out this research.

Contributions: CJ, data collection, data analysis and interpretation, manuscript preparation; HM, data collection (music training) and interpretation; AKU, study conception and design, manuscript revision.

Conflict of interests: the authors report no conflict of interests.

Received for publication: 17 February 2014.
Revision received: 22 August 2014.
Accepted for publication: 27 August 2014.

Audiology Research 2014;4:102
doi:10.4081/audiores.2014.102

Materials and Methods

Participants

A total of 10 normal hearing adults (7 males, 3 females) in the age range of 18-25 years participated in the study. All the participants had their hearing thresholds less than or equal to 15 dB HL at octave frequencies from 250 Hz to 8000 Hz and A type tympanogram. It was also ascertained from a structured interview that these listeners did not have any history of neurologic or otologic disorder. All the participants did not have any complaints of difficulty in understanding speech either in quiet or in the presence of background noise and were amateur or rare listeners of music. All the listeners' participation was voluntary and they were not paid for their participation in the study. Ethical clearance was obtained from the ethics committee of the institute prior to commencement of the experiment.

General procedure

Written consent was taken from all the participants for willingly participating in the study. The study was carried out in three phases. In first phase pre-training evaluation was done on raga identification and various psycho-acoustical measures, including frequency and intensity discrimination, duration discrimination test, gap detection test, modulation detection test, backward masking and duration pattern test. In the second phase, auditory perceptual training with music was given and in third phase post-training evaluation was done using the same tests as mentioned in the pre-training phase. The order of the psychoacoustic tests was randomized among the participants.

Phase I involved raga identification and assessment of various psycho-acoustical abilities.

Phase I: Raga identification

This was assessed by determining: i) minimum number of notes required to identify a Raga; and ii) identification of Raga by listening to small excerpts of music.

Minimum number of notes required to identify Raga

Stimuli and procedure: Stimuli consisted of violin compositions from two Carnatic Ragas [Kalyani (Audio 1) and Mayamalavagola (Audio 2)]. These two are the basic ragas of South Indian classical music wherein Mayamalavagola is a *shudh madhyam raga* and Kalyani is a *prati madhyam raga*. Also Mayamalavagola is a 15^{th} *mela karta* and Kalyani is 65^{th} *mela karta*.[17] A Carnatic violinist with an experience of more than 15 years, who had passed *senior level* examination and practices for at least 2 to 3 h daily played the two Ragas. Musical notes of two Ragas were played in the octave scale where the distance between the first note (*sa*) and the last note (*sa*) is one octave. The notes consisted of *sa re ga ma pa dha ni sa* played either in Kalyani or Mayamalavagola Raga. Eight stimuli were constructed using this composition for each Raga. The first stimulus had only one note, second stimulus had 2 notes, third stimulus had 3 notes and so on, 8 stimuli had all 8 notes. Testing consisted of two phases: familiarization and identification. In the familiarization phase, participants were asked to listen to violin notes played in octave notes for Kalyani Raga and were instructed that hereafter whenever they hear the notes in this particular fashion they had to identify the Raga as *Kalyani*. A similar exercise was done for Mayamalavagola Raga. In identification phase, participants were asked to identify the Raga after listening to notes by pressing the appropriate key on the keyboard. The presentation of the stimuli and a collection of the responses were controlled using DMDX[18] software. Stimuli were presented randomly using a scrambling code of DMDX. During each stimulus trial, participants were presented with different number of notes of a Raga (either Kalyani or Mayamalavagola) along with words Kalyani and Mayamalvagola on the computer screen, *i.e*., Participants were asked to identify the stimulus by pressing the button 1 or 2 on the keyboard of the computer, where 1 and 2 represented Kalyani and Mayamalavagola respectively. The participants were given 3 s after the stimuli to respond. Till then the letters remained on the computer screen. Each stimulus was repeated 10 times in order to reduce the chance factor. This resulted in a total of 80 stimuli for each Raga. The minimum number of notes that were necessary to identify the Raga with 50% accuracy was found through linear regression. Hereafter, this test will be referred to as NOTE-50.

Identification of Raga by listening to small excerpts of music

Stimuli and procedure: The same violinist who participated in the earlier experiment played stimuli in this experiment. He was asked to play several sample songs in both Kalayani Raga and Mayamalavagola Raga each lasting for about 15 min. Pilot study done using NOTE-50 had revealed that the minimum number of notes required to identify a Raga by professional musicians is around 5 notes. Therefore, 10 different, 5 notes excerpts were extracted from one of the songs in each Raga and were used as stimuli. Each stimulus was repeated 10 times, which sums to a total of 100 stimuli in each Raga. This was done in order to reduce the chance factor.

Stimuli were presented bilaterally through a high fidelity headphone (Sennheiser HD 449) at a comfortable level. Testing consisted of two phases- familiarization and identification. In the familiarization phase, participants were asked to listen to an audio sample of a song played on violin in Kalyani Raga for around 15 min. Participants were instructed that hereafter whenever they hear the excerpts from this Raga they had to identify the Raga as *Kalyani*. After that, the participants were asked to listen to a song played on violin in Mayamalavagola Raga for 15 min and were asked to name the Raga as *Mayamalavagola*. After this initial familiarization phase, the identification phase began. Presentation of stimuli and collection of the responses were controlled via the software DMDX.[18] Stimuli were presented in a random manner using a scrambling code of DMDX. During each stimulus trial, participants were presented with 5 notes excerpt from a Raga (either Kalyani or Mayamalavagola) along with words Kalyani and Mayamalavagola on the computer screen. Participants were asked to identify the stimulus by pressing the button 1 or 2 on the keyboard of the computer, where 1 and 2 represented Kalyani and Mayamalavagola respectively. The participants were given a 3 s time after the stimuli to respond. Till then the letters remained on the computer screen. The accuracy in identification was measured. Hereafter, this would be referred to as a Music-test.

Psycho-acoustical assessment

This involved administration of a group of tests to assess frequency, intensity and temporal perception. All psycho acoustic tests except duration pattern test was carried out using maximum likelihood procedure (mlp) toolbox, which implements an mlp in Matlab.[19] The maximum likelihood procedure employs a large number of candidate psychometric functions and after each trial calculates the probability (or likelihood) of obtaining the listener response to all of the stimuli that have been presented. The psychometric function yielding the highest probability is used to determine the stimulus to be presented at the next trial. Within about 12 trials, the maximum likelihood procedure usually converges on a reasonably stable approximation of the most likely psychometric function, which then can be used to estimate threshold.[20] Stimuli were generated at 44,100 Hz sampling rate. A three-interval, alternate forced-choice method using mlp was employed to track a 79.4% correct response criterion. During each trial a stimulus was presented in each of three blocks where two blocks contained the reference stimulus and the other interval randomly chosen had the variable stimulus. The participant task was to indicate which block contained the variable stimulus. All the psycho-acoustical tests were administered as per procedure mentioned above and stimulus presentation and response acquisition were controlled by mlp toolbox. For all the tests 5-6 practice items were given before the commencement of the actual test.

The test stimulus for all psycho-acoustical tests was kept at 80 dB SPL. Stimuli for all the tests were presented via a laptop (Asus) connected to Sennheiser HD- 449 earphones. The output of the earphones was calibrated to produce 80 dB SPL for a 1000 Hz pure tone in a 2 cc coupler.

Difference limen of frequency

Difference limen for frequency (DLF) for pure tones was measured using a three-block forced-choice procedure as mentioned through mlp procedure. On each trial, two of the three observation blocks contained pure tones at a reference frequency and one selected at random had a pure tone of variable frequency, which was always higher than the reference frequency. The participant's task was to identify that block. It was done at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.[21]

Difference limen of intensity

Difference limen of intensity (DLI) for pure tones was measured using a three-block, forced-choice procedure. It was obtained for 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.[21] The rest of the procedure was same as mentioned in DLF testing.

Duration discrimination test

Duration discrimination was done for a 1000 Hz[22] tone at anchor duration 250 ms.[23] The rest of the procedure was same as mentioned in DLF testing.

Gap detection thresholds

The participant's ability to detect a temporal gap in the center of a 500 ms broadband noise was measured.[24] The noise was 0.5 ms cosine ramps at the beginning and the end of the gap. In a three-block alternate forced-choice task, the standard stimulus was always a 500 ms broadband noise with no gap whereas the variable stimulus had the gap.

Modulation detection thresholds

A 500 ms Gaussian noise was sinusoidal amplitude modulated at modulation frequencies of 4 Hz, 8 Hz, 16 Hz, 32 Hz, 64 Hz and 128 Hz.[25] A noise stimulus was two 10 ms raised cosine ramps at onset and offset. The participants were instructed to detect the modulation and determine which blocks had the modulated noise. Modulated and unmodulated stimuli were equated to total root mean square (rms) power. The depth of the modulated signal was varied according to the participant's response up to a 79.4% criterion level. The modulation detection threshold was expressed in dB by using the following relationship:

$$\text{Modulation detection thresholds in dB} = 20 \log10 m \qquad (1)$$

where m= modulation detection threshold in percentage.

Backward masking

A 20 ms, 1000 Hz pure tone (the signal) was presented immediately before (*i.e.*, no silent gap) a band of band pass noise of 300 ms (400-1600 Hz).[26] All sounds were onset and offset gated by means of two raised cosine onset and offset ramps of 10 ms. The participant task was to tell which block has the tone. The rest of the procedure was same as mentioned in DLF testing.

Duration pattern test

The duration pattern test was administered in the similar way as described by Pinheiro and Musiek.[27] A 1000 Hz pure tone was generated at 44,100 sampling frequency with two different durations (*i.e.* short 250 ms and long 500 ms), using Audacity software (ver. 1.3.5).[23] By combining these two durations in three tone pattern six different patterns were generated (short short long; short long short; long long short; long short short; short long long; long short long). Following practice trails, 30 test items were administered. The participants were asked to verbally repeat the sequence.

Phase II: Training

After pre-training evaluations, participants received the musical training in auditory mode. During training everyday participants listened to the 15 min composition of Kalyani and Mayamalavagola Ragas with the help of a personal computer through high fidelity headphones (Sennheiser HD 449). After listening to these compositions in the end of each session, participants performed the Music-test. In this test participants were presented with 5 notes excerpt from a Raga (either Kalyani or Mayamalavagola) along with words Kalyani and Mayamalavagola on the computer screen. Participants were asked to identify the stimulus by pressing the button 1 or 2 on the keyboard of the computer, where 1 and 2 represented Kalyani and Mayamalavagola respectively. The participants were given a 3 s time after the stimuli to respond. Till then the letters remained on the computer screen. This training was given for eight sessions. Eight sessions were selected because previous studies have shown that about eight sessions of auditory perceptual training is enough to show improvement in listening skills.[28,29]

Phase III: Post-training evaluations

All the behavioral tests mentioned in Phase I were re-administered at the end of the 8th day of the training session.

Results

Results are reported for raga identification and psycho-acoustical measures separately. Prior to the statistics, test of normality was performed using the Kolmogorav Smirnov test on all the parameters and it showed that ten parameters were significantly different ($P<0.05$) from the normal distribution. Hence, non-parametric tests were used for the present study.

Raga identification

This was assessed by determining: i) minimum number of notes required to identify a Raga; and ii) identification of Raga by listening to small excerpts of music.

Minimum number of notes required to identify Raga

Figure 1 shows identification of Ragas with different number of notes in participants in pre-training condition. The y-axis represents performance and the x-axis represents the number of notes. It can be noted that the identification of Ragas even with the maximum number of notes was below chance level (0.5) for all the participants in the pre-training condition. Figure 2 shows identification of Ragas with different number of notes for participants in post-training condition and it is evident from the table that the identification scores improved following training. Highest identification scores were obtained for the stimuli that had all 8 notes.

Identification of Raga by listening to small excerpts of music

Mean Raga identification scores in pre-training and post-training conditions are shown in Figure 3. It can be noted that Raga identification scores improved following training. The Wilcoxon Signed Rank test was performed to see the significance of difference in identification scores of Raga in pre- and post-training conditions. Results showed that training significantly improved the identification of Ragas (Z=-2.805, P<0.01).

Psychoacoustic measures

Results are reported for each psychoacoustic test separately. Figures 4 and 5 shows the mean scores and one-standard-deviation error bars for differential limen for frequency and intensity at 500, 1000, 2000 and 4000 Hz in pre-training and post-training conditions. It can be noted that the scores showed improvement in post-training compared to pre-training across all frequencies except at 4000 Hz for the DLF task. Thus, in order to see the effect of training on DLI and DLF Wilcoxon Signed Rank test was performed between the pre-training and post-training conditions. Results showed that there was significant improvement in DLF and DLI after musical training at 1000 Hz in DLF task (Z=-2.497, P<0.01) and for 500 Hz in DLI task (Z=-2.805, P<0.01). Figure 6 shows the mean and one-standard-deviation error bars of the modulation detection scores at 4 Hz, 8 Hz, 16 Hz, 32 Hz, 64 Hz, and 128 Hz across pre-training and post-training conditions. It can be noted that there was an improvement in detection threshold post-musical training with more improvement evident at low modulation frequency. To estimate whether the improvement was significant, a Wilcoxon Signed Rank test was performed between the pre-training and post-training conditions. Results showed that there was no significant difference in the score in pre- *vs* post- training at all the modulation frequencies (P>0.05). Figure 7 shows the mean scores and one-standard-deviation error bars of duration discrimination, gap detection, backward masking and duration pattern in pre- *vs* post- training condition. It can be noted from the figures that there was an improvement in scores for all the tests after musical training except for the gap detection threshold, wherein pre-training thresholds were better than post-training thresholds. To assess the difference in performance after training Wilcoxon Signed Rank test was performed and results showed that the pre- training and post- music training scores was not significant for all the tests (P>0.05).

Discussion

Perceptual learning can be defined as the improvement in the ability to perform a particular task after continuous practice. Ragas in Carnatic music have specific note sequences which can be identified by trained musicians. The results of the present study showed that with short-term perceptual training even non-musicians can learn to identify these Ragas. The main purpose of the present study was to document the differences in psycho-acoustical abilities in individuals after short-term musical training. To the best of our knowledge, the effect of short term music training on psycho-acoustical abilities has not been studied using a group of tests, including frequency and intensity discrimination, duration discrimination, gap detection, modulation detection, backward masking and duration pattern test.

The results of the present study show that there was an improvement in all the psycho-acoustical measures, including frequency, inten-

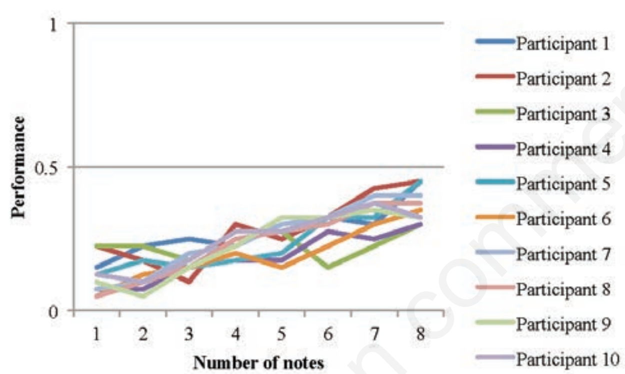


Figure 1. Identification of Ragas with different number of notes for individual participants in pre-training condition.

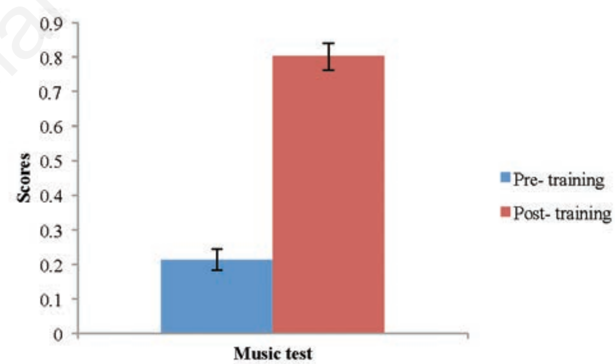


Figure 3. Identification of Ragas in pre- and post-training condition with one standard deviation error bar.

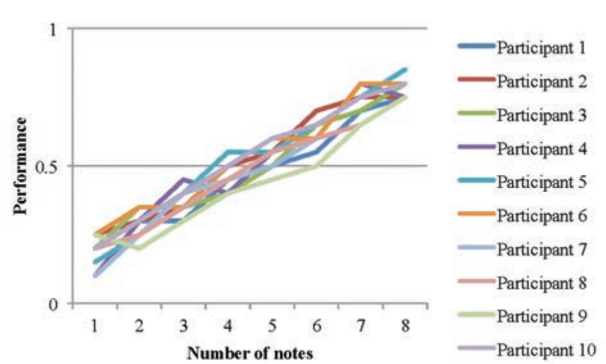


Figure 2. Identification of Ragas with different number of notes for individual participants in post training condition.

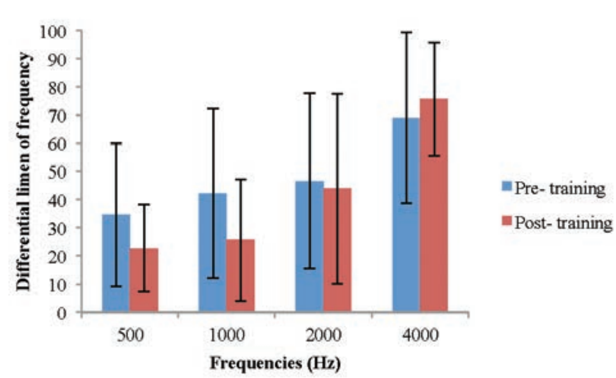


Figure 4. Mean scores and one-standard-deviation error bars for differential limen of frequency at 500, 1000, 2000 and 4000 Hz in pre- and post-training conditions.

sity and temporal measures, but it was not significant. The frequency discrimination abilities did not show a significant change after training which is in contrary to the studies done in the past. Speigel and Watson,[30] compared pitch discrimination ability in musicians and non-musicians and the results showed a clear separation between both the groups with a median threshold difference three times smaller for musicians. However, there are no studies examining the effect of music on intensity perception. The findings of the present study related to temporal perception also showed that with training scores improved in all temporal abilities, though it was not significant. Similar results have been reported by Monteiro *et al.*,[31] where they compared the temporal resolution ability using gaps in noise test in musicians and non-musicians. Results revealed that there was no difference between those groups on the performance of the gaps in noise test. On the contrary, some studies have shown that the temporal processing abilities of musicians are superior to non- musicians. Ishii *et al.*[6] in their study reported that the gap detection thresholds were better in trained musicians when compared to non- musicians. They also reported that the random gap detection threshold was not sensitive enough to differentiate the temporal resolution abilities. However, all the above mentioned studies have taken trained musicians to compare various auditory abilities and it has been reported that temporal resolution abilities improve as the experience in music increases.[32] In a study by Sangamatha *et al.*,[23] they reported that children with one to two years of musical training were able to perform like adults on all the temporal resolution tasks measured, except modulation detection at 200 Hz. This

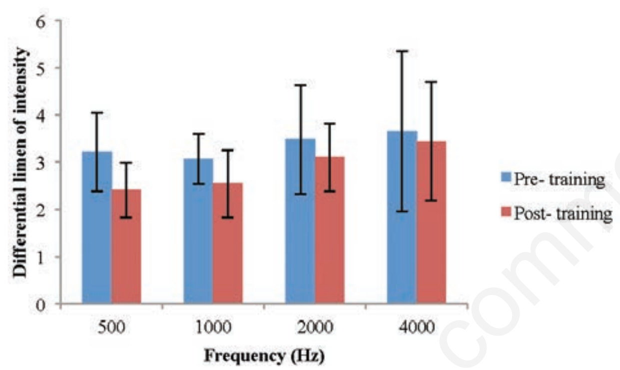


Figure 5. Mean scores and one-standard-deviation error bars for differential limen of intensity at 500, 1000, 2000 and 4000 Hz in pre- and post-training conditions.

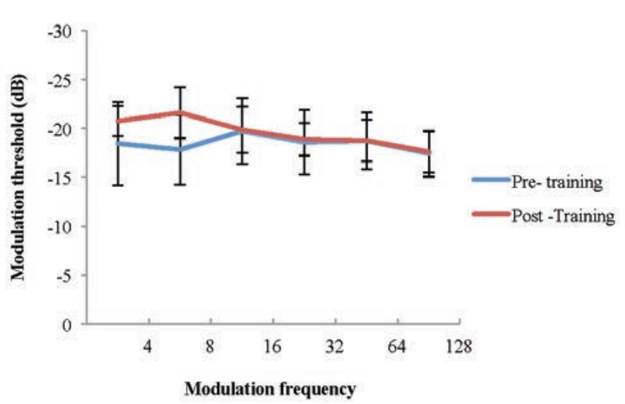


Figure 6. Modulation detectio thresholdes for pre- and post-training conditions. Error bars depict one standard deviation of error.

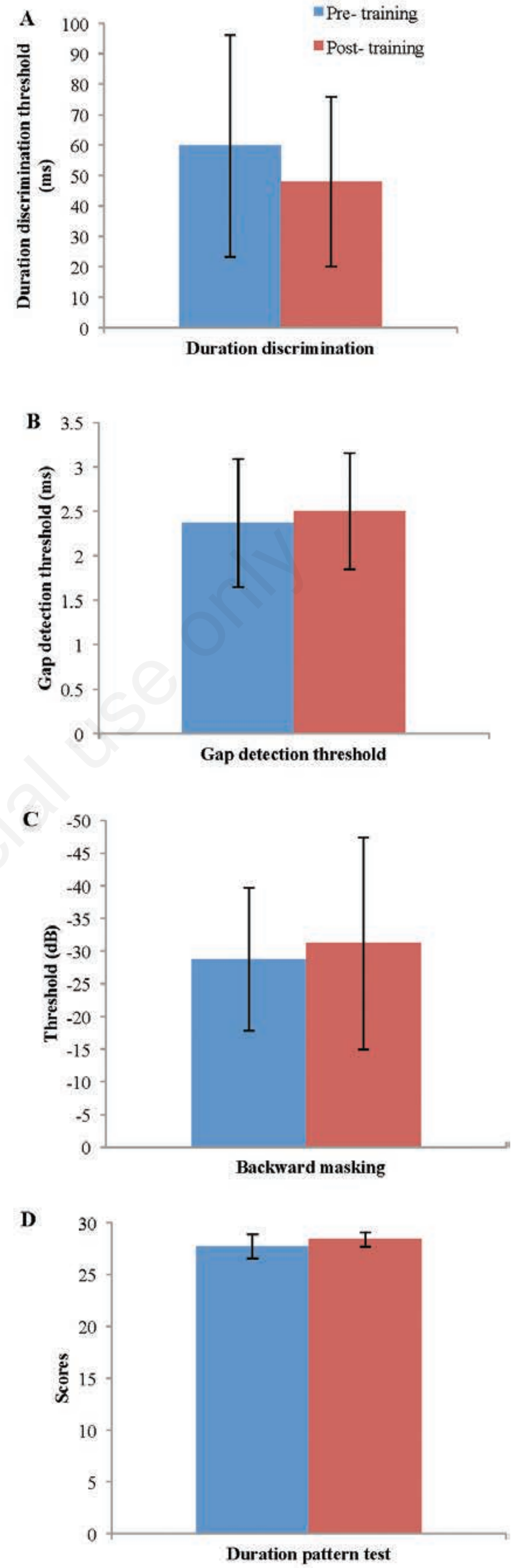


Figure 7. Mean and one-standard-deviation error for (A) duration discrimination thresholds, (B) gap detection thresholds, (C) backward masking (D) duration pattern scores in pre- and post-training conditions.

is in accordance with the present study where the improvement in the modulation detection task was more evident at low modulation frequencies (2 Hz, 4Hz, 8Hz and 16 Hz) compared to higher modulation frequencies. This result could be because music contains fine frequency and amplitude fluctuations and thus individuals with musical training are expected to have better performance on such tasks. Thus, the findings of the present study showed that with short-term musical training there was an improvement in the raga identification, but this was not generalized to the various psycho-acoustical measures. Studies done in the past have shown that with short term musical training participants exhibit superior music related perception.[33] Flohr[33] reported that children performed well on standardized rhythmic discrimination task after receiving training for 25 min twice a week across 12 weeks. Thus, it can be concluded that short term musical training shows an improvement in music perception skills; however the same improvement is not evident in various psycho-acoustical measures.

Conclusions

Short-term perceptual musical training shows an improvement in the identification of ragas but does not show a significant improvement in frequency, intensity or temporal resolution abilities. This could be because short-term music training is not resulting in an efficient neural mechanism for performing various auditory tasks. Further research is needed to explore the effect of duration of music training which can show enhancement in various auditory abilities. Moreover, whether any other type of listening training (non-music based) would also influence the psycho-acoustical abilities was not assessed as the part of the present study. Future research may aim to study pre- and post-psychoacoustic abilities in participants after receiving non-music based listening training.

References

1. Tervaniemi M, Kruck S, deBaene W, Schroger E, Alter K, Friederici AD. Top-down modulation of auditory processing: Effects of sound context, musical expertise and attentional focus. Eur J Neurosci 2009;30:1636-42.
2. Zatorre RJ, Belin B, Benhune VB. Structure and function of auditory cortex: music and speech. Trends Cogn Sci 2002;6:37-46.
3. Kraus N, Chandrasekaran B. Music training for the development of auditory skills. Nat Rev Neurosci 2010;11:599-605.
4. Banai K, Fisher S, Ganot R. The effects of context and musical training on auditory temporal interval discrimination. Hear Res 2012;284:59-66.
5. Barry JG, Weiss B, Sabisch B. Psychophysical estimates of frequency discrimination: More than just limitations of auditory processing. Brain Sci 2013;3:1023-42.
6. Ishii C, Arashiro PM, Pereira LD. Ordenação e resolução temporal em cantores profissionais e amadores afinados e desafinados. Pró-Fono 2006;18:285-92.
7. Nikjeh DA, Lister JJ, Frisch SA. Hearing of note: an electrophysiologic and psychoacoustic comparison of pitch discrimination between vocal and instrumental musicians. Psychophysiol 2008;45:994-1007.
8. Parbery-Clark A, Skoe E, Lam C, Kraus N. Musician enhancement for speech in noise. Ear Hear 2009;30:653-61.
9. Rammsayer T, Altenmüller E. Temporal information processing in musicians and nonmusicians. Music Perc 2006;24:37-47.
10. Micheyl C, Delhommeau K, Perrot X, Qxenham AJ. Influence of musical and psychoacoustical training on pitch discrimination. Hear Res 2006;219:36-47.
11. Parbery-Clark A, Strait DL, Kraus N. Context-dependent encoding in the auditory brainstem subserves enhanced speech in noise perception in musicians. Neuropsychologia 2011;49:3338-45.
12. Strait DL, Kraus N, Parbery-Clark A, Ashley R. Musical experience shapes top-down auditory mechanisms: evidence from masking and auditory attention performance. Hear Res 2010;261:22-9.
13. Gaser C, Schlaug G. Brain structures differ between musicians and non-musicians. J Neurosci 2003;23:9240-5.
14. Schlaug G. The brain of musicians; a model for functional and structural adaptation. Ann N Y Acad Sci 2001;930:281-99.
15. Gaab N, Schlaug G. The effect of musicianship on pitch memory in performance match group. Neuro Rep 2003;14:2291-5.
16. Chandrasekaran B, Krishnan A, Gandour JT. Relative influence of musical and linguistic experience on early cortical processing of pitch contours. Brain Lang 2009;108:1-9.
17. Srikanthan RK, Srinivas IMJ, Sharade T, Rudrapatnavi SP, Vasantha M. Sarvajanik shiksha iilake. Bangalore: Government of Karnataka; 2002.
18. Foster KI, Foster JC. DMDX: A window display program with millisecond accuracy. Behav Res Methods Instrum Comput 2003;35:116-24.
19. Grassi M, Soranzo A. MLP: a MATLAB toolbox for rapid and reliable auditory threshold estimation. Beh Res Meth 2009;41:20-8.
20. Green DM. A maximum-likelihood method for estimating thresholds in a yes-no task. J Acoust Soc Am 1993;93:2096-105.
21. He N, Dubno JR, Mills JH. Frequency and intensity discrimination measured in a maximum-likelihood procedure from young and aged normal hearing participants. J Acoust Soc Am 1998;103:553-65.
22. Abel SM. Duration discrimination of noise and tone bursts. J Acoust Soc Am 1972;51:1210-23.
23. Sangamanatha AV, Fernandes J, Bhat J, Srivastava M, Prakrithi SU. Temporal resolution in individuals with and without musical training. J Ind Speech Hear Assoc 2012;26:27-35.
24. Harris KC, Eckert MA, Ahlstrom JB, Dubno JR. Age-related differences in gap detection: Effects of task difficulty and cognitive ability. Hear Res 2010;264:21-9.
25. Desloge JG, Reed CM, Braida LD, Perez ZD, Delhorne LA. Temporal modulation transfer functions for listeners with real and simulated hearing loss. J Acoust Soc Am 2011;129:3884-96.
26. Roth DA, Kishon-Rabin L, Hildesheimer M. Auditory backward masking and the effect of training in normal hearing adults. J Basic Clin Physiol Pharmacol 2001;12:145-59.
27. Pinheiro ML, Musiek FE. Sequencing and temporal ordering in the auditory system. In: Musiek FE and Pinheiro ML, eds. Assessment of central auditory dysfunction: foundations and clinical correlates. Baltimore: Williams and Wilkins; 1985. pp 219-38.
28. Song JH, Skoe E, Wong PCM, Kraus N. Plasticity in the adult human auditory brainstem following short-term linguistic training. J Cog Neurosci 2008;20:1892-902.
29. Lappe C, Trainor LJ, Herholz SC, Pantev C. Cortical plasticity induced by short-term multimodal musical rhythm training. PLoS One 2011;6:e21493.
30. Spiegel MF, Watson CS. Performance on frequency discrimination tasks by musicians and non musicians. J Acoust Soc Am 1984;76:1690-95.
31. Monteiro RAM, Nascimento FM, Soares CD, Ferreira MD. Temporal resolution abilities in musicians and no musicians violinists. Int Arch Otorhinolaryngol 2010;14:302-08.
32. Ohnishi T, Matsuda H, Asada T, Aruga M, Hirakata M, Nishikawa M, et al. Functional anatomy of musical perception in musicians. Cereb Cortex 2009;11:754-60.
33. Flohr JW. Short-term music instruction and young children's developmental music aptitude. J Res Mus Edu 1981;29:219-23.

The effect of short-term musical training on speech perception in noise

Chandni Jain,[1] Hijas Mohamed,[2] Ajith Kumar U.[1]

[1]Department of Audiology, All India Institute of Speech and Hearing, Manasagangothri, Mysore; [2]Hero Electronic, Siemens Best Sound Centre, Coimbatore, Tamil Nadu, India

Abstract

The aim of the study was to assess the effect of short-term musical training on speech perception in noise. In the present study speech perception in noise was measured pre- and post- short-term musical training. The musical training involved auditory perceptual training for raga identification of two Carnatic ragas. The training was given for eight sessions. A total of 18 normal hearing adults in the age range of 18-25 years participated in the study wherein group 1 consisted of ten individuals who underwent musical training and group 2 consisted of eight individuals who did not undergo any training. Results revealed that post training, speech perception in noise improved significantly in group 1, whereas group 2 did not show any changes in speech perception scores. Thus, short-term musical training shows an enhancement of speech perception in the presence of noise. However, generalization and long-term maintenance of these benefits needs to be evaluated.

Correspondence: Ajith Kumar U., All India Institute of Speech and Hearing, Mysore - 570 006, India.
E-mail: ajithkumar18@gmail.com

Key words: short term music training, speech perception in noise.

Acknowledgements: the authors would like to express gratitude to the Director, AIISH and HOD-Audiology for permitting us to carry out this research.

Contributions: CJ, data collection, data analysis and interpretation, manuscript preparation; HM, data collection (music training) and interpretation; AKU, study conception and design, manuscript preparation.

Conflict of interests: the authors report no conflict of interests.

Received for publication: 12 July 2014.
Revision received: 20 November 2014.
Accepted for publication: 20 November 2014.

Audiology Research 2015;5:111
doi:10.4081/audiores.2015.111

Introduction

Pitch, timing, and timbre are the basic elements of both speech and music. Therefore, expertise in music may help in processing of pitch, timing, and timbre and will enhance speech perception.[1] This could be due to shared neural pathways for both speech and music. Long-term musical practice has been found to result in enhancement of various auditory and cognitive skills such as auditory attention[2] auditory stream segregation,[3] processing of emotion in speech,[4] working memory,[5] temporal resolution abilities[6] and processing of prosody and linguistic features in speech.[7] Studies have demonstrated that musicians have better processing of speech in noise compared to non-musicians.[8,9]

Parbery-Clark *et al.*[8] studied speech in noise perception in musicians and non musicians using HINT and Quick-SIN in younger adults. They reported that musicians had higher speech in noise scores compared to non-musicians. Similar results have also been reported for brain stem responses.[10] They studied the effect of musical experience on the neural representation of speech in noise in a group of trained musicians and compared it with non musicians. Results showed that speech evoked auditory brainstem responses were robust and had early response time in the presence of noise for musicians.

These long-term effects have been attributed to music induced plastic changes in the cortical and sub-cortical neurons. It has been shown that musical training induces plastic changes in the sub cortical and cortical auditory system and strengthens cortical and sub cortical mechanisms of auditory processing.[11,12] It induces both structural and functional changes in the auditory system. Gaser and Schlaug[12] found that gray matter (cortex) volume was highest in professional musicians (practices for at least 1 h per day), intermediate in amateur musicians, and lowest in non-musicians in several brain areas involved in playing music: motor regions, anterior superior parietal areas and inferior temporal areas. Also, at the sub cortical level, musicians have higher brain stem amplitudes for both music and speech when compared to non-musicians.[13]

Thus, the effects of musical training on brainstem processing demonstrates top down modulation and shows enhancement not only in musical sound processing, but also in speech encoding and other non-musical neural functions. Even though there are specific areas in the brain for processing music and speech[14,15] shared mechanisms are also used to process sound in both domains.[16,17] These shared mechanisms can account for the structural[12,13] and functional[18,19] enhancements for auditory processing of speech because of long-term musical training.[15,20,21]

Thus, it is evident that there is a functional and an anatomical difference in the auditory system between musicians and non-musicians and musicians have enhanced auditory perception and speech perception in noise. However, these positive effects have been demonstrated only on those musicians who have undergone long-term formal training in music. Thus, it would be interesting to see whether these advantages would extend for short-term perceptual musical exposure also. Therefore, the present study was taken up to evaluate the perceptual changes in the auditory system, if any, due to short-term perceptual music training. This study measured the effect of short term auditorily perceptual training of two Carnatic ragas on auditory system. Furthermore, this study also measured the effect of short-term perceptual training of music on speech perception in noise.

Materials and Methods

Participants

To fulfill the objectives of the study, two groups of participants were included within the age range of 18-25 years. Participants selected randomly from University College did not undergo any formal musical training. Participants in group 1 consisted of ten adults (7 males, 3 females) and were same as those participated in our earlier study (Jain, Mohamed & Kumar, 2014; in press). Participants in group 2 consisted of eight adults (5 females, 3 males). Participants in group 1 underwent musical training and no musical training was given for participants in group 2. All participants had normal hearing sensitivity, as indicated by their four-frequency (500 Hz, 1000 Hz, 2000 Hz and 4000 Hz) pure-tone average threshold of ≤15 dB HL and *A* type tympanogram with acoustic reflex thresholds in normal limits (90 dB at 1000 Hz). Participants selected for the study did not have any complaints of difficulty in understanding speech either in quiet or in the presence of background noise. They were amateur or a rare listener of Indian classical music, which was ascertained from a structured interview. All the listeners' participation was voluntary and they were not paid for their participation in the study. Ethical clearance was obtained from the relevant ethics committee at the institute prior to commencement of experimentation.

General procedure

Written consent was taken from all the participants for willingly participating in the study. The study was carried out in three stages. In first stage, speech perception in the presence of noise was assessed for both groups. In the second stage, auditory perceptual training was given for raga identification only for group 1 participants. In the third stage, speech perception in noise was assessed again for both groups. Figure 1 shows the block diagram of the experiment. Raga identification by listening to small excerpts of music was also done for group 1 in both pre training and post training phase.

Phase I. Pre training assessment

Phase I involved assessment of speech in noise testing for participants in both group 1 and group 2.

Speech perception in noise

Speech perception in noise was evaluated by measuring signal to noise ratio (SNR) required to understand 50% of the presented speech (SNR-50)[22] in Kannada. SNR 50 was measured in the presence of four talker babble under the earphones (Sennheiser HD 449). Test consisted of 7 equivalent lists and two different lists were used in pre-training and post-training assessments to measure SNR 50. This design ensured that observed results are not due to familiarity or practice effect. Each list contained seven sentences with five key words each. All the sentences in the test were homogenous and the key words were assessed for familiarity. The signal to noise ratio decreased from +8 dB SNR to -10 dB SNR in 3 dB steps from sentence 1 to 7 in each list. The participants were instructed that they will be presented with sentences in Kannada in the presence of multi-talker babble in the background at different SNRs and they were asked to write the target sentences. The number of correct key words identified was counted at each SNR. The SNR-50 was calculated using the Spearman-Karber equation[23] as:

$$\text{SNR-50} = I + \tfrac{1}{2}(d) - (d)(\#\ \text{correct})/(w) \qquad (1)$$

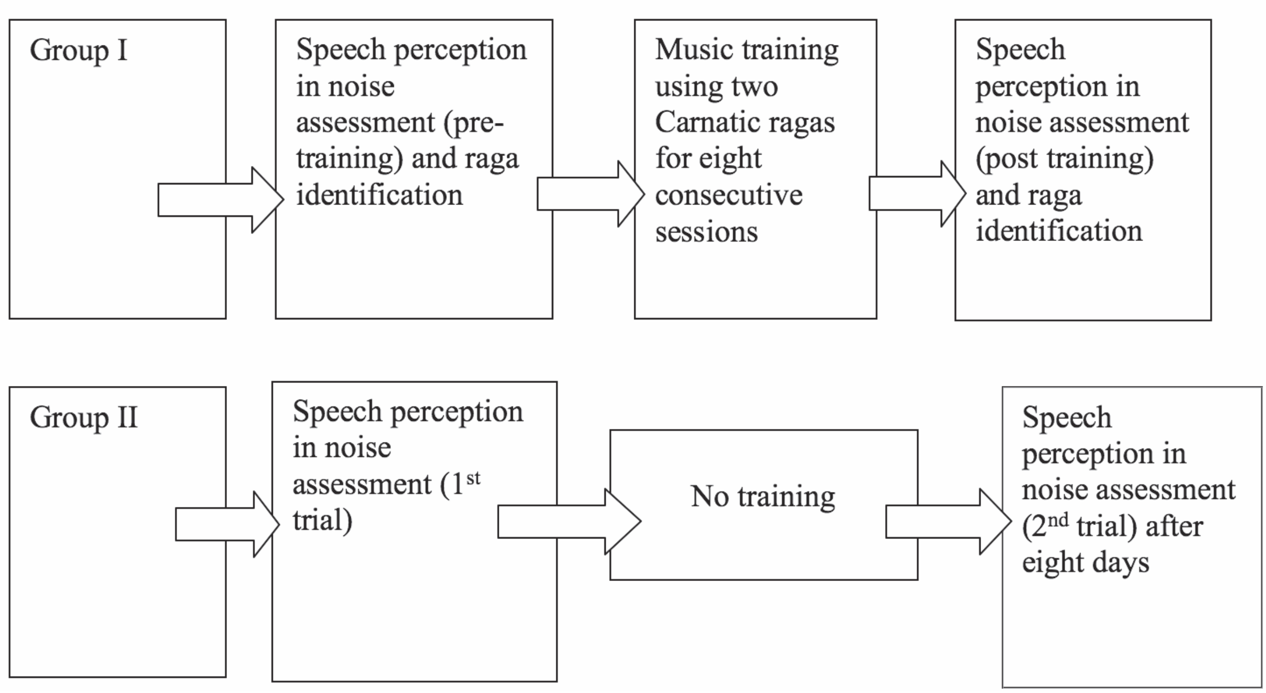


Figure 1. Block diagram of the experiment.

where:
I = the initial presentation level (dB S/B);
d = the attenuation step size (decrement);
w = the number of key words per decrement;
# correct = total number of correct key words.

Phase II. Training

After pre training assessment musical training in auditory mode was given to the participants in group 1. During the training, participants listened to 15 min composition of two Carnatic ragas (*Kalyani* and *Mayamalavagola*) with the help of a personal computer through high fidelity headphones (Sennheiser HD 449) everyday. Stimuli consisted of violin compositions from both the ragas. These two are the basic ragas of South Indian classical music wherein *Mayamalavagola* is a *shudh madhyam raga* and *Kalyani* is a *prati madhyam raga*. Also the frequency of 2nd note (ri), 4th note (ma) and 6th note (da) differs in both the ragas.[24] A Carnatic violinist with more than 15 years of experience and who had passed *senior level* music examination and practices for at least 2 to 3 hours daily was selected to play the two ragas. He was asked to play several sample songs in both *Kalayani* raga and *Mayamalavagola* raga each lasting for about 15 min. After each training session participants were made to listen to small music excerpts from both the ragas and were instructed that whenever they hear the excerpts from *Kalyani* raga they had to identify the raga as *Kalyani*. Similar task was performed for *Mayamalavagola* raga, too. In training sessions, participants were given immediate feedback about their responses. Training was given for eight consecutive days.

Phase III. Post training evaluation

At the end of the 8th day of the training session post training assessment was done using the same test mentioned in phase I of the study for group 1 and it was also done after 8 days for group 2 participants who did not undergo any musical training.

Results

Effect of musical training on speech perception in noise was assessed

Mean and one-standard-deviation error bars of SNR-50 in pre-training and post-training conditions for group 1 participants are shown in Figure 2. In order to find the significance of the difference in means between pre and post-training conditions, a Wilcoxon signed rank test was performed between the pre-training and post-training SNR-50. Results showed that there was a significant improvement in SNR-50 after musical training (Z=3.059, P<0.05). Mean and one-standard-deviation error bars of SNR-50 were also assessed for group 2 participants in trial 1 and trial 2 are shown in Figure 3. In order to find the significance of the difference in means of SNR-50 between the two conditions a Wilcoxon signed rank test was performed. Results showed that there was no significant change in SNR-50 in the two trials (Z=-0.828, P>0.05).

Correlation between raga identification and SPIN scores

Spearman correlation was done to assess the correlation between the ability of the subject to recognize the type of raga and speech in noise score. The difference in pre training scores and post training scores of raga identification and speech in noise was calculated for each individual and it showed positive correlation of 0.63. This shows that as the scores in raga identification improved, there was also an improvement seen in speech in noise scores. Figure 4 shows the scatter plot of both the variables.

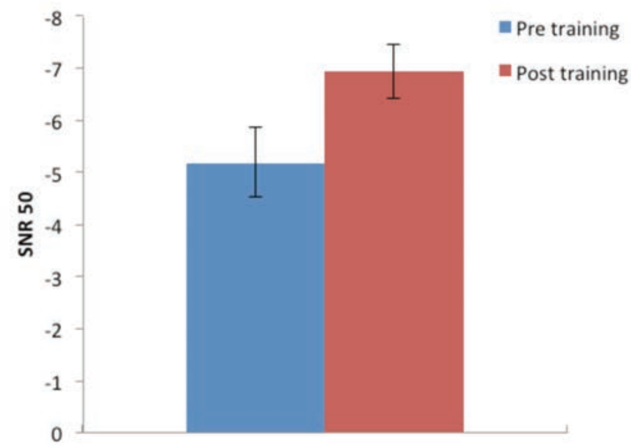


Figure 2. Mean scores and one-standard-deviation error bars for SNR-50 in pre-training and post training conditions.

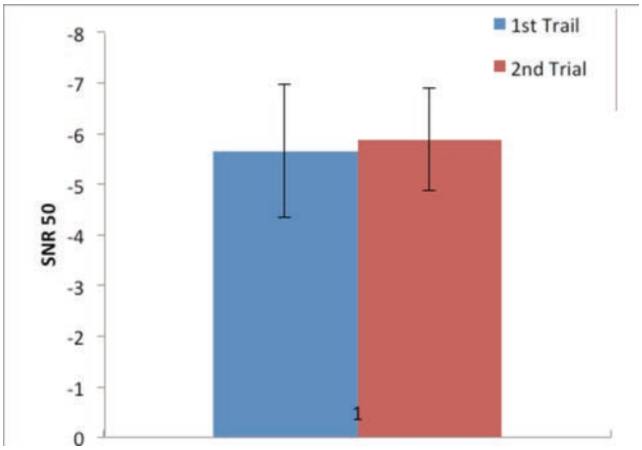


Figure 3. Mean scores and one-standard-deviation error bars for SNR-50 in trial 1 and trail 2 conditions.

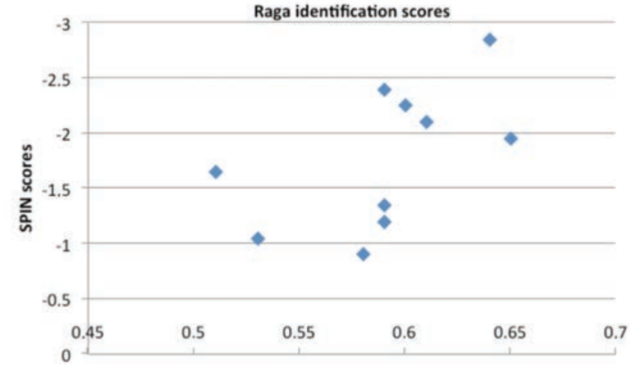


Figure 4. Scatter plot of raga identification scores and SPIN scores.

Discussion

The aim of the present study was to document the effect of short term musical training on speech perception in noise. Ragas in Carnatic music have specific note sequences which can be identified by trained musicians. The results of the present study showed that with short-term perceptual training, even non-musicians can learn to identify these ragas and good correlation was seen between the ability to identify ragas and speech perception in noise scores. Furthermore, the results also indicated that short term perceptual training of music resulted in improved speech perception in noise.

Similar results have been reported in the past and have shown that long-term musical training results in enhanced performance in perceptual identification of music and listening in background noise.[8-10] Parbery-Clark *et al*.[10] investigated speech perception in noise, working memory and frequency discrimination on musicians and non-musicians. The results revealed that musicians outperformed non-musicians on all the tasks. The authors concluded that long-term musical experience could enhance speech in noise performance, working memory and frequency discrimination. There was also a positive correlation between the speech perceptions in noise and working memory performance, which suggests that there lies a shared mechanism for the processing of the two.

Strait and Kraus[9] studied speech perception in noise and auditory attention in musicians and non-musicians. The result revealed that the speech perception in noise and auditory attention was superior in musicians when compared to non-musicians and there was a positive correlation between the perception of speech in noise and auditory attention. Strait *et al*.[2] studied the effect of long-term musical training on auditory attention tasks and the results indicated an enhanced auditory attention performance in musicians when compared to non-musicians.

However, all the above-mentioned studies have taken trained musicians to compare speech perception in noise. To the best of our knowledge, the effect of short-term music training on speech perception in noise has not been studied and the present study shows that even short term training can improve speech perception in noise. Furthermore, in the present study the speech perception in noise scores after a gap to assess long-term effects of perceptual training could not be done as the part of the study due to time constraints.

Conclusions

Short-term perceptual musical training shows an improvement in the identification of ragas and enhancement of speech perception in the presence of noise. However, generalization and long-term maintenance of these benefits needs to be evaluated.

References

1. Anderson S, Kraus N. Sensory-cognitive interaction in the neural encoding of speech in noise: a review. J Am Acad Audiol 2010;21:575-85.
2. Strait DL, Kraus N, Parbery-Clark A, Ashley R. Musical experience shapes top-down auditory mechanisms: evidence from masking and auditory attention performance. Hear Res 2010;261:22-9.
3. Beauvois MW, Meddis R. Time decay of auditory stream biasing. Perc Psych 1997;59:81-6.
4. Strait D, Kraus N, Skoe E, Ashley R. Musical experience and neural efficiency: effects of training on subcortical processing of vocal expressions of emotion. Eur J Neurosci 2009;29:661-8.
5. Chan AS, Ho YC, Cheung MC. Music training improves verbal memory. Nature 1998;396:128.
6. Monteiro RAM, Martins Nascimento F, Debus Soares C, Dornelles da Costa Ferreira MI. Temporal resolution abilities in musicians and no musicians violinists. Intl Arch Otorhinolaryngol 2010;14:302-8.
7. Wong PCM, Skoe E, Russo NM, Dees T, Kraus N. Musical experience shapes human brainstem encoding of linguistic pitch patterns. Nat Neurosci 2007;10:420-2.
8. Parbery-Clark A, Skoe E, Lam C, Kraus N. Musician enhancement for speech in noise. Ear Hear 2009;30:653-61.
9. Strait DL, Kraus N. Can you hear me now? Musical training shapes functional brain networks for selective auditory attention and hearing speech in noise. Front Psychol 2011;2:113.
10. Parbery-Clark A, Skoe E, Kraus N. Musical experience limits the degradative effects of background noise on the neural processing of sound. J Neurosci 2009;29:14100-7.
11. Schlaug G, Forgeard M, Zhu L, Norton A, Winner E. Training-induced neuroplasticity in young children. Ann N Y Acad Sci 2009;1169:205-8.
12. Gaser C, Schlaug G. Brain structures differ between musicians and non-musicians. J Neurosci 2003;23:9240-5.
13. Musacchia G, Sams M, Skoe E, Kraus N. Musicians have enhanced subcortical auditory and audiovisual processing of speech and music. Proc Natl Acad Sci U S A 2007;104:15894-8.
14. Abrams DA, BhataraA, Ryali S, Balaban E, Levitin DJ, Menon V. Decoding temporal structure in music and speech relies on shared brain resources but elicits different fine scale spatial patterns. Cerebral Cortex 2010;21:1507-18.
15. Rogalsky C, Rong F, Saberi K, Hickok G. Functional anatomy of language and music perception: temporal and structural factors investigated using functional magnetic resonance imaging. J Neurosci 2011;31:3843-55.
16. Fedorenko E, Patel A, Casasanto D, Winawer J, Gibson E. Structural integration in language and music: evidence for a shared system. Mem Cog 2009;37:1-9.
17. Slevc LR, Rosenberg JC, Patel AD. Making psycholinguistics musical: self-paced reading time evidence for shared processing of linguistic and musical syntax. Psychon Bull Rev 2009;16:374-81.
18. Marques C, Moreno S, Castro SL, Besson M. Musicians detect pitch violation in a foreign language better than non-musicians: behavioral and electrophysiological evidence. J Cogn Neurosci 2007;19:1453-63.
19. Moreno S, Marques C, Santos A, Santos M, Castro SL, Besson M. Musical training influences linguistic abilities in 8-year-old children: more evidence for brain plasticity. Cerebral Cortex 2009;19:712-23.
20. Koelsch S, Gunter TC, von Cramon DY, Zysset S, Lohmann G, Friederici AD. Bach speaks: a cortical “language-network” serves the processing of music. Neuroimage 2002;7:956-66.
21. Zatorre RJ, Gandour JT. Neural specializations for speech and pitch: moving beyond the dichotomies. Philos Trans Royal Soc London Ser B Biol Sci 2008;363:1087-104.
22. Methi R, Avinash, Kumar UA. Development of sentence material for Quick Speech in Noise test (Quick SIN) in Kannada. J Ind Sp Hear Assoc 2009;23:59-65.
23. Finney DJ. Probit analysis. Cambridge: Cambridge University Press; 1952.
24. Srikanthan RK, Srinivas IMJ, Sharade T, Rudrapatnavi SP, Vasantha M. Sarvajanik shiksha iilake. Government of Karnataka; 2002.