RELATIONSHIP BETWEEN AUDITORY TEMPORAL PROCESSING AND WORKING MEMORY

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Register No. 10AUD025

A Dissertation Submitted in Part Fulfillment of Final Year

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May 2012.

CERTIFICATE

This is to certify that this dissertation entitled **"Relationship between auditory temporal processing and working memory"** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No.: 10AUD025. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this Master's dissertation entitled **"Relationship between auditory temporal processing and working memory"** is the result of my own study under the guidance of Dr. Ajith Kumar U., Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

Mysore Register No. 10AUD025.

May, 2012

Dedicated to the colours of my life…

Mummy,

Daddy,

Ronak,

Chan Aunty

& Amma

Acknowledgements

God cannot reach everywhere... So he created Parents on Earth!

Parents are the living God…!!

Thank you, mummy daddy for your love throughout my life.

Ronak (My brother and my major support). You are my first friend in my life. Thanks for all the care and support.

Chan Aunty… You have been my second mother. Thank you is a very small word to acknowledge you. You are like a backbone to me. I wouldn't have been able to survive in Mangalore without your support.

Amma… Thank you for supporting and pampering your granddaughter always, regardless of whether I was right or wrong.

I would like to thank my guide Dr. Ajith Kumar U. for your constant guidance. You have been an idol and a mentor. Thank you for your abundant patience in guiding me.

I would like to pay homage to our ex-director Dr. Vijayalakshmi Basavaraj. We miss you ma'am. I also thank our Director Prof. S. R. Savithri for permitting me to carry out this study.

I would like to express gratitude to Dr. Animesh Barman for letting me take the instrument outside the campus for data collection.

Thanks to all the thatha s and ajji s who wholeheartedly agreed to participate in the study.

Special thanks to Sujit Sir for tolerating all my questions. I have seen you as my lecturer since the day I stepped in Speech and Hearing. Thank you for sowing the seed of Audiology in my mind.

Special thanks to Rajalakshmi ma'am. You are like a motherly figure to me. Another round of pysam is still pending ma'am.

I would like to thank all the staff in AIISH for the immense knowledge shared in the class and clinics.

I would like to thank my staffs in KMC who have laid my foundation in Audiology. Special thanks to Nambi Sir for helping me with MATLAB. Special thanks to Radish Sir, the few papers that I have presented is only and only because of you Sir. Special thanks to Sangam Sir for tolerating me. Thank you for your academic and emotional support.

Shwetha, Rekha and Kruthika: Thank you for helping me in my hunt for geriatrics. Shwetha without your help I would have never been able to finish my data collection.

I would like to thank Dr. Sandeep M. for permitting me to use the word list.

Deepashree: Thanks for lending me your word list.

Nisha: Thanks for the timely help.

Special thanks to Praveen for keeping your work aside and helping me.

Very special thanks to Dakshyini ma'am for providing me the correct directions and locations in the department.

I would like to thank all my relatives for encouraging me throughout my school days and college. Special thanks to Shashi aunty Vijay uncle, Jug uncle Sham aunty, Yashodha aunty and uncle.

Amit Bhai, Ajit Bhai, Ammu, Deepthi Akka, Divya Akka, Dhiren Anna thanks to all you guys for your love, care and masti. You all are the best cousins ever.

> *"Each friend represents a world in us, a world possibly not born until they arrive, and it is only by this meeting that a new world is born."*

-Anais Nin

Prakrithi, Christina, Sweta, Nita, Prasanna, Vikas… You all make my world.

Pakru- The Snail… You are like some Mother India, ready to help anyone anytime anywhere. Thank you for being with me for all the four years in KMC and bearing all the tortures I gave you there.

Chris- Beauty without Brains… thanks for adding the craziness in my life.

Viki (The bestest)- I'm in short of words to thank you. So I chose not to thank you. Thank you for bearing all my overacting for these 3 years.

Nita (The crisis queen)… without you I would have starved to death in the hostel. Thank you for taking care of my nutritive needs in the hostel.

Sweta (The unimodal turning multi now)… Actually you need to thank me for tolerating your unimodality. Anyways… you are the most genuine and funniest person I have ever met.

Pras… (the photographer, my friend, my brother)… you have played so many roles in my life… thanks for capturing all the cherish able moments we spent in AIISH.

Shabnam… thanks for being a part of my life.

Special thanks to Neha, and Aakash… You both have got a special place in my life in such a short time.

Life without pulling legs of juniors is boring… Thanks to my cute little angel Anumita for all her hyperactive behaviours which amazed me always. Rashika, Shalini, Preeti and Shruthi you all are like my little sisters. God bless you all.

Special thanks to Priyanka Parakh di… you have always made me feel much protected and secured in the hostel.

Thanks to my juniors at KMC Nikita, Shrunga, Amar, Livingstone for all the beautiful memories in Mangalore. Thanks to my seniors Pearl, Ashwini for all the fun while ragging. Muthu, Ritchie, Hassan… you people are fun to be with. Special thanks to my KMC classmates Payal, Anshul, Neitica… Our class rocked..!!

Special thanks to Mahima and Vinsha (my neighbours)… Thanks for always making me feel that all three of us sail in the same boat, and consoling me that you both are also in equally pathetic condition like me.

Mahima… Thanks for showing me your dirty coloured graphs early in the morning.

Special thanks to Shanthi (yee.. tu free hai kyaaa..) for always interrupting me while I work.

Thanks to Jaslin, Shabnam, Pratibha, Swathee, Nimisha, Mona (Corridor mates) to keep the corridor lively and happy.

Special thanks to Merry for patiently tolerating me, Seby for supporting in all possible childish pranks in the hostel and Shachi for your areyy.. chod na, jo ho gaya kal dekha jayega mein sone ja rahi hu attidue…

Thanks to all my dear classmates in AIISH. Thank you for the warm welcome I got in AIISH.

Very special thanks to FACEBOOK for providing me a platform for expressing my emotions both happiness and frustration during the making of the dissertation…

Last but not the least thanks to the books, journals in the library and AIISH digital library because of which writing my dissertation was possible.

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CHAPTER 1

INTRODUCTION

The auditory system analyses sound signal in three basic domains- frequency, intensity and time. Time is an important domain in hearing since most of the sounds fluctuate over time. The perception of the temporal characteristics of a sound or the alteration of durational characteristics within a restricted or defined time interval is called temporal processing (Musiek et al., 2005).

Temporal processing abilities are known to be of crucial importance in daily listening environment. Perception of temporal parameter of sound is important for a wide range of auditory behaviours including rhythm perception, periodicity pitch discrimination, duration discrimination and phoneme discrimination. Furthermore, temporal processing plays a crucial role in language comprehension, perception of prosodic distinctions and speech perception in ambiguous conditions (Chermak & Musiek, 1997). Speech perception becomes poorer in the presence of noise since the presence of noise reduces the temporal variation of the waveform by filling the valleys of the amplitude spectrum which leads to ambiguity in speech. Timing approximation requires some amount of cognitive skills too (Gooch, Stern & Rakitin, 2009). Some researches indicate the associations among working memory, timing, and aging (Brown, Vousden & McCormack, 1999; Baudouin, Vanneste, Pouthas & Isingrini, 2006).

Working memory enables an individual to temporarily store the information and manipulate it if necessary. Broadway and Engle (2011) reported that individuals with low working memory capacity were less sensitive compared to individuals with high working memory in temporal discrimination tasks. Functional magnetic resonance imaging experiments have revealed prefrontal cortex activation when retrieving temporal context information (Rajah, Ames & D'Esposito, 2008). Prefrontal cortex also controls the working memory (Kane & Engle, 2002). Thus, both the temporal processing and working memory skills share a common anatomical site. Hence, it can be hypothesized that temporal processing abilities depend on cognitive functions such as working memory of the individual.

Aging is a natural process which affects all the systems of the body including the auditory system. Age related changes occur anatomically and physiologically as well as peripherally and centrally. Psychophysical evidence documents a broad decline in a variety of auditory abilities because of chronological aging (Zec, 1995). The geriatric group appear to have poorer frequency discrimination compared to adults. Geriatrics with normal hearing thresholds exhibit larger intensity discrimination thresholds with the largest age related changes occurring for the low frequency tones (Murphy, Bruce, Filippo & Giampaolo, 2006). Hence, aging causes auditory processing deficits. Thus, deterioration in temporal processing is not unexpected.

Parra, Iorio, Mizahi and Baraldi (2004) reported that the elderly individuals with normal hearing have temporal patterning ability less than young subjects with normal hearing. Kumar and Sangamnatha (2011) studied extensively gap detection thresholds, duration discrimination, modulation detection thresholds and duration pattern scores across different age groups spanning from 20 years to 85 years. They stated that there was deterioration in scores in all the temporal processing skills as age advanced. The maximum decline was observed in the 60 years and above age group. Daniels (2011) used electrophysiological measures to assess gap detection thresholds in adults and geriatrics. The geriatric group showed delayed P2 latency compared to the young adults. The geriatric group also had an overall poor wave morphology compared to adults.

Aging causes an overall decline which also includes the working memory abilities. Age related decrements are found in working memory tasks (Light & Anderson, 1985; Spilich, 1983; Wright, 1981). The decline in the working memory is evident when the complexity of the task is increased. There is an increase in the time required to respond by the geriatrics as compared to the adults as the grammatical complexity of the sentence was increased (Gick, Craik & Morris, 1988; Baddeley & Hitch, 1974).

Supporting evidences for the decline in temporal processing and working memory with the age also comes from speech perception studies that have used complex and acoustically degraded speech stimulus. It has been reported that geriatrics experience increased difficulty in understanding speech in noise (Cooper & Gates, 1991). This difficulty in perception may be because of the reduced temporal information received by the listener due to the noise (Tremblay, Piskosz & Souza, 2003). Speech perception in the presence of noise also requires memory (Zacks, Hasher & Li, 2000) since it demands the ability to filter out irrelevant competing noise (Tun & Wingfield, 1999; Tun, O'Kane & Wingfield, 2002).

Need for the study

Several studies have demonstrated that temporal processing and speech perception abilities decline with age even when the hearing thresholds are within normal limits (Kumar & Sangamnatha, 2011; Gordon-Salant & Fitzgibbons, 1995; Cruickshanks et al., 1998). One of the factors that influence speech perception and temporal processing abilities is the working memory (Broadway & Engle, 2011; Wong et al., 2009). Age-related decline in speech perception in noise may be supplemented by increased usage of general cognitive abilities like working memory and attention as a means of compensation for these declines (Wong et al., 2009). Therefore, geriatrics who experience decline in memory or attention are particularly affected by decrease in speech perception (Shinn-Cunningham & Best 2008). Hence, the present study was taken up to assess the possible effect of aging on temporal processing, working memory and speech perception in noise and the relationship among these dependent variables.

Statement of the problem

The present study aims to evaluate the temporal processing abilities, working memory skills and speech perception in noise in adults and geriatrics. Furthermore, the study also assesses the relationship between cognitive abilities and temporal processing. Specifically, this study assesses the gap detection in noise, modulation detection thresholds, duration pattern scores and speech perception in noise in young and geriatrics with normal hearing sensitivity. Working memory was assessed using digit forward, digit backward and operation span task. These working memory measures were chosen as all the three measures are well studied in the literature

(Morris, Gick & Craik, 1988) and are quick and easy to administer (Smith et al., 2001).

Aim of the study

The aim of the study is to assess the effect of aging on auditory temporal processing, speech perception abilities and working memory.

Objectives

1. To measure gap detection in white noise, modulation detection thresholds, duration pattern scores and speech perception in noise in adults and geriatrics with normal hearing sensitivity.

2. To measure working memory abilities in adults and geriatrics with normal hearing sensitivity.

3. To assess the relationship among working memory, speech perception in noise and temporal processing in adults and geriatrics with normal hearing sensitivity.

CHAPTER 2

REVIEW OF LITERATURE

Auditory temporal processing may be defined as the perception of the temporal envelope or the alteration of durational characteristics of a sound within a restricted or defined time interval (Musiek et al., 2005). Normal temporal processing is necessary for most of our auditory processing capabilities including pitch perception, voice identification (Yost, Sheft & Opie, 1989) and speech perception (Strouse, Ashmead, Ohde & Grantham, 1998).

TEMPORAL RESOLUTION

Gap detection threshold

Temporal resolution refers to the ability to detect changes in acoustic stimuli over time (Szeto et al., 2008). It is defined as the shortest period over which an ear can discriminate two signals (Gelfand, 2004). Gap detection test is the most commonly used procedure for assessing temporal resolution. This test involves the presentation of two stimuli, one of which contains a short interruption. The listeners are asked to detect the gap in this otherwise continuous stimulus. The procedure intends to determine the smallest interval that a listener can detect. This is also known as the gap detection threshold (GDT). Shinn, Chermak and Musiek (2009) assert that gap detection is dependent on discontinuity in neural activity within the central auditory nervous system. In order to process gaps, the auditory system must be able to perceive a difference in the stimulus, hence perceiving a discontinuity (Phillips, 1999). This ability of detecting the gaps is critically important for phonemic distinctions such as voice-onset time (VOT), lexical and prosodic distinctions, and auditory closure (Chermak & Musiek, 1997). Detection of gaps also helps in the understanding of acoustically degraded speech (Gordon-Salant & Fitzgibbons, 1995; Irwin & McAuley, 1987; Snell, Mapes, Hickman & Frisina, 2002; Tyler, Summerfield, Wood & Fernandes, 1982).

Effect of aging on gap detection threshold

Psychophysical evidence documents a broad decline in a variety of auditory abilities because of chronological aging (Zec, 1995). The geriatric group appear to have poorer frequency discrimination compared to adults and this do not change with presentation level but changes with the frequency of presentation. Frequency discrimination is better at high frequencies than low frequencies (Frisina et al. 2000). Geriatrics with normal hearing thresholds exhibit larger intensity discriminations with the largest age related changes occurring for the low frequency tones (Murphy et al., 2006). Thus, deterioration in temporal processing is not unexpected.

Evidence for deterioration of temporal processing with age predominantly comes from studies on gap detection (Moore & Glasberg, 1988; Schneider, Pichora-Fuller, Kowalchuk & Lamb, 1994; Snell, 1997). These deficits in GDT are more pronounced for complex stimuli, or for increased task demands when compared to simple tonal stimuli (Gordon-Salant & Fitzgibbons, 1995). It has been demonstrated that temporal resolution ability varies as a function of age, with geriatrics demonstrating greater GDT than younger adults (Strouse et al., 1998; Kumar & Sangamnatha, 2011; Snell & Frisina, 2000; Roberts & Lister, 2004; Lister & Roberts, 2005). Geriatrics performed poorly than the young listeners with and without hearing loss (Lutman, 1991). Electrophysiological studies reveal that N1-P2 latency was prolonged and poor morphology was obtained in geriatrics compared to normal adults (Daniel, 2011).

Schneider et al. (1993) assessed the GDT in adults and geriatrics. They reported that GDT for the geriatric group was more variable and twice as compared to the younger age group and also did not correlate with the audiometric thresholds. Snell (1997) measured GDT for noise burst stimuli in younger and elderly listeners with normal pure tone thresholds and reported similar findings.

Lister, Besing and Koehnke (2002) measured gap discrimination across age. The gap discrimination scores were measured for adults, middle aged and geriatrics across 6 frequencies from 500 Hz to 2000 Hz. The results of the study revealed an overlap of scores for the adult and middle aged group but thresholds were elevated for the geriatric group. They suggest that gap discrimination requires between-channel processing across two or more perceptual channels and the measures requiring within-channel processing result in smaller gap thresholds than those that require between-channel processing. For geriatrics, gap discrimination may be more difficult than adults could be due to sharply tuned perceptual channels that compel listeners to use between-channel processing which increases their threshold. Shivaprakash and Manjula (2003) developed norms for GDT across different age groups from 7 to 7.11, 8 to 8.11, 9 to 9.11, 10 to 10.11, 11 to 11.11, 12 to 12.11 and 18 to 35.11 years. He reported there was no significant difference in the scores across the age groups. Thus, GDT matures before 7 years of age.

Baba and Rajalakshmi (2006) studied the effect of GDT on adults and geriatrics with normal hearing sensitivity. They reported a significant difference in both the groups separately for each ear. Lutman (1991) assessed the GDT across age in participants with and without hearing loss. He reported that geriatrics performed poorly than the young listeners even though the geriatrics did not have hearing loss.

Kumar and Sangamnatha (2011) studied extensively GDT across different age groups with normal hearing. The results revealed that the GDT in individuals above 70 years were, on an average, almost 8 fold greater than young adults (20-30 years). The results also indicated that the individuals above 40 years had significantly poorer GDT compared to 20-30, 31-40 years age groups. However, there were no significant differences between the mean GDT of 41- 50, 51-60 and 61-70 years age groups.

Daniels (2011) used electrophysiological measures to assess GDT in adults (19-26 years) and geriatrics (60-82 years) with normal hearing sensitivity. He elicited N1-P2 response for gaps as short as 5 ms. The geriatric group showed delayed P2 latency compared to the young adults with no change in N1 latency, N1amplitude or P2 amplitude. The geriatric group also had an overall poor wave morphology compared to adults.

All the studies mentioned have not considered the effect of other factors such as hearing loss, working memory etc. due to aging on GDT. Hence, in the present study this was taken care of while formulating the method and the influence of hearing loss and working memory was controlled.

Modulation detection threshold (MDT)

Another test widely used for assessing temporal resolution is the detection of amplitude modulation in a broadband noise. The auditory system is highly sensitive to small amplitude fluctuations. Sinusoidal amplitude modulation (SAM) consists of a carrier tone or noise, which periodically varies in amplitude in the same manner as the modulating sinusoid. The procedure is carried out at different frequencies of amplitude modulation typically from 4 Hz to 200 Hz. The listener is asked to detect which among the two stimuli contained the modulation. The function relating SAM detection thresholds to modulation frequency is called the temporal modulation transfer function (TMTF). The detection of modulation is crucial for speech perception since modulation caused by specific vocal tract characteristics results in amplitude fluctuations in the speech waveform and this temporal envelope carries important information relevant to speech perception (Drullman, 1995; Shannon, Zeng, Wygonski, Kamath & Ekelid, 1995). The various factors that affect includes degree, configuration of hearing loss, age etc.

Effect of age on modulation detection threshold

Takahashi and Bacon (1992) assessed the MDT in adults and geriatrics with normal hearing. The modulation frequencies ranging from 2-1024 Hz were used. In the first experiment modulation frequencies from 2-1024 Hz and in the second experiment modulation frequency of 8 Hz was considered. A very weak correlation between age and modulation detection was seen at low modulation frequencies. There were no significant effects of age once the effect of hearing loss was taken into account. The results of the experiments suggest that subjects with even a mild sensorineural hearing loss may have difficulty with a modulation detection task.

He, Mills, Ahlstrom and Dubno (2008) assessed the age-related differences in the temporal modulation transfer function with pure-tone carriers on adults and geriatrics with normal hearing. The carrier frequencies were 500 and 4000 Hz were modulated at different frequencies. The results indicated that for younger subjects, the transition frequency was about 10% of the carrier frequency for both carriers. For the 4000 Hz carrier, MDT was generally constant up to 100 Hz, and then increased as modulation frequency further increased to the transition frequency. For the geriatric group, although transition frequencies were similar to those for the younger subjects, the shapes of the TMTFs differed. Below the transition frequency, geriatrics' MDT continuously increased for both carrier frequencies as modulation frequency increased from 5 Hz, suggesting an age-related decline in temporal resolution for faster envelope fluctuations. Thus, the study concludes that age related chances are observed in the TMTF.

Kumar and Sangamnatha (2011) assessed the MDT for sinusoidally amplitude modulated stimulus across 8, 20, 60 and 200 Hz modulation frequencies across different age groups. They reported that MDT for the higher modulation frequencies (60 & 200 Hz) deteriorated at an earlier age compared to low modulation frequencies (8 Hz & 20 Hz). The deterioration at lower modulation frequencies began at 60 years of age whereas the deterioration for 60 and 200 Hz began by 40 years. Thus, they concluded that the ability to detect modulations in the signal decline with age.

The presence of noise reduces the temporal variation of the waveform by filling the valleys of the amplitude spectrum. These amplitude variations in the temporal envelope of the speech signal and periodicity convey important information about syllable and phrase boundaries, voicing, and consonant identification (Price & Simon, 1984). Loss of temporal resolution might result in poor sensory evidence available to the listener and consequently in reduced phoneme and word identification. Consequently, geriatrics in spite of having normal hearing still complains of difficulty in perceiving speech in these conditions.

All the studies mentioned have not considered the effect of other factors such as hearing loss, working memory etc. on MDT. Hence, in the present study this was taken care of while formulating the method and the influence of hearing loss and temporal processing was controlled.

Temporal Patterning

Temporal patterning is the capacity to perceive accurately the presentation order of sound elements which is presumed to be an integral auditory ability required for processing complex forms of stimulation such as speech. Duration pattern score is an easy measure to assess temporal patterning. The stimulus consists of two durations in three-tone patterns forming six different patterns and the listeners are asked to verbally repeat the sequence. Temporal order judgements are essential for the grouping mechanisms to occur which in turn is important for the perception of sound sequences. The auditory stimuli that reach our ears do not contain separate information from different sound sources, but rather a combination of information from all sources, creating the need for parsing or grouping mechanisms to separate the incoming information into appropriate streams or auditory objects (Bregman, 1981). Trainor and Trehub (1989) reported temporal sequencing impairment in elderly listeners irrespective of the hearing loss. Geriatrics have slower cognitive processing (Salthouse, 1985) which could have led to difficulty maintaining the temporal coherence of sequences (Trainor & Trehub, 1989).

Effect of aging on temporal patterning

Parra et al. (2004) conducted a research on the performance of geriatrics in the temporal pattern test. Duration pattern was used to measure the temporal patterning ability. Geriatrics in the age range of 60-80 years with pure tone thresholds within 25 dB was included. Duration pattern was tested using a 1000 Hz tone of varying duration, the short tone being 250 ms and the longer one 500 ms. They reported a negative correlation between age and duration pattern scores i.e., with increase in age the percentage of correct scores in the tests decreased. Thus, the results of this study suggest that geriatrics with normal hearing have temporal patterning ability less than young subjects with normal hearing.

Kumar and Sangamnatha (2011) obtained duration pattern score across age groups from 20 to above 70 years. They reported no significant difference among mean duration pattern scores across the groups below 60 years. However, the 61-70 years age group & over 70 groups showed significantly poorer duration pattern scores compared to individuals below 60years. Additionally, it was also observed that the high frequency hearing impairment for the geriatric group did not significantly affect the duration pattern scores.

The above mentioned studies have considered separately the effect of aging on each of the temporal processing skills. Except for Kumar and Sangamnatha (2011) all the other studies mentioned have considered only one of the many aspects of temporal processing. All the aspects of temporal processing aren't studied together in one study. Thus, in the present study, this was taken care of while formulating the method and also the influence of hearing loss on temporal processing was controlled which wasn't considered in the previous studies.

Speech perception in noise

The most general characteristic of aging is difficulty perception of speech in the presence of noise (Bergman, 1980; Crandell, 1991; Gordon-Salant, 1987; Walton, Simon & Frisina, 2002). The relationship between pure-tone thresholds and speech in noise (SIN) perception is lesser in geriatrics (Hargus & Gordon-Salant 1995; Kim, Frisina, Mapes, Hickman & Frisina, 2005). The SIN scores fall below predicted scores as age increases (Souza, Boike & Witherell, 2007). The various reasons attributed to decline in SIN in geriatrics include hearing loss (Zekveld, Kramer & Festen, 2011), cognitive decline (Frisina & Frisina, 1997; Gordon-Salant & Fitzgibbons, 1997).

Effect of aging on speech in noise

Accurate subcortical representation of temporal information (is known to contribute to SIN perception (Hornickel, Skoe, Nicol, Zecker & Kraus, 2009; Tzounopoulos & Kraus 2009). Supporting evidences for the decline in SIN comes from temporal processing studies that have used complex and acoustically degraded speech stimulus. The decline in perception may be because of the reduced temporal information received by the listener due to the noise (Tremblay et al., 2003). The presence of noise reduces the temporal variation of the waveform by filling the valleys of the amplitude spectrum.

Takahashi and Bacon (1992) assessed the MDT in adults and geriatrics with normal hearing. The modulation frequencies ranging from 2-1024 Hz were used. Speech in noise was measured as a function SNR in an unmodulated background noise and in sinusoidal amplitude modulated background noise. The results revealed that geriatrics do not perceive speech in noise as good as normal hearing subjects do in a modulated noise background in spite of having normal hearing thresholds. Therefore, age-related decline in temporal processing may lead to decline in SIN perception.

Sommers (1997) studied the speech perception in noise in geriatrics. He reported that speech perception declines with age and he considered the reduction in hearing as the major reason for the decline. He also added that in less favourable listening conditions the cognition also plays a role in speech perception.

Conway, Cowan, & Bunting (2001) evaluated the influence of working memory in speech perception in noise. The adult participants were divided in to two groups- individuals with high working memory capacity (WMC) and individuals with low WMC based on OST scores. The results revealed that the individuals with low WMC performed poorly in the shadowing task as compared to the individuals with high WMC. Hence, working memory plays a role in SIN perception.

The selective attention supports the notion that individuals with greater WMC are better able to focus attention and avoid distraction (Colflesh & Conway, 2007). The working memory is responsible for maintaining activation to relevant information and suppressing the distracting information (Broadbent, 1958; Conway et al., 2001). Thus, cognitive abilities also influence SIN perception.

Colflesh and Conway (2007) assessed the individual differences in WMC and divided attention in the presence of a competing signal. The participants were divided in to two groups based on their WMC. The divided attention was assessed using SIN perception. They reported that participants with high WMC performed better in the divided attention task as compared to individuals with low WMC. Thus, we can conclude that SIN perception is influenced by working memory which declines with age.

Calais, Russo & Borges (2008) assessed the performance of adults and geriatrics in the presence of noise. They reported that geriatrics had difficult in the perception of speech in the presence of noise. They also reported that substitution errors were seen in the geriatrics irrespective of the hearing loss.

Zekveld et al. (2011) assessed the influence of age, hearing loss and cognitive decline on SIN. They reported that individuals with hearing loss showed poor speech recognition scores and with aging the SIN declined even when the audiometric thresholds were normal. An increase in the cognitive load was also reported which was measured through pupillometry which involves the examination of pupil dilation.

The studies mentioned above reveal that MDT and working memory has an influence on SIN. The other temporal processing and working memory measures were not considered in the study. Hence, this was taken in to account while formulating the method in the present study.

Working memory

Working memory is a system whose function is to temporarily store the information, manipulate and then retrieve it. One of the most widely supported theories in working memory is the controlled attention theory of working memory (Engle & Kane, 2004; Kane, Bleckley, Conway & Engle, 2001; Kane & Engle, 2002). According to which there is a general component of working memory responsible for guiding attention as well as domain specific components responsible for maintenance of task relevant information. Individuals with high WMC have better attention skills and can maximally make use of domain specific skills and strategies to aid maintenance (Colflesh & Conway, 2007). Working memory can be assessed by executing higher level cognitive tasks. Tasks such as digit recall, OST can be easily used to test the WMC and has high test reliability (Engle, Tuholski, Laughlin & Conway, 1999; Klein & Fiss, 1999).

Operation span task (OST)

The OST consists of a sequence of items, each item consisting of an equation and an unrelated word; the subject has to determine whether the equation is correct and then commit the word to memory, maintaining the words in order. This requires the individual to perform multi-tasks, which involves both math and memory processes. The task involves processing and storage. The subject applies task-specific arithmetic processes to the first equation, then adds a word to working memory, then processes the second equation while maintaining the working memory load, then updates working memory with the second word and so on. The cycle thus requires switching back and forth between task-specific processes and updating working memory. The construction of OST is such that it taxes the working memory and hence this test has high correlation with measures of higher-level cognition.

Digit span task

The digit span task involves the individual to repeat the clusters of digits were presented in same or backward order for digit forward and digit backward task respectively. Since the digit forward task involves the listener to immediately repeat the digits it taps the immediate memory of the listener. The digit backward task requires the listener to hold it in the memory manipulate the digits and then convey the digits in the reverse order, hence it assesses the working memory of the listener.

Young adults demonstrate good scores on working memory tasks but with increasing age all the functions decline. Advancing age impacts a number of cognitive functions too which includes perception, attention, memory, processing speed, and motor control (Craik & Salthouse, 2000).

Effect of aging on working memory

The concept of working memory (Baddeley & Hitch, 1974; Daneman & Carpenter, 1980) refers to tasks in which subjects must divide their attention between on-going processing and short-term storage. Therefore, age decrements should be found in working memory tasks, and this result has been reported by several authors (Light & Anderson, 1985; Spilich, 1983; Wright, 1981).

Morris et al. (1988) assessed the age differences in working memory. The subjects consisted of adults and geriatrics that underwent an OST. The participants were given a single sentence to verify as rapidly as possible while simultaneously repeating zero, two, or four unrelated words. At the end of each trial, the subjects recalled the word list in the original serial order. The difficulty of the task was varied by increasing the number of words to be held in mind and by varying the grammatical complexity of the sentence to be verified. The results indicated that geriatrics responded more slowly, and that increases in the memory load and in sentence complexity were associated with longer verification latencies. The verification and memory errors were not significantly different for both the groups. Thus, it can be concluded that age related decline is present in the working memory ability.

Hester, Kinsella and Ong (2004) assessed the digit forward and digit backward skills in adults and geriatrics. He reported that an age related decline in both digit forward and digit backward skills and that both the skills deteriorated to the same extent. They attributed the deterioration due to aging to the central executive component of working memory which also declines with age.

Thus, taking in to account the results of the previous studies it can be interpreted that age has a deleterious effect on both temporal processing and working memory. Age is inversely proportional to temporal processing and working memory. Since, this similar trend is observed in both there is a possibility of a relationship between temporal processing and working memory.

The studies stated have shown that OST majorly taps the higher cognitive skills and is a sensitive measure to assess WMC. Hence, OST was included in the present study.

Effect of working memory on auditory processing abilities

Many of the cognitive functions are thought to be components of the mechanism supporting interval time production. Previous results of studies of the influence of aging upon our ability to time short intervals have pointed to differences in attention (e.g., Lustig & Meck, 2001; Vanneste & Pouthas, 1999), or memory (Perbal et al., 2005; Rakitin, Scarmeas, Li, Malapani, & Stern, 2006; Rakitin, Stern & Malapani, 2005), and sometimes both (Baudouin, Vanneste, Isingrini, & Pouthas, 2006; Baudouin, Vanneste, Pouthas et al., 2006).

Broadbent (1958) developed a theoretical model of selective attention, according to which environmental stimulation is filtered out of awareness if it is identified as irrelevant to the subject's current concerns on the basis of its superficial physical features. Thus, this model reveals the significance of selective attention and memory on the perception of speech in the presence of unwanted stimuli. Conway et al. (2001) reported that working memory is responsible for maintaining activation to relevant information and suppressing the distracting information which is similar to the information quoted by Broadbent (1958). They conducted a study on the importance of working memory during cocktail party phenomena. Undergraduate students participated in the study. Half were categorized as having a high working-memory span and half a low working-memory span on the basis of scores that fell in the upper or lower quartile of a larger sample of subjects who carried out the OST.

Selective listening task was carried out using the stimuli which had an onset of the irrelevant message which began 30 sec after the attended message, allowing for a brief practice period without distraction. Subjects were instructed to listen to the message presented to the right ear and to repeat (shadow) each word as soon as it was presented, making as few errors as possible and to ignore the distractions coming to the left ear. Low-span subjects also encountered more difficulty performing the shadowing task. This is reflected in the finding that low-span subjects committed significantly more shadowing errors than the high span subjects. Thus, participants with a lower WMC stated difficulty in perceiving speech in the presence of competing signal.

Colflesh and Conway (2007) evaluated the individual differences in WMC and divided attention in dichotic listening. In this study they hypothesized that individuals with greater working memory capacity (WMC) are better able to control or focus their attention than individuals with lesser WMC. This relationship was studied in a selective attention paradigms i.e., the dichotic listening task. The sample comprised of 118 undergraduate students. The procedures used to measure WMC were adapted from versions of the OST and reading span task used by Kane et al. (2004). In order to assess the divided attention, each participant performed two tasks: divided attention-shadow and divided attention-no shadow. Participants completed the tasks at one of three SNRs:-8, 0, and +8. In the divided attention-shadow condition, participants were instructed to listen to the more relevant message (presented to the right ear) and to repeat (shadow) each word. Participants were informed that their name would be presented in the unshadowed message and upon hearing their name they should press the space bar. Prior to the divided attention- no shadow condition participants were informed that their name would be presented somewhere within the two messages they would listen to, and upon hearing their name, they should press the space bar. The name was always presented to the left ear. Unlike selective attention dichotic listening experiments, participants were not asked at the end of the experiment whether they heard their name. These results suggest that participants with greater WMC made fewer errors than participants with lesser WMC. The results of the present experiment revealed an opposite pattern, such that in the divided attention, shadowing task, 66.7% of high spans and 34.5% of low spans heard their name. The interpretation of the high span data is straightforward, i.e., these participants are better able to adjust the focus of attention according to task goals. They focus attention in the selective attention task, thus hearing their name less often, and they split their attention in the divided attention task, thus hearing their name more often. But, performance of low span participants was not as expected. They were actually less likely to hear their name. Thus, the result of this study was paradoxical to the Conway et al. (2001) study. A critical difference between Conway et al. (2001) selective attention task and the present divided attention task is the way in which one's name was detected. In the selective attention paradigm subjects were asked, after shadowing, if they thought they heard their name in the ignored message. In the divided attention task, participants were required to press the space bar immediately after detecting their name. Thus, in the selective attention task low spans are more susceptible to attention captured by a salient distractor and in the divided attention task they are less able to coordinate the demands of shadowing, listening for their name, and signalling name detection. Selective attention supports the notion that individuals with greater WMC are better able to focus attention and avoid distraction and the present results support the notion that individuals with greater WMC are better able to “zoom out” and divide attention.

Broadway and Engle (2011) studied the individual differences in WMC and temporal discrimination. A total of 52 individuals (27 high WMC, 25 low WMC) participated in the present experiment. Operation Span was used to assess WMC for verbal material. In this study, alphabets were used instead of words for recall along with equations. Symmetry Span was used to evaluate WMC for visual-spatial material. Participants judged whether black and white images were symmetrical, in between encoding the location in which a red square sequentially appeared in a 4*4 grid. Participants were prompted to report the square locations in order after 2-5 of these symmetry square events, by clicking on their choices in the cells of a 4*4 grid. The temporal discrimination task used the difference between comparison interval as 250 ms, 500 ms, or 750 ms on each trial which was randomly determined. Absolute durations of comparison intervals were multiples of the shortest comparison intervals (250 ms); the longest absolute duration was 2750 ms. Ravens matrices was also evaluated wherein the participants selected mouse the figure that would best complete an incomplete abstract pattern. The results revealed that discrimination sensitivity increased monotonically for both WMC groups as duration differences increased. High WMC group were better able to discriminate the longer of two temporal intervals than low WMC across the range of duration differences. The results are consistent with predictions from a recent theory proposing that individual differences in WMC are closely related to the ability to discriminate events by their temporal relations (Zakay & Block, 1997; Grondin, 2010).

Thus, working memory plays has an influence on the temporal processing and speech perception abilities. All these studies point towards the role of selective attention in working memory. Previous studies also support the fact that selective listening is a pre requisite for hearing in the presence of competing signal. Therefore, it can be concluded that working memory has an effect on speech perception abilities. Hence, decline in working memory may lead to reduction in the speech perception and temporal processing abilities.

CHAPTER 3

METHOD

Participants

A total of 60 participants contributed to the present research. The participants were divided into 2 groups. Group I consisted of 30 young adults in the age range of 18-30 years. The Group II consisted of 30 normal hearing geriatric individuals in the age range of 60-70 years. Normal hearing sensitivity was operationally defined as audiometric thresholds within 15 dB HL in octave frequencies from 250 Hz to 2 kHz and thresholds within 30 dB HL at 4 kHz and 8 kHz. A brief case history was noted before initiating the study. The participants with history of middle ear pathology or surgery and complaint of any neurological problems were not included in the study.

A modified version of the Hughson-Westlake procedure (Carhart and Jerger, 1959) was used to measure the hearing thresholds of all participants using a calibrated clinical audiometer (Maico MA52) in an acoustically treated booth with ambient noise level within permissible limits (ANSI, 1999). All participants in the group I had air and bone conduction hearing thresholds less than 15 dB HL at the octave frequencies between 250 Hz and 8 kHz. 9 out of the 30 participants in group II had hearing thresholds up to 30 dB HL at 4 kHz and 8 kHz and at other frequencies the thresholds were within 15 dB HL. The study was divided into 3 experiments- Psychoacoustic experiments, speech perception experiment and working memory measures.

I. Psychoacoustic experiments

Stimulus & Procedure

All of the temporal processing measures except for the duration pattern were carried out using 'mlp' tool box which implements maximum likelihood procedure in Matlab (Grassi & Soranzo, 2009). The maximum likelihood procedure employs a large number of candidate psychometric functions and after each trial calculates the probability (or likelihood) of obtaining the listeners response to all of the stimuli that have been presented given each psychometric function. The psychometric function yielding the highest probability is then used to determine the stimulus to be presented on the next trial. Within about 12 trials, the maximum likelihood procedure usually converges on a reasonably stable estimate of the most likely psychometric function, which then can be used to estimates the threshold (Green 1993; Green, 1990). Stimuli were generated at 44,100 Hz sampling rate. A two-interval alternate force choice method using a 'maximum likelihood procedure' was employed to track an 80% correct response criterion. Thirty test trails were used. During each trial, stimuli were presented in each of two intervals; one interval contained a reference stimulus, the other interval the variable stimulus. The participant indicated, after each trial, which interval contained the variable stimulus.

Gap Detection Thresholds

The participant's ability to detect a temporal gap in the centre of a 750 ms broadband noise was measured. The noise had 0.5 ms cosine ramps at the beginning and end of the gap. In a two-interval alternate forced-choice task, the standard stimulus was always a 750 ms broadband noise with no gap whereas the variable stimulus contained the gap.

Modulation detection thresholds

Temporal modulation refers to a reoccurring change (in frequency or amplitude) in a signal over time. A 500 ms Gaussian noise was sinusoidally amplitude modulated at modulation frequencies of 8 Hz, 20 Hz, 60 Hz and at 200 Hz. Noises had two 10 ms raised cosine ramps at the onset and offset. Subject had to detect the modulation and tell which interval had the modulated noise. Modulated and un-modulated stimuli were equated for total root mean square (rms) power. Depth of the modulated signal was varied according to the participant's response up to an 80% criterion level. The modulation detection thresholds were expressed in dB by using the following relationship

Modulation detection thresholds in dB = 20 log10 m

Where m= modulation detection threshold in percentage

Duration pattern scores

The duration pattern was administered in the manner described by Musiek, Baran and Pinheiro (1990). 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). By combining these two durations in three-tone patterns six different patterns were generated (Short, Short Long, Short Long Short, Long Long Short, Long Short Short, Short Long Long, Long, Short Long). Inter-stimulus interval was 250 ms within a tone sequence and 6 secs between two tone sequences.

Following practice trails, 30 test items were administered. Participants were asked to verbally repeat the sequence.

II. Speech perception experiment

Speech perception in noise was evaluated using the test developed by Methi, Avinash and Kumar (2009). Seven equivalent lists from the original test were selected for the present study. Each list contained 7 sentences mixed with the eight talker speech babble noise at different signal to noise ratios (SNRs). First sentence in each list was at +20 dB SNR, second sentence was at +15 dB SNR, third sentence was at +10 dB SNR, fourth sentence was at +5 dB SNR, fifth sentence was at 0 dB SNR, sixth sentence was at -5 dB SNR and last sentence was at -10 dB SNR. Each sentence had 5 key words. These sentences were presented through a personal computer (Dell Inspiron 15R) at comfortable listening levels through circumaural headphones (Intex). The listener’s task was to repeat the sentences presented and each correctly repeated key word was awarded one point for a total possible score of 35 points per list.

III. Working memory measures

Auditory Working memory

Auditory Digit Span

Auditory working memory was assessed using the auditory digit span. The auditory digit span is divided into forward and backward phase. The numbers were recorded from 1 to 9 and 6 lists were prepared with increasing level of difficulty with level 1 being the easiest and level 6 being the toughest. Level 1 contained 3 digits while the level 6 contained 8 digits which were randomly presented. An inter stimulus interval of 25 ms was maintained for all the levels. These clusters of digits were presented and the participants were asked to repeat the numbers in same or backward order for digit forward and digit backward task respectively. The scoring was based on the number of digits correctly repeated by the participant.

Operation Span Task (OST)

The procedure and scoring was adapted from versions of the OST used by Kane et al. (2004). In the OST, each element consisted of a mathematical operation and a word (e.g., 3+5-4=4, yes or no? /mara/). The words used in the test were familiarity rated initially and then the most familiar and least familiar words were eliminated from the list. The participant's task was to read the math problem aloud, say "yes" or "no" to indicate whether the given answer is correct or incorrect and then say the word. After all the elements in an item are presented the participants were required to write the words in correct serial order. The difficulties of the items were randomized such that the numbers of elements were unpredictable at the outset of an item. Guidelines recommended by Conway et al. (2005) were followed during the scoring. A score of 1 was assigned for every word correctly recalled which sums up to a maximum score of 20.

Statistical analysis

Appropriate statistical analysis was computed using SPSS version 20. The following statistical procedures were used to analyse the data.

i. Descriptive statistics was computed to calculate the mean and standard deviation for the temporal processing measures and speech in noise test across the two groups.

ii. Analysis of covariance (ANCOVA) was administered to assess the effect of aging on gap detection threshold and duration pattern scores.

iii. Multivariate analysis of covariance (MANCOVA) was administered to assess the effect of aging on modulation detection thresholds for sinusoidally amplitude-modulated noise and speech perception in noise by eliminating the influence of working memory and minimal hearing loss.

iv. Independent t test was computed to assess the effect of age on working memory measures.

v. Karl Pearson's Co-efficient Correlation was calculated to assess the correlation between temporal processing and working memory, temporal processing and speech perception in noise.

CHAPTER 4

RESULTS

The analysis aimed at assessing the following

a. Effect of age on temporal processing abilities,

b. Effect of age on working memory,

c. Effect of age on speech perception

d. And relationship between temporal processing, working memory and speech perception in noise

Effect of age on temporal processing

Gap detection threshold (GDT)

Figure 1 shows the mean GDT along with the one standard deviation (SD) variation for the adult and the geriatric group. The mean scores noticeably indicate that the performance of the adult group was better when compared to the geriatric group. Additionally, the variability as evidenced by the standard deviations was more for the geriatric group when compared to the adult group. ANCOVA was performed to assess the significance of differences between the mean GDT between two groups. As working memory and hearing thresholds can affect the GDT, these were used as co-variates (numerical independent variables) in the model. ANCOVA results showed a significant main effect of subject group on GDT [$F(1, 54) = 15.461$ $p<0.05$] after controlling the effect of minimal hearing loss in the high frequency region (4 kHz and 8 kHz) and working memory. The covariate operation span task (OST) significantly influenced the participant's GDT [F (1, 54) = 15.879 p<0.05]. However, the hearing thresholds [F (1, 54) = 0.410 p>0.05], digit forward [F (1, 54) = 3.228 p>0.05] and digit backward [F (1, 54) = 1.811 p>0.05] did not influence the GDT of the participants.

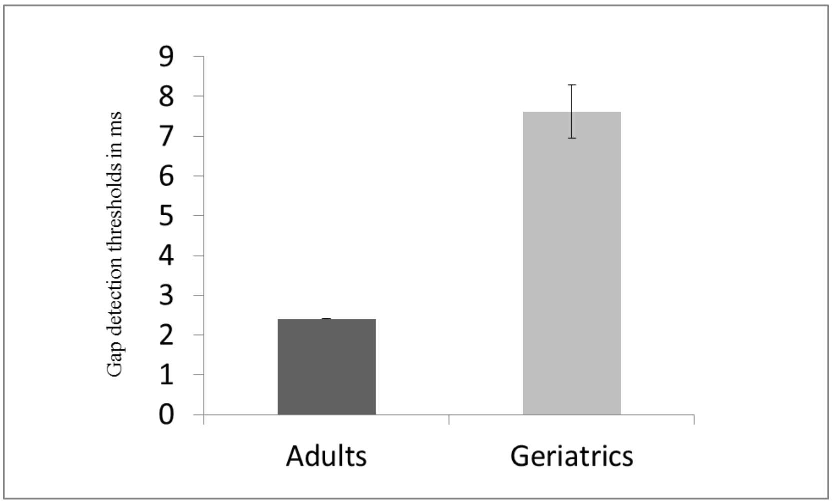

Figure 1: The mean gap detection thresholds in adults and geriatrics. The error bars indicate 1 SD of error.

Modulation detection threshold (MDT)

Figure 2 shows the mean for MDT at 8 Hz, 20 Hz, 60 and 200 Hz along with the one SD variation for the adult and the geriatric group. From the Figure 2 it can be seen that mean modulation detection thresholds were better in the adult group as compared to the geriatric group. Additionally, the variability as evidenced by the standard deviations was more for the geriatric group when compared to the adult group.

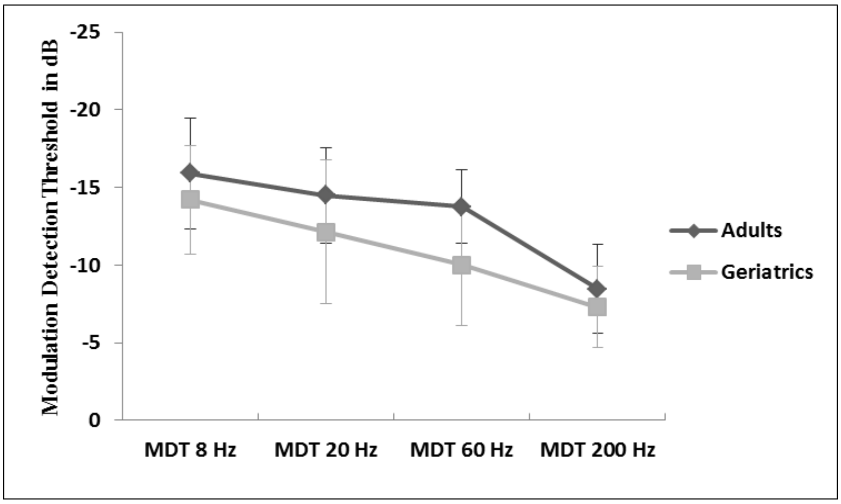

Figure 2: The mean modulation detection thresholds at 8 Hz, 20 Hz, 60 Hz and 200 Hz in adults and geriatrics. The error bars indicate 1 SD of error.

[MDT- modulation detection threshold]

MANCOVA was performed with MDT at 8 Hz, 20 Hz, 60 Hz and 200 Hz as dependent variable, subject group as independent variable and average of hearing thresholds in high frequencies (2 kHz, 4 kHz and 8 kHz in both the ears) and working memory measures as covariate. MANCOVA results showed no significant main effect of subject group on MDT 8 Hz [$F(1, 54) = 0.877$ $p>0.05$], MDT 20 Hz [$F(1, 54) = 2.412$ $p>0.05$], MDT 60 Hz [$F(1, 54) = 4.592$ $p>0.05$] and MDT 200 Hz [$F(1, 54) = 0.156$ $p>0.05$] after factoring out the effect of minimal hearing loss and working memory. This means that modulation detection thresholds were comparable between the adults and geriatrics at all the modulation frequencies tested.

<u>Duration pattern scores</u>

Figure 3 shows the mean duration pattern scores along with the one SD variation for the adult and the geriatric group. The Figure 3 illustrates that the mean duration pattern scores for adults was much higher than the geriatric group.

Additionally, the variability as evidenced by the standard deviations was more for the geriatric group when compared to the adult group. ANCOVA was performed with duration pattern scores as dependent variable, age as independent variable and average of hearing thresholds in high frequencies (2 kHz, 4 kHz and 8 kHz in both the ears) and working memory measures as covariate. ANCOVA results showed a significant main effect of subject group on duration pattern scores [$F (1, 54) = 9.192$ $p<0.05$] after factoring out the effect of minimal hearing loss and working memory. The covariates hearing thresholds [$F (1, 54) = 5.004$ $p<0.05$], operation span [$F (1, 54) = 4.392$ $p<0.05$] and digit forward [$F (1, 54) = 5.610$ $p<0.05$] significantly influenced the participant's duration pattern scores. However, the digit backward [F (1, 54) = 0.268 $p>0.05$] did not influence the duration pattern scores of the participants.

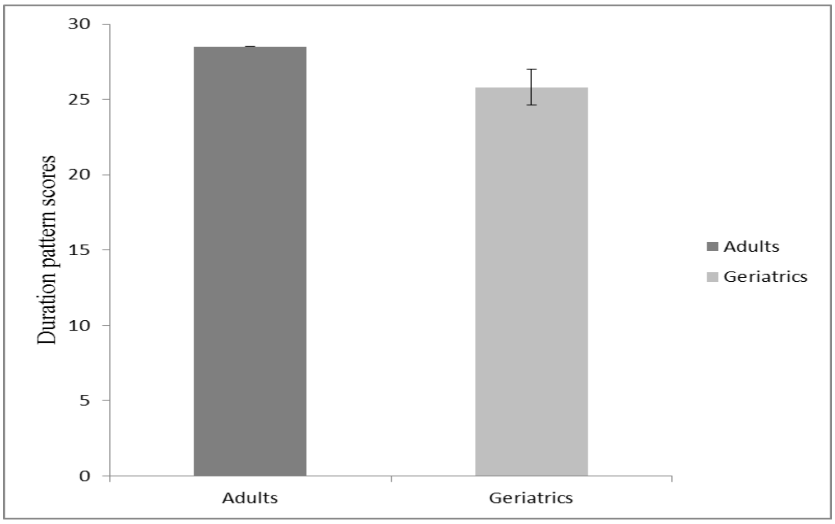

Figure 3: The mean duration pattern scores in adults and geriatrics. The error bars indicate 1 SD of error.

Effect of age on working memory measures

Figure 4a shows the mean scores for digit forward and digit backward and Figure 4b shows the mean scores for OST along with the one standard deviation (SD) variation for the adult and the geriatric group. The mean scores indicate that the working memory is better for the adult group as compared to the geriatric group. The results of the independent samples t-test revealed that the adult group had significantly better digit forward ($t = 4.175$, $p<0.05$), digit backward ($t = 3.971$, $p<0.05$) and operation span ($t = 4.953$, $p<0.05$) scores when compared to the geriatric group.

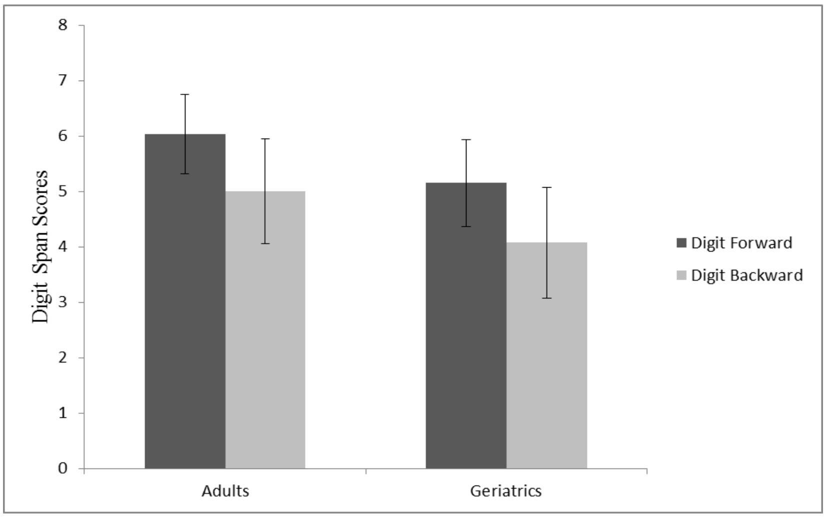

Figure 4a: The mean digit forward and digit backward scores in adults and geriatrics. The error bars indicate 1 SD of error.

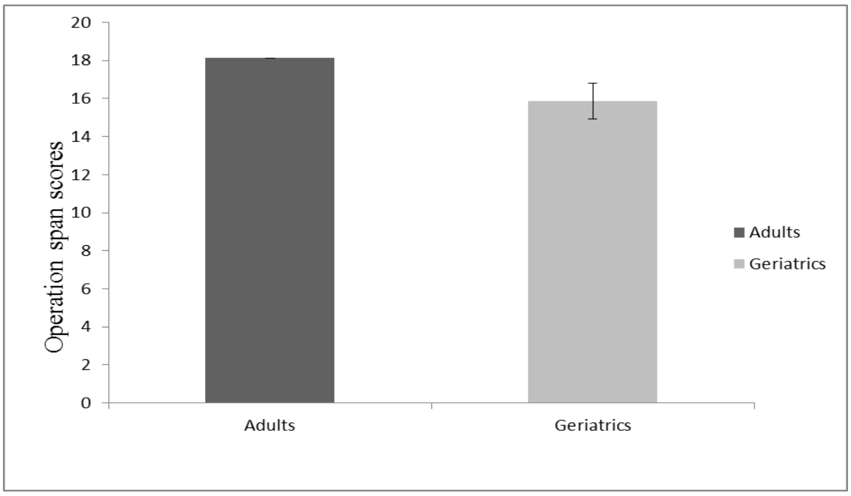

Figure 4b: The mean operation span scores in adults and geriatrics. The error bars indicate 1 SD of error.

Effect of age on speech perception in noise (SIN)

Figure 5 shows the mean scores for SIN along with the SD variation for the adult and the geriatric group. The mean scores indicate that the SIN is better for the adult group when compared to the geriatric group especially at higher SNRs. The raw speech perception scores were converted in rationalized arcsine units (rau). The conversion of raw scores to rau scores was done using the formula by Sherbecoe and Studebaker (2004) which was implemented in MATLAB. All the further statistical analysis was carried out using the rau speech perception scores. At +20 dB SNR, +15 dB SNR, +10 dB SNR participants in both the groups obtained 100% correct identification and hence these SNRs were excluded from further statistical analysis. MANCOVA was performed to see the significance of differences in the speech perception scores between the groups. The speech identification scores at 5 dB, 0 dB, -5 dB and -10 dB SNR as dependent variable, subject groups as independent variable and average of hearing thresholds in high frequencies (2 kHz, 4 kHz and 8 kHz in both the ears) and working memory measures were used as covariates in the model. MANCOVA results revealed a significant main effect of subject group on speech perception at 5 dB SNR [F (1, 54) = 12.79, p< 0.05], 0 dB SNR [F (1, 54) = 37.611, p<0.05], -5 dB SNR [F (1, 54) = 22.241, p<0.05] and -10 dB SNR [F (1, 54) = 6.889, p< 0.05].

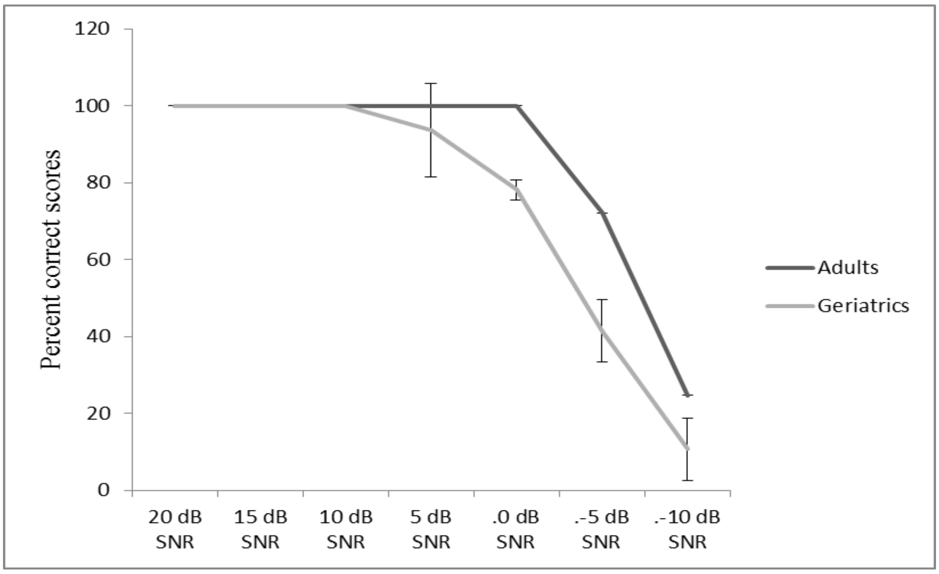

Figure 5: The mean speech in noise scores at 20 dB, 15 dB, 10 dB, 5 dB, 0 dB, -5 dB and -10 dB SNR in adults and geriatrics. The error bars indicate 1 SD of error.

Relationship between temporal processing and working memory

Karl Pearson's correlation co-efficient was computed to evaluate the possible relationship between temporal processing and working memory. Each of the temporal processing measures was correlated with the working memory measures. Data from adult and geriatric were pooled in for this purpose. Table 1, shows the correlation co-efficient 'r' between the variables. The analysis showed a significant negative correlation between GDT, MDT at 8, 20, 60, 200 Hz and all the working memory measures. Duration pattern scores showed a high positive correlation with the working memory measures. A negative correlation indicates that GDT and MDT were better in individuals with higher working memory capacity (WMC) as measured using digit forward, backward and OST. A positive correlation indicates that individuals who had higher WMC also had better duration pattern sores. The levels of significances are mentioned for each of the variables in the table below. A scatter plot was drawn between the variables to verify the validity of correlation (Figure 6). From the scatter plots it can be observed that correlation were not because of the outliers and there is an actual trend existing between working memory and temporal processing measures.

Table 1: Correlation between temporal processing and working memory

Temporal processing measures	Working memory measures		
	Digit forward	Digit backward	OST
GDT	-0.600**	-0.563**	-0.734**
DPT	0.683**	0.660**	0.705**
MDT 8 Hz	-0.416**	-0.385**	-0.388**
MDT 20 Hz	-0.248	-0.296*	-0.415**
MDT 60 Hz	-0.549**	-0.491**	-0.478**
MDT 200 Hz	-0.435**	-0.321*	-0.314*

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

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

[GDT- Gap detection threshold, DPT- Duration pattern scores, MDT 8 Hz- Modulation detection threshold at 8 Hz, MDT 20 Hz- Modulation detection threshold at 20 Hz, MDT 60 Hz- Modulation detection threshold at 60 Hz, MDT 200 Hz- Modulation detection threshold at 200 Hz]

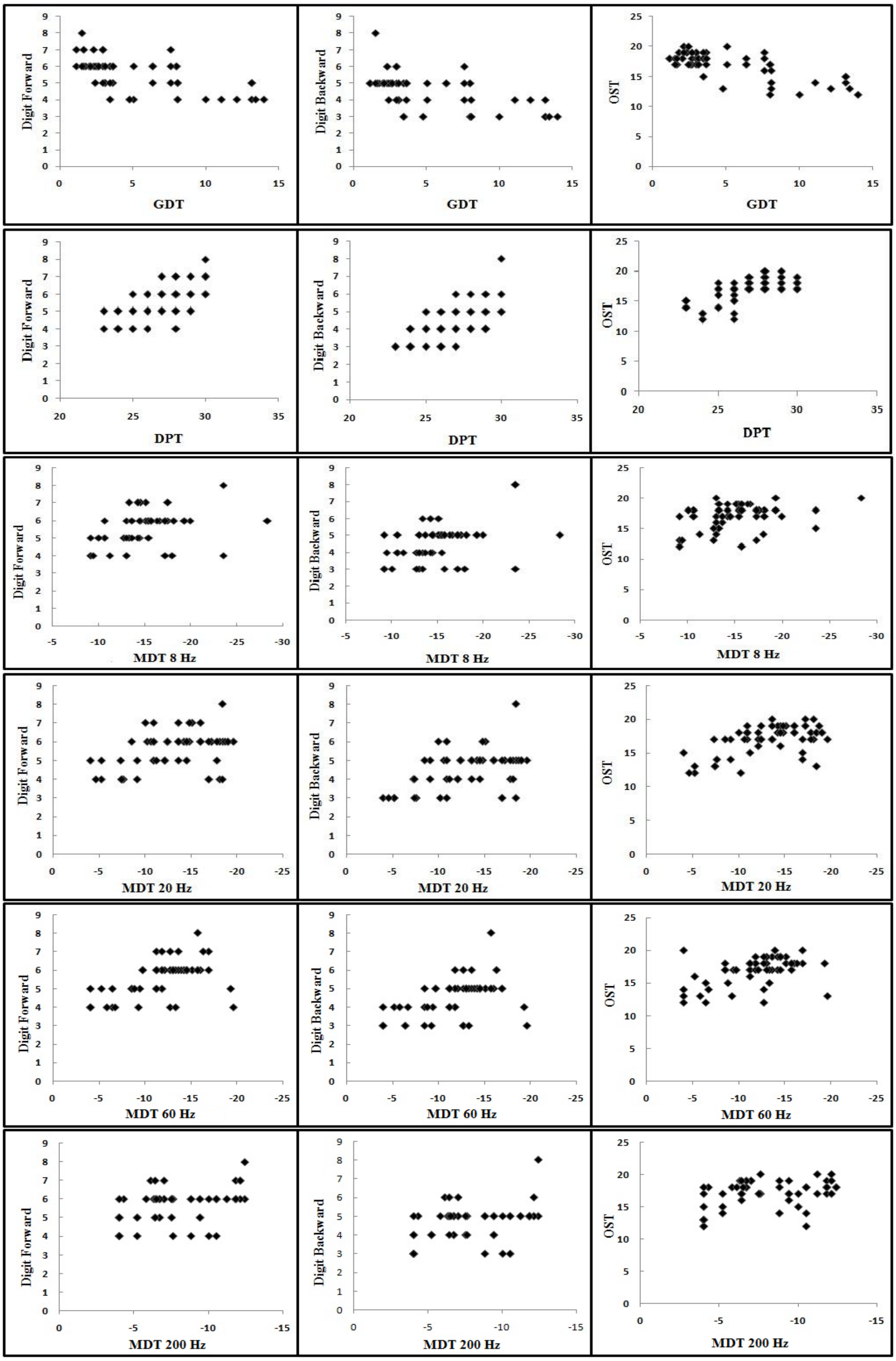

Figure 6: Correlation matrix between temporal processing and working memory.

Relationship between speech perception in noise and working memory

Karl Pearson's correlation co-efficient was computed to evaluate the possible relationship between working memory and speech in noise. Each of the working memory measures was correlated with the speech in noise scores at +5, 0, -5 and -10 dB SNR. Data from adult and geriatric were pooled in for this purpose. Table 2, shows the correlation co-efficient 'r' between the variables. The analysis showed a significant positive correlation between all the working memory measures and speech in noise at poorer SNRs ie., 0 dB, -5 dB and -10 dB SNRs. Additionally, OST showed a positive correlation with speech in noise even at 5 dB SNR. A positive correlation indicates that individuals who had higher WMC also had better speech in noise scores. The levels of significances are mentioned for each of the variables in the table below. A scatter plot was drawn between the variables to verify the validity of correlation (figure 7). From the scatter plots it can be observed that correlation were not because of the outliers and there is an actual trend existing between working memory and speech perception in noise.

Table 2: Correlation between working memory and speech in noise.

Working memory measures	Speech in noise test			
	5 dB SNR	0 dB SNR	-5 dB SNR	-10 dB SNR
Digit forward	0.178	0.392**	0.542**	0.586**
Digit Backward	0.166	0.385**	0.553**	0.610**
OST	0.277*	0.514**	0.663**	0.685**

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

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

[OST- operation span task]

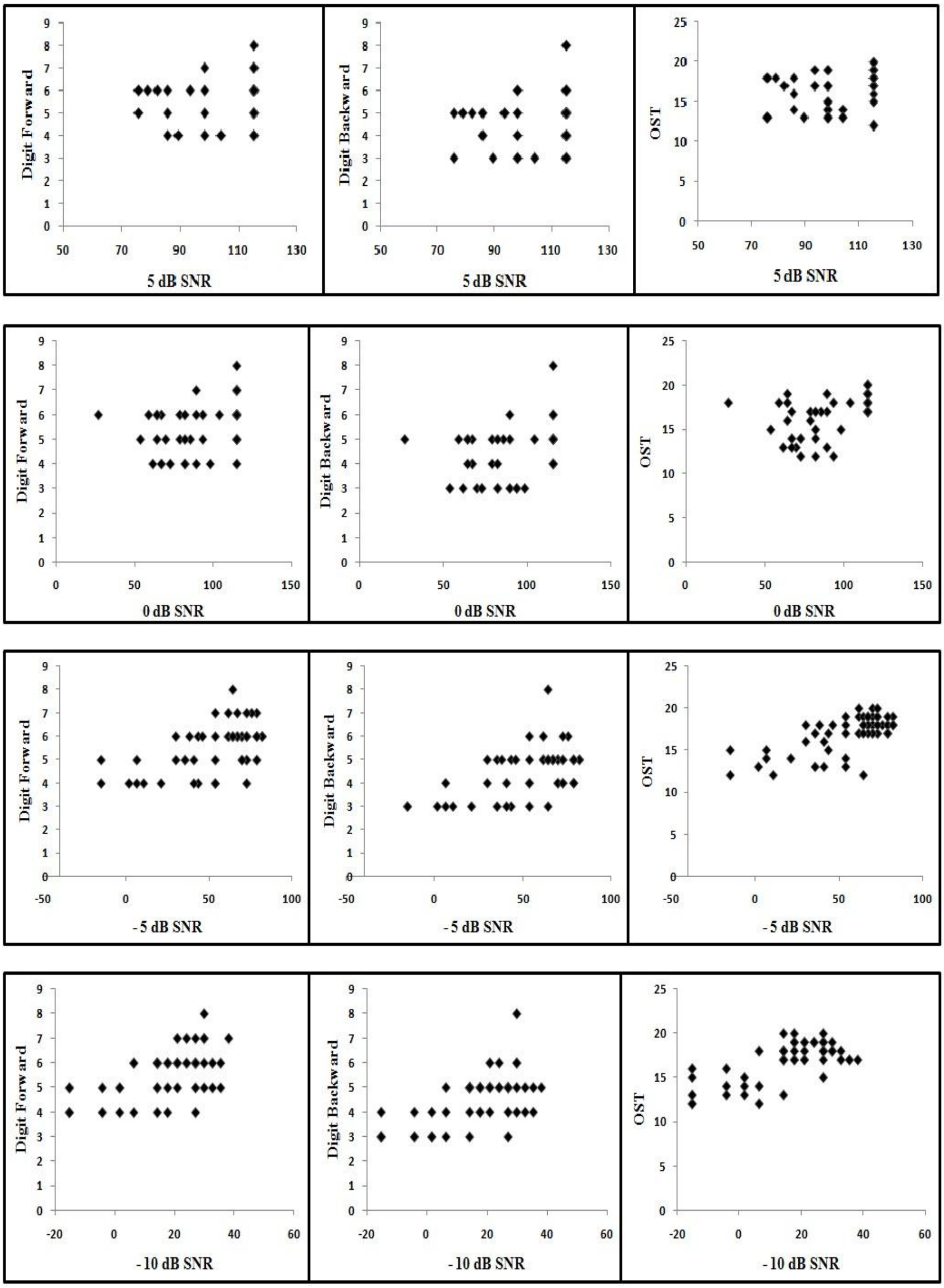

Figure 7: Correlation matrix between working memory and speech in noise

CHAPTER 5

DISCUSSION

The main aim of this study was to assess effect of aging on temporal processing, working memory and speech perception in noise. This study also explored the relationship between working memory capacity (WMC) and temporal/speech perception skills. Results revealed that temporal processing (except modulation detection thresholds), speech perception and working memory skills declined with the advancing age. Furthermore, the working memory measures were significantly correlated with the temporal processing and speech perception skills.

Effect of age on temporal processing

Gap detection thresholds and duration pattern scores showed a significant deterioration with age. Several studies in the past quote the evidence for deterioration in gap detection thresholds with age (Robin & Royer, 1987; Moore & Glasberg, 1988; Schneider et al., 1994; Snell, 1997; Kumar & Sangamanatha, 2011). Snell (1997) assessed the gap detection thresholds in young adults and geriatrics with normal hearing sensitivity. He reported a poor gap detection threshold in the geriatric group when compared to the adults. Kumar and Sangamnatha (2011) reported gap detection thresholds to be 8 fold greater in individuals above 70 years of age as compared to individuals in 20-30 age range. Trainor and Trehub (1989) reported temporal sequencing impairment in elderly listeners irrespective of the hearing loss. Several studies have reported that temporal patterning skills decline with age (Kumar &

Sangamnatha, 2011; Parra et al., 2004) especially after the 6th decade of life (Kumar & Sangamnatha, 2011).

Results of the present study also revealed that gap detection thresholds were significantly influenced by the participant's operation span skills. Duration pattern scores were significantly affected by digit forward and operation span skills. This means that both of these measures depend on participants' WMC. To our knowledge this is the first report evaluating the relationship between working memory measures and auditory temporal processing skills. However, there are several indirect evidences in the literature which shows that there is a relationship between temporal processing and cognition in general. Unsworth and Engle (2007) stated that individuals differ in their performance in memory tasks such as serial order recall because of the differences in their WMC. Individuals with low WMC are unable to use the temporal contextual cues to the same extent as the individuals with high WMC. Evidence for changes in temporal judgment is reported throughout the lifespan (McCormack, Brown, Maylor, Darby & Green, 1999; Baudouin, Vanneste, Pouthas et al. 2006) and markedly tends to differ in WMC as well (Brown et al. 1999). Thus, an association exists among WMC, timing and aging (Baudouin, Vanneste, Pouthas et al. 2006). Conway and Engle (1994) stated that individuals who were categorised as having high WMC based on operation span task scores demonstrated to have better blocking out or are less affected by distracting information. Conway et al. (2001) stated that individuals with low WMC based on operation span task had difficulty in repeating the stimulus as compared to the high WMC individuals in the presence of competing signal. Broadway and Engle (2011) reported low working memory capacity individuals were less sensitive than the high working memory individuals in the temporal discrimination task. They also reported that individual differences in working memory capacity also had individual differences in temporal discrimination. This finding is supported by the theory of individual differences in working memory capacity (Unsworth & Engle, 2007) and theory of short-term memory (Brown, Preece & Hulme, 2000) which propose that recall and recognition depend on discriminating memory.

Modulation detection thresholds did not show a significant difference between the adults and the geriatrics after eliminating the influence of hearing thresholds and working memory measures. The modulation detection thresholds were comparable between the adults and geriatrics at all the modulation frequencies tested. This is in contrast to other studies which have reported an age related decline in the modulation detection thresholds (Kumar & Sangamanatha, 2011; He et al., 2008). This discrepancy between the present study and the others may be because previous studies have not controlled the effect of minimal hearing loss in the high frequency region, which is often encountered while testing geriatric individuals, and also the WMC. For example, Kumar and Sangamanatha (2011) reported that modulation detection thresholds deteriorated by the 6^{th} decade for lower modulation frequencies (8 Hz and 20 Hz) and by the 4^{th} decade for higher modulations (60 Hz and 200 Hz). But they did not measure the working memory capacities in their participants and decline in the working memory may be one of the contributors for poor modulation detection thresholds seen in their participants. He et al. (2008) also assessed the modulation threshold in adults and geriatrics. Geriatrics up to mild hearing loss at high frequencies was considered in the study. They reported deterioration in modulation thresholds with age. But, the influence of neither hearing loss nor working memory was controlled in the study. Results of the present study are similar to that of Takahashi and Bacon (1992). They showed that even minimal hearing loss had an effect on modulation detection threshold whereas aging did not show much difference in the modulation detection threshold when hearing loss was controlled. In the current study, effects of these two independent numerical variables ie., hearing loss and working memory were factored out as they were used as covariates in the statistical analysis.

Effect of age on working memory

Results revealed that performance of geriatric individuals were significantly poorer than adults on all the working memory measures that were tested. Verhaeghen and Salthouse (1997) assessed the WMC across age. They reported a significant negative correlation between age and cognition and also reported the decline in memory accelerated after 50 years of age. Lustig and Meck (2001) described an age related decline in the memory. Similar results have been documented by Hasher and Zacks (1988); Babcock and Salthouse (1990) wherein they report a decline in the working memory with increasing age. Hasher and Zacks (1988) justify that age related deficit in filtering or supressing irrelevant information lead to excessive load on WMC and thus reduce performance. One possible reason for this decline could be the reduced ability to attend to the stimuli (Lustig & Meck, 2001). This reduced attention having an effect on the working memory is supported by the controlled attention theory of working memory by Engle and Kane (2004). According to this hypothesis there is a general component of working memory responsible for guiding attention as well as domain specific components responsible for maintenance of task relevant information. Individuals with high WMC have better attention skills and can maximally make use of domain specific skills and strategies to aid maintenance (Colflesh & Conway, 2007).

Effect of age on speech in noise (SIN)

In favourable SNRs (up to +10 dB SNR), performance of the geriatric group was comparable to that of adult group. However, at less favourable SNRs (5 dB and below up to -10 dB SNR) performance of the geriatric group was significantly worse when compared to adult group. It has been reported that geriatric listeners experience increased difficulty in understanding speech in noise (Cooper & Gates, 1991). Kumar and Sangamnatha (2010) reported a decline in the speech in noise scores in spite of having normal audiometric thresholds after 40 years of age which significantly deteriorated further as the age increased. This difficulty in speech perception in noise may be because of the reduced temporal information received by the listener due to the noise (Tremblay et al., 2003). In the unfavourable condition listening is highly effortful. When the listening conditions are unfavourable words cannot be identified on the basis of the signal cues alone. Stored information must be used to achieve the correct identification. Although, the supportive context in the sentence helps in the lexical access, this is cognitively more demanding when compared to the auditory input is less ambiguous as in better SNR conditions. Older listeners had working memory capacity that was significantly less than the young adults. This decline in the working memory capacity of older adults is one of the reasons for observed poor speech perception scores in older adults.

Relationship between temporal processing and working memory

Correlation analyses showed that there is a significant relationship between the working memory measures and speech in noise. This means that individuals with high WMC which was measured using digit forward, backward and OST also had better temporal processing skills. The working memory measures, digit forward and digit backward task taps the auditory memory of the individual and the OST requires the listener to selectively attention to the words to be recalled. Previous studies have reported that abilities to discriminate short intervals depend on differences in attention (Lustig & Meck, 2001; Vanneste & Pouthas, 1999) or memory (Perbal et al., 2005; Rakitin et al., 2006; Rakitin et al., 2005), and sometimes both (Baudouin, Vanneste, Isingrini et al. 2006; Baudouin, Vanneste, Pouthas et al.2006). Aging causes deterioration of both memory and attention (Park & Hedden, 2001; Reuter-Lorenz & Sylvester, 2005). Hence, a possible relationship exists between gap detection threshold, modulation detection threshold and working memory.

Temporal patterning requires additional cognitive skills like memory as the complexity of the task rises by increasing the length of the stimulus (Fogerty, Humes & Kewley-Port, 2010). The auditory digit span task taps the memory component of cognition and the load on auditory memory increases by increasing the number of digits in the digit span task. Temporal patterning abilities are thus assumed to be better in individuals with better auditory memory. Hence, there is a relationship between working memory and temporal patterning abilities.

Relationship between working memory and speech in noise (SIN)

The results revealed that SIN deteriorated with age and OST had an influence on the SIN scores. Moreover, the SIN scores showed high correlation working memory measures. The influence of working memory on SIN was seen at 0 dB, -5 dB and -10 dB SNR but not at +5 dB SNR. Thus, the results of the present study shows that greater level of cognition is required for perception of speech in noise when the SNRs are poor and not when the speech is well above the noise levels. Wong et al. (2009) reported similar results based on fMRI studies. The results showed reduced activation in the auditory cortex but an increase in working memory and attention-related cortical areas which are the prefrontal and precuneus regions in geriatrics, especially in the poorer SNR condition. Colflesh and Conway (2007) reported that the selective attention supports the notion that individuals with greater WMC are better able to focus attention and avoid distraction. Conway et al. (2001) also reported that working memory is responsible for maintaining activation to relevant information and suppressing the distracting information.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Temporal processing and speech perception abilities decline with age even when audiometric thresholds are within normal limits. One of the factors that influence the speech perception and temporal processing is working memory. The present study was taken up to assess the possible relationship between temporal processing, working memory capacity and speech perception in noise.

The objectives of the present study are as follows

1. To measure gap detection in noise, modulation detection thresholds, duration pattern scores and speech perception in noise in adults and geriatrics with normal hearing sensitivity.

2. To measure working memory abilities in adults and geriatrics with normal hearing sensitivity.

3. To assess the relationship among working memory, speech perception in noise and temporal processing in adults and geriatrics with normal hearing sensitivity.

In the present study, two groups of participants were tested. Group I consisted of 30 young adults in the age range of 18-30 years. The Group II consisted of 30 geriatric in the age range of 60-70 years. The study was divided into 3 experiments- Psychoacoustic experiments, Speech perception experiment and working memory measures. Psychoacoustic experiments included temporal processing measures- gap detection thresholds, modulation detection threshold for sinusoidally amplitude modulated noise and duration pattern scores. Speech perception experiment involved assessing speech perception scores for sentences at 20 dB, 15 dB, 10 dB, 5 dB, 0 dB, -5 dB, -10 dB signal to noise ratios. Working memory measures contained digit forward, digit backward and operation span test.

The results were obtained in the study

1. Gap detection thresholds and duration pattern scores declined with age whereas, aging did not show an effect on modulation detection thresholds.

2. All the working memory measures digit forward, digit backward and operation span task showed deterioration with age.

3. Speech perception in noise in the geriatric group was comparable to that of adults at favourable SNRs (+20, +15, +10, +5 dB SNR) but as the SNR became poorer (0, -5, -10 dB SNR) the geriatric group had significant deterioration when compared to adults.

4. Working memory had significant influence and relationship with the temporal processing and speech perception in noise scores.

Implications

Based on the information provided from this study, activities tapping working memory can be used to train geriatrics to improve temporal processing and speech perception. The present study attempted to assess the relationship between working memory, temporal processing and speech perception in noise. But there is a need to evaluate whether other aspects of cognition also influence temporal processing and speech processing skills.

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