Relationship between Auditory Temporal Processing and Working Memory

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Abstract

The study evaluated the effect of aging on auditory temporal processing, speech perception abilities and working memory and assessed the relationship among them. A total of 30 young adults in the age range of 18-30 years and 30 geriatric individuals in the age range of 60 to 70 years with normal hearing sensitivity participated in the study. 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 revealed that the gap detection thresholds and duration pattern scores declined with age whereas, aging did not show an effect on modulation detection thresholds. All the working memory measures digit forward, digit backward and operation span task showed deterioration with age. 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. Thus, it can be concluded that working memory has a significant influence and relationship with the temporal processing and speech perception in noise.

Keywords: *Aging, temporal processing, speech perception, working memory.*

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 appears 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

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hearing. Kumar and Sangamnatha (2011) extensively studied 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).

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.

Therefore, the aim of the study was to assess the effect of aging on auditory temporal processing, speech perception abilities and working memory and assess the relationship between them.

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 to30 years. The Group II consisted of 30 normal hearing geriatric individuals in the age range of 60 to70 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 & 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.

Psychoacoustic Experiments

Stimulus and Procedure: All of the temporal processing measures except for the duration pattern were carried out using 'mlp' tool box (Grassi & Soranzo, 2009) which implements maximum likelihood procedure in Matlab. 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, 1990: 1993). 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 which interval contained the variable stimulus after each trial.

*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 = $20 \times log_{10}\, m$

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 seconds between two tone sequences. Following practice trails, 30 test items were administered. Participants were asked to verbally repeat the sequence.

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.

Working Memory Measures

*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, Cowan, and Bunting (2001) 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

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

Independent t test was computed to assess the effect of age on working memory measures. Karl Pearson's coefficient correlation was calculated to assess the correlation between temporal processing and working memory, temporal processing and speech perception in noise.

Results

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

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 & 8 kHz) and working memory. The covariate 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.

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. 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.

Duration pattern scores: 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.

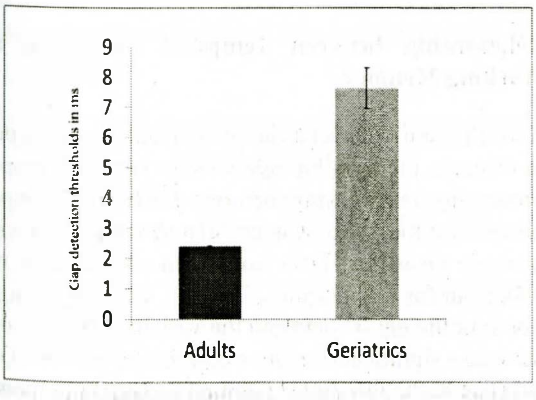

Figure 1: The mean gap detection thresholds in adults and geriatrics. The error bars indicate 1 SD of error.

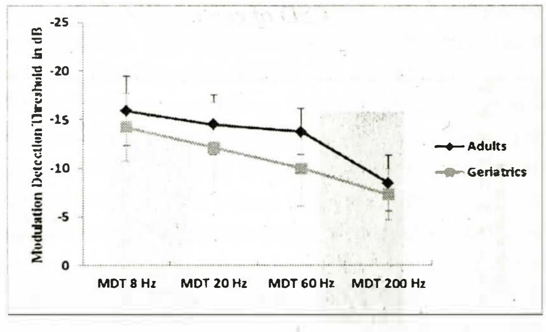

Figure 2: The mean modulation detection thresholds at 8 Hz, 20 Hz, 60 Hz and 200 Hz in adults and geriatrics. The error bars indicate 1 SD of error. [MDT- modulation detection threshold]

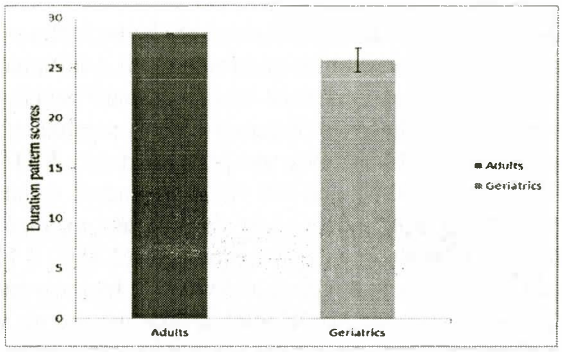

Figure 3: The mean duration pattern scores in adults and geriatrics. The error bars indicate 1 SD of error.

Effect of Age on Working Memory Measures

Figure 4 shows the mean scores for digit forward and digit backward and Figure 5 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.

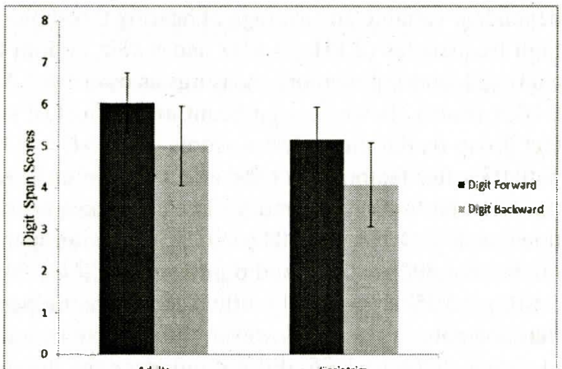

Figure 4: The mean digit forward and digit backward scores in adults and geriatrics. The error bars indicate 1 SD of error.

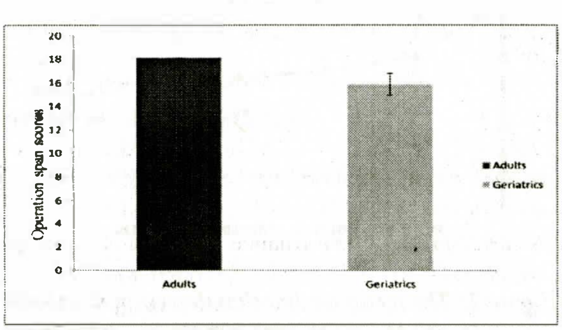

Figure 5: The mean operation span scores in adults and geriatrics. The error bars indicate 1 SD of error.

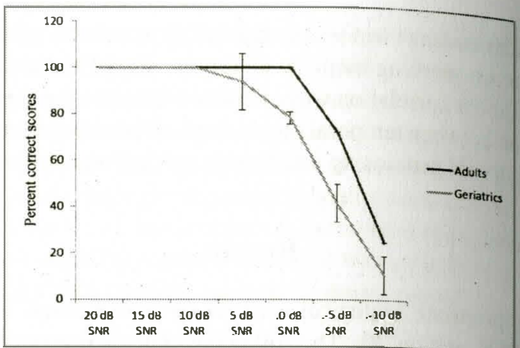

Figure 6: The mean speech in noise scores at 20 dB, 15 dB, 10 dB, 5 dB, 0 dB, -5 dB and -10 dB SNR in adults and geriatrics. The error bars indicate 1 SD of error.

Effect of age on speech perception in noise (SIN)

Figure 6 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 [$F(1, 54) = 6.889, p< 0.05$].

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.

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]

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.

Table 2: Correlation between working memory and speech in noise

Working memory measures	Speech in noise test (dB SNR)			
	5	0	-5	-10
Digit forward	0.18	0.39**	0.54**	0.59**
Digit Backward	0.17	0.39**	0.55**	0.61**
OST	0.28*	0.51**	0.66**	0.69**

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).
[OST- operation span task]

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, Pichora-Fuller, Kowalchuk & Lamb, 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 20to 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 6^{th} 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, 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, Mills, Ahlstrom, & Dubno, 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 tasks tap the auditory memory of the individual and the OST requires the listener to selectively attend 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 & Pouthas 2006; Baudouin 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.

Conclusions

To summarize, the present investigation showed that auditory temporal processing and speech processing abilities were strongly dependent on WMC. Performance of individuals with high WMC on temporal and speech processing tasks was superior to individuals with low WMC. Therefore, observed speech understanding difficulties of older individuals may be due to combined effect of reduced WMC affecting multiple domains of auditory processing.

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