CENTRAL AUDITORY PROCESSING SKILLS IN OLDER INDIVIDUALS

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To My 6 Years of college life...Coz Work will never cease to exist, But COLLEGE will..

CERTIFICATE

This is to certify that this dissertation entitled "**Central Auditory Processing Skills in Older Individuals**" is the bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student with Registration No. 11AUD023). 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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CERTIFICATE

This is to certify that this dissertation entitled "**Central Auditory Processing Skills in Older Individuals**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This dissertation entitled "**Central Auditory Processing Skills in Older Individuals**" is the result of my own study under the guidance of Prof. Asha Yathiraj, Professor of Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in any other University for the award of any Diploma or Degree.

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INTRODUCTION

Psalms 71:9 - *Cast me not off in the time of old age; forsake me not when my strength faileth.*

Over the last century, there has been an extensive amount of research in the area of age related changes in the auditory system and hearing. Research has made it possible to document the physiological, anatomical as well as audiological changes showcased by the aging auditory system (Fitzgibbons & Gordon-Salant, 1996; Frisina & Walton, 2001; Willott, 1991). These changes majorly include progressive deterioration of the cochlear hair cells, degeneration of neurons in the central auditory pathway, and reduction in the plasticity of the central auditory nervous system. In addition, when these factors interact with reduced cognitive ability, it is known to lead to a myriad of classic features apparent in age related hearing loss, such as threshold elevation, diminished speech perception in difficult listening conditions such as in the presence of noise and reverberation, perception of rapid fluctuations or modulations in the signal, and impaired localization (Koehnke & Besing, 2001; Willott, 1991).

Hearing loss is reported to be the third most chronic health condition in older individuals (Lethbridge, Schiller & Bernadel, 2004). The prevalence of significant hearing impairment is estimated to be 40 to 45% in individuals above 65 years and reaches 80% as they approach 70 years of age (Cruickshanks et al., 1998).

Besides peripheral hearing being affected in older individuals, it is documented that with aging, individuals develop an auditory processing problem (APD). Studies by Antonelli (1970), Bergman (1971) and Jerger and Hayes (1977) report that with advance in age, the presence of APD in older individuals becomes apparent. In contrast, Marshall (1981) proposed that older individuals perform in a similar manner as younger adults with the same degree of hearing loss. Researchers such as Fabry and Van Tasell (1986), Humes and Roberts (1990), and Humes and Christopherson (1991) attempted to recreate the study using hearing loss simulations in young healthy normal hearing young adults. They found that young normal individuals performed similar to elderly individuals when hearing loss was simulated. While other researchers like Helfer and Wilber (1990) are of the opinion that even when the hearing loss is relatively equal between younger adults and older adults, the older individuals often encounter far greater hurdles when it comes to speech perception in day to day scenarios.

Changes in cognition have also been suggested as the factor accounting for the variability in these individuals. It has been noticed that cognitive abilities like memory and speed of information processing are vital for some of the auditory tests such as dichotic speech tasks, duration and pitch pattern sequence as well as time compression with reverberation tests. It has been suggested that different individuals might experience different degrees of cognitive decline, thereby leading to increased likelihood of variability in the tests (Van Rooije & Plomp, 1992).

A plethora of studies, however have now shown that many of the listening challenges encountered by older individuals can be mainly attributed to their presbyacutic high frequency sensorineural hearing loss (Humes et al., 1994; Pearson et al., 1995; Cruickshanks et al., 1998; Halling & Humes, 2000). However there is evidence of individuals who face far greater communication impediments than what their audiometric configuration would suggest. Upon deeper diagnostic inspection in such individuals, a vast majority of them reported to have speech understanding difficulties stemming from decline in higher order auditory processes, a general decline in cognitive ability or a combination of both.

Gaeth (1948) has been reported by Jerger, Jerger, Oliver & Pirrozolo (1989) to be among the earliest researchers to describe speech understanding problems in many older individuals that correlated poorly with their degree and configuration of hearing loss. He referred to this phenomenon as 'phonemic regression'. Since then a bevy of researchers have explored central auditory processing deficits and affirmed its presence in older individuals (Bergman, 1971; Jerger & Hayes, 1977; Jerger et al., 1989; Bergman, 1980; Johnson, Watson & Jensen, 1987; Yonan & Sommers, 2000).

Timing or temporal aspects of the signal are generally reported to be poorly coded in older individuals. While the decline has been attributed to cochlear mechanisms, many studies have indicated the involvement of central auditory processes. Over the decades different psychoacoustic procedures have been described by Fitzgibbon and Gordon-Salant (1996) to study temporal acuity. These includes procedures like gap detection, ordering tasks, temporal masking. It has been shown by numerous studies (Fitzgibbon & Gordon-Salant, 1996; Lutman, 1991; Phillips, Gordon-Salant, Fitzgibbons, & Komshian, 1994; Moore, Peters & Glasberg, 1992) that temporal resolution is a process that is affected in older individuals. Schneider and Hamstra (1999) reported that even those who did not have a peripheral hearing loss had affected temporal resolution, especially when certain features of the test stimuli were varied, like the marker durations and Gap onset.

The impact of temporal ordering in older individuals has been less extensively evaluated. Among the few studies done in this domain, there is no clear consensus as to whether temporal ordering is affected or not. While some researchers indicated that temporal ordering was affected in the older populations (Parra et al., 2004) others reported of only a minimal reduction (Kolodziejczyk & Szelag, 2008).

Monaural separation or auditory closure has been explored in more detail in the older population. Most of the research done in the domain of monaural separation indicates that older individuals perform poorly when their auditory system is taxed. This has been achieved by researchers by utilizing various strategies such presenting speech in the presence of different maskers such as white noise, speech babble or adding reverberation, time compression or by using different speaker styles (Smith & Prather, 1971; Harris & Reitz, 1985; Versfeld & Dreschler, 2002; Hododshima & Arai, 2002).

Binaural processes such as binaural integration, binaural separation and binaural interaction have been found to be affected in the older individuals. The majority of these studies suggest the presence of a right ear advantage on dichotic verbal tasks. However, this advantage has been shown to change in a separation paradigm, when the opposite ear is pre-cued (Jerger & Jordan, 1992).

Binaural interaction has been studied in the older individuals primarily by utilizing the Masking Level Difference test along with electrophysiological measures such Binaural Interaction Component. It has been shown in older individuals that binaural processing is generally reduced, when even the pure-tone thresholds are symmetrical (Paffenroth, Roup & Noe, 2011).

NEED FOR THE STUDY

Older individuals have often been found to have a disability that seldom correlates with their audiometric pattern (Jerger & Hayes, 1977). There is no accepted consensus as to whether the decline in auditory performance is due to a peripheral hearing loss or due to a central hearing loss. Hence, there is a need for further studies to resolve this conflict.

Deterioration of the central auditory perceptual skills in older individuals has been noted to have a profound effect on how speech is perceived by them (Martin & Jerger, 2005). If it is proven that central auditory problems do exist in older individuals, it is necessary that this deterioration be taken into account when evaluating and rehabilitating them. In such individuals, Duquesnoy and Plomp (1983) recommended that the rehabilitative techniques should be altered so as to account for their shortcomings. They observed that fitting such individuals with conventional amplifications have proved to be fruitless and in some cases may do more harm than good. Hence, alternative methods of rehabilitation should be considered for such individuals. To implement this into practice, it is first necessary to study how the central auditory system helps in processing. Further, analyzing the auditory process that is maximally affected would help in making rehabilitative decisions.

Although there are many studies describing the effects of aging on the central auditory processes, most of them have evaluated only selected processes (Schneider & Hamstra, 1999; Fitzgibbon & Gordon Salant, 1996; Fuller & Schneider, 1998; Calais & Russo, 2008). The numbers of studies where a larger number of auditory processes have been extensively studied are considerably less (Snell & Frisina, 2000). Also, most of the studies have been carried out on a single age group with large heterogeneity (Rodrigo &

Di Sarno, 1990; Clark & Knowles, 1973). Hence, there is a need to study the effects of aging on several auditory processing skills and see how they vary across age groups. Further, it is also essential to determine the degree to which the different processes are affected.

AIM

The primary aim of the present study is to investigate the effect of aging on central auditory processing abilities. The secondary aim of the study is to determine the extent to which the different processes are affected within an age group.

The various processes studied included, monaural separation, temporal resolution, temporal ordering and binaural integration. The tests used to evaluate them were Speech-in Noise in Kannada (SPIN-K), Gap detection test (GDT), Duration Pattern Test (DPT), and Dichotic Consonant Vowel Test (DCV) respectively.

REVIEW OF LITERATURE

It is widely observed that older individuals often encounter great difficulty in understanding speech when compared to their younger counterparts. The condition is found to exacerbate in certain situations such as noisy environments, in the presence of competing speakers, or when listening to a fast rate of speech. It is observed that the most common complaint reported by such individuals are usually that they are aware that the speaker is talking but are unable to comprehend what is being said (Rodriguez, & Di Sarno, 1990).

The listening difficulties faced by individuals with advance in age have been attributed to several reasons. Some of the reasons include change in hearing acuity (Fabry & Van Tasell, 1986; Zurek & Delhorne, 1987; Humes & Roberts, 1990; Cruickshank et al., 1998; Halling & Humes, 2000), reduction in speech intelligibility (Zurek, & Delhorne, 1987; Humes, & Roberts, 1990; Fozard, 1990; Pearson et al., 1995; Dubno et al., 2008), and the presence of an auditory processing disorder (Jerger & Hayes, 1977; Johnson et al., 1987; Divyeni, Stark & Haupt, 2005).

Aging and changes in hearing acuity and speech intelligibility

It has been observed that elderly individuals encounter a drop in pure-tone and speech recognition thresholds significantly as the age increases. A longitudinal study done by Brant and Fozard (1990) on 813 male subjects (20-85 years), in which pure-tone thresholds and speech discrimination performance were studied as a function of aging over a 20 year period. Thresholds were determined at 11 frequencies ranging from 125 Hz to 8 kHz. The results indicated that there was an average longitudinal loss of 35.2 to

53.0 dB for the 50 year olds and 69 to 84 dB in the 80 year olds. The rate of change of thresholds was found to be faster for elderly males especially in the speech frequency range. A reduction in speech discrimination was also observed which did not correlate well with the peripheral elevation of thresholds.

Gates and Cooper (1991) conducted a longitudinal study spanning 6 years on 1475 subjects who ranged from 55 to 88 years at the start of the experiment. The results revealed a significant progression and rate of change of pure-tone thresholds for frequencies below 2 kHz for both male and female subjects. The absolute changes in threshold were however largest for higher frequencies.

Pearson et al. (1995) also indicated in their study that hearing sensitivity in men deteriorated twice as fast as that of women and they generally had better hearing acuity in the higher frequencies as opposed to men who had better sensitivity in the low frequencies. It was also observed that the reduction in speech recognition performance negatively co-related with elevation of thresholds in both males and females.

However, Dubno et al. (2008) reported of a sharp decline in threshold in the speech frequencies in both males and females with aging. A significant reduction in speech recognition performance for the NU 6 was also observed. The report was based on a longitudinal study of 835 subjects.

Most of the difficulties in speech understanding in the elderly have often been attributed to their high frequency hearing loss. The estimated prevalence of high frequency hearing loss in individuals who exceed 65 years was noted to be 40 to 45% and those over 75 years was more than 83% (Cruickshank et al., 1998).

Fabry and Van Tasell (1986) studied the effect of simulated sensorineural hearing loss on consonant perception abilities. They studied six individuals with unilateral sensorineural hearing loss and simulated sensorineural hearing loss in the normal ear using filtering and masking by spectrally shaped noise. The results indicated a similar loss in speech perception in the normal simulated ear as seen in the impaired ear. Again the pattern of errors was not similar.

Similarly, Zurek and Delhorne (1987) studied effects of mild-to-moderate sensorineural hearing loss on speech perception in 21 elderly individuals with sensorineural hearing loss. They determined the perception of consonants in the presence of speech spectrum noise which was varied to simulate a myriad of listening conditions. The same test was performed on normal hearing individuals with noise level increased to match the tone detection thresholds of the impaired listeners. The results showed similar performance for both groups. Hence, it was concluded that most of speech perception difficulties are primarily due to loss of audibility.

Humes and Roberts (1990) considered loss of peripheral hearing sensitivity to be an important factor in determining the variability seen in speech discrimination problems faced by older individuals. They studied four elderly listeners in the age range of 65 to 75 years with hearing impairment and 23 young normal hearing listeners ranging in age from 19 to 34 years. Hearing loss was simulated using spectrally shaped noise in 10 of these normal hearing subjects. The results revealed that the elderly individuals with hearing impairment and noise masked normal hearing listeners had similar speech discrimination performance. However, the error patterns were not similar. Also, it was noted that two of the elderly individuals displayed better scores than the noise masked individuals, indicating that not all older individuals with peripheral hearing loss have an accompanying marked reduction in speech intelligibility.

Humes and Christopherson (1991) examined the speech perception and central auditory processing skills of four groups of participants using Test for Basic Auditory Capabilities. The four groups were a young normal hearing group, a young normal hearing group with spectral noise simulated hearing loss, an elderly group with hearing impairment ranging in age from 65 to 75 years and an elderly group with hearing impairment ranging in the age range of 76 to 85 years. The two elderly groups performed poorer than the young normal hearing group in four of the 8 tests in Test for Basic Auditory Capabilities, namely the frequency discrimination test, embedded test tone task, temporal ordering task for syllables and tones. Although scores were slightly better for the younger noise masked group their performance was similar to that of the two elderly groups. It was noted that elevation of peripheral hearing sensitivity associated with aging was the most important factor affecting speech perception.

Humes et al. (1994) studied the speech recognition abilities for a range of test materials including nonsense syllables, sentences and monosyllables in 50 elderly listeners in the age range of 63 to 83 years. In addition, the 'Test of Basic Auditory Capabilities' (Watson, 1987) and Weschler adult intelligence scale were also administered. Principal component analyses were carried out for the three measures, namely auditory, speech perception, cognitive. It was observed that peripheral hearing sensitivity emerged as the largest contributor to variability seen in speech perception performance in older adults.

The above investigations indicate that most often, the poor speech perception, often seen in older individuals is primarily due to the effects of sensorineural hearing loss and general loss of audibility. However, it was also noted that not always is this poor speech perception linked with a peripheral hearing loss.

Aging and auditory processing deficits

As opposed to the studies that linked poor speech perception and peripheral hearing loss in older individuals, it was noted by Jerger and Hayes (1977) that although speech understanding in the elderly population was affected by peripheral hearing sensitivity, the speech understanding difficulties encountered were sometimes much more than what their audiometric pattern suggested. It was opined that speech understanding difficulties in older listeners had more to do with a general decline of cognitive abilities and central auditory perceptual skills.

Further, Bergman (1980) reported that in older individuals, the signal is degraded by the cochlea and transmitted onto a central auditory system that is unable to make fine discriminations or they are unable to use their inherent intrinsic redundancy. Both these aspects were considered vital for good speech recognition performance.

Several research studies carried out over the years have confirmed the presence of an auditory processing problem with advance in age. Dubno, Lee, Mathews and Mills (1997) studied the effect of age and gender on monaural speech recognition longitudinally on 129 individuals ranging from 55 to 84 years. Their study revealed that considerable decline in word recognition, synthetic sentence identification and high and low probability sentences in speech perception in noise were observed for males with increasing age. However, for females a significant decline was not seen in the study.

Also, the reduction in these measures did not correlate well with the change in pure-tone thresholds. Overall, the study indicated that females performed much better than their male counterparts did.

The auditory processing abilities of seven older individuals aged 65 to 82 years were studied by Johnson, Watson and Jensen (1987) using the ‘Test for basic auditory capabilities’. They found that there was a decline in performance in the participants which they attributed to a combination of cochlear pathology and general decline in central auditory processing.

Yonan and Sommers (2000) reported that ideal listening conditions and familiar speakers greatly improved the performance of older individuals in spite of reduced high frequency sensitivity. Similarly, Divyeni et al. (2005) reported of the presence on auditory processing problems in a group of 29 elderly subjects with mild hearing loss ranging from 60 to 83 years. The participants were studied again 5 years later. Pure-tone thresholds and word recognition in both quiet and noise were tested. The results showed that word recognition performance reduced significantly in both the conditions, however it did not correlate well the change in pure-tone thresholds. Hence, it was concluded that auditory processing disorder and cognitive factors could be the reason for the poor correlation.

In literature, several studies have been reported that support that specific central auditory processes are affected in older individuals. The processes that are reported to be affected include auditory closure / monaural separation, temporal resolution, temporal patterning, and binaural integration. The section below, details are provided about the specific auditory processing problems seen in older individuals.

Auditory closure / monaural separation in older individuals

Older individuals are found to have great deal of difficulty listening in noisy and reverberant conditions, even when they apparently possess normal peripheral hearing sensitivity. Auditory closure is described as the ability to fill gaps in the message using intrinsic and extrinsic redundancy. Speech performance in noise has been considered as a monaural separation or low redundancy closure task (Chermak & Musiek, 1997; Bellis, 2003).The tests used to assess it include speech-in-noise test (SPIN), low pass filtered speech, and time compression with reverberation tests.

To test monaural auditory separation, Smith and Prather (1971) studied aging effects on speech perception using synthetic sentence identification with ipsilateral competing noise. Elderly and young adults were assessed across a range of sensation levels and signal to noise ratios (SNR's). The results showed that elderly listeners, when compared to young adults had greater difficulty when sensation levels were increased and SNR's were less.

The effect of different speech babble and cafeteria noise on speech discrimination of the elderly was studied by Kaplan and Pickett (1982). The stimuli were presented in monotic, diotic and dichotic conditions with and without low band attenuation. They found that attenuation of low band did not improve scores in cafeteria noise but improved scores in speech babble. Additionally, they reported that diotic and dichotic conditions yielded superior scores as compared to monotic.

Harris and Reitz (1985) studied normal hearing young adults, normal hearing elderly adults and elderly adults with hearing impairment. The participants were evaluated in both quiet and noisy environments at two levels of reverberation. From the results it was observed that both the young adults and elderly adults with normal hearing performed similarly in quiet and noise and their performance was similar at the two levels of reverberation as well. However, when reverberation was added to the noisy condition, the performance of the elderly group with normal hearing significantly dropped. The performance of the group with hearing impairment was worse than both groups in all conditions.

Versfeld and Dreschler (2002) compared the performance of young normal hearing adults and elderly individuals with normal hearing sensitivity in speech reception in fluctuating noise and time compressed speech. A high correlation between the two tests was found. In the elderly participants, the scores for both tests were reduced significantly compared to the younger group.

Hodoshima and Arai (2007) conducted an experiment on 21 elderly individuals using recoded speech materials having different speaking styles (normal & clear styles under reverberant conditions). The results indicated that the listeners performed significantly poorer when reverberation times were longer, but no significant relationship between speaking styles or rates were observed indicating increased possibility of individual variability.

The effects of aging on speech perception in noise (SPIN) in 55 males and females were studied by Calais and Russo (2008). All the participants were above 60 years of age and were divided into two groups consisting of a control and a study group. The control group consisted of individuals with normal hearing sensitivity and the study group consisted of individuals who had symmetrical sensorineural impairment. The results indicated that speech perception in noise performance was similar across the two groups. However, the group with the hearing loss performed relatively poorer.

Helfer and Wilber (1990) also studied the effect of noise and reverberation in younger normal hearing individuals as well as older individuals with mild to moderate hearing loss and minimal hearing loss. The responses of the participants to nonsense syllables in quiet and in +10 dB SNR and at different levels of reverberation times (0.0, 0.6, 0.9, 1.3 s) indicated that age and reduction in pure-tone sensitivity reduced speech perception in noise scores. However, they also observed that even elderly individuals with minimal reduction in peripheral sensitivity displayed difficulty in perceiving consonants in noisy and reverberant conditions.

From the review of literature, it can be observed that the test that is used most often to determine auditory separation abilities in older individuals is SPIN. This is despite other tests being available to evaluate auditory separation. From the findings of studies that used SPIN, it is apparent that older individuals perform poorly in the presence of noise unlike young adults.

Temporal resolution in older individuals

It is observed that temporal resolution is affected in most older individuals in spite of normal hearing sensitivity. Reduced temporal resolution has been studied in older individuals using the random gap detection test (Keith, 2000), Gap-in-Noise (GIN) by Musiek in 2004 or using temporal modulation transfer function developed by Viemeister in 1979.

Moore, Peters, and Glasberg (1992) studied gap detection thresholds in the elderly using sinusoidal signals as a function of frequency. They evaluated both elderly individuals with hearing impairment and normal hearing individuals. They observed that even though the elderly individuals had near normal hearing sensitivity, they still obtained larger gap detection thresholds as compared to the younger group. Furthermore, when the gap detection scores of the elderly group with near normal hearing and those with hearing impairment was compared, they found no significant difference. This was considered to indicate the role of central auditory processing in the accurate processing of temporal information.

Similar to the findings of Moore et al. (1992), Schneider et al. (1994) observed that older adults with normal hearing performed poorly and in general had very variable results as compared to the younger normal hearing group. These findings were obtained when 2000 Hz Gaussian modulated tones were utilized.

Strouse, Ashmead, Ohde, and Grantham (1998) also reported of a similar finding on 12 young and 12 elderly individuals who had normal hearing. The participants were compared using gap detection test and a binaural sensitivity test that evaluated inter-aural time difference. The results indicated that the performance of the elderly group was poor compared to the younger in both the gap detection as well as the binaural sensitivity task. Also, in the younger individuals there was a correlation between the monotic gap detection test and the binaural sensitivity measures. There was no such correlation in the elderly group. They attributed it to large differences in the gap detection thresholds between the two ears in elderly individuals as reported by Schneider (1994).

In an earlier study, Fitzgibbon and Gordon-Salant (1996) attributed the reductions in gap detection thresholds seen in the elderly to poor sensory cochlear processing as a result of presbyacusis. However, a study by Snell and Frisina (2000) indicated that the reduced gap deduction thresholds in older individuals did not correlate with their audiometric thresholds. They measured the gap detection thresholds of 40 younger and older individuals who had normal peripheral sensitivity. The gaps were marked by low-pass 150 ms modulated noise bursts with cutoff frequencies of 1 or 6 kHz. An overall level of 80 dB SPL was used in three different background conditions. They found that older listeners performed significantly poorer than the younger group and had longer gap detection thresholds. Furthermore, the audiometric thresholds and the gap detection measures did not correlate well in the elderly group like it did in the younger group. The authors suggested that auditory temporal acuity begins degrading with age at a much faster rate than the age related changes in thresholds or word recognition ability.

Roberts and Lister (2004) studied gap detection in three groups. The first group consisted of young normal hearing adults and second and third group consisted of elderly individuals with and without normal hearing respectively. The test was performed in two paradigms, one with within channel gap detection and the other across channel gap detection processing. Their results indicated that across channel processing of gaps carried out by using a dichotic task was significantly affected as compared to within channel processing. In both the elderly group the across channel processing was affected, however, the hearing impaired group had much poorer results in both within and across channel processing, indicating an influence of hearing loss on certain gap detection tasks as well.

The studies on temporal processing indicate that there is consensus regarding the adverse effect of aging in the processing of temporal information. A large body of literature supports the view that even in the absence of any hearing impairment, older individuals still perform poorly when compared to normal young adults. This suggests the involvement of the central mechanisms as opposed the peripheral mechanisms in the processing of temporal resolution.

Temporal patterning in older individuals

Duration Pattern Test (DPT) and Pitch Pattern Test (PPT)have been widely used for the evaluation of temporal ordering or temporal patterning abilities. Temporal patterning is considered to be an auditory task that primarily recruits higher levels such as the cortex. The tests used to measure temporal patterning are duration pattern test described by Musiek, Baran and Pinheiro (1990) as an alternative to the Pitch pattern test given by Pinheiro (1977).

Musiek et al. (1990) initially studied duration pattern tests on individuals who had normal hearing acuity, individuals who had cochlear hearing loss and individuals who were known to have auditory cortical lesions. It was found that there was no significant difference between the pattern recognition scores of the two groups comprising of normal and cochlear hearing loss individuals. In contrast, in individuals with cortical lesions, the temporal pattern recognition scores significantly dropped. Hence, the authors suggested the use of the test clinically for detection of individuals having cortical lesions. The study also showed that the test was largely resistant to peripheral hearing sensitivity.

Parra et al. (2004) studied frequency and duration patterns in 25 elderly individuals with hearing sensitivity within normal limits. The test was carried out at 50 dB SL independently in both the right and left ears. The results showed no significant difference in performance between the two ears and also in the duration pattern test, the subjects obtained an average score of 67.5%, which was below the normative range for young adults. The authors attribute the results to central auditory processing deficits resulting from aging.

The performance of centenarians was compared with that of young and elderly subjects in a temporal order judgment task by Kolodziejczyk and Szelag (2008). Slight deterioration related to age was apparent in the elderly subjects when compared to younger subjects. However, significant reduction was observed in the centenarians compared to both the young adults as well as elderly participants.

Fogerty, Humes and Port (2010) studied the auditory temporal order judgment of vowel sequences in young and elderly individuals. The tasks involved a monotic-two item identification, monotic-four item identification, dichotic two item identification, and dichotic ear identification. The results revealed significant poorer performance in the older subjects especially in the monotic-four item judgment task as compared to the younger adults.

In order to study the effects of audiogram configuration of those with peripheral hearing loss on the performance of monotic auditory processing tests, Cox, McCoy, Tun and Wingfield (2008) evaluated in 45 older adults aged 66 to 85 years. The participants were divided into three groups: normal hearing till 4 kHz with a slight high frequency slope; normal hearing in the speech range with greater high frequency loss; and hearing loss in both high and low frequencies. It was found that most of the monotic tests were not affected by chronological age. Only for the pitch pattern test, the chronological age accounted for additional variability beyond that accounted for by hearing, memory, processing speed. This could indicate a change in the temporal processing with aging.

The literature suggests that duration pattern and pitch pattern test are primarily used for evaluating temporal patterning. Use of tests like temporal order judgment tasks has also been documented. From the existing literature it is evident that there is deterioration in the temporal patterning ability in older individuals when compared to younger adults. Deterioration in the temporal patterning is evident even when the peripheral hearing sensitivity is well within the normal range. This deterioration continues to increase with advance in age.

Binaural integration in older individuals

Dichotic tests are primarily used to assess a central process known as the binaural integration, wherein an individual has to process different information coming from both the ears. The most commonly utilized stimulus for dichotic testing are majorly dichotic speech materials such as dichotic CV, dichotic sentences or dichotic digits (Musiek & Pinheiro, 1985; Bellis, 2003).

Dichotic digit is reported to be more resistant to hearing loss. In contrast, dichotic CV is reported to be dependent on intact cochlear processing for resolution of the frequency and intensity fluctuations in the CV portions (Chermak, 2001). Several research studies using dichotic listening paradigms have been carried out with the aim to determine the effect of aging on the scores as well as to establish the effect on an ear advantage.

Horning (1972), who compared young and older adults (23 to 80 years), reported that there was a significant effect of aging on dichotic listening. Clark and Knowles (1973) who studied dichotic listening in subjects aged 15 to 74 years also reported finding similar to that of Horning (1972), with older individuals having a considerably larger right ear advantage.

The poor performance of older individuals on a dichotic digit test has been demonstrated by Rodrigo and DiSarno (1990). They observed that their 25 older participants, aged between 60 to 85 years showed a decline in performance, even when factors such as linguistic decline, cognitive decline and peripheral hearing sensitivity were controlled. It was found that most of the individuals had a large right ear advantage in this task.

Jerger, Alford, Lew, Riveira and Chmiel (1994) studied dichotic listening in 40 participants divided into four groups. The groups included normal hearing young adults, elderly individuals with hearing impairment, elderly individuals with hearing impairment and marked reduction in dichotic performance, and individuals with callosal lesions. They employed both electrophysiological methods as well as behavioral measures. The experiment was carried out using both verbal as well as non verbal paradigms. Jerger et al. reported of a marked reduction in the left ear performance for verbal paradigms and an increasing deficit in the right ear performance for the non-verbal tasks in all elderly listeners. The performance of the elderly group with hearing impairment and reduction in dichotic performance yielded similar results to that of the subjects with callosal lesions. It was concluded that inter-hemispheric transfer was affected in individuals with advancing age hence giving rise to the particular result.

Goncales and Cury (2011) studied dichotic listening by using the staggered spondaic word test (SSW) in elderly listeners who did not complain of any hearing difficulties. The authors reported of very poor performance in the left ear of the participants, especially in the competing conditions. Older individuals above 65 performed much poorer than those who were 55 to 60 years old. There was no significant gender effect reported.

In contrast to the above studies, Borod and Goodglass (1980) reported of no significant changes in dichotic listening abilities with aging. Their finding was based on the evaluation of 102 right-handed individuals in the age range of 24 to 79 years.

From the above literature it is evident that Dichotic CV is utilized primarily for assessing binaural integration. Most of the studies point to the conclusion that binaural integration in older individuals are significantly affected when compared to their younger counterparts, even when peripheral hearing sensitivity is relatively spared.

Cognitive factors and central auditory processing in older individuals

The speech perception performance in older individuals has been noted to be affected by cognitive factors such as memory, speed of information processing, and verbal ability even when hearing sensitivity is near normal (Wingfield, Poon, Lombardi, & Lowe, 1985). Studies to determine the association between cognition and auditory processing have conducted have been conducted to see if there is a link between the two.

The effects of aging and associated cognitive decline on speech perception performance were studied by Van Rooije and Plomp (1992). Although they found that non-auditory cognitive factors such as slow information processing and reduced working memory capacity were responsible for reduced performance, they majorly attributed the reduction in performance in the older individuals to auditory factors such as reduced temporal and spectral resolution.

Janse (2012) revealed that cognitive factors did have a role in poor speech perception associated with aging. The performance to variable compression speeds was used to identify pre-assigned target words. The results showed that even in aged individuals with good hearing sensitivity thresholds, performance deteriorated at fast rates of speech indicating the effect of slowed information processing. Hence, it was evident that apart from reduced hearing sensitivity, aging also affected temporal and cognitive domains.

Mythri and Yathiraj (2012) studied memory and sequencing abilities in three groups consisting of a young adult group (20 to 30 years) and two older groups 50 to 64 years & 65 to 80 years). The result revealed that the younger group performed significantly better than the two older groups. Also the younger of the two older groups also showed better performance than the other.

Thus, from the review of literature, it is evident that some studies attribute the decline in performance with aging to the presence of a cochlear pathology (Fitzgibbon & Gordon Salant, 1996; Bergman, 1980) or peripheral hearing loss (Watson, Johnson, Jensen, 1987; Humes & Roberts, 1990; Halling & Humes, 2000). On the contrary, several other studies demonstrated that reduced peripheral hearing sensitivity might not be the only entity contributing to poor speech perception abilities in older individuals.

In addition, a general decline in central auditory processing and cognitive abilities were also considered to significantly affect speech perception in older individuals (Rodrigo & Di Sarno, 1990; Calais & Russo, 2008; Helfer & Wilber, 1990; Snell & Frisina, 2000). Hence, the existing literature is divided on the issue as to which factor majorly contributes to reduced speech perception in older individuals.

METHOD

The present study was undertaken to investigate auditory processing skills in older individuals. The study was carried out by comparing four auditory processing abilities in two groups of older individuals and a group of young adults. The four auditory processing tests that were assessed included ‘Speech-in-noise’ test (SPIN) developed by Ramya and Yathiraj (2012), ‘Gap detection test’ (GDT), reconstructed by Shivaprakash (2003), ‘Duration pattern test’ (DPT), reconstructed by Gauri (2003) and ‘Dichotic CV’ test (Yathiraj, 1999). These tests evaluated monaural separation, temporal resolution, temporal patterning and binaural integration respectively.

Participants

Three groups of participants, two older groups (Groups I & II) and one younger group (Group III) were studied. Each group comprised of 20 individuals. The ages of the individuals in Groups I and II ranged from 55 to 65 years and 66 to 75 years respectively while those in Groups III ranged from 18 to 30 years. All the participants were native speakers of Kannada and had no report of any speech or language problem. They had pure-tone air conduction thresholds within normal limits after applying correction for age related hearing loss as given by Indrani (1981). Additionally, it was ensured that all the participants had pure-tone hearing thresholds within 20 dB HL between the frequencies 250 to 2000 Hz as considered by Grose (1994). The participants also had normal ‘A’ type tympanograms with acoustic reflexes less than 110 dB at both 1000 Hz and 500 Hz. It was ensured that the participants were not under any medication considered to be central nervous depressants. None of them had any prior history of chronic middle ear infection or noise exposure. In the older participants (Groups I & II), the presence of any cognitive decline or impairment was ruled out based on their results the Mini Mental Status Examination (MMSE) given by Folstein, Folstein and McHugh in 1975. Only those who were right handed were selected for the study.

Instrumentation

A calibrated dual channel diagnostic audiometer, Madsen OB 922 with air conduction (TDH-39) and bone conduction (B-71) transducers were be used to carry out pure-tone audiometry, speech audiometry, and the APD tests. A calibrated immittance meter (GSI Tympstar) was used to carry out the immittance evaluation to ensure normal middle ear functioning. The CD versions of the APD tests were played through a desktop personal computer with Windows XP service pack-2 operating system and an Intel Core 2 duo processor.

Test Environment

The test to rule out cognitive problems was carried out in an environment that was quiet and distraction free. All the audiological tests were carried out in an acoustically treated suite that met ANSI S3.1 (1991) specifications. The centrally air conditioned suites had optimum temperature and lighting.

Procedure

Procedure for selection of the participants

The pure-tone thresholds of all the participants at octave intervals between 250-8000 Hz were determined for air conduction and bone conduction thresholds were obtained for octave intervals between 250-4000 Hz using the modified Hughson-Westlake method (Carhart & Jerger, 1959). Speech reception thresholds were obtained using spondee word list developed in the Department of Audiology at the All India Institute of Speech and Hearing. Immitance evaluation was carried out which included conventional 226 Hz tympanometry and acoustic reflex threshold measurement.

The Mini mental status examination (MMSE) was used to assess cognitive impairment in the older individuals. Only participants who had scores of 25 and above, indicating that they had no cognitive impairment as per the recommendations of Folstein, Folstein and McHugh (1975) were selected for further testing.

Procedure for assessing auditory processing

The three participants groups were assessed on the four different auditory processing tests that tapped monaural separation, temporal resolution, temporal patterning and binaural integration. The tests used to assess the four processes were 'Speech-in-noise' test (SPIN), 'Gap detection test' (GDT), 'Duration pattern test' (DPT) and 'Dichotic CV test'. The instructions to all three groups were similar except that the older participants were instructed in a slow and clear manner.

For all the monaural tests (SPIN, GDT, & DPT), half the participants from each group were initially tested in the right ear and the other half in the left ear. This was done to avoid any possible ear order effect. Additionally, the order in which the four tests were presented was also randomised across the participants to avoid any test order effect. The procedure to evaluate the four processes is described below.

Speech perception in noise-Kannada:

The speech-perception-in-noise test (SPIN-K) in Kannada, constructed by Ramya and Yathiraj (2012) was used to assess auditory monaural separation. The test stimuli consisted of phonemically balanced words developed by Yathiraj and Vijayalakshmi (2005) and eight-speaker babble (2012), presented monaurally at 0 dB SNR at 40 dB SL. The participants were instructed to listen to the words and repeat them as accurately as possible. The responses were noted and a correct response was given a score of one and an incorrect response a score of zero.

Gap Detection test:

The Gap detection test (GDT) was carried out to assess the temporal resolution abilities of the participants. The test was performed monaurally at 40 dB SL. The participants were asked to indicate which stimulus among a triad of noise bursts had a gap present. The minimum duration of the gap that could be detected by each participant was noted as being their gap detection threshold.

Duration pattern test:

The duration pattern test (DPT), that consisted of a three-tone sequence where one differed from the other two (E.g. Long-Long-Short) was presented at 40 dB SL under headphones. While the short stimuli had a duration of 250 ms, the long stimuli had a duration of 500 ms, with both having a frequency of 1 kHz. The participants were instructed to verbally indicate the duration pattern that they heard. Each ear was scored separately. Every correct response was given a score of 1 and an incorrect response was given a score of zero.

Dichotic CV test:

The dichotic CV test was used to assess binaural integration in the participants. The stimuli were presented binaurally at 0 ms lag at 40 dB SL under headphones and the participants were asked to repeat what they heard. The single correct and the double correct scores were calculated for all the three groups. For both scoring procedures, a score of one was given for a correct response and a score of zero for an incorrect response.

Test- Retest reliability

Test-retest reliability was checked by administering all the tests on 40% of participants. This test was done after a period of 1 month following the initial assessment.

<u>Statistical Analyses</u>

The raw scores on the four different central auditory processing tests obtained on all the participants were tabulated and analysed using SPSS software (version 17). Repeated measures Mixed ANOVA was done to study the effect of age on the scores for the monaural tests. Further, repeated measures ANOVA was carried out in each group to determine the within group ear effect. A Bonferroni multiple comparison test was done to check for any significant ear difference.

For the DCV test, a repeated measures ANOVA was initially carried out to determine the presence of a significant interaction between age and scores. Three separate repeated measures ANOVA were then carried out to check for any significant difference in the scores, within each age group. MANOVA was done to study the effect of age on the scores. A Bonferroni multiple comparison test was again done to study statistical significance between the groups.

RESULTS

The scores for the four tests of central auditory processing were compared to obtain information about the difference between the two ears within each age group and also between the groups for the monaural tests (SPIN, GDT, & DPT). For the dichotic CV test, the three scores (single for each ear & double correct) were compared within each age group and also across the three age groups. The data were analyzed for each test to obtain information regarding the effects of ear / scores and age. The mean and the standard deviation of the scores for the four tests for each of the age groups, is provided in Table 1.

Table 1: Mean (M) and Standard Deviation (SD) for the four auditory processing tests for the three age groups.

GROUPS	**Speech in Noise Test-Kannada**				**Gap Detection Test**				**Duration Pattern Test**				**Dichotic CV**					
	RIGHT		**LEFT**		**RIGHT**		**LEFT**		**RIGHT**		**LEFT**		**DCV -Rt**		**DCV-Lt**		**DCV-DC**	
	M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
I	20.5	2.2	21	2.2	5.7	2.1	5.6	1.5	27.4	1.5	27.3	1.8	23.1	2.9	15.6	6.3	10.1	7.0
II	18.8	2.4	19	2.1	9.3	2.3	8.8	2.4	25.1	2.7	24.8	3.0	20.9	3.5	11.3	5.6	6.0	5.3
III	23.3	1.4	23.5	1.1	3.6	0.4	3.0	0.5	29.3	0.8	29.3	0.9	27.7	0.9	25.3	0.9	23.1	1.6

DCV - Rt = Dichotic Consonant Vowel- Right single correct scores; DCV - Lt = Dichotic Consonant Vowel- Left single correct scores; DCV - DC = Dichotic Consonant Vowel- Double correct scores.

For each of the three monaural auditory processing tests (SPIN-K, DPT, & GDT) that were administered on the three age groups (55 to 65 years, 66 to 75 years, & 18 to 30 years), analyses were done to check if there existed any difference between the left and right ear. For the dichotic CV test, ear effect (single correct left vs. right) as well as effect of the scoring procedure (single correct vs. double correct scores) was checked. Additionally, for all four tests, the effect of the age of the participants was evaluated.

a) Speech in noise test-Kannada (SPIN-K)

Between ear effect

From the mean scores provided in Table 1 and Figure 1, it is apparent that the scores between the two ears of the participants were similar. This can be seen in each of three age groups. A repeated measure ANOVA indicated that there was no significant difference between the ears of the participants when the groups were combined [$F(1, 57) = 2.32$, $p > 0.05$] as well as no interaction between the ears and the groups [$F(2, 57) = 0.205$, $p > 0.05$]. This indicated that the SPIN scores was not significantly different for any of the age groups.

Between group effect

The mean scores for the SPIN, determined for the three groups (Table 1 & Figure 1), indicates that the scores for the two older groups (Group I &Group II) was lesser than that of the younger group (Group III). Additionally, it can be observed that the SDs were larger for the older two groups (Groups I & II) compared to the younger group (Group III).

To confirm if the difference between groups was statistically significant, repeated measure mixed ANOVA was carried out. The results showed a significant difference between the groups [$F(2, 57) = 32.865$, $p < 0.001$]. To determine which of the age groups differed from each other, Bonferroni multiple comparison tests was carried out. It showed that the scores of Group I and II scores were significantly different from that obtained by Group III ($p < 0.001$) and were also significantly different from each other as well ($p < 0.01$).

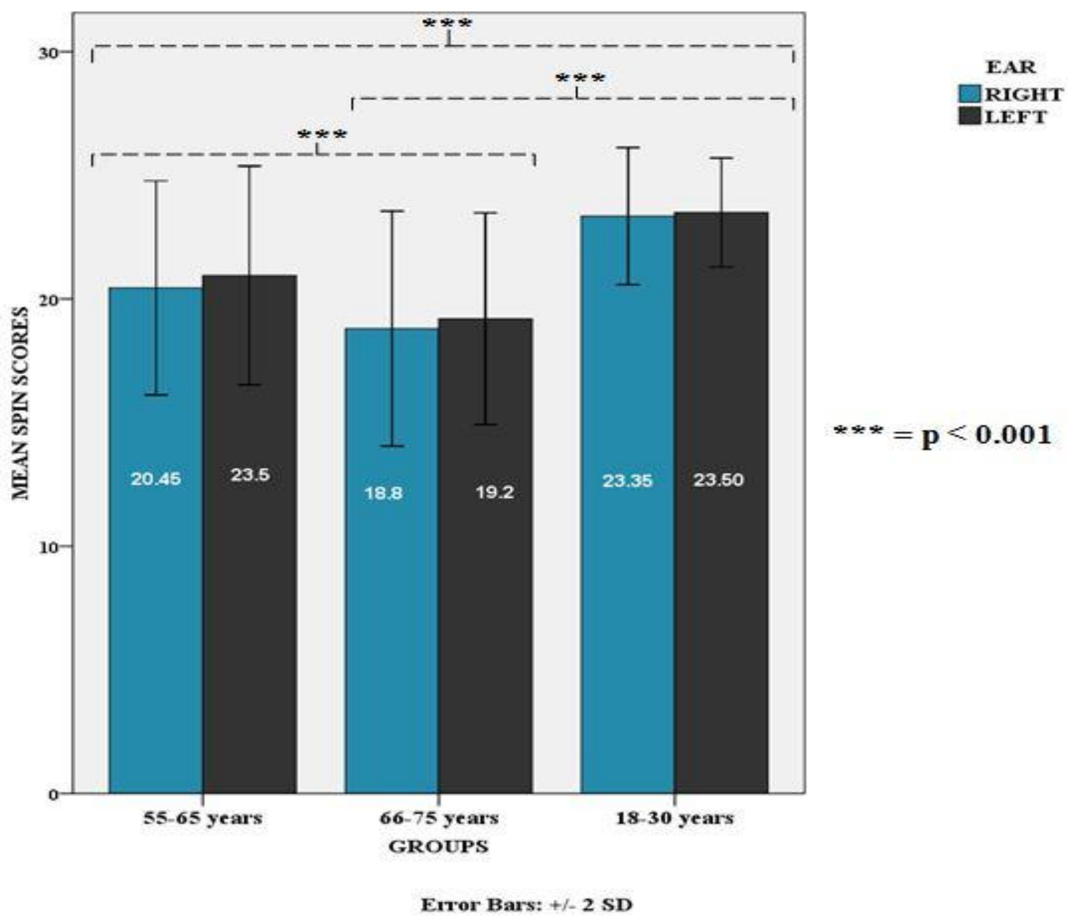

Figure 1: Mean and Standard deviations for the SPIN scores for each ear, across age groups

b) Gap Detection test

Between ear effect

From Table 1 and Figure 3, it is clearly observable that the mean gap detection thresholds for the two ears in all the groups are similar. A repeated measure ANOVA indicated that there was no significant difference between the two ears for the gap detection when groups were combined [$F (1, 57) = 1.748$, $p > 0.05$]. Additionally, it was found that there was no significant interaction between the scores for the two ears and the three age groups [$F (2, 57) = 0.598$, $p > 0.05$]. This indicated that in none of the age groups was there any difference between the two ears for the GDT.

Between group effect

The mean thresholds and the standard deviations for the GDT for Groups I, II and III (Table 1 & Figure 3) indicated that the values varied depending on the age groups. The mean thresholds for Groups I and II were higher compared to that of Group III. To see if these observations were statistically significant, a repeated measure mixed ANOVA was carried out. The findings reveal that there was a significant group effect [$F (2, 57) = 71.150$, $p < 0.001$]. The Bonferroni multiple comparison test showed that there was a difference between all the groups, which were found to be statistically significant. Groups I and II were significantly different from group III ($p < 0.001$), as well from each other ($p < 0.001$).

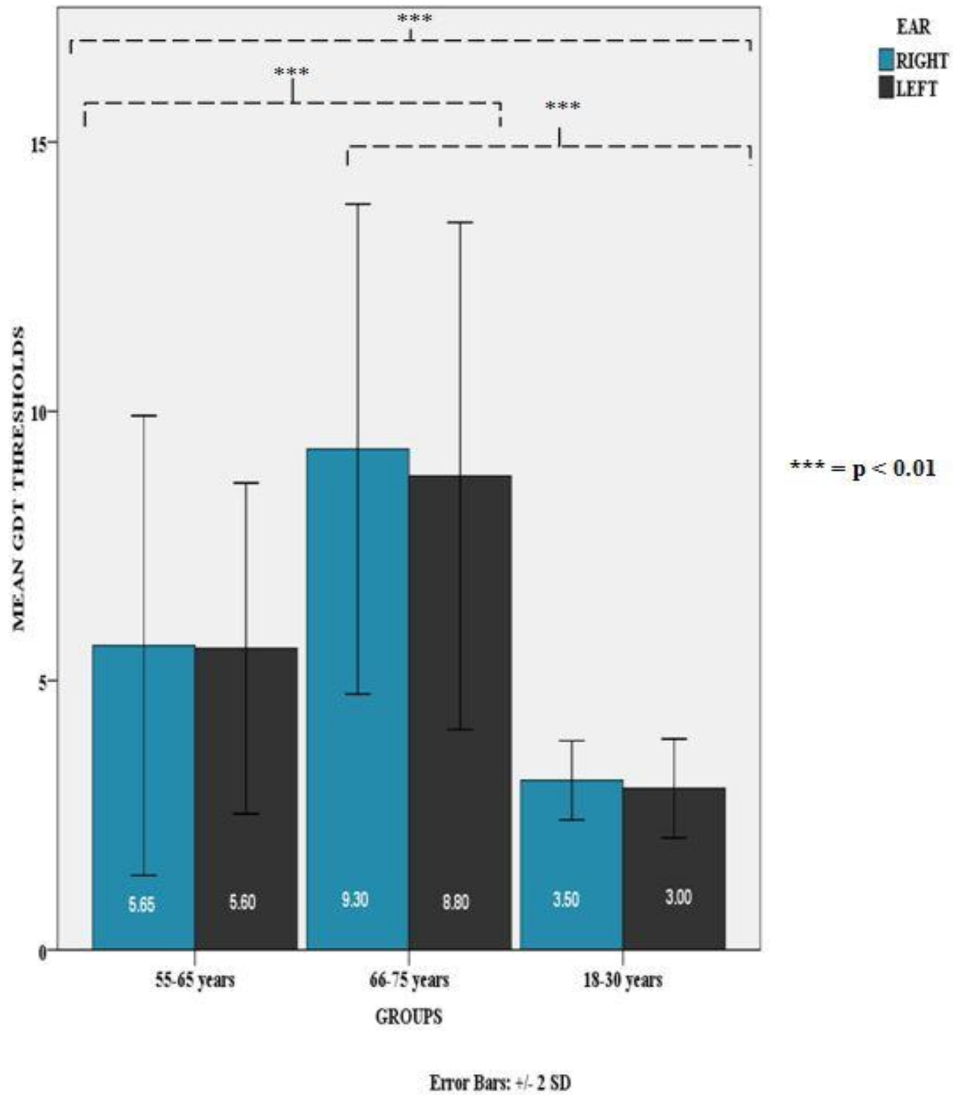

Figure 2: Mean and Standard deviations for the Gap detection threshold across the three age groups

c) *Duration Pattern Test*

Between ear effect

From Table 1 and Figure 4, it is apparent that the mean DPT scores for right and left ears are almost equal. Repeated measure ANOVA revealed no significant ear effect when the groups were combined [$F(1, 57) = 0.389$, $p > 0.05$]. In addition, no significant interaction was observed between the scores of the two ears and the three age groups combined [F (2, 57) = 0.127, $p > 0.05$]. Since no interaction was seen between the ear and age groups, no further analysis was done to check ear differences within each age group.

Between group effect

The mean scores and the standard deviations for the DPT determined for the two ears in each of the three groups (Table 1 & Figure 4) indicates a difference between the three groups. Group III obtained slightly higher scores than Groups I & II. Statistical analysis done using a repeated measure mixed ANOVA indicated a significant difference between the age groups [F (1, 57) = 29.018, $p < 0.001$]. The Bonferroni multiple comparison test revealed a significant difference between Group I and Group II ($p < 0.001$). The scores of Groups I and II were also found to be significantly different from that of Group III ($p < 0.001$, & $p < 0.01$ respectively).

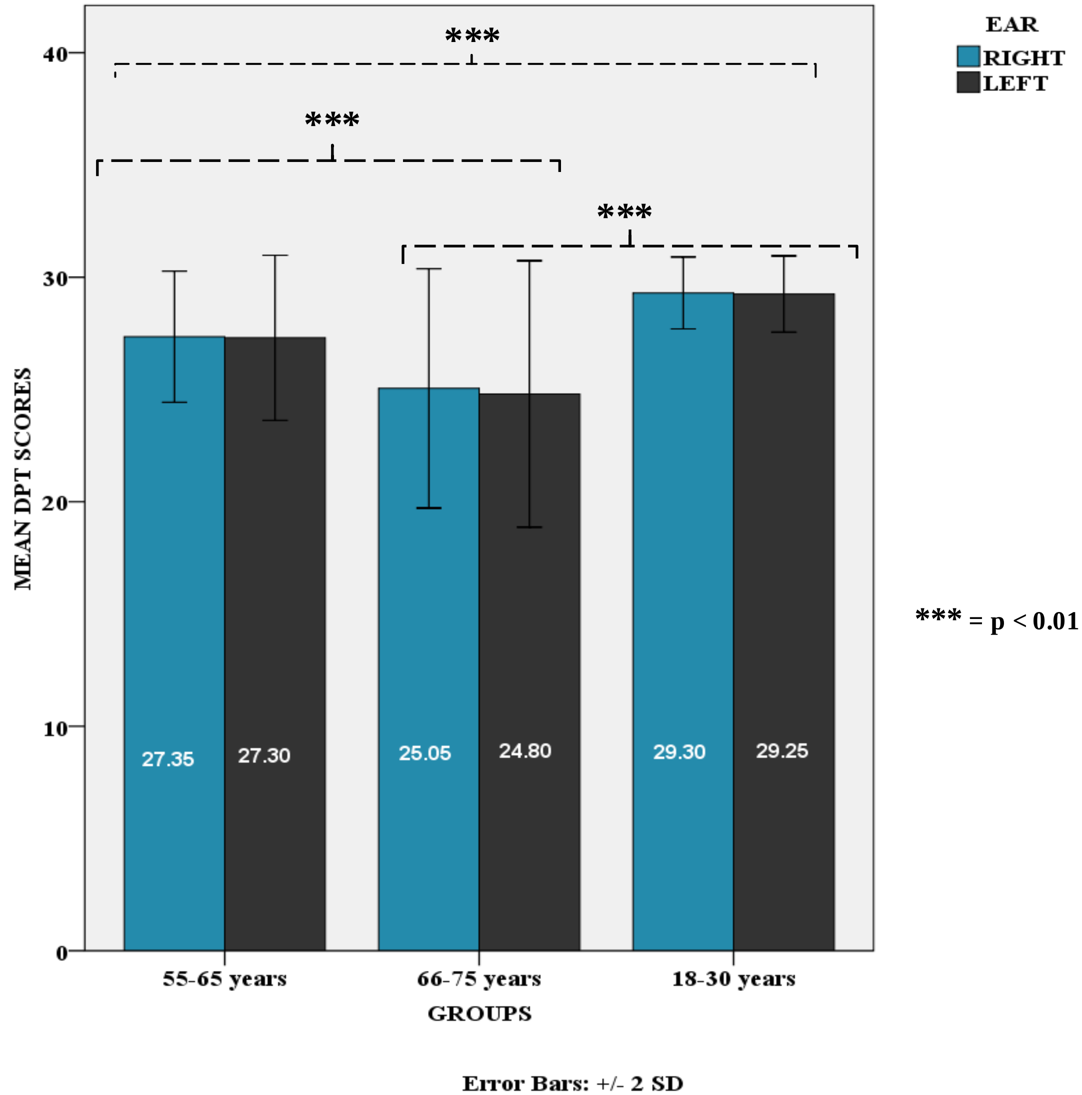

Figure 3: Mean and Standard deviations for the Duration Pattern test across age groups.

d) Dichotic Consonant Vowel (Dichotic CV)

Between score effect

The mean scores given in Table 1 indicate a difference in scores obtained by the participants within the single correct scores (right ear vs. left ear) as well between the single correct scores and the double correct scores. This difference is observable in all three age groups, though to a lesser extent in the younger age group (Group III) and is more apparent in the older groups (Groups I & II). In all three groups, the performance was best for the right ear score followed by the left ear score and was the least for the double correct score. Further, the SD was the least for the right ear scores and similar for the left ear scores and the double correct scores.

A repeated measure ANOVA indicated that there was a significant interaction between scores and age [$F(2, 57) = 35.654$, $p < 0.001$] when the three scores were combined as well as the three groups were combined. To determine if there existed a significant difference between the scores in each age group, three separate repeated measures ANOVAs were carried out. For each age group a significant difference was observed between the scores for each age group {Group I: [$F(2, 38) = 66.68$, $p < 0.001$]; Group II: [$F(2, 38) = 210.01$, $p < 0.001$]; & Group III: [$F(2, 38) = 281.98$, $p < 0.001$]}. Bonferroni multiple comparison tests indicated that in each of the three age groups there existed a significant difference between all three scores ($p < 0.001$).

Between group effect

From the mean single correct scores (left ear & right ear) and double correct scores for the three age groups given in Table 1 and Figure 2, it is evident these scores differed from each other in all the three groups. MANOVA was carried out to check if these scores across the groups were statistically significantly different. The results of the MANOVA indicated a significant main effect for groups with the scores of their right ear combined [F (2, 57) = 33.82, p < 0.001], left ear combined [F (2, 57) = 43.60, p < 0.001] and the double correct scores combined [F (2, 57) = 60.43, p < 0.001]. Bonferroni multiple comparison test was done and it revealed that Group I and Group II were significantly different from Group III (p < 0.001) and also significantly different from each other (p < 0.05). This trend was seen for the scores of the right ear, left ear as well as the double corrects scores.

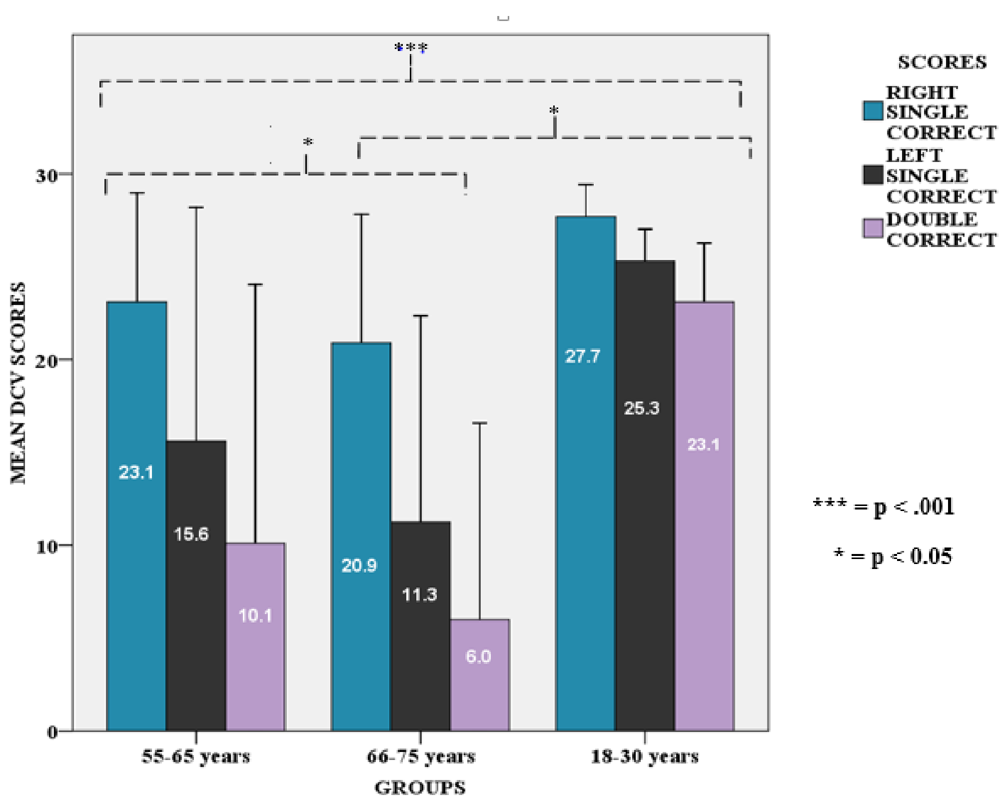

Figure 4: Mean and Standard deviations for the three DCV scores across age groups

Table 2: Summary of the significance of difference between the three age groups for the four tests (SPIN-K, GDT, DPT, & DCV).

Test	**SPIN-K**		**GDT**		**DPT**		**DCV**					
Groups	**II**	**III**	**II**	**III**	**II**	**III**	**II**	**III**	**II**	**III**	**II**	**III**
I	***	***	***	***	***	***	*	***	*	***	*	***
II		***		***		***		***		***		***

*[Note: * = $p < 0.05$, *** = $p < 0.01$]*

From the findings it can be observed that that Group III consisting of young adults (18 to 30 years) performed significantly better than the two older groups namely, Group I (55 to 65 years) and Group II (66 to 75 years), in all of the tests chosen for the evaluation of central auditory processing. It is also notable that upon comparison of the two older groups, the participants in Group I, in the age range of 55 to 65 years performed much better than the Group II where the age range spanned from 66 to 75 years. In all of the monaural tests (SPIN-K, GDT, & DPT), no significant ear effects were observed. However, for the dichotic CV test, a right ear advantage was clearly apparent in all the groups, with the advantage particularly pronounced in the two older groups. In both the older groups, a disproportionate reduction in the left ear scores was observable.

A comparison across tests to determine the degree, to which each process was affected, was done by calculating the total number of older individuals falling beyond the 1 SD and 2 SD values obtained for the younger group. To decide if the scores of the older groups were different from that of the younger group, for the SPIN-K, DPT, and

DCV tests, the lower cut-off was considered. On the other hand, for the GDT, the upper cut-off was considered. This was done since former set of tests lower scores were considered poorer unlike the latter test.

Table 3: Cut-off values at 1 and 2 Standard Deviations (SD) based on the scores of the younger group (Group III)

Group III	SPIN-K		GDT		DPT		DCV		
	Right	**Left**	**Right**	**Left**	**Right**	**Left**	**DCV-Rt**	**DCV-Lt**	**DCV-DC**
At 1 SD	21.9	22.2	4	4.1	28.5	28.4	26.8	24.4	21.5
At 2 SD	20.5	21.3	4.4	4	27.7	27.5	25.9	23.5	19.9

Note: DCV - Rt = Dichotic Consonant Vowel- Right single correct scores; DCV - Lt = Dichotic Consonant Vowel- Left single correct scores; DCV - DC = Dichotic Consonant Vowel- Double correct scores.

The total number of older individuals (Groups I & II) falling 1 and 2 standard deviations beyond the mean values for the younger adults (Group III) was calculated. The results indicated that all the tests were affected to similar degrees. However, among the tests, the maximum number of individuals who had scores beyond the 1 SD was for DCV, followed by GDT. The number affected on DPT and SPIN-K was similar.

Table 4: Number of older individuals (Groups I & II) falling beyond the SD values of the younger individuals (Group III)

	Age group	SPIN	GDT	DPT	DCV		
					DCV-Rt	DCV-Lt	DCV-DC
1 SD	Group I (55 to 65)	13	17	14	17	19	19
	Group II (66 to 75)	20	20	19	20	20	20
	Total	33	37	33	37	39	39
2 SD	Group I (55 to 65)	11	15	11	15	18	18
	Group II (66 to 75)	16	19	18	18	20	20
	Total	27	34	29	33	38	38

The results of the study showcased that:

- The performance of the older individuals, in all four auditory processing tests, was considerably poor when compared to their younger counterparts.
- Among the older groups, Group I (55 to 65 years) performed significantly better than Group III (66 to 75 years).
- No significant inter-aural differences were observed for the monaural tests (SPIN-K, GDT and DPT) in any of the three groups.
- For the binaural test (DCV), a significant difference between the scores were seen (Right single correct scores, Left single correct scores, Double correct scores) for all the three groups. Apart from this, a significant Right ear advantage was also seen for the three groups.

- Among the four tests, DCV had the maximum number of individuals with scores beyond 1 SD cut-off score of the younger group. This was followed by GDT, while SPIN-K and DPT had equal number of individuals falling beyond this cut-off.

DISCUSSION

The present study reveals that the performance of older individuals in the tasks of central auditory processing was significantly poorer when compared to their younger counterparts. It is widely reported in the literature that the presence of a peripheral hearing loss exacerbates the speech perception difficulties encountered by older individuals. However, the present study showcases the difficulties seen in auditory processing in older individuals despite their peripheral hearing sensitivity being almost within normal limits. The results of the four auditory processing tests (SPIN-K, DCV, GDT, & DPT) that were administered on three age groups (18 to 30, 55 to 65, & 66 to 75 years) are discussed.

Comparison of SPIN-K scores between ears and across age groups

The *SPIN-K scores between the two ears* were found to be similar and not statistically significant, in the current study. This was observed in all three age groups, indicating that the ear similarity that is seen in young adults is maintained with aging.

This finding is in agreement with the results obtained by Wong, Ettlinger, Sheppard, Gunasekera and Dhar (2010). They used QuickSIN to compare speech perception in noise between an older group in the age range of 62 to 75 years and a younger group in the age range of 18 to 27 years. They reported of no significant ear effects within each age group. .

However, unlike the findings of the current study and Wong et al. (2010), Sanchez, Nunes, Barros, Gananca and Caovilla (2008) reported of the left ear scores being better than that of right ear scores in individuals aged 60 to 65 years and 70 to 75 years. A similar outcome was also obtained by Thais et al. (2011), who evaluated 45 right handed and 36 left handed individuals in the age range of 18 to 65 years using a Portuguese speech-in-noise test. Unlike the present study, they reported of a poorer performance in the right ear compared to the left ear. The authors supported their results using evidence from the findings of Veenstra et al., (2010) who showed that there was increased activation of regions in the right hemisphere homologous to the Broca's and Wernicke's areas during complex challenging linguistic tasks such as the presence of noise or while performing closure tasks, resulting in a left ear advantage. However, Veenstra et al. (2010) used a dichotic paradigm in their study unlike the authors who have used a monaural auditory separation paradigm. Hence, the findings of Veenstra et al. cannot be generalized to that of Thais et al., as the two studied evaluated two different processes.

Thus, there is no consensus in the literature regarding the ear effect with aging when evaluating auditory separation. In the literature it has been suggested that different individuals might experience different degrees of cognitive decline (Van Rooije & Plomp, 1992). This could have resulted in the variability seen in the different studies on SPIN.

Further, in the current study, on *comparison of the scores across the three age groups* on the SPIN-K, it was found that the performance of the youngest age group (Group III aged 18 to 30 years) was significantly better than that obtained by the older two groups (Groups I aged 55 to 65 years and Group II aged 66 to 75 years). It was also observed that with increase in age the deterioration in performance continued. This deterioration was similar in the two ears. Thus, the results of the study indicate that with increase in age the monaural auditory separation ability progressively becomes worse.

The findings of the current study conform to the results attained by many studies reported in the literature. The results of the study are in consonance with the findings of Rodriguez et al. (1990) that speech identification with ipsilateral competing signals was affected with age even in normal hearing, cognitively intact elderly listeners. Likewise, Sanchez, et al. (2008), also reported of a similar finding, wherein sentence identification in the presence of competing ipsilateral signal was poor in elderly listeners with normal audiometric pattern. They also found deterioration in performance in with advance in age. Those aged 70 to 75 years performed poorer when compared to those aged 60 to 65 years, which is in concordance with the results obtained in the present study.

However, the findings of the current study do not match with the study done by Surr (1977), who found that in participants ranging in age from 30 to 90 years speech perception in noise did not deteriorate with age. The findings of Surr were obtained with the use of phonetically balanced words presented at an SNR of + 6 dB. In contrast, the present study employed a 0 dB SNR to evaluate the participants. Hence, it can be construed that only when the listening condition is more adverse, such as that used in the current study, can the age related deterioration be discerned.

Thus, the result of the current study indicates that there is a substantial reduction in speech perception in noise in older individuals as compared to younger individuals. This reduction continues with advance in age. As the contribution of the peripheral hearing sensitivity was controlled in the study, the reduction in the performance can be attributed to the deterioration of the auditory processing skills along with increased load on the working memory capacity as reported by Van Rooije and Plomp (1992). Listening in noise is taxing, and recruits a considerable amount of working memory stores. As working memory in older individuals is known to be affected (Salthouse, Mitchell, Skovronek & Babcock, 1989; Craik & Jennings, 1992; Kemper, 1992), their speech perception in noise can be severely affected.

Comparison of Gap Detection Thresholds between ears and across age groups

The *gap detection thresholds obtained for the left ear and the right* ear were similar and statistical analysis confirmed that they was no significant difference between them. This inter-aural symmetry in the gap detection thresholds was maintained across all the age groups indicating that both ears functioned similarly even as individuals grew older.

The findings of the present study are in accordance with that of Musiek et al. (2005) who found that the Gap-in-Noise test performance in 50 normal hearing adults ranging in age from 18 to 50 years resulted in no ear effect. Likewise, Prem, Shankar and Girish (2012), in a study to establish the normative data for Gap-in-Noise test for the Indian population on 100 individuals ranging in age from 17 to 60 years, revealed a finding that was in concordance with the results obtained in the present study. They too found no significant effect of ear for the gap detection task. They observed this trend in both the older as well as the younger participants.

However, an investigation carried out by Sininger and Bhatara (2012) to study laterality effects in basic auditory processing using a gap detection test, revealed a significant left ear advantage for the gap detection task. This finding contradicts the results of the present study. This discrepancy could probably be due to the different stimuli used in the two studies. Sininger and Bhatara used tonal stimuli to carry out the gap detection task whereas the present study utilizes broadband noise. It has been reported in the literature that processing of slowly varying, narrowband tonal stimuli is an operation primarily done by the right hemisphere. On the other hand, auditory stimuli that are more complex in the temporal domain, have wider bandwidth and rapid transitions or modulations such as noise and speech stimuli are processed majorly by regions in the left hemisphere (Zatorre, Belin, & Penhune, 2002; Tervaniemi & Hugdahl, 2003)

Although there were no significant ear effects, the mean gap *thresholds across age groups* obtained in the current study revealed a significant difference between the younger group (Group III) and the two older groups (Group I & Group II) with the younger group performing better than the two older groups. Also, the younger of the two older groups had much better thresholds.

It is well established in the literature that there is difficulty experienced in the gap detection task in older individuals even when the sensorineural hearing loss is accounted for. Moore et al. (1992) reported that their older group with clinically normal hearing performed poorer than their younger group. Similarly, Schneider, Pichora-Fuller, Kowalchuk & Lamb (1994) also reported that their older individuals with normal peripheral hearing sensitivity performed poorer than the younger group and generally had a lot of variability in the results. The result of the present study is consistent with this finding, wherein the older groups (Groups I & II) had larger standard deviations compared to the younger group (Group III).

The results of the current study with reference age related changes and gap detection were consistent with the findings of Snell and Frisina (2000). They observed that the subnormal gap detection thresholds correlated poorly with the pure tone thresholds in their older group, despite the latter being normal. In the present study, poor gap detection thresholds were observed in older participants even when they had near normal pure-tone thresholds. The findings of present study are also in consonance with that of Snell (1997) who used noise burst stimuli and again found considerably poorer gap detection thresholds in elderly participants as compared to younger participants even when high frequency hearing loss was stringently controlled.

However, a study done by Owens, Campbell, Lidell, DePlacido, Wolters, (2007) contradicts the findings of the present study. They found that their younger group of participants aged 20 to 30 years and older group aged 50 to 65 years had no significant difference in gap detection thresholds. This discrepancy could be due to the fact that they used click stimuli for the gap detection task whereas the present study used broadband noise. Additionally, their older age group was also slightly younger than the participants of the current study which could also be a contributing factor in the difference in findings.

Thus, in general from the results of the current study and that reported in literature, temporal resolution remains symmetrical with progress in age. However, with increase in age, there is a steady decrease in the performance that is progressive. This indicates that the areas responsible for temporal processing continue to deteriorate with as age progresses.

Comparison of the Duration Pattern Test between ears and across age groups

The *DPT scores between the left and right ears* did not significantly differ in the present study. This finding was apparent in all the three age groups indicating that temporal ordering of duration changes symmetrically between the two ears with aging. However, there was a significant difference in the DPT scores *between the all three age groups*. This difference was more between the oldest age group (66 to 75 years) and the youngest age group (18 to 30 years) than between the two older age groups (Groups 1 & II) or between the middle and the youngest group (Groups II & III). Thus, similar to findings seen with the SPIN-K and the GDT, with increase in age the performance steadily dropped.

Parra et al. (2004) who studied DPT in older individuals with normal hearing sensitivity also obtained a similar outcome as the results obtained in the present study. They too did not find any noticeable ear effects, but reported of considerable reduction in the DPT scores in the elderly, similar to that observed in the present study.

The DPT is a temporal processing measure that is relatively resistant to peripheral hearing loss and as hearing loss was controlled in the present study, the decrease in DPT performance in older individuals could be attributed to a weaker processing of stimuli in the central auditory nervous system. Lesions in the posterior part of the temporal lobe, insular cortex and brainstem have been shown to reduce temporal processing ability (Steinbuechel, Wittmann, Strasburger, & Szelag, 1999; Bamiou, et al., 2006). It is possible that a general deterioration in the regions responsible for temporal processing occurs with age, as indicated by the impairment in both of the temporal tasks evaluated in the present study (GDT & DPT) in the older individuals.

Comparison of Dichotic Consonant Vowel test between ears and across age groups

Unlike the results observed for the other tests conducted in the study, the Dichotic CV showcased a significant *ear effect* within each group studied. The findings revealed a large right ear advantage, especially in the older groups. The larger right ear advantage in the older individuals was primarily due to a marked reduction in scores in the left ear.

This result is consistent with many studies in the literature that report of a disproportionate reduction in the left ear scores giving rise to a substantial increase in the right ear advantage. Clark and Knowles (1973), who studied dichotic listening in subjects in the age range of 15 to 74 years, reported of a large right ear advantage. Similar findings have been demonstrated by Rodrigo et al. (1990) for a verbal dichotic task. They too reported of a 'left ear disadvantage' with an increase in right ear advantage in individuals ranging in age from 60 to 85 years. These findings occurred despite factors such as linguistic decline and peripheral hearing sensitivity being controlled.

Likewise, Jerger, Chmiel, Allen and Wilson (1994) reported of a marked decrease in left ear scores in elderly individuals with hearing impairment especially when verbal stimuli were used. They observed that the scores obtained by the elderly were similar to that of individuals with callosal lesions, therefore, attributed to the age related deterioration to problems in inter-hemispheric transfer.

Contrary to the findings of the present study, Borod and Goodglass (1980) reported that even though the overall dichotic scores diminished, there was no apparent change in the right ear advantage for verbal material with aging in 102 right handed individuals aged 24 to 79 years. This result could be due to the pre-cueing paradigm used by the authors whereas no such procedural variations were employed in the present study.

With reference to the *age effect on the DCV test*, the findings of the present study indicate poor performance of the older groups as compared to that of the younger group. Both the single correct as well as the double correct scores were significantly poorer in the older participants than that the scores obtained by the younger group. The scores obtained for Group I (55-65 years) were again found to be significantly better than that of Group II (66-75 years).

The age related findings of the DCV test are in consonance with the findings of Horning (1972) who reported of reduced dichotic performance as a function of age, after comparing younger and older subjects ranging in age from 23 to 80 years. From the literature, it is known that the defects in several areas in the central auditory nervous system such as the splenial callosal system (Pollmann, Maertens, von Cramon, Lepsien & Hugdahl, 2002) and pre sensory motor areas and planum temporale (Jänckea, Spechtb, Shahc, & Hugdahld, 2003) and even auditory brainstem structures (Musiek, 1983), are known to be affected when deviant scores are obtained on dichotic tests for verbal stimuli. Hence, it is possible that with advance in age, the some or all of the above areas are affected, resulting in a reduction in DCV scores in older individuals.

Comparison across the four auditory processing tests

In general, all four tests chosen for the evaluation of central auditory processing showed a significant deficit in the two older groups compared to the younger group. With both older groups combined, the test that the maximum number of individuals obtained scores beyond the 1 SD value obtained by the younger individuals was for DCV (98%), followed by GDT (93%). The number who got poor scores on the DPT and SPIN-K was similar (83%). On observation of the difference in performance among the older two groups, it is evident that almost all the older participants (66 to 75 years) had problems on all four tests. The younger of the older group were less effected on the APD tests, with DCV being affected in 95%, GDT in 85%, DPT in 70% and SPIN-K in 65%. Thus, it can be construed that as individuals get older, the process that is more likely to be affected is auditory integration, followed by temporal processing and then auditory separation. However, Van Rooije and Plomp (1992) reported that different individuals might experience different degrees of cognitive decline, thereby leading to increased likelihood of variability in test findings. Hence, it is necessary to confirm on a larger group whether the trend seen with reference to the deficits in APD tests are replicable.

SUMMARY AND CONCLUSIONS

Older individuals often have distinct speech perception difficulties regardless of whether they have a peripheral hearing loss or not. Their difficulties are particularly amplified in the presence of unfavorable degraded conditions such as in the presence of background noise, reverberation or multiple talkers speaking at a fast rate. These specific difficulties have been demonstrated in the literature to be primarily due to deterioration of higher order auditory processing abilities as reported by Bergman (1971) and Jerger et al. (1989).

The current study was carried out to study the effects of aging on various measures of central auditory processing. Three age groups, with 20 participants in each, were selected for the study. Group I and Group II contained older individuals aged 55 to 65 years and 66 to 75 years, respectively. The older participants were selected only if they had peripheral hearing sensitivity within normal limits after applying correction for age related hearing changes, as given by Indrani (1981). The participants also had pure-tone hearing thresholds within 20 dB HL between the frequencies 250 to 2000 Hz, as considered by Grose (1994). Group III included normal hearing young adults in the age range of 18 to 30 years. Age related cognitive decline was ruled out using the Kannada version Mini Mental Status Examination, given by Folstein (1978). The presence of middle ear pathology, degenerative neural conditions, history of noise exposure was also ruled out.

All the participants were assessed on four different auditory processes. Monaural auditory separation was assessed using the 'Speech-in-noise' test in Kannada (SPIN-K) developed by Ramya and Yathiraj (2012); temporal resolution utilising the ‘Gap detection test’ (GDT), reconstructed by Shivaprakash (2003); temporal patterning with the ‘Duration pattern test’ (DPT), reconstructed by Gauri (2003); and binaural integration using the ‘Dichotic CV’ test (Yathiraj, 1999). The tests were employed to determine the performance of the three age groups. The tests were administered using the CD version of the stimuli that were presented through a computer the output of which was routed to a calibrated diagnostic audiometer (Madsen OB 922). The signals were heard by the participants through headphones.

The results highlighted the following:

- The older individuals performed significantly poorer in all four auditory processing tests when compared to their younger counterparts.
- The younger of the two older groups (55 to 65 years) performed significantly better than the oldest group (66 to 75 years).
- For the monaural tests (SPIN, GDT & DPT) no significant ear difference was observed in any of the age groups.
- For the binaural test (DCV), a significant difference was seen between the three scores that were obtained (right single correct, left single correct, & double correct). A right ear advantage was seen in all three age groups. However, in the older groups, a disproportionate reduction of the left ear scores gave rise to a much larger right ear advantage.
- Among the four tests, Dichotic Consonant Vowel test was affected the most, followed by the Gap Detection Test. Duration Pattern test and Speech in Noise test were equally affected.

Implications

The findings of the study can be used to:

- Detect auditory perceptual problems in older despite their peripheral hearing sensitivity and speech recognition ability being seemingly spared.
- Further, from the findings it is evident that different processes are affected to different degrees. This will enable audiologists to make a hierarchy of auditory processing tests that are to be administered on older individuals.
- Based on the findings of auditory processing tests, older individuals and their caregivers can be counseled regarding the perceptual problems seen. Suitable remedial techniques can be suggested / employed for these individuals.
- The findings of auditory processing tests will enable audiologist to chalk-out tailor-made training programmes for older individuals who experience difficulty in challenging listening conditions.

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