Effect of Spectro-Temporal Enhancement on Speech Perception in Younger and Older Adults with Normal Hearing Sensitivity

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MAY 2015

Dedicated to my Guru

CERTIFICATE

This is to certify that this dissertation entitled "**Effect of Spectro-Temporal Enhancement on Speech Perception in Younger and Older Adults with Normal Hearing Sensitivity**" is a bonafide work submitted in part fulfilment for the Degree of Master of Science (Audiology) of the student (Registration No.: 13AUD021). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any of the University for the award of any other Diploma or Degree.

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This is to certify that this dissertation entitled "**Effect of Spectro-Temporal Enhancement on Speech Perception in Younger and Older Adults with Normal Hearing Sensitivity**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "**Effect of Spectro-Temporal Enhancement on Speech Perception in Younger and Older Adults with Normal Hearing Sensitivity**" is the result of my own study under the guidance of Dr. Animesh Barman, Reader, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

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Abstract

Normal aging is mostly associated with global decline in almost all aspects of human body structure including auditory system. This might led to no significant change to significant change in auditory physiology. The older adults with and without hearing loss usually exhibit difficulty in perception of speech than young listeners, especially in the presence of background noise. The best management options for these individuals could be the modification of acoustic signal that would improve speech perception. Thus in the present study, two types of enhancement strategies (companding and consonant enhancement) were taken to see if they bring about any change in speech intelligibility in the presence of noise. To analyse the same, consonant identification scores were obtained from two groups of individuals (10 younger adult individuals and 10 older adult individuals with normal hearing sensitivity). Both the groups did not show any advantage with processed stimuli when compared to unprocessed condition across different signal to noise ratios. Sequential information transfer analysis showed more voicing errors followed by place and manner in both the groups. Consonant enhanced stimulus have shown significantly better scores than companded stimulus in older adults. This may be due to the spectral enhancement at the consonant part which made the consonant part to be more audible.

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Chapter 1

Introduction

Communication is an exchange of information from one individual to another. Communication through speech forms most of our daily lives and hence is an important aspect of life. Speech is heard and understood through a series of events which occur in the auditory system. The ear converts sound waves into mechanical signal and then to electrical signals. These electrical signals then generates nerve impulses and sent to the brain where they are interpreted and perceived as meaningful sound. Different sounds having different frequency composition stimulate different parts of the inner ear and sent to the auditory cortex thus helping the brain to distinguish among various sounds. Human auditory system also has the ability to extract important information in the presence of noise and helps us to understand what has been said. Extracting a speaker's voice from background of competing voices is essential for communication. This process is often challenging, even for young adults with normal hearing and cognitive abilities (Assmann & Summerfield, 2004; Neff & Green, 1987). In realistic acoustical environments where various sounds reach our ears simultaneously, we can listen adaptively to a particular sound in the mixture of sounds by focusing our attention to it. This phenomenon is termed as the "cocktail party" effect (Cherry, 1953; Yost, 1997).

A healthy auditory system helps us to understand speech even in adverse listening situation. However, human auditory system undergoes numerous structural and functional changes from external ear to brain with advancing age (Willott, 1991).

Evidence of neural degeneration with aging has been found in the auditory nerve, brainstem, and cortex. At the level of the brainstem, majority of these structural or functional changes have been reported in the cochlear nucleus intern of decline in neuronal number (Willot, Parham & Hunter, 1988), and also decrease in the overall volume of the cochlear nucleus (Konigsmark & Murphy, 1972; Gandolfi, Horoupian & DeTeresa, 1981). Hearing sensitivity and other aspects of hearing also gradually deteriorate in the older population (Divenyi, Stark & Haupt, 2005).

The change in hearing sensitivity can occur as early as third decade of life (Davis, 1994). In spite of all these structural changes many investigators have observed that in older individuals understanding of speech does not change significantly in quiet situations (Vanrooji & Plomp, 1990; Pedersen, Rosenhall & Moller, 1991; Tun 1998). But, it significantly reduces in adverse listening conditions (Gelfand, Piper & Silman, 1998; Humes & Christopherson, 1991; Divenyi & haupt, 1997; Dubno, Lee, Matthews & Mills, 1997). Many physiological changes have been reported in the central auditory pathway as a result of aging. Such as increase in the spontaneous neural activity, possibly resulting from a decrease in the inhibitory GABA. This causes an increased "neuronal noise" in the aging (CANS) (Morris et al., 1994). Increasing neuronal noise may underlie the speech perception difficulties in competing backgrounds. The involvement of central auditory system is also reported to cause difficulty in adverse listening conditions in spite of having essentially normal peripheral hearing sensitivity in older adults (Helfer & Wilber, 1990; Dubno et al., 2002; Wingfield et al., 2006). Increased difficulty in speech comprehension commonly occurs as a function of aging. This problem in older adults may be exacerbated by noise (Dubno, Dirks, & Morgan, 1984; Gelfand, Ross, & Miller, 1985; Heifer & Wilber, 1990) or reverberation (Heifer & Wilber, 1990; Nabelek, 1988; Nabelek & Robinson, 1982). It has been reported that the speech perception ability of older adults is poorer than younger adults in the presence of background noise or when some part of speech content is filtered out (Helfer & Wilbur, 1990; Cheesman, Hepburn, Armitage & Marshall, 1995). Older individuals usually require at least 4 dB greater signal to noise ratio (SNR) than young adults (Humes & Roberts, 1990).

The older adults with and without hearing loss have more difficulty in perception of speech than young listeners, especially in the presence of background noise (CHABA, 1988). Several explanations have been suggested to account for age-related changes in speech perception, such as changes in hearing sensitivity or a more general decline in cognitive functioning. Numerous studies have documented this age-related decline in the ability to comprehend speech in the presence of a masker (Dubno, Dirks, &Shaefer, 1987; Plomp & Mimpen,. 1979). Many studies have shown that there is reduction in speech perception in older individuals with no hearing loss (Calais, Russo & Borges., 2008).

The perception of speech involves various psychophysical abilities such as, identification of temporal modulations, gap detection, frequency discrimination, etc (Kumar & Jayaram, 2005; Rance et al., 1999; Zeng et al., 2005). These cues helps to identify the spectral –temporal component of speech and hence perceive it. Much of the studies on temporal processing in older individuals have been done using the detection of brief temporal gaps between successive stimuli, usually noises or tone bursts. Moore et al

(1992) used tonal stimuli and measured the gap thresholds in elderly adults (62 - 86yrs). They obtained that the average performance of the older subjects was significantly poorer than the younger group. These larger than normal gap thresholds were independent of any effects of hearing loss. Similar results were also obtained by Lutman (1991) who observed age-related temporal resolution deficits in the elderly population.

To improve speech perception ability different signal enhancement techniques has been used. One such technique is clear speech. Clear speech is characterized by a somewhat slower rate of speech compare to conversational speech. Clear speech has shown to be more intelligible compare to conversational speech in both hearing impaired (Schum, 1996; Picheny, Durlach, & Braida, 1985; and Payton, Uchanski, & Braida, 1994) and normal hearing individuals (Uchanski, Choi, Braida, Reed, & Durlach, 1996). This is seem to be beneficial under different conditions, including presentation level, speaker, and environment conditions are varied.

Envelope enhancement is yet another technique which was tend to enhance speech perception. Narne and vanaja (2008) reported improved consonant identification in individuals with auditory dys-synchrony when the envelope of speech signal was digitally enhanced. Ajith and Jayaram (2005) reported that lengthening of transition duration significantly improve speech identification scores in auditory dys-synchronics.

Turicchia and Sarpeshkar (2005) proposed a new strategy for time domain spectral enhancement, based on relatively broadband compression followed by more frequency selective expansion. This technique is termed as companding. This compression and expansion approach was basically derived by the certain physical properties shared by the peripheral auditory system. Using this spectral enhancement techniques algorithm they have shown some improvement in speech intelligibility for cochlear implant users and for normal-hearing subjects.

Shachi (2012) observed an improvement in speech identification in auditory neuropathy for companded speech compare to unprocessed speech at quiet and in noise. Deepthi (2012) also observed better syllable identification and sentence identification at lower SNR's in processed (companding) condition compare to unprocessed condition in individuals with cochlear hearing loss. Similarly Narne, Suma, Kalaiah, Chandan, Deepthi & Barman. (2014) studied the effect of companding strategy in individuals with Auditory Neuropathy Spectrum Disorder (ANSD) and reported that there is an improvement in both sentence identification and consonant identification tasks in quiet and at higher SNRs.

Consonant enhancement is yet another spectral enhancement technique where the consonant portion of a syllable is given a gain (in dB) without altering the vowel part of the stimulus. Guelke (1987) reported that individuals with cochlear hearing loss identified stop consonants better with consonant enhancement than unprocessed stimulus.

Need for the study:

Above literature highlight that there is a decline in the auditory system, both anatomically and physiologically, which happens throughout the lifespan of an individual. A significant change in both anatomy and physiology can be noticed in the middle age i.e from 40 years of age. (Engstrom, Hillerdal, Laurell & Bagger-Sjoback. 1987; Felder & Schrott-Fischer, 1995; Scholtz et al. 2001). This may leads to difficulty in understanding speech in noisy environments in older adults. Even though the pure tone hearing thresholds remains with in normal limits they have more difficulty in understanding speech in noisy environments.

Gelfand, Piper and Silman (1986) stated that older individuals has reduced consonant identification compare to young adults. Similarly Wiley,Chappel, Carmichael, Nondahl, Cruickshanks (2008) reported that speech perception abilities were reduced in the elderly population compared to younger listeners. Thus there is need to check whether speech enhancement techniques would help to improve speech perception ability in older adults especially in different adverse listening conditions. Thus attempt was made to check whether different technique used to enhance spectro-temporal features would actually improve speech perception abilities in older adults.

Also, most of the techniques are used in hearing impaired individuals either cochlear hearing loss (Deepthi 2012) and auditory neuropathy (Narne et al., 2014). Recently researchers have used companded stimulus to study speech perception ability in hearing loss population and found effective. However, there is dearth of researches regarding whether the companded speech will helps in improving speech perception in older adults. Thus the study has been taken to see the effect of companding on speech perception in older population.

Similarly consonant enhancement strategy is yet another technique which also been carried out on individuals with cochlear hearing loss (Guelke, 1987). There is lack of research regarding whether the consonant enhanced speech would help to improve speech perception in older individuals. Therefore the study has also been taken to study the effect of consonant enhancement on speech perception in older adults.

Till date there is no study which compare the effect of companding and consonant enhancement on speech perception in same group of individuals. Thus this study has been taken up to see whether companding and consonant enhancement technique is effective in improving speech perception in older individuals especially in different stimulus condition. If these techniques are found useful, then among these which technique is more useful in improving speech perception in this population can be stated.

Aim of the study

The aim of the study was to know whether the Companding and Consonant enhancement algorithm is effective in improving speech perception in younger and older adults having normal hearing sensitivity.

Objectives

- To compare the speech perception ability at each of the five SNRs under processed (companding and consonant enhancement) and unprocessed stimuli between younger and older adults with normal hearing sensitivity.
- To compare the benefit obtained from processed speech across young and older adults.
- To see the effect of SNR on speech perception for each stimulus condition within each of the two groups.
- To see the effect of stimulus condition on speech perception at each SNR within each of the two groups.

- To see the error patterns obtained with respect to phonetic features of place, manner and voicing cues in both the groups.

Chapter 2

Literature Review

Elderly adults often find difficult in understanding speech in noisy environments. It is reported that elderly individuals with normal hearing sensitivity and those with peripheral hearing loss suffer common central auditory dysfunction at the level of brainstem (Frisna & Frisna, 1997). Older adults tend to have more difficulty in speech perception than younger adults in the presence of noise and they experience still more difficulty when the noise is temporally modulated (Dubno et al., 2002).

As the age increases from 50 years to 89 years the prevalence of auditory processing disorders increases from 20% to 95% (Stach, Spetnjak & Jerger, 1990). Among individuals aged 55years or older the prevalence of auditory processing disorder found to be 76.4% (Golding et al, 2004). This probably happens due to consequence of structural changes that happens in the auditory system.

2.1: Age related changes in auditory system

Aging can lead to a structural or functional deficit at various levels of the auditory system. These changes may occur in outer ear, middle ear, inner ear, auditory nerve and central auditory nervous system. The changes which associated with aging occur in outer ear are; excessive production of cerumen (Miyamoto & Miyamoto, 1995), growth of hair around the ear canal (Maurer & Rupp, 1979), ear canal collapse (Ballachanda, 1995), changes in physical property of the skin including loss of elasticity, atrophy and dehydration which leads to trauma and breakdown (Ballachanda, 1995) and enlargement of pinna (Tsai et al. 1958). It has been reasonably documented that surface ridges of pinna alter frequency response of incoming complex signals. These surface ridges provide acoustic gain at higher frequency components which are responsible for speech intelligibility. Pinna plays a major role in localization and elevation of sound. It's the angular shape enables a comparison between reflected and incidental sound waves, thus providing a peripheral model for sound localization (Brttau, 1968; Gatehouse & Oesterrech, 1972). This structural capability, when enhanced by head movement and by additional information received by the other ear, supports ability to hear meaningful signals in adverse listening conditions. Hence changes in pinna with aging may contributes for hearing loss at higher frequency region , reduced speech discrimination and difficulty in listening in noisy environment. Although functional changes in pinna may alter some extent of frequency response of auditory system.

The changes which occur primarily in middle ear associated with aging are; thinning, stiffening and loss of vascularity of tympanic membrane (Covell, 1952; Rosenwasser, 1964), atrophy and degeneration of the fibers of middle ear muscles and the ossicular ligaments (Covell, 1952), ossification of the ossicles (Covell, 1952), calcification of cartilaginous support of the Eustachian tube and muscle function that opens the tube (Belal, 1975). Covell (1952) and Rosenwasser (1964) stated that the deterioration of function of two middle ear muscles may lessen the amount of protection provided by these to ear during contraction of these muscles in the presence of intense sound. Rosenwasser (1964) reported that degenerative changes in middle ear muscles and ligaments results in inefficient operation of middle ear ossicles, thus causing minor decreasing in hearing acuity and producing some degree of disorientation within conductive mechanism.

The organ of corti in inner ear is most susceptible to age related changes (Schuknect, 1993). It is reported that there is decrease in outer hair cells and inner hair cells number in individuals after 45 years of age (Engstrom et al. 1987). In individuals more than 60 years of age the degeneration was wide spread along the turns of cochlea (Scholtz et al. 2001). The number of spiral ganglion cells reduces with increasing age with loss of 2000 neurons per decade (Otte et al. 1978). It is reported that the atrophy of spiral ganglion cells in individuals above 50 years of age (Suzuki et al.2006). Individuals above 50 years of age auditory nerve appeared to be normal. However, there might be some myelin abnormalities in neurons (Xing et al.2012). Schuknect, (1964) reported structural atrophy of stria vascularis resulting in substantial interruption of transduser action activity within cochlea. The degeneration of stria vascularis is major factor in explaining the depression in hearing acuity observed in presbycusis.

Brain stem also undergoes major structural changes in older individuals (Kirake, Sato & Shitara, 1964). The fibers of lateral lamnisci also reduces with aging (Willott, 1991). It is reported that poor response to auditory stimuli in inferior colliculus with advancing age (Palombi & Caspary, 1996). Hansen and Reskenelson (1965) found severe degeneration in glial part of acoustic nerve as well as in white matter of brainstem. They reported that alterations were more pronounced in white matter of the hemispheres, next in the brainstem and finally in nuclei and the cochlea.

2.2 Audiological profile of elderly individuals:

Brant and Fozard, (1990) reported that the pure tone threshold decreases throughout the life with greater rate of change occurs after 50 years of age. High frequency pure tone thresholds are affected more compared to low frequency pure tone thresholds and generally decline after 50 years of age (Wiley, Chappell, Carmichael, Nondahl & Cruickshanks, 2008).

There is minimal or no effects of aging on immittance findings. However, it has been reported that there is presence of excessive middle ear pressure among older adults which is due to the poor Eustation tube function (Nerbonne, Schow & Bliss, 1978). Thompson, Sills, Reckey and Bui (1979) analyzed the immittance in 60 subjects between the age ranges of 20 to 70 years and reported that there was no change in acoustic admittance values across different age groups. Hall (1979) reported that static compliance values for males and females are maximum between 31 to 40 years of age and reduces relatively with aging. However several studies showed that there is no change in immittance findings (Nerbonne, et al. 1978; Wilson, 1981). It is also reported that no change in admittance values across young and older individuals (Osterhammel & Osterhammel, 1979).

Oto acoustic emission is the one which is most likely to be affected in elderly population. This is because loss of outer hair cells (OHC's) is most common abnormality seen due to aging. It has been reported that DPOAE amplitude reduce after 40 years of age in individuals with normal hearing sensitivity and there is reduction in amplitude at higher frequencies (Uchida et al 2008). However, it has been reported that older individuals will have poorer Oto acoustic emission amplitude than younger individuals (Betroli & Probst 1997; Uchida et al 2008). The prevalence of TEOAEs is only 60% in older individuals (Betroli & Probst 1997).

Auditory brain stem responses are mostly affected in terms of amplitude in older individuals. It was reported that in older individuals there is significant reduction in amplitude of brainstem evoked response and there was no change in latency (Beagely & Sherdrake, 1978). Mamatha and Barman (2003) reported that there is a shift in latency and decrease in amplitude with increasing reputation rates and this effect is more in older adults compare to young adults.

Event related potentials are also affected with advancing age. Studies such as, Pefferbaum, Ford, Roth and Koppel (1980) reported that N1 early component did not change with aging. But P2 and P3 components were affected. P3 component was more affected than P2 with increasing age. This was based on results of 12 older female individuals and 12 younger female individuals.

It is reported that with aging, the temporal processing cues available for speech sounds will be affected. Tremblay, Piskosz and Souza (2002) investigated that the neural representation of voice onset time a temporal cue which distinguishes voiced from voiceless sounds. Event related potentials were recorded from 10 younger individuals with the age group of 10 to 32 years of age and 10 older individuals with the age group of 61 to 79 years of age with normal hearing. Results indicated that in older individuals longer N1 and P2 latency compare to younger individuals. So, they concluded temporal processing is affected in older adults.

Anderer, Semlitsh and Saletu (1996) evaluated the effect of aging on event related potentials such as, N1, P1, N2 and P300 in 172 healthy normal hearing subjects aged between 20 and 88 years by using odd ball paradigm. With aging, N1 latency partially increased, P2 latency increased frontally whereas N2 and P300 latency increased all over scalp.

2.3: Speech perception in older individuals

It is well documented that older individual's have difficulty in understanding speech. The most common problem that they report is inability to comprehend speech in the presence of a background noise irrespective of their hearing threshold.

Yilmaz, Sennaroglu, Sennaroglu and Kose (2007) assessed the speech recognition in noise at +10 dB SNR. They considered 53 women and 48 men having normal hearing sensitivity in six different age, ranging from 10 to 69 years with 10 years interval between the groups. They noticed reduction in speech recognition scores after 50 years and significant reduction occurs after 60 years of age. The authors concluded that with advancing age the ability to identify speech in the presence of background noise decreases.

Many researches demonstrated that the speech understanding ability and temporal processing gets affected in older adults. Helfer and Vargo (2009) obtained speech understanding in the presence of steady state noise and competing speech. Gap in Noise test was administered to assess temporal resolution. Results indicated that, performance of subjects with the age range of 45 to 54 years was significantly poorer than that of young adult group in the presence of competing noise. Although performance in this listening condition was unrelated to pure tone threshold, it was strongly correlated with scores obtained on Gap In Noise test. So the authors concluded that the temporal processing may be an underlying cause for difficulty in understanding speech in competing speech.

Wiley, Chappel, Carmichael, Nondahl and Cruickshanks K J (2008) investigated age related changes across different age groups of 48 to 59 years, 60 to 69 years, 70 to 79 years and 80 to 92 years using word recognition in quiet and in the presence single talker competing message. They found that older individuals performed poorer than younger groups in both condition. It also showed that males perform poorer than females. Detailed analysis revealed that degree of hearing loss accounted for largest portion of variance in speech identification in quiet and in the presence of single talker babble (competing message).

Calais, Russo and Borges (2008) assessed the hearing abilities of older individuals using monoaural speech perception test in quiet and in the presence of background noise. Fifty five subjects in the age range of 60 years and above having normal hearing sensitivity were considered for the study. There was no gender effect noticed. All the participants had significantly lesser speech perception scores in the presence of noise. Thus they concluded that the results per se is not an indication of speech perception problem in noisy condition.

Gelfand, Piper and and Silman (1986) evaluated consonant recognition abilities in younger and older individual. They presented speech materials at most comfortable levels in quiet and in the presence of noise at +10 and +5 dB SNR. The results indicated that older individuals had reduced consonant recognition and the performance decreased with aging. But the age factor did not interact with different SNR conditions. However there was no difference in terms of nature of phoneme confusion between younger and older individuals in the presence of noise.

Wong, Jin, Gunashekhara, Abei, Lee and Dhar (2008) performed a functional examination of the brain using functional magnetic resonance imaging (fMRI) during speech in noise performance. They noticed that declined speech in noise performance in the older individuals in -5 SNR but there were no significant difference behaviourally in +20 SNR. In fMRI they noticed that reduction in the activity of the auditory cortex during speech in noise but increased activities in the prefrontal and precuneus area (related to attention and working memory). Showing that cognition is more used in these individuals for speech in noise performance. Considering the younger individuals the older individuals had more diffuse area of stimulation.

Helfer and Huntley (1991) compared the performance of consonant recognition in older adults in the presence of cafeteria noise. The word list presented was City University of New York nonsense syllable test. The groups considered were young normal hearing individuals, older individuals with minimal hearing loss and with moderate high frequency hearing loss. Error patterns across age group was observed. Manner errors: though the errors were more in older adults the error pattern followed similar trend as that of young group. Plosives and fricatives were most affect by noise and nasals were least affected. Place errors were b ilabials and dentals were most affected both in young and older group but older individuals showed more errors. Alveolar and palatal errors were also noticed in older group which was absent in younger group.

The above mentioned studies suggests that speech perception in quiet and noise is poorer in older adults. This may coexists with or wthout hearing loss. Hence, there is a need to adopt some strategy to improve speech perception in this population as a part of rehabilitation.

2.4: Speech enhancing strategies to improve speech perception:

2.4.1 Clear speech:

Older adults appear to have unique speech processing problems, their performance often is poorer than that of young adults with matched audiometric characteristics. Considering the speech perception problem in older adult individuals, it is essential to include different speech enhancing technique to improve speech perception ability. One of the simple and effective means of improving speech intelligibility is to speak clearly. However, reduced speaking rate, extended voice pitch range, enhanced temporal modulation, and vowel space are the features of clear speech (Krause & Braida, 2002). Gordon (1996) compared clear speech and conversational (natural) speech in adverse listening condition on young adults with the age range of 21 to 33 years and elderly adults with the age range of 65 to 72 years with normal-hearing sensitivity. The results were better for clear speech mode compare to conversational speech mode in both the groups.

2.4.2.Envelope enhancement:

Narne and Vanaja (2008) studied speech perception in auditory neuropathy individuals by digitally enhancing the envelope of the speech signal by 15 dB for different modulation bandwidth. They reported that better perception of speech with envelope enhancement technique in individuals with auditory neuropathy. They also reported that manner cues will be perceived better than voicing in those individuals.

Kumar and Jayaram (2005) demonstrated the importance of temporal envelope and effects of smearing of temporal envelope on speech perception in individuals with auditory neuropathy. Increased degree of temporal masking results in masking of speech events such as, transition, burst and voice onset time by the succeeding or preceding vowel steady state portion. Masking effects were more when short duration signals were used compare to longer duration signals. They reported that increasing the duration of some important short speech events might lead to better speech perception in individuals with auditory neuropathy.

2.4.3: Companding strategy:

Companding strategy was proposed by Turicchia and Sarpeshkar (2005). This technique performed simultaneous multichannel syllabic compression and spectral-contrast enhancement by using two-tone suppression method. Multichannel compression will improves audibility but it degrades spectral contrast of the stimulus. A weak tone of one frequency was strongly amplified so that the weak sound concurrently be audible with a strong tone at another frequency. This two tone suppression leads to spectral enhancement which helps in improving SNR of stronger component (Sachs et al 1983).

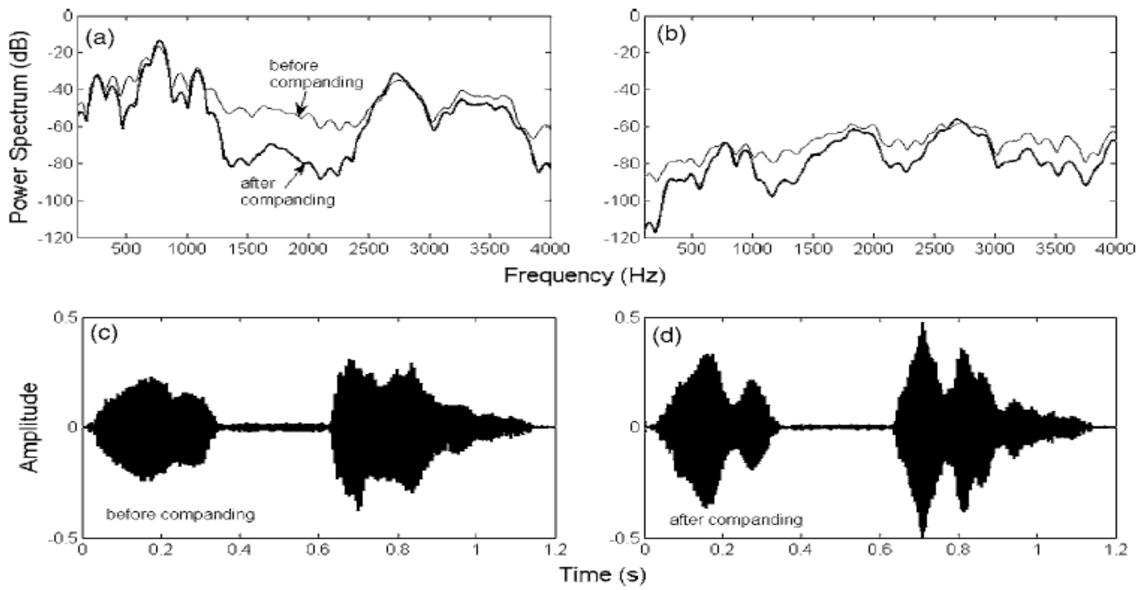
Many researchers have suggested that compression and expanding together as companding happens along auditory pathway. Zeng and Shenon (1999) reported that cochlea and cochlear nucleus perform the logarithmic compression for the input signals whereas brain performs as an exponential expansion. This companding strategy leads to enhancement of spectral peaks relative to spectral valleys. This strategy will leads to increasing in performance of improving speech intelligibility.

Similarly, many researches (Oxenham, Simonson, Turicchia, & Sarpeshkar, 2007; Bhattacharya & Zeng, 2007) examined the advantage of companding for cochlear implant listeners by using simulation studies. They reported that in a steady-state noise companding improved speech perception scores by 10 – 20%. The improvement of speech perception was attributed to enhanced spectral and temporal cues in the speech signal (Bhattacharya & Zeng, 2007).

The bird's eye view of spectral and the temporal wave forms of the consonant /aFa/ is represented in the Figure 2.1. Panel (a) shows the spectra of the initial vowel part of /aFa/ and panel (b) shows the spectra of the consonant part following the initial vowel part. The lighter traces correspond to the input i.e., the original consonant and the darker traces correspond to the data after companding. We see that the formant peaks are enhanced during the initial vowel part but the spectral sharpening during the consonant part is relatively weak. This result is understandable, because, unlike vowels, consonants generally have flat spectra and lack prominent spectral peaks. Panels (c) and (d) show the temporal wave forms of the same consonant before and after companding, respectively.

Similar to the vowel results, companding enhances changes in the temporal wave form envelope of the consonants (Bhattacharya & Zeng, 2007).

Figure 2.1 (a) Spectra of the initial vowel part of the consonant /aFa/. (b) Spectra of the consonant part following the initial vowel part. Lighter traces correspond to the original stimuli and the darker traces represent the stimuli after companding. (c), (d) Temporal wave forms of the same consonant before and after companding, respectively.



Narne, Suma, Kalaiah, Chandan, Deepthi, and Barman (2014) studied the effect of companding strategy in individuals with Auditory Neuropathy Spectrum Disorder (ANSD) and reported there is an improvement in both sentence identification and consonant identification tasks in quiet and higher SNRs. Shachi (2012) studied speech identification by using companding strategy on individuals with auditory neuropathy and reported that improvement in speech perception for companded speech compare to unprocessed speech at quiet and at noise situation. This shows companding increases the spectral and temporal contrast. Similarly Deepthi (2012) studied companding on cochlear hearing loss individuals and reported better syllable identification and sentence identification at lower SNR's in processed (companding) condition compare to unprocessed condition.

2.4.4: Consonant enhancement:

Consonant enhancement is technique which increases spectral contrast. In this strategy the consonant portion of the syllable is enhanced in terms of intensity as well as duration. It is done because the energy of a consonant is much lesser than that of a vowel. Guelke (1987) found that the Consonant enhancement technique aided in improving the perception of speech in hearing impaired individuals. This was supported by Baer, Moore and Gatehouse, 1993 who showed that for consonant enhanced stimuli there is an improved subjective quality and intelligibility rating. Smith and Harry (1999) studied consonant enhancement on twelve congenitally hearing-impaired children with moderately to severely and gradually sloping sensorineural hearing loss. They reported that there was significant benefit for consonant enhancement stimulus condition in children with hearing impairment.

Although companding and consonant enhancement strategies differ in the method of enhancement, their ultimate goal is to enhance the cues available for identification of speech. Hence, it is also important to compare the benefit across the companding and consonant enhancement in the same set of population. The literature does not report of studies comparing the two strategies. Similarly spectro-temporal enhancement techniques mainly studied under hearing impaired population (cochlear hearing loss & ANSD). There are no studies on older population which uses spectro-temporal enhancement to check the improvement in speech perception in literature. However there is dearth of studies on older individuals regarding companding and consonant enhancement techniques, there is a need to study on older individuals and to compare companding and consonant enhancement strategy across different levels of noise in the same population to see which technique gives better intelligibility in speech perception in the present study.

Chapter 3

Method

The objective of this study was to compare the effect of spectro- temporal enhancement of signal using companding and spectral enhancement in various listening conditions. Two groups of participants were taken in order to study these objectives and the following procedure was administered for the same.

3.1: Participants:

The study consisted of two groups of individuals, the older adult group and the younger adult group. Both groups had participants with healthy individuals with normal hearing sensitivity.

Group I: older adults

Participants were selected based on the following criteria:

- Participants in the age range of 40 to 60 years with the mean age of 52.1 years constituted this group.
- They had hearing sensitivity less than or equal to (four frequency average pure tone threshold, 500 Hz, 1000 Hz, 2000 Hz & 4000 Hz) 15 dB HL.
- All of them exhibited 'A' type tympanogram with ipsilateral and contralateral reflexes to rule out presence of middle ear pathology. .
- All had SPIN scores of 60% and above at 0 dB SNR to rule out presence of CAPD.

- Normal auditory brainstem responses at 80 dB nHL were obtained with a repetition rate of 11.1/s in all the participants.
- Presence of trancient otoacoustic emissions in both ears was observed in all the participants.
- No history or complaint of difficulty in understanding speech in noise was reported by the participants.
- No other otological or neurological symptoms and any speech or language problems were reported by participants.

Group II: Young adults group

Participants in this group were selected based on the following criteria:

- Participants in the age range of 20 to 30 years with the mean age of 24.7 years constituted this group.
- They had hearing sensitivity less than or equal to (four frequency average pure tone threshold, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz) 15 dB HL.
- All of them exhibited 'A' type tympanogram with ipsilateral and contralateral reflexes were present.
- All had SPIN scores of 60% and above at 0 dB SNR.
- Normal auditory brainstem responses at 80 dBnHL were obtained with a repetition rate of 11.1/s in all the participants.
- Presence of otoacoustic emissions in both ears was observed in all of the participants.

- No history or complaint of difficulty in understanding speech in noise was reported by the participants.
- No other otological or neurological symptoms and any speech or language problems were reported by participants.

3.2: Instrumentation:

The following instruments were used for the study,

- A calibrated two channel diagnostic audiometer, GSI-61 (Grason-Stadler Incorporation, USA) with Telephonics TDH 50 supra aural headphones and Radio ear B-71 bone vibrator calibrated as per ANSI S-3.6, (2004) was used for threshold estimation and speech audiometry.

- A calibrated GSI-tympstar (Grason-Stadler Incorporation, USA) clinical immittance meter, calibrated as per ANSI (1987) was used for tympanometry and reflexometry.

- ILO 292 DPEcho port system (Otodynamics Inc., UK) was used to assess transient evoked otoacoustic emissions.

- Intelligent Hearing Systems (IHS smart EP windows USB version 3.91) with AgCl electrodes and ER-3A insert earphones was used to record brainstem auditory responses.

- MATLAB- 7 (Language of Technical computing, USA) was used to generate signal, mix the generated signal with noise and process the same for temporo-spectral modification.

- UCL enhance version 101.exe (2002) was used to enhance (gain in dB) the consonant portion of the syllable.

- Adobe Audition v5 was used to normalise the recorded CV syllables.

- Dell Inspiron 14R laptop (Realtek sound card) with AHUJA AUD- 101XLR dynamic unidirectional microphone was used for recording and presenting the stimulus.

- MA-53 Audiometer was used to control the presentation level by routing the signal through the audiometer.

- Output from the calibrated audiometer was delivered through Sennheiser HDA 200 headphones.

3.3: Stimulus generation:

- Nineteen consonant-vowel combinations (CV syllables) were recorded digitally thrice from a native male Kannada speaker.
- The syllables were recorded in the context of vowel /a/ (pa, ba, da, ga, cha, jha, ra, va, na, ma, va, ya, ka, la, da, sa, sha, cha, dha).
- The recording was done on a data acquisition system using 16 kHz sampling frequency with a 16 bit analogue to digital converter.

- All the recorded syllables were subjected to intelligibility rating on a three point rating scale (3-good, 2-fair, 1-poor) from five individuals with normal hearing sensitivity and a native speaker of Kannada language.
- The syllables which received maximum score for intelligibility were selected against the other two recordings of the same syllable.
- The selected signal was mixed with six speaker speech babble developed by Jain, Konadath, Vimal, and Suresh (2014) to achieve various signal to noise ratios i.e., 0, +5, +10 and +15 dB SNR using MATLAB- 7.8.
- Syllables were mixed at the centre of the speech babble.
- Syllables without the babble mixed were also retained to carry out testing in quiet condition.
- Both the mixed and the unmixed syllables were enhanced spectro-temporally by companding and consonant enhancement algorithm.
- These were carried out after mixing with speech babble to imitate a realistic situation where any signal reaching the ear would already be mixed with the surrounding noise.
- All the speech stimuli tokens at four SNRs and quiet condition that were processed with a companding algorithm were labelled as ‘companded’ while, the signals that underwent consonant enhancement were labeled as ‘enhanced’. The unaltered stimuli tokens were labeled as ‘unprocessed’.
- Companding and consonant enhancement were done using MATLAB 7.8 and UCL Enhance softwares respectively.

Companding was done following procedure:

- The syllables were spectrally enhanced using companding strategy with MATLAB- 7.8 software following the algorithm given by Bhattacharya and Zeng, (2007).
- The process involves a series of compression and expansion which is achieved using different filters which is based on the two-tone suppression.
- The incoming signal was first divided into 50 frequency channels by a bank of relatively broad band-pass filters.
- The signal within each channel was then subjected to amplitude compression.
- The amount of compression was dependent on the output of the envelope detector (ED) and the compression index (n1) which had a value of 0.3.
- The compressed signal was then passed through a relatively narrow band-pass filter before being expanded.
- The gain of the expansion block depended on the corresponding ED output and the ratio of (n 2- n 1)/ n 1.
- The n2 parameter of the algorithm is the expansion index and had a value of 1.
- The outputs from all the channels were then summed to obtain the processed signal.
- The signal output after processing was normalized with RMS amplitude normalization for -15dB in Adobe Audition software which was then equated to that of the original signals.

Below mentioned figure 3.1 and 3.2 give a bird's eye view of the procedure used for companding.

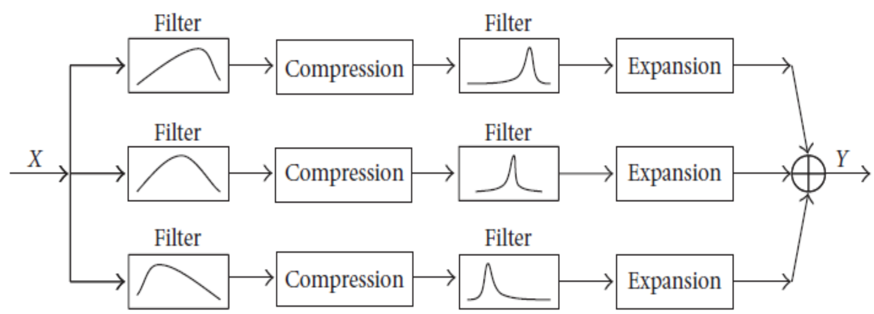


Figure 3.1: Block diagram of the companding architecture showing the stimulus being analysed by a bank of broad band prefilters. The output of each prefilter was then subjected to compression, and the output was filtered again using sharper postfilters before it was subjected to expansion. The outputs from all the channels were then summed to obtain the processed signal. (Narne, Suma, Kalaiah, Chandan, Deepthi, & Barman., 2014)

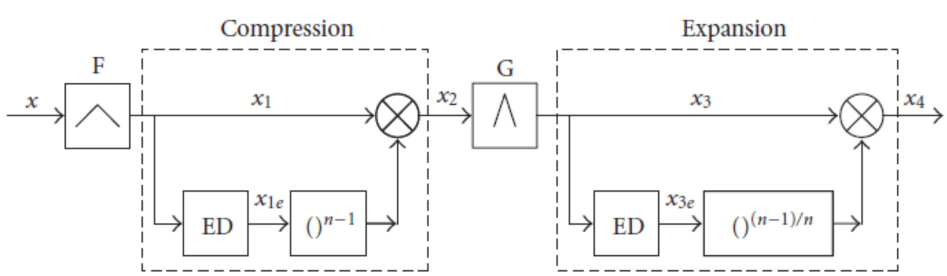


Figure 3.2: Detailed architecture of a single channel processor.

Consonant enhancement was done using the following procedure:

- By using UCL enhance software the burst portion of each syllable was increased in amplitude with the consonant enhancement technique.
- The method followed was similar to the method previously used by Guelke (1987).
- The procedure involved an algorithm where the location of different parts of the syllable i.e., vowels, nasals, fricatives and gaps were automatically identified based on broad class phonetic recognition system.
- The algorithm then increased the amplitude of the selected portion of the syllable up to 6 dB. The following options were selected for the enhancement of the stimuli:

Table 3.1: Table showing details of options chosen to enhance the consonant part of various consonants in the context of /a/

Syllable	Options chosen (among Burst, Fricative, Nasal and transition)	Enhancement level
Stops (p, b, ţ, th, ḍ, dh, k, g)	Burst + Transition	6 dB
Fricatives and Affricates (tʃ, ʤ, s, ʃ)	Frication + Transition	6 dB
Nasals (m, n)	Nasal + Transition	6 dB
Glides (j, r, l, v, ḷ)	Transition	6 dB

- For all the syllables, RMS amplitude gain was given along with the amplitude compression degree of 10 as recommended by the software.
- This was recommended as it maintains an overall average of the non-silent portions of the signal which would not vary with additions of gaps due to variables like noise.
- This option was combined with amplitude compression to make sure that the increase in intelligibility is due to enhancement and not due to a general increase in signal to noise ratio.

The unprocessed stimulus condition on top, consonant enhanced stimulus in the middle and companding stimulus condition is shown in the Figure 3.1

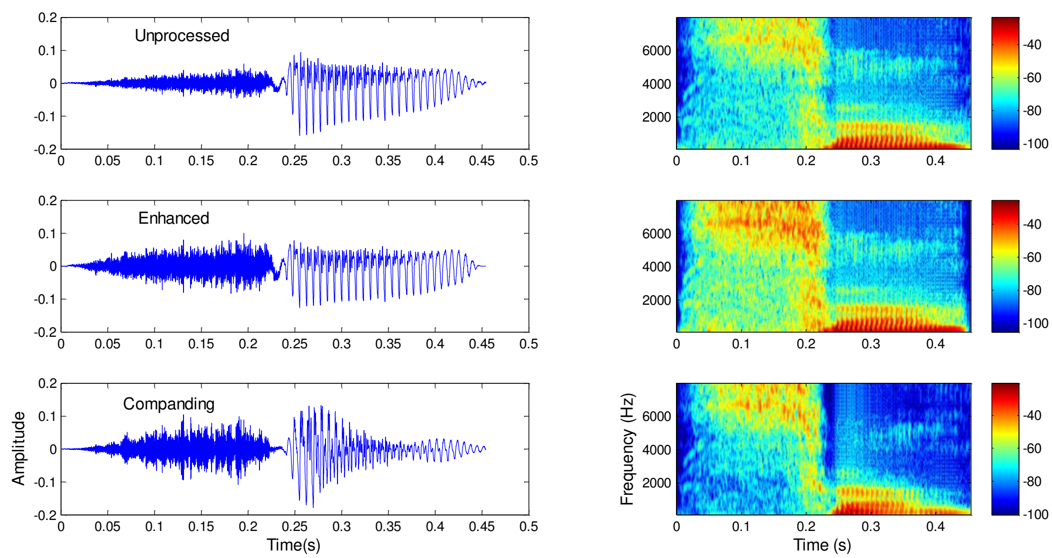


Figure 3.3: Figure showing the spectrum and spectrogram of the syllable /sa/ in all the three conditions without noise.

3.4: Testing environment:

All the tests were carried out in an acoustically treated room. The ambient noise in the test room was within the permissible noise levels as recommended by ANSI-S3.1 (1991).

3.4.1 Procedure:

- ***A detailed case history** was taken for all the participants before the routine audiological assessment* was *carried out in order to ensure that they do not report of symptoms that would exclude them based on the subject selection criteria as described before.*
- ***Pure-tone thresholds*** were obtained using a calibrated GSI – 61 audiometer. The modified version of Hughson and Westlake procedure (Carhart & Jerger, 1959). The air conduction and bone conduction thresholds was obtained at octave frequencies between 250 Hz to 8000 Hz and 250 Hz to 4000 Hz respectively.
- **Speech audiometry:** To obtain speech recognition threshold (SRT) speech audiometry was carried out using a standardized paired word list developed by Rajashekhar (1978). PB word list developed by Vandana (1998) was used to obtain speech identification scores (SIS). Speech Identification Scores were obtained at 40 dB SL with reference to SRT or Most Comfortable Level. At this supra threshold level, the numbers of correct words uttered over the total words was calculated and converted into percentage to obtain the speech identification scores.

- ***Speech perception in noise*** scores were obtain by the above mentioned PB word list presented at 0 dB SNR. Both the stimulus and noise were presented at 40 dB SL. The procedure used to obtain SIS was also adopted to obtain SPIN scores. The corresponding speech identification score in quiet and at 0 dB SNR was obtained from each subject mono-aurally for both ears.
- ***Immittance audiometry*** was carried out with a probe tone frequency of 226 Hz and pressure varying from +200 dapa to -400 dapa to evaluate middle ear status. Ipsilateral and contralateral stapedial acoustic reflexes thresholds were measured for 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz pure tones. The minimum intensity of the reflex eliciting acoustical signal that lead to 0.03 ml changes in admittance value was taken as the threshold
- ***Otoacoustic emissions*** were obtained for 260 nonlinear click stimuli presented at 80 dBpeSPL. SNR of more than 6 dB SPL in at least 3 consecutive octave frequencies in both ears, with reproducibility greater than 70% was considered as presence of OAEs.
- ***Auditory Brainstem Responses*** was recorded using standard ABR protocol (Hall, 2006) with 11.1/ sec repetition rate and 100micro second click stimulus to 80 dB nHL in all the participants. The band pass filter settings was kept at 100 Hz to 3000 Hz. At least two recordings with stimulus in rarefaction polarity were done for each ear to ensure reproducibility.

3.5: Procedure used to obtain consonant identification values at different SNRs and for different stimulus condition:

- This phase was carried out similarly in both the groups.
- The stimulus was presented at their most comfortable level with an inter stimulus interval varying depending on participant's response.
- The stimulus sequence was automatically randomized by the MATLAB-7.8 software.
- The next syllable was present as soon as he/she responded to the previous one.
- A two minute interval between each SNR presentation in both processed and unprocessed stimulus condition was included.
- The testing was carried out in two sessions to avoid fatigue.
- The presentation was done through calibrated audiometer connected to a calibrated output system of a laptop interface via the software MATLAB- 7.8 software.
- Laptop was connected to an audiometer to control the stimulus intensity.
- From the calibrated audiometer the output was delivered through Sennheiser HDA 200 headphones to the participants.
- The participant was presented with a screen consisting of all the syllables as choices which has arranged in the alphabetical order followed in Kannada language, out of which the participant was asked to choose the appropriate syllable as response by clicking on the same.

- The presentation consisted of three trials under each stimulus condition and the participants were to respond after hearing the stimulus thrice.
- The stimulus sequence was automatically randomized by the software for every trial.
- The correctly identified syllables were scored as 1 whereas the others were scored as 0.
- The total score of each different SNR in all the three condition were obtained separately.
- In order to get the objective of the study the scores were compared across SNR's, across 3 different strategy and across 2 groups.

Chapter 4

Results

The present study was aimed to know whether the Companding and Consonant enhancement algorithm is effective in improving speech perception in younger and older adults having normal hearing sensitivity. This was performed in five different stimulus SNR such as quiet, 15 dB SNR, 10 dB SNR, 5 dB SNR and 0 dB SNR for unprocessed and processed stimulus. The stimulus consisted of 19 CV syllables in the context of vowel /a/. The consonant identification data were obtained from 10 young adults with normal hearing sensitivity and 13 older adults with normal hearing sensitivity. The consonant identification data obtained were tabulated and analyzed using Statistical Package for Social Sciences (SPSS, version 20).

The data obtained were initially checked for normal distribution by administering Shapiro-Wilk's test in SPSS (v 20). Most of the data did not follow the normal distribution, so, non-parametric tests were administered for the consonant identification scores obtained across each SNRs and conditions. The following is a summary of the statistical analysis that was performed to investigate the objectives of the present study.

- Descriptive analysis was done to obtain mean, median and standard deviation for both the groups across different conditions and SNRs
- Mann-Whitney U test was done to compare the data between the groups at each SNRs and conditions.

- As these data in the current study are not normally distributed Friedmann test was done to see the significant effect of SNR's within each condition and stimulus conditions within each SNR within the groups.
- If Friedmann test showed any significant difference, then further Wilcoxen signed rank test for pairwise comparison was done to see between which two SNR and condition there exists a significant difference.
- SINFA analysis was done to check the information transfer function.

For better understanding the results of these tests are discussed under the following subheadings:

1. Descriptive statistics across groups.
2. Comparison of consonant identification scores across group (younger vs older adults).
3. Comparison between groups for benefit received by each stimulus condition across SNR
4. Comparison of consonant identification scores obtained across conditions within each SNR and within the group.
5. Comparison of consonant identification scores obtained across SNRs within each condition and within the group.
6. Consonant confusion matrix across different groups.

4.1: Descriptive statistics across groups:

Descriptive statistics was carried out to obtain mean, median and standard deviation of consonant identification scores obtained at different SNRs and at different stimulus condition in both the groups. The mean, median and standard deviation of the correct scores obtained for consonant identification under each stimulus condition and at 15, 10, 5, 0 dB SNRs and quiet from both the groups of the population are tabulated in the Table 4.1.

Table 4.1: Mean, median and standard deviation of consonant identification scores across different condition, SNRs and groups.

Condition	SNR	Older adults			Young adults		
		Mean	**Median**	**Standard deviation**	**Mean**	**median**	**Standard deviation**
Unprocessed	0	9.62	9.00	2.8	17.60	13.50	1.07
	5	14.00	13.00	2.6	17.60	17.50	1.43
	10	16.46	16.00	1.6	18.70	19.00	0.48
	15	16.92	17.00	1.3	19.00	19.00	0.00
	Quiet	17.38	17.00	1.8	18.90	19.00	0.31
Enhanced	0	9.92	10.00	2.5	13.60	14.00	2.17
	5	14.69	14.00	1.5	16.90	17.00	1.10
	10	16.77	17.00	1.1	18.60	19.00	0.51
	15	17.15	17.00	.98	18.70	19.00	0.48
	Quiet	17.15	18.00	2.3	18.10	18.00	0.99
Companding	0	8.00	8.00	2.7	11.80	12.00	2.15
	5	13.85	14.00	2.6	17.60	18.00	1.07
	10	16.38	17.00	2.1	18.70	19.00	0.67
	15	17.46	17.00	1.05	18.90	19.00	0.31
	Quiet	17.54	18.00	1.6	18.60	19.00	0.69

From the above Table 4.1, it can be said that the older adults had a poor identification scores when compared to younger adults. However, both the groups followed a common trend of reduction in mean and median value with decrease in SNR in all the stimulus conditions. However for stimulus condition it can be observed that all the conditions showed similar scores across SNRs in both the groups. Median values are higher for processed condition compare to unprocessed stimulus condition in older adult group. Whereas, in younger adults unprocessed median values are higher than processed median values.

4.2:Comparison of consonant identification scores across group (younger vs older adults):

Mann-Whitney U test was administered to compare the consonant identification scores between the two groups at each SNR and for each stimulus condition. The results of Mann-Whitney U test is given in the Table 4.2 for all the conditions at different signal to noise ratio.

Table 4.2: |Z| -values obtained for consonant identification scores between the older adults and younger adults at all SNRs and conditions.

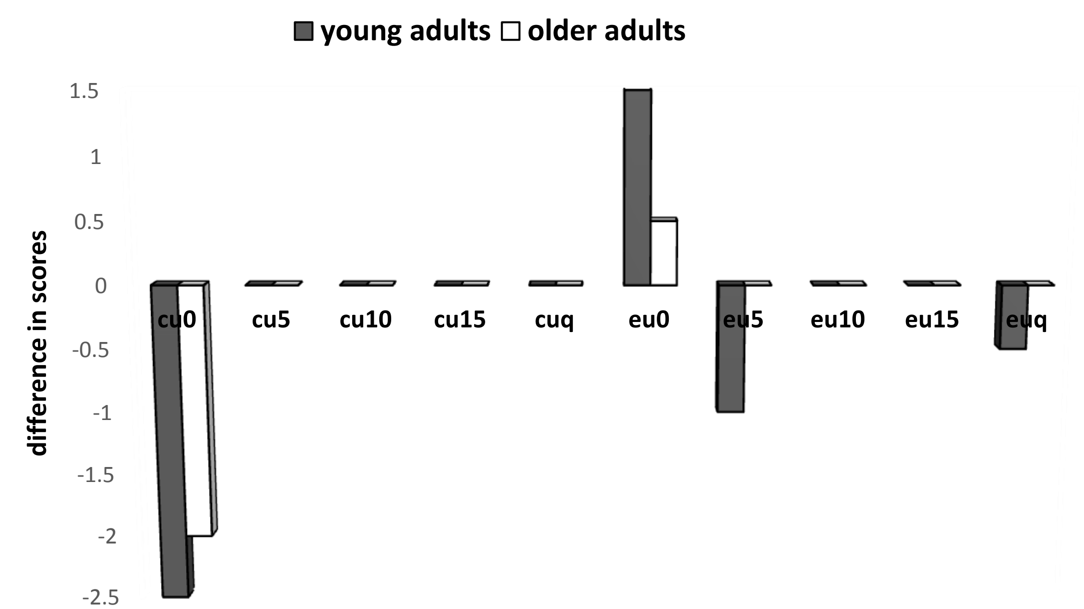
Stimulus Condition		SNR (dB) 0	5	10	15	Quiet
Unprocessed	Zvalue	2.624	3.968	3.160	2.984	2.376
	p value	0.009	0.000	0.002	0.003	0.017
Companding	Zvalue	1.818	3.216	3.707	3.441	3.027
	p value	0.069	0.001	0.000	0.001	0.002
Enhancement	Zvalue	0.841	3.504	3.594	3.173	3.087
	p value	0.400	0.000	0.000	0.002	0.002

Note: p<0.05, 2-tailed

Mann Whitney test showed a significant different on consonant identification scores between the groups at all SNRs and at all condition. Younger adults showed significantly higher consonant identification scores than older adults as seen in Table 4.1.

4.3: Comparison between groups for benefit received by each stimulus condition across SNR:

Changes in consonant identification scores obtained for processed stimulus compare to unprocessed stimulus was calculated for both the groups at each SNRs. This was obtained by subtracting unprocessed from processed stimulus condition. To start with, the difference in scores obtained (consonant identification scores obtained in companding/consonant enhancement – unprocessed) across SNRs were calculated.



	cu0	cu5	cu10	cu15	cuq	eu0	eu5	eu10	eu15	euq
young adults	-2.5	0	0	0	0	1.5	-1	0	0	-0.5
older adults	-2	0	0	0	0	0.5	0	0	0	0

Figure 4.1: Median of difference between consonant identification scores between processed and unprocessed stimulus conditions for both the groups

In the Figure 4.1, the negative values indicate processed stimulus condition had lesser consonant identification scores compare to unprocessed stimulus condition. Mann Whitney u test was administered to see the benefit obtained by both groups differed significantly or not. The results of the Mann- Whitney U test is given in the Table 4.3.

Table: 4.3: the |Z| - values obtained for difference scores between the groups across SNRs

Difference between stimulus condition	**SNR**				
	0	**5**	**10**	**15**	**Quiet**
Companding-Unprocessed	0.28	0.06	0.06	1.9	0.84
Consonant enhancement-unprocessed	0.28	1.66	0.66	2.09	0.89

Note: * indicates p<0.05

From the Table 4.3 it was observed that there was no significant difference between the difference of companding and unprocessed in the quiet and all SNRs between the groups. Similarly consonant enhanced stimulus scores did not differ significantly from unprocessed stimulus condition at all SNRs. That is, there was not much improvement seen with the processed stimulus condition in both the groups.

4.3: Comparison of consonant identification scores obtained across conditions within each SNR and within the group:

To see the effect of stimulus conditions on consonant identification scores within each SNR, Friedman's test was administered. This was done separately for each group. The results of the effect of stimulus conditions on consonant identification scores is given in the Table 4.4 where the three stimulus conditions are compared at each SNR for each group seperately.

Table 4.4: χ^2 value along with degrees of freedom obtained across stimulus conditions at each SNR for each group.

SNR (dB)	χ^2 **(2)** **Young adults**	χ^2 **(2)** **Older adults**
Quiet	6.33*	1.72
15	3.50	3.93
10	0.33	0.51
5	2.74	3.5
0	3.00	13.2*

Note: * p value < 0.05

It was observed that all the conditions were not significantly different at each SNR except for quiet condition which was observed only in younger adults and at 0 dB SNR in older adults. Hence, pairwise comparison was carried out by using Wilcoxon's signed rank test only for 0 dB SNR in older adult population and for quiet condition in younger adult group. The results are represented in the following Table 4.5.

Table 4.5: Pairwise comparison of conditions in quiet situation for younger adults and 0 dB SNR for older adults.

Younger adults			Older adults		
Quiet	**Unprocessed**	**Companding**	**0 dB SNR**	**Unprocessed**	**Companding**
Companding	(p>0.05)		**Companding**	(p<0.05)	
Enhancement	(p<0.05)	(p>0.05)	**Enhancement**	(p>0.05)	(p<0.05)

Note: shaded area indicates the significant difference between the SNR pair difference

It was observed that, at quiet situation identification scores in consonant enhancement condition is significantly lesser than that of unprocessed condition. But, no other condition pairs (unprocessed v/s enhancement and enhancement v/s companding) showed any significant difference between them in the quiet situation. This difference in the conditions was obtained only in the younger adult population.

It was observed that, scores obtained for companding condition was significantly poorer than the scores obtained for consonant enhanced stimulus and unprocessed stimulus at 0 dB SNR. But, there was no significant difference in consonant identification scores in unprocessed and consonant enhancement condition. This differences in the conditions were obtained only in older adult population. The scores can be seen in Table 4.1.

4.4: Comparison of consonant identification scores obtained across SNRs within each condition and within group.

The non-parametric Friedman's test was administered to compare the consonant identification scores across SNR's. The analysis was done separately for each stimulus condition and also separately done for each group. The χ^2 values were obtained under each condition across different SNRs. The test results showed a significant ($p<0.05$) effect of SNR on consonant identification scores in all stimulus conditions. This statistical trend was same in both the groups of population. The χ^2 values for both groups are reported in the Table 4.6.

Table 4.6: χ^2(df) obtained across SNRs within each condition for both the groups.

Groups	**Stimulus Conditions**	χ^2 **(4)**
Younger adults	**Unprocessed**	30.18*
	Companding	31.11*
	Enhancement	35.22*
Older adults	**Unprocessed**	38.55*
	Companding	46.10*
	Enhancement	39.38*

* p value < 0.05

From the above table, it can be observed that SNRs has significant effect on consonant identification scores at each stimulus condition in both the groups. Hence, to see which pair of SNR has brought about a significant difference in each condition a pairwise comparison was performed. This was carried out using Wilcoxon's signed rank test. The same test was done for both the groups separately. The Wilcoxon's signed rank test results are tabulated in Table 4.6 for each condition.

Table 4.7: Pairwise comparison of consonant identification scores obtained between SNR at each stimulus condition and each group.

Groups	Conditions	quiet v/s15	10 v/s quiet	5v/s quiet	0 v/s quiet	15 v/s 10	15 v/s 5	15 v/s 0	10v/s5	10v/s0	5 v/s0
Young adults	Unprocessed	p>0.05	p>0.05	p<0.05	p<0.05	p>0.05	p<0.05	p<0.05	p<0.05	p<0.05	p<0.05
	Companding	p>0.05	p>0.05	p<0.05	p<0.05	p>0.05	p<0.05	p<0.05	p<0.05	p<0.05	p<0.05
	Enhanced	p>0.05	P>0.05	p<0.05	p<0.05	p>0.05	p<0.05	p<0.05	p<0.05	p<0.05	p<0.05
Older adults	Unprocessed	p>0.05	p<0.05	P<0.05	p<0.05	p>0.05	p<0.05	p<0.05	p<0.05	p<0.05	p<0.05
	Companding	p>0.05	p<0.05	p<0.05	p<0.05	p<0.05	p<0.05	p<0.05	p<0.05	p<0.05	p<0.05
	Enhanced	p>0.05	p>0.05	p>0.05	p<0.05	p>0.05	p<0.05	p<0.05	p<0.05	p<0.05	p<0.05

Note: shaded area indicates the significant difference between the SNR pairs.

From the above Table 4.7 it can be observed that there is no significant difference across all pairs of SNRs. However, with few exception quiet condition is not significantly different from scores obtained at 15 dB SNR or 10 dB SNR. Also scores obtained at 15 dB SNR and 10 dB SNR was not significantly differed. The rest of the pair differed significantly in all the stimulus condition in younger adult group.

In older adult group quiet condition is not significantly different from scores obtained at 15 dB SNR in all the three condition. Also scores obtained at 15 dB SNR and 10 dB SNR was not significantly differed in unprocessed and enhanced condition. In enhanced condition quiet condition is not significantly different from scores obtained at 10 dB SNR or 5 dB SNR. The rest of the pair differed significantly in all the stimulus condition.

4.6:Consonant confusion matrix across different groups:

In the current study 19 CV syllables were assessed in three stimulus conditions they are unprocessed, companding and consonant enhancement. The listeners were instructed to guess within 19 syllables for every stimulus presentation. The obtained responses were arranged in matrix form for each stimulus condition and SNR. The responses obtained across participants were added for respective stimulus condition in all the SNRs for both the groups. These added matrices were considered for further analysis. An example of the matrix is provided in Table 4.8.

In a stimulus response matrix in the Table 4.8, the first row indicates the responses and the consonants listed in first column indicate the stimulus presented. The numbers in each cell represents the frequency of the particular stimulus-response pair. The frequency of responses along the diagonal axis indicates the correct stimulus response pair.

Table 4.8: Stimulus response matrix for companded signal at 0 dBSNR for older adults.

	B	tʃ	D	D̲	g	k	l	l̲	m	n	p	r	s	ʃ	t	t̲	j	dz	v
b	**3**				1	1			1		3	1							
tʃ		**5**																5	
d			**4**	6															
d̲			3	**4**											2	1			
g	8		1								1								
k					1	**9**													
l			1				**2**	6				1							
l̲			2	3				**5**											
m									**10**										
n									1	**9**									
p											**10**								
r	2		2		1					1		**4**							
s													**10**						
ʃ														**10**					
t			1												**4**	5			
t̲											1				3	**6**			
j																	**8**	2	
dz		3																**7**	
v																	7	3	

Sequential information transfer analysis (SINFA) (Wang & Bilger, 1973) was performed using the software 'Feature Information Xfer (FIX)' developed by the Department of Linguistics, University College of London. The analysis is carried out to check the amount of information transmitted from stimulus to response for each phonetic feature. SINFA gives the amount of information transmitted in terms of electronic units of 'bits'. For the current study the features place, manner and voicing were considered. The feature matrix of the 19 syllables is shown in the Table 4.9.

Table 4.9: Feature matrix of the 19 syllables considered

	b	**D**	**g**	**dz**	**k**	**l̲**	**l**	**m**	**n**	**p**	**r**	**s**	**t̲**	**v**	**j**	**tʃ**	**d̲**	**ʃ**	**t**
Voicing	+	+	+	+	-	+	+	+	+	-	+	-	-	+	+	-	+	-	-
Place	b	A	v	P	v	p	a	b	a	b	a	a	a	l	p	P	d	p	p
Manner	p	P	p	A	p	l	l	N	n	p	l	f	p	g	g	A	p	f	p

Note: Voicing: + = voiced, - = voiceless
Place: b=bilabial, a=alveolar, v=velar, p=palatal, l=labial, d=dental
Manner: p=plosives, a=affricates, l=laterals, n=nasals, f=fricatives, g=glides

The transmitted information function for the consonant identification scores at different SNRs and at different stimulus condition is represented separately as place manner and voicing of younger adults is represented in the Table 4.10.

Table 4.10 Relative information transmitted for each feature in younger adults

SNR	STIMULUS CONDITION	VOICING	PLACE	MANNER	TRANSMITTED INFORMATION
0	Unprocessed	0.524	*0.704*	*0.765*	*3.303*
	Companding	*0.540*	*0.584*	*0.757*	*3.088*
	Enhancement	*0.668*	*0.760*	*0.737*	*3.471*
5	Unprocessed	*0.900*	*0.910*	*1.000*	*4.007*
	Companding	*0.832*	*0.921*	*1.000*	*4.003*
	Enhancement	*0.846*	*0.834*	*1.000*	*3.891*
10	Unprocessed	*0.954*	*1.000*	*1.000*	*4.223*
	Companding	*0.954*	*1.000*	*1.000*	*4.223*
	Enhancement	*1.000*	*0.964*	*1.00*	*4.177*
15	Unprocessed	*1.000*	*1.000*	*1.000*	*4.248*
	Companding	*1.000*	*1.000*	*0.967*	*4.223*
	Enhancement	*0.954*	*0.971*	*1.000*	*4.177*
Quiet	Unprocessed	*0.954*	*1.000*	*1.000*	*4.223*
	Companding	*0.918*	*1.000*	*1.000*	*4.207*
	Enhancement	*0.859*	*0.940*	*1.000*	*4.053*

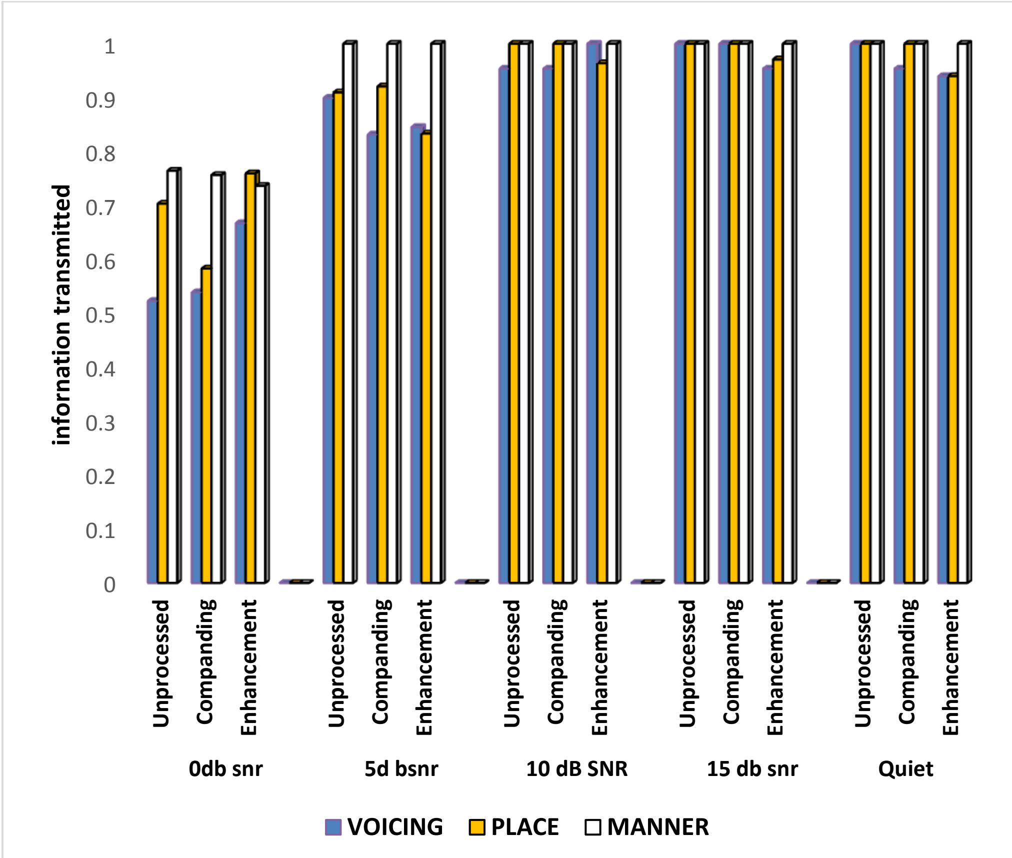


Figure 4.2: Extent of information transmitted in bits for voicing place and manner at all SNR and stimulus conditions in younger adult group.

In the above Figure 4.2 it can be observed that voicing is transmitted least information followed by place then the manner cue which has transmitted the most information in all the stimulus condition in all the SNR and in younger adults. The information transmitted increases with increasing SNR. Manner cues reaches ceiling at 5 dB SNR. Whereas, place cues reaches ceiling effect at 10 dB SNR and voicing reaches ceiling effect at 15 dB SNR. So, the amount of information transfer was greater for manner > place > voicing. There is not much change in information across stimulus condition (unprocessed, companding and enhancement). It also revealed manner cues are maximally transmitted across all stimulus condition and all SNRs followed by place cues and voicing is the least transmitted information. Further voicing and place showed a marginal improvement at 0 dB SNR in consonant enhancement condition. Whereas, companded did not show any improvement across all SNRs in younger adults.

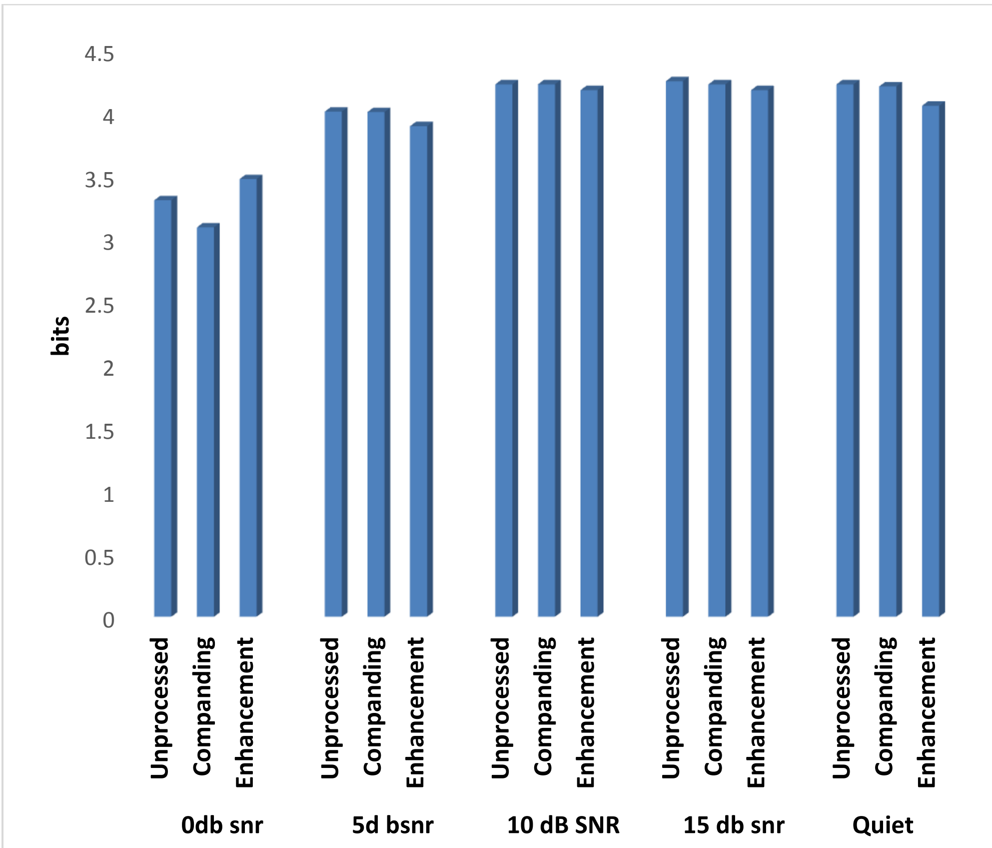


Figure 4.3: Total information transmitted in bits at all SNR and stimulus conditions in younger adult group.

In the above Figure 4.3 it can be observed that the total information which is transmitted is almost similar in all the conditions. However with increasing SNR the transmitted information also increased in younger adults.

The transmitted information function for the consonant identification scores at different SNRs and at different stimulus condition is represented separately as place manner and voicing of older adults is represented in the Table 4.11.

Table 4.11 Relative information transmitted for each feature in older adults

SNR	STIMULUS CONDITION	VOICING	PLACE	MANNER	TRANSMITTED INFORMATION
0	Unprocessed	0.380	*0.426*	*0.434*	*2.250*
	Companding	*0.262*	*0.410*	*0.461*	*2.087*
	Enhancement	*0.439*	*0.538*	*0.438*	*2.581*
5	Unprocessed	*0.669*	*0.732*	*0.853*	*3.329*
	Companding	*0.653*	*0.712*	*0.829*	*3.307*
	Enhancement	*0.662*	*0.733*	*0.862*	*3.402*
10	Unprocessed	*0.875*	*0.867*	*0.932*	*3.877*
	Companding	*0.762*	*0.809*	*0.914*	*3.613*
	Enhancement	*0.826*	*0.865*	*0.959*	*3.859*
15	Unprocessed	*0.963*	*0.915*	*1.000*	*4.009*
	Companding	*1.000*	*0.969*	*1.000*	*4.173*
	Enhancement	*0.966*	*0.928*	*1.000*	*4.070*
Quiet	Unprocessed	*0.930*	*0.944*	*1.00*	*4.111*
	Companding	*0.934*	*0.956*	*1.000*	*4.131*
	Enhancement	*0.900*	*0.937*	*1.000*	*4.047*

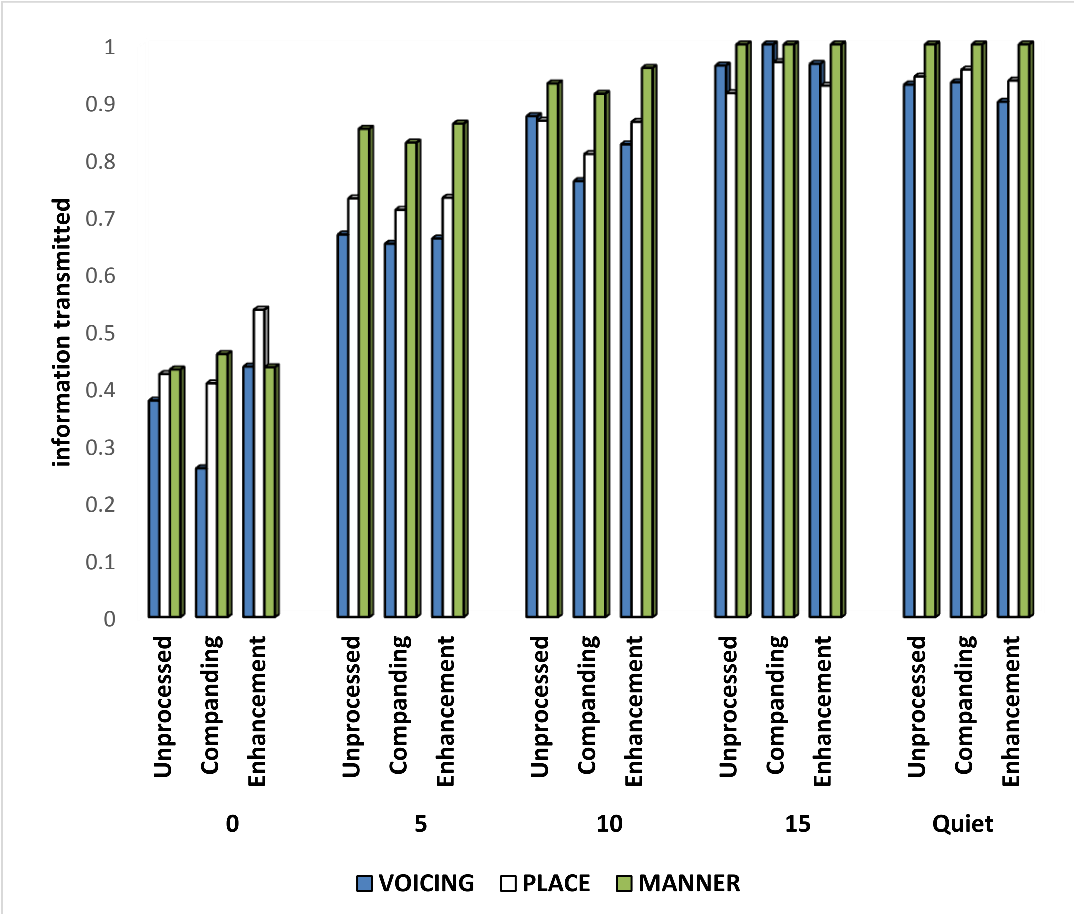


Figure 4.4: Extent of information transmitted in bits for voicing place and manner at all SNR and conditions in older adults.

In the above Figure 4.4 it can be observed that voicing is transmitted the followed by place then the manner cue which is transmitted the most in all the stimulus condition in all the SNR and in older adults. The information transmitted increases with increasing SNR. Manner cues reaches ceiling at 15 dB SNR. Whereas, place cues reaches ceiling effect at 10 dB SNR and voicing reaches ceiling effect at 15 dB SNR. There was not much change in information across stimulus condition (unprocessed, companding and enhancement). It also revealed manner cues are maximally transmitted across all stimulus condition and all SNRs followed by place cues and voicing is the least transmitted information. Further place cues showed a marginal improvement at 0 dB SNR in consonant enhancement condition. Whereas, companded condition did not show any improvement across all SNRs in older adults.

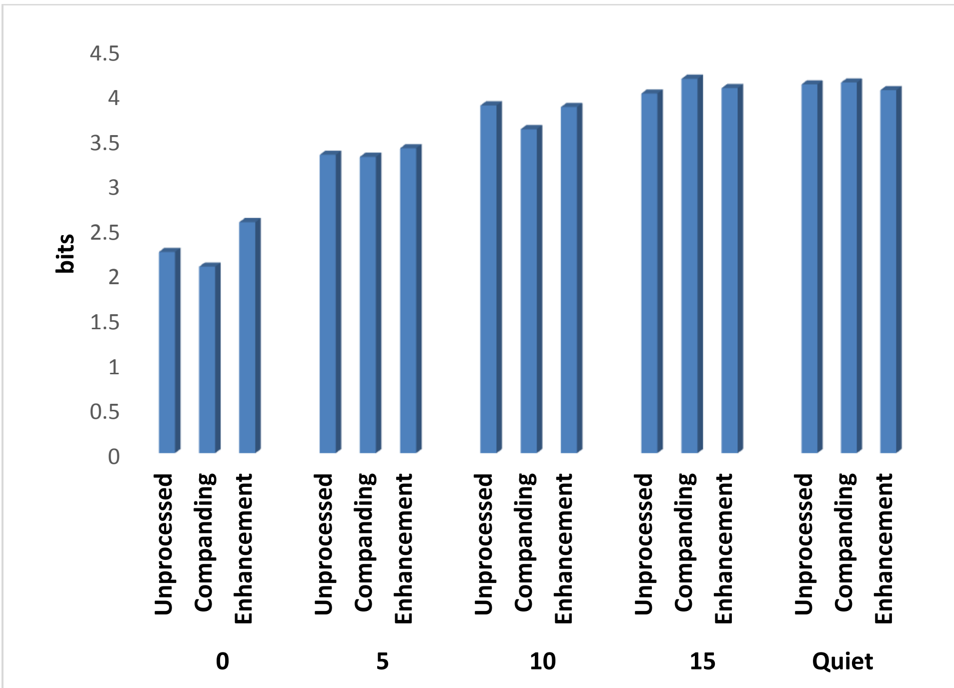
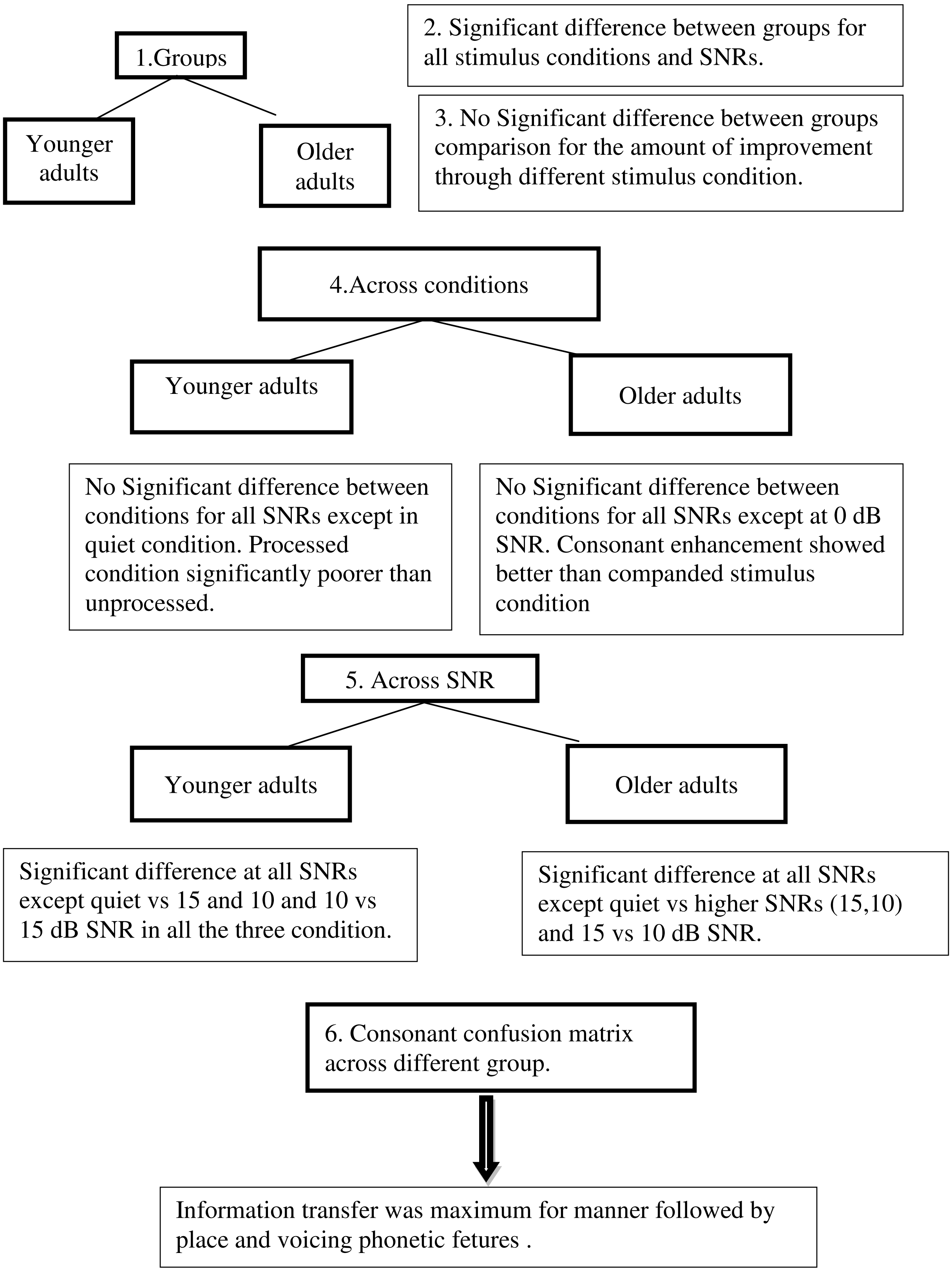


Figure 4.5: Total information transmitted in bits at all SNR and stimulus conditions in older adult group.

In the above Figure 4.5 it can be observed that the total information which is transmitted is almost similar in all the conditions. However with increasing SNR the transmitted information also increased in older adults.

4.7: The summary of statistical findings is illustrated below:



Chapter 5

Discussion

The aim of the study was to know whether the Companding and Consonant enhancement algorithm is effective in improving speech perception in younger and older adults having normal hearing sensitivity. Nineteen consonants in the context of vowel /a/ was presented and the consonant identification scores obtained were tabulated and analyzed using Statistical Package for Social Sciences (version 20.0). Results obtained from both the groups are discussed below.

The findings are discussed under the following headings:

1. Effect of signal enhancement techniques and SNRs on speech perception between younger and older adults.
2. Comparisons of amount of improvement in consonant identification with processed stimulus between groups at all SNRs.
3. Effect of stimulus condition on consonant identification scores obtained across SNRs and within the groups.
4. Effect of SNR on consonant identification scores obtained across stimulus condition and within the groups.
5. Consonant confusion matrix

5.1 Effect of signal enhancement techniques and SNRs on speech perception between younger and older adults:

Consonant identification scores were significantly affected in older adults when compare to younger adults at all SNRs.

The results of the present study agrees with the previous investigators where they showed older adults perform poorer than younger adults (Yilmaz, Sennaroglu, Sennaroglu & Kose., 2007; Gelfand, Piper & Silman., 1986; Calais, Russo & Borges 2008). This reduction in scores were seen in both at quiet and in noise.

But there was not much difference seen in quiet situation. However, in noise (5 dB SNR & 0 dB SNR) the scores decrement were more for older than younger adults.

This poorer in performance in noise may be due to temporal processing deficit noticed in older adults which was supported by Helfer and Vargo (2009). They reported that, performance of subjects with the age range of 45 to 54 years were significantly poorer than that of young adults in the presence of competing noise which was strongly correlated with scores obtained on Gap In Noise test which assesses temporal resolution. This suggests that older individuals will have temporal resolution abnormalities which leads to poor speech perception in the presence of noise.

Yilmaz, Sennaroglu, Sennaroglu and Kose (2007) also noticed reduction in speech recognition scores after 50 years and significant reduction occurs after 60 years of age. They also reported that with advancing age the ability to identify speech in the presence of background noise decreases. Similarly in the present study there is decrement in speech perception in the presence of noise in older individuals (with the mean age of

51.4 years). Gelfand, Piper and and Silman (1986) also suggested that older individuals had reduced consonant recognition and the performance decreased with aging.

Aging can lead to a structural or functional deficit at various levels of the auditory system. Brain stem undergoes major structural changes in the auditory system (Kirake, Sato & Shitara, 1964). The fibers of lateral lamnisci also reduces with aging (Willott, 1991). It is reported that poor response to auditory stimuli in inferior colliculus with advancing age (Palombi & Caspary, 1996). These findings were well correlated with electrophysiological studies where, auditory brain stem response amplitude reduces with aging (Beagely & Sherdrake, 1978). These findings also in consonance with study done using functional magnetic resonance imaging (FMRI) studies where the results were reduction in the activity of the auditory cortex during speech in noise (Wong, Jin, Gunashekhara, Abei, Lee & Dhar 2008). It was also reported that in older adults there is structural and functional changes occur in external ear where the surface ridges of pinna alter frequency response of incoming complex signals. These surface ridges provide acoustic gain at higher frequency components which are responsible for speech intelligibility. Hence anatomical changes in auditory system with aging might have contributed for reduced speech perception especially in noisy environment in older adults in current study also.

5.2 Comparisons of amount of improvement in consonant identification with processed stimulus between groups at all SNRs:

The findings obtained showed that there was no significant difference obtained in improvement seen for the processed speech between both the groups at each SNR.

This may be due to individuals with normal hearing sensitivity could utilize the envelop cues and fine structure cues available in speech in quiet and noisy conditions. These individuals may not appreciate any modification in the stimulus and also altered stimulus condition due to use of these techniques which changed either the spectral characteristics or the transition whichmight have led to a distortion to naturally available cues. This might have led to reduced scores especially in low SNRs in the processed conditions. However, it was not significant in younger adults. Whereas, in older adults there was not much difference seen between the conditions (Companding – unprocessed & consonant enhancement – unprocessed condition). This showed individuals with normal hearing sensitivity did not get any benefit with processed stimulus condition in quiet and also in the presence of noise.

5.3: Effect of stimulus condition on consonant identification scores obtained across SNRs and within the groups:

5.3.1. Younger adults:

The results in the present study did not show any significant difference between all the 3 conditions except at quite situation. There was significant difference between consonant enhancement and companding condition at quiet situation. There was no significant difference between consonant enhancement and unprocessed condition.

These individuals usually do not face any difficulty in perceiving envelop or fine structure cues in quiet or higher SNR situations. Hence, the role of enhancement or companding contributing to the intelligibility could not be appreciated especially in the quiet situation or at high SNRs. This could be due to ceiling effect which has been seen for unprocessed condition. At lower SNR situation they performed well with unprocessed condition. These findings can be explained on the basis that the normal hearing individuals depends majorly on the spectral characteristics and the format transition to perceive the consonants (Liberman, 1952; Blumstein & Stevens, 1979). Thus the findings explained that with the modification of spectral and temporal characteristics of the signal did not help younger individuals to improve speech perception. So, these individuals performed equally well with processed stimuli as well as unprocessed stimuli.

These findings did not correlated with previous studies with modification techniques where they have obtained an improvement in consonant identification scores in normal hearing individuals especially at low SNRs (Shachi, 2012). These discrepancies may be due to stimulus and noise that they had used in their study.

5.3.2. Older adults:

The results in the present study did not show any significant difference between all the 3 conditions except at 0 dB SNR. Consonant enhancement stimulus condition and unprocessed condition was significantly higher scores than companding at 0 dB SNR. But, there was no significant difference between consonant enhancement stimulus condition and unprocessed condition.

Mitchell, Nancy, Tye-Murray, and Brent (2005) reported that older adults with normal hearing sensitivity do not have any problem in speech perception even in adverse listening situation. Consonant enhancement basically done to provide gain to the consonant portion of the stimulus so that it will be audible if the person with hearing loss. However, these techniques may not be useful as all the participants are normal hearing indviduals. Thus, they performed similar to that was observed for unprocessed stimulus condition. Thus enhance stimulus and unprocessed stimulus performed equally well..

5.4: Effect of SNR on consonant identification scores obtained across stimulus condition and within the groups:

The consonant identification scores obtained were maximum in quiet situation and was found to deteriorate with decreasing SNR. The number of syllables identified were least at 0dB SNR. The same trend was noted across all the stimulus conditions in both the groups.

This was similar to results obtained by previous investigators (Nishi, Lewis, Hoover, Choi, & Stelmachowicz., 2010; Dorman, Loizou & Tu., 1998) they also reported with decrease in SNR speech perception abilities deteriorates. Baer and Moore, (1993) reported that with the addition of a background noise there is reduction in the distance between the peaks and troughs, thereby reducing the available spectral cues in order to identify speech. Hence, speech scores are poorer in the presence of noise. The individuals with normal hearing sensitivity (younger adults & older adults) identified almost all consonants in unprocessed stimuli condition at quiet situation. This may be due to normal hearing individuals perceive envelop or the fine structure cues at quiet or higher SNRs. With the decrease in SNR there was a significant reduction in consonant identification scores which could be due to masking effect. Also, noise decreases the modulation of speech envelop and also distort the temporal fine structure of speech making it difficult to access envelop and fine structure cues of speech (Houtgast & Steeneken, 1985; Drullman, 1995). Thus making it difficult to perceive speech in the presence of noise.

5.4.1: Younger adults:

There was no significant difference between quiet and 15 dB SNR and quiet and 10 dB SNR. Also scores obtained at 15 dB SNR and 10 dB SNR was not significantly different. Rest of the SNR pairs showed significant difference in all stimulus condition.

Current findings is in consonance with the several other studies (Nishi, Lewis, Hoover, Choi, & Stelmachowicz., 2010; Dorman, Loizou & Tu., 1998). They reported that speech perception in noise deteriorates with increase in noise even in normal hearing individuals. But, this effect is seen mainly till 5 dB SNR and a significant reduction in mainly at 0 dB SNR. In the current study also there is significant change in consonant identification scores was noticed only between lower SNRs and no significant difference between high SNRs and quiet.

This may be due to the speech babble noise is not sufficient enough to mask the consonants at higher SNRs. So, the consonant identification scores were similar at 10 dB SNR, 15 dB SNR and quiet. There are several studies that show that normal hearing individuals are able to extract spectral and temporal cues even in noisy situations (Heifer & Huntley, 1991). As the noise level decreases, the spectral and temporal cues available increase by a substantial amount which helps in improving the speech perception. Therefore, reducing the noise level up to 10 dB SNR from 0 dB SNR shows a significant improvement in consonant identification scores in all conditions. A further decrease in noise level did not provide a significant increase in consonant identification scores.

5.4.2: Older adults:

There was no significant difference between quiet condition and 15 dB SNR in all the three stimulus condition. Also scores obtained at 15 dB SNR and 10 dB SNR was not significantly differed in unprocessed and enhanced condition.

Since, older adult individuals has poor temporal perception ability there is decrease in speech perception in the presence of noise (Helfer & Vargo., 2009). So, as the SNR decreased below 10 dB SNR there is significant reduction of scores noted for both processed and consonant enhancement condition.

In companding there was a significant difference between all SNRs except quiet condition and 15 dB SNR.

In companding condition, a possible distortion caused by the processing of stimulus would have led to significantly poorer consonant identification scores. The possibility of addition of spurious artefacts due to processing of speech stimulus might have decreased with the addition of noise. So, consonant identification scores significantly reduced from quite to 15 dB SNR.

5.5: Consonant confusion matrices:

SINFA was done to analyze the phonetic features like place, manner and voicing for both the groups. *SINFA revealed manner cues are maximally transmitted across all stimulus condition and all SNRs followed by place cues and voicing is the least transmitted information. Further voicing and place showed a marginal improvement at 0 dB SNR in consonant enhancement condition. Whereas, companded condition did not show any improvement across all SNRs in younger adults. In older adults, there is marginal* *improvement at 0 dB SNR in consonant identification for place cues. However, companding did not show any improvement at 0 dB SNR.*

5.5.1 Voicing cues:

The major cues for voicing are voicing bars, voice onset time (VOT) and transition (Lisker, 1978). These can easily be masked in the presence of noise as both have a low frequency constitution. This might have affected the voicing perception in the present study. There was an increase in the information transmitted in consonant enhancement condition at 0 dB SNR. This can be attributed to the enhancement given to the transition which probably might have improved the contrast and might have helped the individuals to extract the voicing cues better. However the same was not seen in the older adults this might be due to their inability to extract the enhanced cues owing to reduced temporal processing (Helfer & Vargo., 2009).

5.5.2 Place cues:

This can be because high level noise might have affected the ability to extract the transient changes (Formant transition and burst) of the stimulus which is the major cue for perceiving place of articulation (Raphael 1980).There was an increase in the information transmitted in consonant enhancement condition at 0 dB SNR in both the groups. This can be attributed to the enhancement given to the transition and burst portion of the stimulus which probably led to improvement in transmitted information (Hazan, & simpson., 1998). In consonant enhancement condition there was gain provided to the consonant portion of the syllable by 6 dB. This led to a marginal improvement in transmission of information of place cues at 0dB SNR in both the groups. At higher SNRs this effect is not much seen due to ceiling effect.

5.5.3 Manner cues:

Manner cues were least affected among the phonetic features (place, manner and voicing). However, very low SNR can reduce the modulation of speech envelop and also distort the temporal fine structure of speech (Houtgast & Steeneken, 1985; Drullman, 1995). This might have led to the reduction in the transmission of manner cue at very low SNR. Though the same trend was followed by the older adults, the reduction in information transmitted was noted at 10 dB SNR in older adults. This can be because the ability to extract the fine structure cues probably reduce with age (Helfer & Vargo, 2009). The participants who were selected for the present study had no history or complaint of difficulty in understanding speech in noisy situation and their SPIN scores were more than 60% at 0 dB SNR. This gives a conclusion that older individuals performed similar to younger adults in consonant identification.

Chapter 6

Summery and Conclusion

Older adults with normal hearing sensitivity do have difficulty in perceiving speech in the presence of noise. Many psychophysical studies reported that older adults have a problem in temporal processing (Helfer & Vargo., 2009). Management for older individuals with normal hearing sensitivity for speech perception in the presence of noise are limited.

Thus, this study was taken with the purpose (a) to determine how younger adults and older adults differ in their performance for speech identification across different SNRs and different stimulus condition and also (b) to know whether the processed stimuli (companding and consonant enhancement) helps to improve speech intelligibility in younger and older adults with normal hearing sensitivity.

To achieve this 10 younger adults with normal hearing sensitivity with the mean age of 24.7 years and 13 older adults with normal hearing sensitivity with the mean age of 52.1 years were taken. Speech identification abilities of these individuals are assessed at five different SNRs (quite, 15, 10, 5, 0 dB) for 19 CV syllables with processed and unprocessed condition (companding and consonant enhancement). Six talker speech babble was used to achieve various signal to noise ratios (Jain, Konadath, Vimal, & Suresh 2014). Companding was carried out using a program developed in MATLAB which uses compression and expansion of the speech signals and consonant enhancement was carried out by UCL enhance software where, the consonant portion of the syllable was enhanced and by not altering the vowel portion. The collected data was statistically analyzed. Finally for the obtained data the Sequential information transfer analysis (SINFA) (Wang & Bilger, 1973) was performed using the software 'Feature Information Xfer (FIX)' from the Department of Linguistics, University College of London. This was done to check the amount of information transmitted from stimulus to response for each phonetic feature.

Analysis of the data revealed the following results.

- As SNR decreases the consonant identification scores also decreases under processed and unprocessed stimulus condition in both the groups.
- Older adults performed significantly lower than younger adults with normal hearing sensitivity for all the stimulus conditions across all SNRs.
- Younger adults showed significantly lesser scores for consonant enhancement condition compare to unprocessed and companding condition and in the other 4 SNRs the stimulus conditions did not showed any significant difference.
- Older adults showed significantly lesser scores for companding condition compare to enhancement and unprocessed condition and in the other 4 SNRs the stimulus conditions did not showed any significant difference.
- Younger adults showed significant different in consonant identification scores between lower SNRs till 10 dB SNR and not seen below two any SNRs.
- Older adults showed significant different in consonant identification scores between lower SNRs till 15 dB SNR and not seen below quiet and 15 dB SNR.

- SINFA analysis revealed voicing is transmitted the least, followed by place than the manner cue which is transmitted the most information in all the stimulus condition at all SNRs and in both the groups.
- In younger adult group the total information transmitted was more for unprocessed stimulus condition compare to the processed condition at all SNRs.
- In older adult group the total information transmitted varied with SNR at quiet and 15 dB more with companding. At 10 dB SNR more for unprocessed condition and at 5 dB and 0 dB SNR more for consonant enhancement.

Reduction in speech identification abilities as SNR reduces, for both younger and older adult groups, which is explained with the fact that noise reduces the modulation of speech envelope and temporal fine structure (Drullman, 1995).

Individuals with normal hearing sensitivity depends mainly on the spectral characteristics and the format transition to perceive the consonants (Liberman, 1952; Blumstein and Stevens, 1979). With the modification of spectral and temporal characteristics of the signal there was no significant improvement notice would not due to distortion happened for the processing of sigmal.

Conclusion:

SNR decreases, speech perception decreases. This decrease is more for older adults compare to younger adults. Though older adults have normal hearing sensitivity their ability to perceive speech in the presence of background noise decreases. This may be due to poor temporal processing abilities in older adults. The results of the current study suggest that older adults with normal hearing may not benefit with any modification of the stimulus. If tried consonant enhancement technique may be preferred as it showed better scores in older population.

Implication

- This can be used to study speech perception in older adults with normal hearing sensitivity.
- This can be used to study the physiological basis of speech perception abilities in older individuals.
- The result of the current study suggests the consonant identification techniques to be a better option for rehabilitation.
- Added information to the literature.

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