ROLE OF AUDITORY WORKING MEMORY IN PRESCRIBING HEARING AID GAIN AND TYPE OF COMPRESSION IN GERIATRICS

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Certificate

This is to certify that this dissertation entitled "Role of Auditory Working Memory in Prescribing Hearing Aid Gain and Type of Compression in Geriatrics" is a bonafide work in part of fulfilment for the degree of Master of Science (Audiology) of the student with Registration number: 09AUD029. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

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Certificate

This is to certify that this dissertation entitled "Role of Auditory Working Memory in Prescribing Hearing Aid Gain and Type of Compression in Geriatrics" has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other university for the award of any diploma or degree.

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Declaration

This is to certify that this master's dissertation entitled "Role of Auditory Working Memory in Prescribing Hearing Aid Gain and Type of Compression in Geriatrics" is the result of my own study and has not been submitted earlier to any other university for the award of any degree or diploma.

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Dedicated to my amazing family..

Families are the compass that guide us. They are our inspiration to reach great heights, and our comfort when we occasionally falter.

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Chapter 1

INTRODUCTION

Elderly individuals constitute one of the most rapidly growing segments in the population. Aging is usually associated with global decline in almost all the sensory and cognitive processes including memory and thinking. Decline of auditory performance with advancing age is well known. This is known as presbycusis and is becoming more prevalent as the percentage of geriatric population itself is increasing (Wilson, Fleming, & Donaldson, 1993).

The most obvious auditory deficit in elderly individuals is the presence of bilateral high frequency hearing loss (Gates, Cooper, Kannel, & Miller, 1990). In addition to this, studies have reported that these individuals have reduced speech identification in quiet and noise. Gaeth (1948) was among the first to state that some elderly individuals show poor performance in unaided tests of monosyllabic word intelligibility than expected on the basis of the degree and configuration of the audiometric loss. He coined the term 'phonemic regression' to describe the above phenomenon. This poor performance in speech identification is more evident in adverse listening conditions. Nabelek and Mason (1981) studied the effect of noise on the word identification scores of individuals with bilateral sensorineural hearing loss. They reported that the word identification scores decreased as a function of the signal to noise ratio.

Hearing aids are one of primary forms of rehabilitation for hearing impairment in elderly individuals. The main aim of fitting of hearing aids is to ensure that the audibility of speech is restored. Studies have also reported improvements in speech identification in quiet and in noise when individuals use hearing aids.

Humes, Halling, and Coughlin (1996) studied the aided speech identification ability of twenty elderly individuals in the age range of 63-78 years. They reported that there was a significant difference in the speech identification scores before and after fitting of hearing aids in quiet and noise.

However, even with suitable amplification device, many of the elderly hearing impaired individuals reject the hearing aid. Some factors which attributed to this include auditory factors such as hearing loss (Humes & Christopherson, 1991; Humes & Roberts, 1990), listening conditions and auditory processing (Humes et al., 1994), and non-auditory factors such as age (Bronkhorst & Plomp, 1992), expectation and attitude towards the hearing aid (Cox, Alexander, & Gray, 2005), motivation (Rupp, Higgins, & Maurer, 1977), manual dexterity (Maurer & Rupp, 1979), social stigma (Wax, 1982) and cognitive abilities of the individual (Gatehouse, Naylor, & Elberling, 2003; Gatehouse, Naylor, & Elberling, 2006; Lunner, 2003; Pichora-Fuller & Singh, 2006).

Humes (2003) analyzed the results of three studies of hearing aid outcomes in older adults to determine predictors of hearing aid success. For speech recognition performance, the best predictors were the degree of hearing loss, cognitive performance, and age of the subject.

Among the factors listed above, cognitive factor has gained a lot interest off late. This is because some aspects of cognitive performance tend to decline with age, and these deficits are associated with corresponding difficulties in speech comprehension. This could be to a large extent due to the resource of working memory spent in perceptual processing and few resources available for storage. For a person with hearing loss because of aging, more resource of working memory is required especially in complex tasks (Cohen, 1987).

Studies have reported the influence of cognitive factors in prescribing compression time parameters of hearing aids (Gatehouse, Naylor, & Elberling, 2003, 2006; Lunner & Sundewall Thoren, 2007 and Cox & Xu, 2010).

One such study was conducted by Lunner and Sundewall-Thoren (2007). They studied the cognitive abilities of individuals with hearing impairment using a visual letter monitoring task. This was correlated to the performance on speech recognition in noise using a hearing aid with slow time constants and fast time constants. They measured the signal to noise ratio required for an 80% score using modulated and unmodulated noise. The results indicated that individuals who got a poor score on the cognitive test performed better with slow acting compression and performed better in the presence of unmodulated noise than the modulated noise. Similar results were also reported by Gatehouse, Naylor, and Elberling (2003, 2006) and Cox and Xu (2010).

Hence, it is clear that with slow time constants, listeners who achieved lower performance on a cognitive measure tended to perform better on a sentence test. Whereas those who achieved higher performance on the cognitive measure tended to perform better using fast time constants in modulated background noise. This was attributed to the fact that the fast acting compression reduces the information carrying spectral and temporal contrasts that are required in speech while providing greater moment to moment audibility. For the individuals with good cognitive abilities the disadvantage of reduced contrasts is outweighed by the benefits obtained from the audibility. On the other hand, for the individuals with poor working memory, the disadvantages of reduced contrasts outweigh the audibility provided.

NEED FOR THE STUDY

The selection of hearing aid features is influenced by the cognitive abilities of the individual, especially, in the presence of noise. This is especially true for compression time constants. Though, there are studies which evaluated the influence of cognitive abilities in selection of compression time constants, these studies varied the attack time and release time, to represent fast and slow acting compression systems. In our clinic, some of the commonly prescribed hearing aids have the option of dual compression and syllabic compression. These two modes of compression in hearing aids have been evaluated in adult listeners with sensory neural hearing impairment (Geetha & Manjula, 2004-05).

However, there is no research, to our knowledge, evaluating dual compression system in elderly population to study the contribution of cognitive factors. Dual compression system, even though considered as a form of slow compression system, works differently when compared to either fast or slow acting system, as it involves generation of two gain-control signals, one with long attack and recovery times and the other with shorter attack and recovery times. Normally, the operation of the system is determined by the slow acting control system. However, if there is a sudden increase in sound level then the fast acting control system rapidly reduces the gain, thus, avoiding uncomfortable loudness. If the increase in sound level is brief, the gain returns to the original value determined by the overall level of the speech (Moore, 2008).

Hence, we were interested to study how the performance of elderly listeners, who differed in their cognitive abilities, would vary with dual and syllabic compression in speech identification tasks in quiet and in noise.

Further, it is well known that the main aim of fitting the hearing aids is to ensure that the audibility of speech is restored due to the amplification. Several authors have studied the importance of audibility on the speech recognition performance by individuals with hearing impairment (Hogan & Turner, 1998; Turner & Cummings, 1999) and have found that increasing the audibility improves speech intelligibility with some exceptions. Even in elderly individuals, audibility has been found to be an important factor in the speech recognition ability (Souza, Boike, Witherell, & Tremblay, 2007). Hence, it can be assumed that increasing the gain of the hearing aid would result in some amount of increase in speech identification. By setting the appropriate amount of gain in the hearing aid, the individual would be provided with enough audibility for adequate speech recognition. However, whether there is any difference in gain requirement in good and poor cognitive abilities for providing best speech identification is not evaluated.

Hence, there is a need to study the influence of working memory on the selection of gain, and dual and syllabic compression system in elderly population. Such a study will help in successful prescription of hearing aids and in planning the effective rehabilitation programmes based on the needs of the elderly clients.

AIM OF THE STUDY

Hence, the present study aimed to evaluate the role of auditory working memory on the amount of gain required for obtaining best speech identification and its effect on the performance with dual and syllabic compression in elderly individuals in noise.

OBJECTIVES OF THE STUDY

The objectives of the study are to compare

1. The amount of gain required in good and poor working memory geriatric individuals for obtaining best speech identification.
2. The performance between dual and syllabic compression in the geriatric individuals with good and poor working memory in noise.

Chapter 2

REVIEW OF LITERATURE

Hearing loss is found to be the third most common chronic condition reported in the geriatric population (Lethbridge-Cejku, Schiller, & Bernadel, 2002). One in three people older than 60 years, and half of the population greater than 85 years old have hearing loss. This hearing problem due to aging is termed as presbycusis. With an increase in the elderly population, an increase in the number of individuals suffering from hearing loss is expected (Cienkowski, 2003).

Pichora-Fuller, Schneider, and Daneman (1995) reported that cochlear damage and age related changes in auditory processing affect speech understanding, especially in complex testing conditions. The effortful listening conditions demand more cognitive resources for the message to be completely understood. Furthermore, there is an evidence that there are age related cognitive changes in elderly individuals (Stewart & Wingfield, 2009), along with changes in sensory organs.

These age related changes in hearing loss and cognitive function result in a slowing of processing, decision making and reactions. These changes in function pose constant challenges to professionals. The professionals have to make decisions regarding appropriate modification in the testing procedures, and appropriate modification of the hearing instrument's output characteristics. Hence, the probable effects of aging in the selection of hearing aids and the features should be evaluated, as it is not a simple task.

Presbycusis

High frequency hearing loss associated with aging was first described in 1891 as presbycusis (as cited in Sandlin, R. E., 2000). It appears to be collection of different entities that occur in various combinations and affect the entire auditory system from the external ear up to and including the central nervous system.

Schuknecht (1974) described four types of inner ear loss in presbycusis. They are sensory, neural, mechanical and metabolic presbycusis. Sensory presbycusis refers to the condition where the changes bring about a precipitous drop in the high frequency thresholds of the individuals with preserved speech identification scores. Neural presbycusis refers to the condition where there is no precipitous drop in the pure tone thresholds with disproportionate speech identification scores. Metabolic (strial) presbycusis results in a decrease in the pure tone hearing thresholds in a flat configuration with preserved speech identification scores. Lastly, mechanical (cochlear conductive) presbycusis results in a gradually sloping high frequency sensorineural hearing loss with speech identification scores which correlate with the pure tone thresholds. Rout, Mohapatra, and Mishra (2010) found sensory presbycusis to be the most common type of presbycusis.

Goswami et al., (2005) conducted a study to check for the prevalence of hearing impairments in individuals greater than 60 years in Haryana. Out of 1117 subjects, 11% were found to have hearing impairment. According to the National Sample Service Organization (2003), the geriatric population in India is 7.5%, 14% of who have hearing impairment.

Amplification for the elderly

Commonly considered treatment option for age related hearing impairment is with suitable amplification. In the elderly population, the hearing aid benefits are well documented (Harless & McConnell, 1982; Kricos, Lesner, Sandridge, & Yanke, 1987; Malinoff & Weinstein, 1989; Murlow, Tuley, & Aguilar, 1990; Newman, Weinstein, Jacobson, & Hug, 1991; Taylor, 1993) and most people with hearing impairment have been found to perform better with hearing aids. Humes, Halling, and Coughlin (1996) assessed the hearing aid benefit in quiet and noise over 180 days post fit of the hearing aid. The results indicated that there was a significant improvement in the speech recognition using the hearing aid.

Yet, more than three-fourths of the individuals who require hearing aids do not use them (Gabbard, 1994). Wilson, Fleming, and Donaldson (1993) studied the use of hearing aids by individuals aged greater than 65 years. Out of 322 patients, 34 were already using a hearing aid. Other than these patients 142 others were recommended a hearing aid. Only 69 of them accepted the hearing aid.

Successful utilization of amplification by the geriatric population is dependent on a number of factors. The factors could be the magnitude of loss in threshold sensitivity, reduced tolerance for loud sounds, and the subsequent reduction in word identification skills. In addition to changes in sensory and neural processes there may be changes in problem solving capacities, emotional states, perception and memory (Mauldin, 1976). The end result of the many factors that cause hearing loss in the aged individual is multifaceted and highly complex. Although conventional word identification may help in identifying the best hearing aid among several choices, some other factors may affect the application of amplification.

Rupp, Higgins, and Maurer (1977) listed the prognostic factors for the effective use of a hearing aid by the elderly individuals. They used the Feasability Scale for Predicting Hearing Aid Use (FSPHAU) which has a list of eleven factors which indicate the effectiveness of amplification. The factors were motivation, self assessment of difficulties, magnitude of hearing loss and understanding difficulties, the subject's general state of adaptability and flexibility, age of the subject, manual dexterity, visual ability and the financial resources available to the individual. Among all these factors, the authors reported that motivation, self assessment and magnitude of hearing loss should be given more importance for an elderly individual.

However, in a recent research done by Humes (2002), loss of audibility, age related decline in cognitive function of the subjects and temporal processing were found to be the main factors affecting speech recognition performance in elderly individuals with hearing impairment. He studied aided and unaided speech-recognition scores from a group of 171 elderly hearing-aid wearers. All hearing-aid wearers were fit with identical hearing instruments and evaluated with a standard protocol. Measures of speech recognition, physiological and perceptual measures of auditory function and measures of cognitive function were assessed before the hearing aid fitting. The results indicated that the main factors accounting for the variance in the aided speech recognition ability was the loss of audibility (14.8%), age related decline in cognitive function of the subjects (15.3%) and temporal processing (3.8%).

Thus, it is clear that there are several factors that play a role in the successful use of hearing aids. Among these, a lot of evidence has been obtained for cognition as a factor for hearing in everyday life. This is because, as age increases, along with hearing, even cognitive abilities tend to decline. In addition, hearing impairment has also been found to increase the cognitive decline (Pichora-Fuller, 2003). Further, the ability of older individuals to use the knowledge stored in long term memory to match the distorted input to understand the distorted message is more important (Rudner, Foo, Sundewall-Thoren, Lunner, & Ronnberg, 2008). Hence, the challenges faced by individuals with hearing impairment in everyday listening environments cannot be assessed on the basis of the hearing loss alone (Keissling et al., 2003). Thus, it has become important to study the effect of cognitive abilities in speech perception of elderly individuals with hearing impairment.

Effect of cognition on speech identification in elderly

Audiologists are now keenly interested in the link between audition and cognition as various cognitive measures, especially the working memory is significantly correlated with performance on speech tests.

Humes and Floyd (2005) measured the working memory, sequence learning and speech recognition in elderly hearing impaired listeners. Working memory and sequence learning was measured using the simon device which had four coloured panels arranged in a circular arrangement. Speech recognition was assessed using the CUNY Nonsense Syllable Test (NST; Levitt & Resnick, 1978) and the Competing Sentence Test (CST; Cox, Alexander, Gilmore, & Pusakulich, 1988). The results indicated that there was significant differences in the tasks of the elderly hearing impaired listeners with the young normal hearing listeners. A significant correlation was found between the cognitive tests and the unaided speech recognition measures. Further, significant correlation was obtained in the aided condition with the sentence based CST and the cognitive tests.

Stewart and Wingfield (2009) also attempted to study the correlation between speech recognition and cognition. They studied the cognitive effort in 16 young adults with normal hearing and 32 older adults, 16 who had normal hearing and 16 with mild sensorineural hearing loss. The subjects were tested on forward and backward digit span, digit symbol substitution and a trail making test to assess their cognitive function. The subjects were also tested on word recognition using 20 common monosyllabic words and 12 sentences. The results showed that there were small differences in the speech recognition scores of the young adults on these tests which became exaggerated in the older adults with normal hearing. This was attributed to the differences in cognitive skills of the older adults. These differences further increased as a result of hearing loss in the older adults.

From the above, it can be deduced that the speech recognition ability is affected by the cognitive abilities of the individual in the unaided condition. There are studies which evaluated the effect of this on speech recognition with hearing aids.

Cognition and hearing aid use

Lunner (2003) studied the effect of cognition on hearing aid use. Reading span tests and tests of verbal information processing speed were carried out to assess the cognitive function of 72 hearing impaired subjects with a mean age of 67 years. The speech recognition performance was assessed in the presence of noise by finding out the minimum signal to noise ratio at which 40% scores was obtained. Results indicated that as the subjects grew older, there was a decrease in the cognitive performance. It was observed that those subjects with shorter reaction times on the cognitive task had a higher working memory capacity. These subjects obtained a lower signal to noise ratio in the unaided and aided conditions. The results suggest that individuals with better cognitive functioning showed a better performance with the hearing aid systems in noise.

Further, emerging evidence indicates the importance of acknowledging the role of individual cognitive function when developing new signal processing schemes and fitting rules for hearing aids (Gatehouse, Naylor, & Elberling, 2003, 2006; Lunner, 2003; Pichora-Fuller and Singh, 2006). Research has suggested that there is a relationship between cognitive status and benefit from some of the hearing aid algorithms such as the dynamic compression characteristics of the complex signal processing hearing aids (Lunner, 2003; Gatehouse, Naylor, & Elberling, 2003).

Individuals with sensorineural hearing loss generally have a reduced dynamic range when compared to individuals with normal hearing. Thus, when amplification is considered for such individuals, this narrow dynamic range must be kept in mind. Linear hearing aids amplify all the sounds by the same amount, thus the high intensity sounds would become very uncomfortable for individuals with sensorineural hearing impairment (Dillon, 1996). On the other hand, compression hearing aids provide reduced gain for higher intensity sounds, thus compressing the range of speech sounds into the dynamic range of these individuals (Lunner, Hallgren, Arlinger, & Elberling, 1997).

An important parameter of compression hearing aids is the speed with which compression is applied to changes in input levels. This is described in terms of attack and release times. Attack time is the time it takes the hearing aid to stabilize to a state of reduced amplification following an abrupt increase in input level. Ideally, compression should respond quickly to reduce amplification of sudden loud sounds that might cause the listener discomfort, and thus typically attack times are short. Release time is the time it takes the hearing aid to increase amplification following a decrease in input level and may range from a few milliseconds to several seconds. Systems with release times greater than 200 ms are referred to as slow acting while systems with release times less than 200 ms are referred to as fast acting (Hickson, 1994).

Slow-acting compression results in amplification similar to linear amplification, which preserves syllable characteristics to a higher degree. On the other hand, fast-acting compression is similar to nonlinear amplification which results in syllable compression and an alteration of the temporal envelope which determines the acoustical form of the speech signal and therefore the cues used during phonological processing (Dillon, 2001).

Fast-acting compression leads to better performance in speech recognition in noise than with linear processing, although this does not always happen (Olsen, Olofsson, & Hagerman, 2004; Stone & Moore, 2008). Poor performance with fast-acting compression may be because the fast acting compression introduces changes in the amplitude of formants (Lindemann & Worrall, 2000) and reduces the intensity contrasts and modulation depths of speech, which may have an adverse effect on the speech perception cues (Plomp, 1988).

In slow acting compression systems, the temporal envelope of the signal is not distorted and hence the speech intelligibility is preserved (Drullman, Festen, & Plomp, 1994). Short term changes in the spectral patterns, which convey important information in speech, are also not distorted (Kluender, Coady, & Kiefte, 2003). However, such systems may not deal well with situations in which two signals vary at markedly different levels. When trying to listen to one voice in the presence of another voice in the background, it is important to extract information from the target during the temporal dips in the background signal. Hearing impaired individuals have a reduced ability to listen in the dips (Duquesnoy, 1983). Slow compression systems are of limited benefit in such situations as the gain does not increase in the brief dips of the background signal.

Thus, it would seem that an individual would require more cognitive capacity to understand speech in noise using fast acting compression than slow acting compression (Gatehouse, Naylor, & Elberling, 2003, 2006; Lunner & Sundewall-Thoren, 2007).

Gatehouse, Naylor, and Elberling (2003) evaluated the different types of compression. Fifty elderly individuals with bilateral mild to moderate sensorineural hearing loss took part in the study. Their cognitive ability was assessed using the visual digit monitoring and the visual letter monitoring tests. The speech identification scores in the presence of noise were assessed using the Four Alternative Auditory Feature test (FAAF), given by Foster and Haggard, 1987. Results indicated that as the cognitive ability increased, the unaided FAAF scores improved. This was more evident in the more adverse listening condition, suggesting that individuals with lower cognitive ability were more affected with adverse signal to noise ratios. The individuals were assessed with five aided conditions in the presence of noise. They were 1) a single channel linear setting (referred to as NAL-RP), 2) a dual channel linear setting (Linear), 3) condition with fast release times in both channels (Fast-Fast), 4) slow release times in both channels (Slow-Slow) and 5) condition with fast compression in the low frequency channel and slow compression in the high frequency channel (Fast-Slow).

Among the aided conditions, the slow-slow condition showed greater benefit than the NAL-RP and linear conditions. Further, the benefit was greater for the fast-fast and fast-slow conditions than the slow-slow condition. Two types of noises were used, a steady state noise and the International Collegium of Rehabilitative Audiology (ICRA) noise which has a varying temporal envelope. Individuals with good cognitive abilities were able to better understand the speech in the temporal dips in noise when using fast acting compression. This was exhibited by increased scores in the ICRA noise as compared to the steady noise condition. Whereas, the listeners with poor cognitive abilities performed poorly with both the types of noises. Thus, as the tasks become more representative of the real world listening conditions, the hearing aid algorithm will interact more with the cognitive abilities of the hearing impaired listeners.

In 2006, they further studied the candidature for linear, slow acting automatic volume control and fast acting wide dynamic range compression hearing aids and the effect of cognitive abilities on this, in the elderly population. The results showed positive correlation between the cognitive function and speech performance, such that individuals with better cognitive abilities performed better with the fast acting compression in both channels of the hearing aid. This was attributed to the fact that the fast acting compression reduces the information carrying spectral and temporal contrasts that are required in speech while providing greater moment to moment audibility. For the individuals with good cognitive abilities the disadvantage of reduced contrasts is outweighed by the benefits obtained from the audibility. On the other hand, for the individuals with poor working memory, the disadvantages of reduced contrasts outweigh the audibility provided.

Similar results were also found by Lunner and Sundewall-Thoren (2007). They studied the interaction between cognition, compression and listening conditions focussing on the speech in noise performance in 23 individuals with hearing loss. They reported that the group with high cognition performed better than the low cognition group for all the test conditions. The group with better cognitive functioning performed best in the fast time constant condition with modulated noise.

Another recent study done by Cox and Xu (2010) also revealed that the listeners with lower cognitive ability perform better with longer release times when they are challenged by the need to identify some information based on audibility alone. When the speech material has a lower context and lesser predictable keywords, the individuals with less cognitive capacity require longer release times to understand the speech material.

From the review of literature, it is clear that the cognitive abilities influence the benefit obtained from the slow and fast acting compression systems. However, dual compression systems have not been evaluated on this aspect. Further, although a large amount of research has been done on the settings of compression time constants, gain requirement for providing best speech identification in individuals with different cognitive abilities has not been studied. Hence, the present study aimed to evaluate the gain requirement, and dual and syllabic compression in geriatric individuals with good and poor cognitive abilities.

Chapter 3

METHOD

The present study consisted of 3 stages to test the objectives of the study

Stage I: Assessment of auditory working memory in geriatric population

Stage II: Assessment of gain requirement in individuals with good and poor working memory

Stage III: Assessment of the effect of dual and syllabic compression in the presence of noise in geriatric individuals with good and poor working memory

Selection of participants:

Case History:

A detailed case history was taken. This was done to rule out the factors which are listed later as the exclusion criteria in the participants' selection.

Pure tone Audiometry:

Pure tone thresholds were obtained using an OB922 dual channel diagnostic audiometer using the modified Hughson and Westlake procedure (Carhart & Jerger, 1959). This was done at octave frequencies from 250 Hz to 8000 Hz for air conduction through TDH-39 headphones housed in MX-41AR supra-aural cushion and from 250 Hz to 4000 Hz for bone conduction through the Radio Ear B-71 bone vibrator. The pure tone average was taken as the average of the air conduction thresholds for 500 Hz, 1000 Hz and 2000 Hz. Speech recognition thresholds were obtained to correlate with the pure tone average. Speech Identification Scores were obtained at a level of SRT + 40 dB using the PB word list in Kannada developed by Yathiraj and Vijayalakshmi (2005).

Immittance Evaluation:

Immittance evaluation was done on all the individuals. Tympanometry and Acoustic Reflex assessments were carried out using the standard procedure using GSI-Tympstar middle ear analyzer.

Inclusion criteria:

22 elderly subjects in the age range of 60-70 years, with bilateral mild to moderate symmetrical sensorineural hearing loss were included in the study. Symmetrical hearing loss was defined as less than or equal to 15 dB difference in the pure tone average (PTA) of the right and left ears (Gatehouse, Naylor, & Elberling, 2003, 2006).

Exclusion criteria:

Subjects who presented with one or more of the following conditions were excluded from the study

- Any history or presence of middle ear disorders
- Neurological involvement
- History of exposure to noise
- Any systemic disease
- Any psychological problems
- Type B or C tympanogram obtained in immittance evaluation

Stage I: Assessment of auditory working memory

The present study used digit span test from Post Graduation Institute (PGI) battery of brain dysfunction (Pershad & Verma, 1989) to assess the working memory of the participants. The test consists of two parts: digit forward test and digit reverse test. All the tasks in both the tests have two sets. The digit forward test consists of six tasks. The first task has three digits. Each of the subsequent tasks increases in length by a single digit. The last task has eight digits. The digit reverse test consists of seven tasks increasing in length from two digits to eight digits. A maximum score of 16 can be achieved on the test. The test has normative values for individuals in the age range of 20 – 70 years (given in the Appendix). The testing was carried out at the most comfortable level of the participants.

The digit forward test was started from the task 1 of both the sets which had three digits. The participants were instructed to repeat the digits in the same order as the clinician instructed. The digits were read at a steady state of one digit per second. When the participants repeated the numbers in the correct order, they were asked to repeat the items from the task 2 which had four numbers, first from set 1 and then from set 2. The same procedure was repeated until the participants failed to repeat the numbers from both the sets of the same task. The procedure for the digit reverse test was the same except that the participants were asked to repeat the numbers in the reverse order of the presentation. The following method was used for scoring:

- For the digit forward test, the score was the total number of digits in the longest series the participant repeated exactly as presented.
- For the digit reverse test, the score was the total number of digits in the longest series the participant repeated in reverse order.

- The total score was calculated by the sum of the scores in the digit forward and digit reverse tests

Based on the total score, the subjects were grouped into either of the following two groups:

Group I: Participants with scores greater than the mean minus standard deviation of the test norms were classified as having good working memory. This group comprised of 12 individuals in the age range of 60 to 70 years with mean age of 64.67 years (SD=3.80). The mean digit span score in this group was 9.33 (SD=1.43).

Group II: Participants with scores lesser than the mean minus standard deviation of the test norms were classified as having poor working memory. This group included 10 individuals in the age range of 60 to 70 years with mean age of 66 years (SD=3.86). The mean digit span score in this group was 5.8 (SD=0.42).

Stage II: Assessment of gain requirement

A two channel digital non-linear hearing aid with the feature of dual and syllabic compression was used for the study. It was programmed using NOAH software with a Hi-Pro connected to a PC. The National Acoustic Laboratory Non-linear 1 (NAL-NL1) prescriptive formula was used to calculate the target gain.

1. The first fit was carried out to match the hearing aid gain to the target gain curve prescribed by NAL-NL1.
2. To verify the adequacy of gain and frequency shaping, identification of the Ling's six sounds (Ling, 1976) was done and five unrelated questions were asked at 40 dB HL. Depending on the response, changes were made in the gain and frequency shaping.

3. After the verification, for studying the objectives, Speech Identification Scores (SIS) with the PB word list was assessed in quiet with this level of gain at a level of 40 dB HL. To check how much of increase in gain was required to obtain best SIS, the gain was increased in 2 dB steps till a plateau in SIS was reached. The plateau was said to be achieved, when SIS obtained was same at two consecutive steps of increase in gain. The lower level of gain at which the plateau started was noted down.
4. The difference between the gains at first fit and the gain at plateau for each individual was calculated, which will be referred as G_{diff} hereafter.

Stage III: Assessment of effect of dual and syllabic compression on speech identification in noise in geriatric individuals with good and poor working memory

Speech recognition in noise in different compression conditions was assessed through the signal to noise ratio-50 (SNR-50) procedure using the PB word list. This procedure was adopted from the Tillman and Olsen (1973) procedure for speech audiometry. The gain settings were those at which the subject obtained a plateau in the speech identification scores. The level of speech was kept constant at 45 dB HL. The level of the noise was varied with the initial level being 30 dB HL. The participant was instructed to repeat the words heard. The noise level was increased in 5 dB steps until a score of 50% was obtained. At this level, to get the precise value of SNR-50, the noise was varied in 2 dB steps so as to obtain a 50% correct word recognition score. The testing was stopped when the participant obtained a 50% correct score in the presence of noise. The difference between the level of the speech and the noise at this stage was noted as the SNR-50. The SNR-50 for each of the participants was measured in three conditions; unaided and aided with dual and syllabic compression settings.

Chapter 4

RESULTS AND DISCUSSION

The two main objectives of the present study were to evaluate gain requirement by individuals with good working memory and poor working memory to obtain best speech identification scores, and to assess the effect of dual and syllabic compression on speech recognition in noise by geriatric individuals with good working memory and poor working memory.

The G_{diff} was compared between the two groups (individuals with good working memory and individuals with poor working memory). Further, the speech recognition in noise measured through the signal to noise ratio-50 was compared in the three conditions of unaided, hearing aid with dual compression and hearing aid with syllabic compression, using statistical measures. All the statistical analysis was conducted using Statistical Package for Social Sciences, SPSS (version 18).

1) Comparison of gain requirement between the good and poor working memory groups:

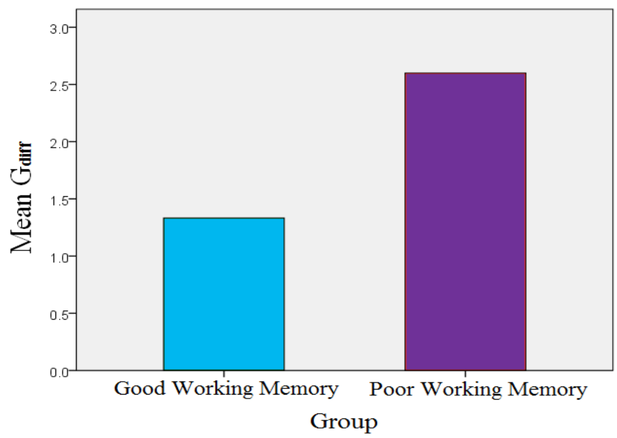

Figure 4.1: Mean G_{diff} between the two groups.

It can be observed from figure 4.1 that most of the individuals in the good working memory group achieved a plateau of SIS at first fit itself. Even those individuals who required gain increase, required lesser increase in the gain to achieve a plateau of SIS when compared to poor working memory group. On the other hand, most of the individuals with poor working memory required increase in the gain to achieve a plateau in the SIS.

Table 4.1

Comparison of the G_{diff} in the good working memory and poor working memory groups

Group	Number of subjects	Mean G_{diff}	SD	T	df	Sig (2 tailed)
Good Working Memory	12	1.33	1.96	-1.61	20	0.122
Poor Working Memory	10	2.60	1.64			

Independent T-test was done to see if this difference is statistically significant. Table 4.1 shows the results of the independent T-test along with the mean and standard deviation of the two groups. It can be seen from table 4.1 that the G_{diff} was not statistically significant.

As it can be observed from table 4.1, the standard deviation is greater than the mean and, hence, a nonparametric test is needed to verify the results of the independent T-test. Mann Whitney U test was conducted to verify the results obtained through the Independent t-test. The results of Mann Whitney U test are given in table 4.2.

Table 4.2

Results of Mann Whitney U test for verification of the Independent t-test

Null Hypothesis	Test	Sig	Decision
G_{diff} is same for both the groups	Independent Samples Mann-Whitney U test	0.081	Retain the null hypothesis

It can be seen from table 4.2 that even Mann Whitney U test did not show statistically significant difference in the amount of gain required to obtain best SIS between the two groups ($p=0.081$, $p>0.05$).

Though there was a difference in G_{diff} between the two groups, this difference was not statistically significant. The reason for this may be that the evaluation was done in a quiet situation. Studies show that under favourable listening conditions, the speech signal can be immediately matched to the stored representations in long term memory even in the elderly population. However, in adverse listening conditions this matching process may fail (Rudner et al., 2008). In such conditions, there may be a difference in the amount of information understood depending on the cognitive ability of the individual. Hence, testing in adverse listening conditions which is more close to real world situations might give a clearer picture on the effect of cognition on the gain requirement. However, in the present study, the gain requirement could not be assessed in noise, as it required many number of word lists in Kannada, and in Kannada language, at present there are only four word lists available.

2) Evaluating the effect of dual and syllabic compression on SNR-50 in the two groups:

In order to evaluate the effect of dual and syllabic compressions, comparisons were done between the two groups and also within the groups.

a) Between the group comparison of SNR-50 for dual and syllabic compression conditions:

Table 4.3 shows the mean and standard deviation of the signal to noise ratio-50 values obtained in unaided, dual and syllabic compression conditions. The same is also given in figure 4.2. In the analysis, even the unaided condition was included, to compare with the two aided conditions, to ensure that there was no degradation of speech recognition scores in the aided condition because of the compression.

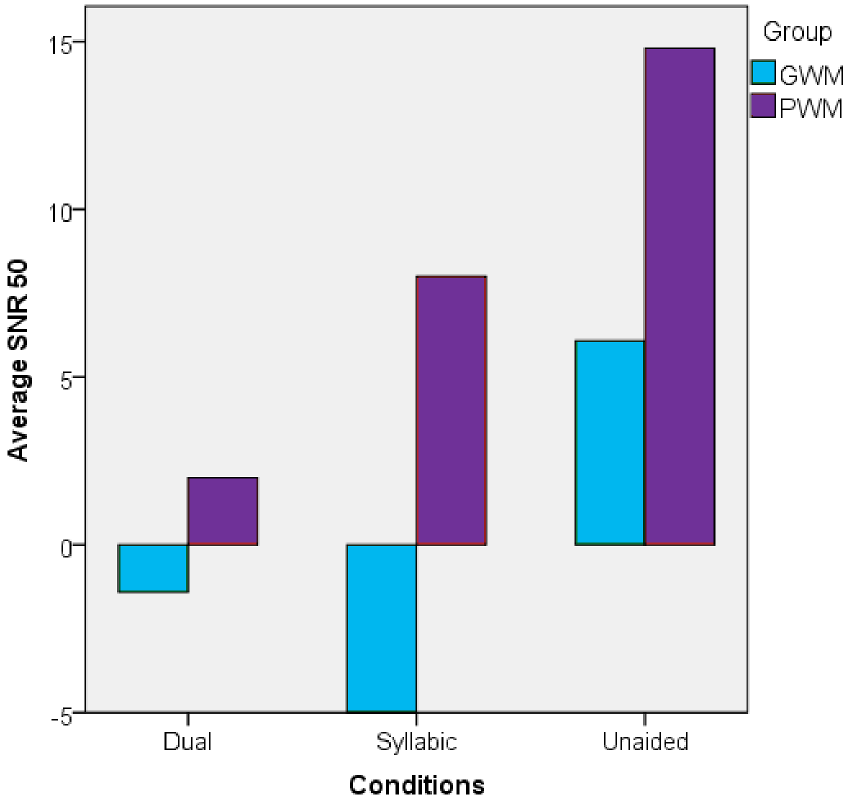

Fig 4.2: Mean SNR-50 for good working memory (GWM) group and poor working memory (PWM) group in unaided, dual and syllabic compression.

Table 4.3

Mean and Standard deviation (SD) of SNR-50 values for unaided, dual and syllabic compression

Condition	Group	Mean	SD	Number of subjects
Unaided	Good Working Memory	6.08	5.45	12
	Poor Working Memory	14.80	6.81	10
Dual	Good Working Memory	-1.42	5.56	12
	Poor Working Memory	2.00	5.65	10
Syllabic	Good Working Memory	-5.00	6.09	12
	Poor Working Memory	8.00	5.75	10

Here, it should be noted that more negative the value of SNR-50, better is the performance. From table 4.3 it can be observed that the scores in the dual and syllabic compression conditions are better than the unaided condition. Further, in all the three conditions (unaided, dual compression mode and syllabic compression mode), the individuals in the good working memory group performed better than the individuals in the poor working memory group.

MANOVA was done to verify if this difference was statistically significant. Results of MANOVA are given in table 4.4.

Table 4.4

Comparison of unaided, dual compression and syllabic compression using MANOVA between the two groups

Source	Dependent variable	F (1,20)	Sig.
Groups (Good and Poor Working Memory)	Unaided	11.133*	0.003
	Dual	2.025	0.170
	Syllabic	26.114*	0.000

Note: *- p< 0.05

Table 4.4 shows that there is a statistically significant difference between the good and poor working memory groups for the unaided and syllabic compression conditions at 95% confidence interval ($p < 0.05$). That is, the individuals in the good working memory group performed significantly better than the individuals in the poor working memory group. These results are supported by other studies, which report that in adverse listening conditions, the individuals with a good cognitive capacity require lesser signal to noise ratio to obtain 50% performance (Lunner, 2003; Rudner, Foo, Ronnberg, & Lunner, 2007; Rudner et al., 2008). Poor performance with fast-acting compression in individuals with poor working memory may be because the fast acting compression introduces changes in the amplitude of formants (Lindemann & Worrall, 2000) and reduces the intensity contrasts and modulation depths of speech, which may have an adverse effect on the speech perception cues (Plomp, 1988).

However, there was no statistically significant difference found for the dual compression condition between the two groups for the dual compression conditions ($p=0.170$, $p>0.05$). These results support the findings of Gatehouse, Naylor, &

Elberling (2003, 2006), Lunner and Sundewall-Thoren (2007) and Cox and Xu (2010). In dual compression mode, the temporal envelope of the speech is not distorted and, hence, the syllable features are preserved (Drullman, Festen, & Plomp, 1994). Further, the short term changes which convey information in the spectral patterns of speech sounds are not distorted (Kluender, Coady, & Kiefte, 2003). These features are important in maintaining the speech intelligibility. Thus, even the individuals with poor working memory were able to obtain good scores in the dual compression mode.

b) Within the group comparison of SNR-50 for dual and syllabic compression conditions in good working memory group:

Table 4.5

Results of Repeated measures ANOVA comparing SNR-50 for good working memory group

Condition	Mean	SD	F (2,22)	Sig
Unaided	6.08	5.45	50.384*	0.000
Dual compression	-1.42	5.56		
Syllabic compression	-5.00	6.09		

Note: *- p< 0.05

Repeated measures ANOVA was done to compare the performance with unaided, dual and syllabic conditions within the group. It can be observed in table 4.5 that there is a statistically significant difference found between the unaided, dual and syllabic compression conditions for the good working memory group ($p < 0.05$). To find out which of the conditions were differing, Bonferroni's post hoc analysis was done.

Table 4.6

Bonferroni's post hoc analysis comparing SNR-50 for good working memory group

Condition (I)	Condition (J)	Mean Difference (I-J)	Sig
Dual	Syllabic	3.583*	0.012
	Unaided	-7.500*	0.000
Syllabic	Dual	-3.583*	0.012
	Unaided	-11.083*	0.000
Unaided	Dual	7.500*	0.000
	Syllabic	11.083*	0.000

Note: *: $p < 0.05$

Bonferroni's post hoc analysis revealed that unaided, dual compression and syllabic compression are significantly different from each other ($p < 0.05$). It can also be observed that the good working memory group performed better with syllabic compression than with dual compression, as given in table 4.6.

These findings are supported by the findings of Gatehouse, Naylor, and Elberling (2003, 2006), Lunner and Sundewall-Thoren (2007), Rudner et al., (2008) and Cox and Xu (2010) who also found that individuals with good working memory match the distorted information to the long term memory storage and still perceive the entire information.

As mentioned earlier, syllabic compression introduces amplitude fluctuations in the different frequency bands as well as reduces the amplitude modulation depth and intensity contrasts (Stone & Moore, 2003). Hence, higher cognitive skills are required to understand the entire message. Hence, in the present study, the group with good working memory perform better with syllabic compression.

c) Within the group comparison of SNR-50 for dual and syllabic compression conditions in poor working memory group

Repeated measures ANOVA was done to compare the performance with unaided, dual and syllabic conditions within the group. It can be observed in table 4.7, there is a statistically significant difference found between the unaided, dual and syllabic compression conditions for the poor working memory group ($p < 0.05$). To find out which of the condition was significantly different, Bonferroni's post hoc analysis was done.

Table 4.7

Results of Repeated measures ANOVA comparing SNR-50 for poor working memory group

Condition	Mean	SD	F (2,22)	Sig
Unaided	14.80	6.81	44.013*	0.000
Dual compression	2.00	5.56		
Syllabic compression	8.00	5.75		

Note: *- p< 0.05

Table 4.8

Bonferroni's post hoc analysis for poor working memory group

Condition (I)	Condition (J)	Mean Difference (I-J)	Sig
Dual	Syllabic	-6.000*	0.000
	Unaided	-12.800*	0.000
Syllabic	Dual	6.000*	0.000
	Unaided	-6.800*	0.002
Unaided	Dual	12.800*	0.000
	Syllabic	6.800*	0.002

Note: *: $p < 0.05$

The post hoc analysis results are shown in table 4.8. It can be observed that the individuals with poor working memory performed better with dual compression than with syllabic compression.

These individuals did not have sufficient cognitive capacity to match the distorted information to the long term memory. Thus, since the dual compression mode has more preserved phonological characteristics, these individuals are able to obtain better scores in this condition. Further, it is evident from the above finding that, though the dual system involves the generation of two gain control signals, its operation is more like the slow acting compression system. These results are correlated with Gatehouse, Naylor, and Elberling (2003, 2006), Lunner and Sundewall-Thoren (2007), Rudner et al., (2008) and Cox and Xu (2010).

Chapter 5

SUMMARY AND CONCLUSIONS

Hearing loss is a common problem reported in elderly individuals. The most common form of rehabilitation for them is by providing a suitable amplification device. However, a lot of factors must be considered while fitting hearing aids to elderly individuals with hearing impairment. One of the important factors is the cognitive level of the individual. Studies have shown that individuals with good cognitive abilities perform better with fast acting compression and individuals with poor cognitive abilities perform better with slow acting compression. (Gatehouse, Naylor & Elberling, 2003, 2006; Lunner & Sundewall-Thoren, 2007). However, no research has been done, to the best of our knowledge, to study the effect of cognitive abilities on gain requirement and dual compression.

The present study aimed to evaluate the role of auditory working memory on the amount of gain required for obtaining best speech identification, and its effect on the performance with dual and syllabic compression in elderly individuals in noise. Following were the objectives of the present study:

- To compare the amount of gain required for best speech identification by elderly individuals with good and poor working memory.
- To compare the aided speech performance in noise using dual and syllabic compression in individuals with good and poor working memory.

The present study included 22 elderly individuals in the age range of 60-70 years. The digit span test from the PGI battery of brain dysfunction was administered on these individuals to assess the working memory. Based on the results of the working memory, they were grouped into two groups; good working memory group which had 12 individuals and poor working memory group which had 10 individuals.

For evaluating the gain requirement for obtaining best SIS in both the groups, the gain setting was increased till the plateau of SIS was obtained. The results of the study showed that the individuals with good working memory required lesser increases in the gain to obtain best SIS. Individuals with poor working memory required more increases to obtain the best SIS. However, these results were not found to be statistically significant. The reason for this could be that these evaluations were conducted in quiet situations while individuals with poor working memory report more difficulties in the adverse listening conditions.

Further, the performance of the individuals in the presence of noise in unaided and aided conditions for dual and syllabic compression conditions was noted down. SNR-50 was obtained in each of the above conditions for both groups of individuals.

In noise, the individuals with good working memory performed better with syllabic compression and the individuals with poor working memory performed better with dual compression. When the hearing aid is set to syllabic compression, the temporal envelope of the speech becomes distorted, thus reducing the syllabic features. Individuals with good working memory manage to match this distorted speech to the representations in the long term memory and are able to understand the signal. However, individuals with poor working memory do not manage to do so. Thus, they obtain poor scores while using syllabic compression. While using dual compression, the syllable features are not lost and hence these individuals tend to obtain good scores in this mode.

Hence, it can be concluded that the gain requirement may not be different between individuals with good and poor working memory in quiet. In complex listening situation, there may be a difference. However, this needs to be researched upon. Further, it can also be concluded that it is important to consider the cognitive abilities of the individual while setting the compression time constants. Therefore, a simple test of cognition must be included in the audiological test battery especially while evaluating elderly individuals. This knowledge will help in better prescription and fine tuning of hearing aids. The results of this study help in the successful rehabilitation of elderly individuals with hearing impairment.

REFERENCES

Bronkhorst, A. W., & Plomp, R. (1992). Effect of multiple speech like maskers on binaural speech recognition in normal and impaired hearing, *Journal of Acoustical Society of America*, *92,* 3132–3139.

Carhart, R., & Jerger, J. F. (1959). Preferred method for clinical determination of pure-tone thresholds. *Journal of Speech and Hearing Disorders, 24,* 330-345.

Cienkowski, K. M. (2003). Auditory aging: A look at hearing loss in older adults. Hearing Loss. *The Journal of Self Help for Hard of Hearing People May/June,* 12-15.

Cohen, G. (1987). Speech perception in the elderly: The effects of cognitive changes. *British Journal of Audiology, 21,* 221-226.

Cox, R. M., Alexander, G. C., Gilmore, C. G., & Pusakulich, K. M. (1988). Use of the Connected Speech Test (CST) with hearing-impaired listeners. *Ear & Hearing, 9,* 198–207.

Cox, R. M., Alexander, G. C., & Gray, G. A. (2005). Hearing aid patients in private practice and public health clinics: Are they different? *Ear and Hearing, 26(6),* 513-28.

Cox, R. M., & Xu, J. (2010). Short and long compression release times: speech understanding, real world preferences, and association with cognitive ability. *Journal of American Academy of Audiology, 21,* 121-138.

Dillon, H. (1996). Tutorial compression? Yes, but for low or high frequencies, for low or high intensities, and with what response times?. *Ear and Hearing, 17(4),* 287-307.

Dillon, H. (2001). *Hearing Aids*. 1st edition, Thieme publishers, New York.

Drullman, R., Festen, J. M., & Plomp, R. (1994). Effect of temporal envelope smearing on speech reception. *Journal of the Acoustical Society of America, 95*, 1053-1064.

Duquesnoy, A. J. (1983). Effect of a single interfering noise or speech source on the binaural sentence intelligibility of aged persons. *Journal of the Acoustical Society of America, 74*, 739-743.

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

Gabbard, S. A. (1994). AARP's report on hearing aids. *Audiology Today, 6,* 15.

Gaeth, J. H. (1948). A study of phonemic regression in relation to hearing loss. Unpublished doctoral dissertation, Northwestern University.

Gates, G. A., Cooper, J. C., Kannel, W. B., & Miller, N. J. (1990). Hearing in the elderly: the Framingham cohort, 1983–1985, part I. *Ear and Hearing, 4*, 247–56.

Gatehouse, S., Naylor, G., & Elberling, C. (2003). Benefits from hearing aids in relation to the interaction between the user and the environment, *International Journal of Audiology, 42*, S77-S85

Gatehouse, S., Naylor, G., & Elberling, C. (2006). Linear and nonlinear hearing aid fittings – 2: Patterns of candidature. *International Journal of Audiology, 45,* 153-171.

Geetha, C., & Manjula, P. (2004-05). Effect of syllabic and dual compression on speech identification scores. *Student Research at AIISH, Mysore (Article based on dissertation done at AIISH), 3*, 57-66.

Goswami, A., Reddaiah, V.P., Kapoor, S. K., Singh, B., Singh, U., Dey, A. B., Dwivedi, S. N., & Kumar, G. (2005). Prevalence and determinants of disability in the rural elderly population in Northern India. *Indian Journal of Physical Medicine and Rehabilitation, 16(2),* 39-44.

Harless, E. L., & McConnell, F. (1982). Effects of hearing aid use on self concept in older persons. *Journal of Speech and Hearing Disorders, 47,*305-309.

Hickson, L. M. H. (1994). Compression amplification in hearing aids. *American Journal of Audiology*, *3*, 51-65.

Hogan, C. A., & Turner, C. W. (1998). High frequency audibility: benefits for hearing impaired listeners. *Journal of the Acoustical Society of America, 104*, 432-441.

Humes, L. E. (2002). Factors underlying the speech recognition performance of elderly hearing-aid wearers. *Journal of the Acoustical Society of America*, *112,* 1112–1132.

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

Humes, L. E., & Floyd, S.S. (2005). Measures of working memory, sequence learning, and speech recognition in the elderly. *Journal of speech, language and hearing research, 48,* 224-235.

Humes, L. E., Halling, D., & Coughlin, M. (1996). Reliability and stability of various hearing aid outcome measures in a group of elderly hearing aid wearers. *Journal of Speech and Hearing Research, 39,* 923–935.

Humes, L. E., & Roberts, L. (1990). Speech-recognition difficulties of the hearing-impaired elderly: The contributions of audibility, *Journal of Speech and Hearing Research, 33,* 726–735.

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

Kiessling, J., Pichora-Fuller, M. K., Gatehouse, S., Stephens, D., Arlinger, S., Chisholm, T. H., Davis, A. C., Erber, N. P., Hickson, L., Holmes, A. E., Rosenhall, U., & von Wedel, H. (2003). Candidature for and delivery of audiological services: special needs of older people. *International Journal of Audiology, 42(2),* S92–S101.

Kricos, P. B., Lesner, S. A., Sandridge, S. A., & Yanke, R. B. (1987). Perceived benefits of amplification as a function of central auditory status in the elderly. *Ear and Hearing, 8,* 337-342.

Kluender, K. R., Coady, J. A., & Kiefte, M. (2003). Sensitivity to change in perception of speech. *Speech Communication*, *41*, 59-69.

Lethbridge-Cejku, M., Schiller, J. S., & Bernadel, L. (2002). Summary health statistics for US adults: National Health Interview Survey, 2002. *Vital and Health Statistics,10,* 1–160.

Levitt, H., & Resnick, S. B. (1978). Speech reception by the hearing impaired: methods of testing and development of materials. *Scandinavian Journal of Audiology, S6,* 107-129.

Lindemann, E., & Worrall, T. L. (2000). *Continuous frequency dynamic range audio compressor* (U.S. Patent No. 609,7824). Washington, DC: U.S. Patent and Trademark Office.

Ling, D. (1976). *Speech and the hearing impaired child: Theory and Practice*. Washington, DC: Alexander Graham Bell Association for the Deaf.

Lunner, T. (2003): Cognitive function in relation to hearing aid use. *International Journal of Audiology, 42,* S49-S58.

Lunner, T., Hallgren, M., Arlinger, S., & Elberling, C. (1997). A digital filterbank hearing aid: Three DSP algorithms – user preference and performance. *Ear and Hearing, 18,* 373–387.

Lunner. T., & Sundewall-Thoren. (2007). Interactions between cognition, compression, and listening conditions: Effects of speech in noise performance in a two channel hearing aid. *Journal of American Academy of Audiology, 18,* 604-617.

Malinoff, R., & Weinstein, B. (1989). Measurement of hearing aid benefit in the elderly. *Ear and Hearing, 10,* 354–356.

Mauldin, C. (1976). *Communication Considerations in the Health Care of Aging. Aging and Communication*. 1st edition. University Park Press, Baltimore.

Maurer, J. F., & Rupp, R. R. (1979). *Hearing and aging* (pp. 33-66, 96-178). New York: Grune and Stratton.

Moore, B. C. J., (2008). The choice of compression speed in hearing aids: theoretical and practical considerations and the role of individual differences. *Trends in Amplification, 12,* 102-112.

Murlow, C. D., Tuley, M. R., & Aguilar, C. (1992). Sustained benefits of hearing aids. *Journal of Speech and Hearing Research, 35 (6),* 1402-1405.

Nabelek, A. K., & Mason, D. (1981). Effect of noise and reverberation on binaural and monaural word identification by subjects with various audiograms. *Journal of Speech and Hearing Research, 24,* 375-383.

National Sample Survey Organization (2003): Disabled Persons in India, NSS 60th Round Ministry of Statistics and Programme Implementation, Government of India.

Newman, C. W., Weinstein, B. E., Jacobson, G. P. & Hug, G. A. (1990). The Hearing Handicap Inventory for Adults: psychometric adequacy and audiometric correlates. *Ear and Hearing, 11(6),* 430–433

Olsen, H. L., Olofsson, A., & Hagerman, B. (2004). The effect of presentation level and compression characteristics on sentence recognition in modulated noise. *International Journal of Audiology, 43(5),* 283-294.

Pichora-Fuller, M. K. (2003). Processing speed and timing in aging adults: psychoacoustics, speech perception and comprehension. *International Journal of Audiology, 42(S1),* S59-S67.

Pichora-Fuller, M. K., Schneider, B. A., & Daneman, M. (1995). How young and old adults listen to and remember speech in noise. *Journal of the Acoustical Society of America, 97,* 593-608.

Pichora-Fuller, M. K., & Singh, G. (2006). Effects of age on auditory and cognitive processing: Implications for hearing aid fitting and Audiologic rehabilitation. *Trends in Amplification, 10,* 29-59.

Pershad, D., & Verma, S. K. (1989). Handbook of PGI Battery of Brain Dysfunction (PGI -BBD), Agra: National Psychological Corporation.

Plomp, R. (1988). The negative effect of amplitude compression in multichannel hearing aids in the light of the modulation-transfer function. *Journal of the Acoustical Society of America, 83,* 2322-2327.

Rout, N., Mohapatra, B., & Mishra, S. (2010). Hearing loss in elderly: an Indian perspective. *Journal of All India Institute of Speech and Hearing, 29(2),* 253-261.

Rudner, M., Foo, C., Ronnberg, J., & Lunner, T. (2007). Phonological mismatch makes aided speech recognition in noise cognitively taxing. *Ear and Hearing, 28(6),* 879-892.

Rudner, M., Foo, C., Sundewall-Thoren, E., Lunner, T., & Ronnberg, J. (2008). Phonological mismatch and explicit cognitive processing in a sample of 102 hearing aid users. *International Journal of Audiology, 47(S2),* S91-S98.

Rupp, R. R., Higgins, J., & Maurer, J. (1977). A feasibility scale for predicting hearing aid use with older individuals. *Journal of the Academy of Rehabilitative Audiology, 10,* 81-104.

Sandlin, R. E. (2000). *Textbook of hearing aid amplification: Technical and clinical considerations.* 2nd edition. San Diego: Singular Publishing.

Schuknecht, H. F. (1974). Pathology of the ear. Cambridge, MA. Harvard University Press.

Stewart, R., & Wingfield, A. (2009). Hearing loss and cognitive effort in older adults' report accuracy for verbal material. *Journal of American Academy of Audiology, 20(2),* 147-154.

Stone, M. A., & Moore, B. C. J. (2003). Effect of the speed of a single channel dynamic range compressor on intelligibility in a competing speech task, *Journal of Acoustical Society of America, 114,* 1023–1034.

Stone, M. A., & Moore, B. C. J. (2008). Effects of spectro-temporal modulation changes produced by multi-channel compression on intelligibility in a competing-speech task. *Journal of the Acoustical Society of America, 123(2),* 1063–1076.

Souza, P. E., Boike, K. T., Witherell, K., & Tremblay, K. (2007). Prediction of speech recognition from audibility in older listeners with hearing loss: Effects of age, amplification, and background noise. *Journal of American Academy of Audiology, 18,* 54 – 65.

Taylor, K. (1993). Self-perceived and audiometric evaluations of hearing aid benefit in the elderly. *Ear and Hearing, 14,* 390–395

Tillman, T. W., & Olsen, W. O. (1973). Speech Audiometry. In Jerger, J. Modern Developments in Audiology (pp 37-74). New York. Academic Press.

Turner, C. W., & Cummings, K. J. (1999). Speech audibility for listeners with high-frequency hearing loss. *American Journal of Audiology, 8,* 47–56.

Wax, T. (1982). The hearing impaired aged: Double jeopardy. *Gallaudet Today, 12,* 3-7.

Wilson, P. S., Fleming, D. M., & Donaldson, E. (1993). Prevalence of hearing loss among people aged 65 years and over: screening and hearing aid provision. *British Journal of General Practice, 43,* 406-409.

Yathiraj, A., & Vijayalakshmi, C. S. (2005). Phonemically Balanced word list in kannada. Developed in the department of Audiology, AIISH.

Appendix

Digit Forward

Set I	Set II
5-7-3	4-1-7
5-3-8-7	6-1-5-8
1-6-4-9-5	2-9-7-6-3
3-4-1-7-9-6	6-1-5-8-3-9
7-2-5-9-4-8-3	4-7-1-5-3-8-6
4-7-2-9-1-6-8-5	9-2-5-8-3-1-7-4

Digit Backward

Set I	Set II
8-5	2-8
4-3-7	8-5-1
8-5-6-3	3-7-5-9
4-7-2-9-1	9-2-5-8-4
2-5-9-4-8-3	7-1-5-3-9-6
3-5-8-6-1-9-2	6-3-7-1-4-8-5
8-5-2-3-6-1-9-4	2-8-4-5-9-7-1-7

Normative Value:

Age range of 60-70 years

Educational level	Mean	SD	Mean – SD
0-5 years	7.61	2.61	5
6-9 years	9.14	2.42	6.72
> 10 years	10.66	2.89	7.77