# WORKING MEMORY AND LOW REDUNDANCY SPEECH PERCEPTION IN THE NORMAL EAR OF INDIVIDUALS WITH UNILATERAL HEARING LOSS


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A Dissertation Submitted in Part Fulfilment of Degree of Masters of Science (Audiology)

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MAY 2017

# CERTIFICATE

This is to certify that this dissertation entitled **"Working memory and low redundancy speech perception in the normal ear of individuals with unilateral hearing loss"** is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number 15AUD008. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
May, 2017

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Mysuru,
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# DECLARATION

This is to certify that this dissertation entitled **"Working memory and low redundancy speech perception in the normal ear of individuals with unilateral hearing loss"** is the result of my own study under the guidance of Dr. Jijo. P M, Lecturer of Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru, **Registration No.: 15AUD008**
May, 2017

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**Abstract**

**Objective:** The study aimed to investigate the effect of working memory on speech perception abilities in the normal ear of individuals with unilateral hearing loss. The objectives of the study were to compare performance of normal ear of individulas with unilatearl hearing loss and any one ear of individuals with normal hearing on speech perception in noise (SNR-50), low pass filtered speech and time compressed speech. Additionally, to investigate the effect of working memory on the speech perception abilities in these two groups. **Methods:** There were two groups of participants in the age range of 15-20 years and each group consisted of 23 participants. Group I consisted of individuals with unilateral hearing loss and group II consisted of individuals with normmal hearing sensitivity. Speech perception abilities were measured using low pass filtered speech test, time compressed speech test and SNR-50. Working memory was assessed using forward digit span test, backward digit span test, ascending span test and descending span test. **Results:** It was found that there was significant difference between the normal hearing group and unilateral hearing loss group for low pass filter speech test, time compressed speech test and ascending span test. However, there was no significant difference between normal hearing group and unilateral hearing loss group for SNR-50, forward span test and backward span test. Further, there was no correlation between speech perception abilities and working memory tests in both normal hearing group and unilateral hearing loss group. No correlation was found between duration of deafness and low redundancy speech tests as well as working memory tests in unilateral hearing loss group. **Conclusion:** Normal ear of individuals with unilateral hearing loss showed some deficits in low redundancy speech perception. However, working memory abilities are relatively spared in them.

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# Chapter 1

## Introduction

Sensorineural hearing loss (SNHL) is reported to be 90% of the hearing impairments and the main pathology lies in cochlea and/or the vestibulo-cochlear nerve (Agrawal, Platz, & Niparko, 2008). Of all the SNHL, bilateral impairment is of majority as compared to unilateral hearing loss. At least 60,000 new cases of unilateral SNHL occur annually in United States alone. In India, at the department of Audiology, AIISH, there were 1687 clients having unilateral hearing loss among the 13808 clients evaluated (Annual report 2015-16).

Studies have demonstrated that individuals with unilateral deafness may experience significant disability which may lead to communication difficulties and speech perception, particularly in noisy and in acoustically poor environments (Andersson, Ekvall, Kinnefors, Nyberg, & Rask-Andersen, 1997; Hansson., 1993; Ruscetta, Arjmand, & Pratt, 2005). Hansson (1993) found that audiological and psychosocial consequences of unilateral deafness lead to increased stress levels and feeling of exclusion in social settings. In a study by Giolas and Wark (1967) and Sargent, Herrmann, Hollenbeak, and Bankaitis (2001) reported that individuals with unilateral hearing loss may experience verbal communication difficulties even though they have normal hearing in one ear and this difficulty is aggravated in the presence of background noise.

Wie, Hugo Pripp, and Tvete (2010) investigated self reported consequences of unilateral profound hearing loss in adults regarding communication, social interaction in everyday situations. They found that unilateral hearing loss affects the auditory functions such as speech, communication, and social interaction. Communication in background noise, poor acoustic surroundings, and limited access to speech-reading or direct listening cues were the most difficult areas. They also found that the communication handicap experienced by subjects was not correlated with the results of a test for speech perception in noise. They reported that psychosocial consequences of hearing loss cannot be predicted from audiological data alone. Finally, they observed that participants having long-standing unilateral hearing loss had no benefit over the unilateral hearing loss that caused recently, since the former had poor speech perception in noisy situation as compared to the latter who experienced temporary unilateral hearing loss.

One of the major challenges for any listener is the capacity to understand speech in the presence of background noise. Speech understanding in the presence of noise is a major complaint, whether or not some hearing impairment exists (Sbompato, Corteletti, Moret, & de Souza Jacob, 2015). The amount of effort put in listening is related to the demand for cognitive processing resources. Many studies have considered the effects of noise on cognitive skills (Banbury & Berry, 1998; Boman, Enmarker & Hygge, 2005; Ellermeier & Zimmer, 1997). One cognitive function of high importance for speech perception is working memory. Researchers have indicated the association among speech perception in noise and working memory (Green, 2007) .

Ead, Hale, DeAlwis, and Lieu (2013) reported their initial data on cognitive functioning of children with unilateral hearing loss. The study was carried out to identify, quantify, and interpret differences in cognitive and language functions between children with unilateral hearing loss and those having normal hearing. They found that children with normal hearing performed better than the unilateral hearing loss group on the complex letter span task. This implies that deficits in working memory that may adversely affect their speech understanding in noise.

In a recent study, Calderón-Leyva, Díaz-Leines, Arch-Tirado, and Lino-González (2016) investigated perception of filtered, time compressed and word in noise task. Additionally, the role of duration of hearing loss on cognitive abilities was studied. They found that auditory performance of unilateral hearing loss in filtered word and time compressed disyllabic test was poor compared with normal hearing, whereas there was no statistically significant difference was found in speech in noise test. Further, cognitive abilities showed variable results. Those having hearing loss greater than 10 years had better performance in calculation and memory for sentences. Others, with less than 10 years duration were better in spatial relation, auditory visual learning.

Welsh, Rosen, Welsh, and Dragonette (2004) explored the interaction between unilateral hearing loss and central auditory functions like speech perception in noise and 30% compressed speech. They found that unilateral hearing loss individual's performance score was not affected for compressed sentences but their performance in a noisy situation for speech discrimination was affected. They concluded that profound unilateral sensorineural hearing loss resulted in impairment in communication in presence of noise. In contrast, UHL is not as affected by accelerated speech.

Thus, it can be summarized that that individuals with unilateral hearing loss showed decreased cognitive abilities. However, variable results have been found regarding their speech perception in noise.

**Need for the study**

Majority of studies in unilateral hearing loss carried out in children, that studied cognitive abilities, speech recognition in noise, speech, language and education consequences (Culbertson & Gilbert, 1986; Jensen, Børre, & Johansen, 1989; Lieu, 2004; Ruscetta et al., 2005). Their results indicates that the unilateral hearing loss can cause poor academic performance, extracurricular failure and need assistance in school. Their IQ has been found to have normal scores but lower than their normal listening peers, highlighting deficiencies and phonological working memory, attention and processing speed, behavioral, emotional, social and language problems are also reported (Fischer & Lieu, 2014). They exhibit severe deficits in speech understanding in noise (Agrawal et al., 2008; Tibbetts et al., 2011; Welsh et al., 2004). Hence, it is possible that adults having late onset unilateral hearing loss also exhibit cognitive decline and difficulty in speech perception in adverse listening conditions. Their cognitive decline might also vary with duration of deafness. Further, a few studies that are conducted on speech perception in noise in individuals with unilateral hearing loss showed variable results (Calderón-Leyva et al., 2016; Welsh et al., 2004). Additionally, the impact of duration of hearing loss on speech perception abilities not determined. Hence, the present study assess the role of working memory in speech understanding under challenging listening conditions in individuals with unilateral hearing loss and also to investigate the impact of duration of hearing loss.

**Aim**

To study the effect of working memory on low redundancy speech perception tasks in the normal ear of individuals with unilateral hearing loss.

**Objectives**

To compare performance of normal ear of individuals with unilateral hearing loss and any one ear of individuals with bilateral normal hearing sensitivity on their speech perception in noise (SNR-50), low pass filtered speech and time compressed speech.

To investigate the effect of working memory on these low redundancy speech tasks (Speech perception in noise, low pass filtered speech and time compressed speech) in the normal ear of individuals with unilateral hearing loss and any one ear of individuals with bilateral normal hearing sensitivity.

## Chapter 2

## Review of Literature

Person with unilateral hearing loss exhibit normal hearing sensitivity in one ear and hearing loss in the other ear. It can be acquired or congenital. It can be sudden or gradual in onset. It can range from mild to profound degree in the ear having hearing loss. Individuals with unilateral hearing loss exhibit various problems in listening. Lack of binaural summation, head shadow effect and the inability to use intensity, time and/or phase differences which are important for binaural hearing are the reason for hearing problems for individuals with unilateral hearing loss (Markides, 1977; Valente, Valente, Enrietto, & Layton, 2002).

As the number of speech understanding cues is reduced in a noisy environment the speech understanding is difficult for individuals with unilateral hearing loss. This makes the subjects understand speech with the minimal information available to them (Mondelli, Santos, & José, 2016).

Welsh et al. (2004) investigated the effect of unilateral hearing loss on two tests of central auditory functions those are speech discrimination in a noisy environment and ability to perceive 30% compressed speech. They found that individual with unilateral hearing loss showed deficits in speech discrimination in noisy situation. However, their score was not affected for compressed sentences. They concluded that profound unilateral sensorineural hearing loss resulted in impairment in communication in presence of noise.

Wie et al. (2010) determined the self assessed consequences of profound unilateral hearing loss which is related to communication and social interaction. They also compared speech perception scores of subjects with normal hearing and those who had temporary unilateral hearing loss. The study was conducted on 30 participants with unilateral hearing loss and 30 normal hearing individuals between the age range of 14 to 75 years. Subjects were tested for three conditions like audio and visual, auditory-only and visual-only speech perception. The outcome was such that the communication was affected in 93% of the individuals with permanent unilateral hearing loss. In 87% percent of the individuals with unilateral hearing loss poor speech understanding in the acoustically poor environments was reported. They reported that the other consequences of unilateral hearing loss were the feelings of exclusion, reduced well-being, and extensive use of speech perception strategies to understand speech. Similar findings were found in individuals with induced temporary unilateral hearing loss on speech perception. They concluded that a notable amount of disability of auditory function was experienced in individuals with unilateral hearing loss which affected the verbal communication and social interaction. These individuals faced challenges when communicating in noisy background, poor acoustic surroundings, and where there is poor access to speech-reading and/or direct listening. In many listening conditions, there was no advantage of the long-standing unilateral hearing loss over the temporary unilateral hearing loss of short duration.

Mondelli et al. (2016) evaluated the speech perception with and without competitive noise in participants with unilateral hearing loss, where testing was done before and after the hearing aid fitting . 30 adults who were diagnosed as having moderate or severe sensorineural unilateral hearing loss were included in the study. Speech perception abilities were assessed using the Hearing in Noise Test -Brazil, in the 3 conditions: silence, frontal noise, noise to the right, and noise to the left, before and after the hearing aid fitting process. They found that individuals with unilateral hearing loss had greater difficulties than normal-hearing group to understand when the speech was presented together with a competing noise, even though the ear with normal hearing was faced towards the speech.

Ruscetta et al. (2005) compared the signal-to-noise ratio for children with normal hearing and children with severe to profound unilateral hearing loss. Participants aged between 6-14 years, who had communication limitations, particularly when the information is presented to the ear with hearing loss. These subjects were presented with Hearing in Noise Test-Children (HINT-C) and Nonsense Syllable Test in the free field condition at various azimuths with constant noise presented from all quadrants. The test included the repeating of 20 items, from each sub test under each listening condition. The authors observed that on both the speech tests, greater signal to noise ratios were required in majority of the listening conditions for the individuals with unilateral hearing impairment than those with normal hearing. Under all listening conditions, both the groups demanded greater SNR to perform better on the Nonsense Syllable Test as on the HINT-C. Normal hearing children required significantly greater signal to noise ratios when receiving the signal than the normally hearing ear (monaural direct condition) is receiving the signal in the Hearing-In-Noise Test-Children. Significantly greater SNRs were required for children with unilateral hearing loss more in the monaural direct condition in both the tests. The study concludes that more advantageous listening condition was required to children with unilateral hearing loss to match the performances with the age matched children with normal hearing. The participants benefitted when the signal presented in a monaural direct condition. The performances of children with unilateral hearing impairment was best in the monaural direct condition or when facing the signal at zero degrees or directly from the front.

Both the groups demanded significantly greater SNRs when contextual cues were restricted than when sentential cues were available.

Working memory ability is important for individuals with hearing loss to perceive speech in noisy environment (Rudner, Rönnberg, & Lunner, 2011). Cognitive capacity refers to the storage and processing of information of individual's mental resources. Whereas long-term storage capacity is for semantic memory and episodic memory is virtually limitless (Tulving, 2002) . Short-term storage and processing capacity, or working Memory, is highly confined and it differs between individuals (Baddeley, 2000). Working memory is generally deployed in communicative situations, in particular under challenging conditions, and measures of working memory capacity are good predictors of communicative success in different settings (Daneman & Merikle, 1996).

Jensen et al. (1989) assessed cognitive abilities in children with unilateral hearing loss respect to right/left ear difference. The study included 30 children in the age range of 10-16 years with age matched control group. Cognitive ability was assessed using battery of psychological tests (verbal and non verbal subtests). The results showed that children with right ear impaired showed significantly poorer performance on verbal tests compared to left ear impaired children. Hence, they concluded that individuals with right ear impaired are at risk in education.

Ead et al. (2013) obtained initial data on the cognitive function of children with unilateral hearing loss intended to identify, quantify, and interpret differences in cognitive functions between children with unilateral hearing loss and with normal hearing. The study included 14 children between the age 9-14 years, where 7 were with unilateral severe to profound SNHL and 7 were normal children. These children were assessed with simple verbal working memory tests using letter span and complex verbal working memory tests using counting span test. The results revealed that the two groups performed similarly on the simple letter span task, whereas normal hearing group performed better than unilateral hearing loss group the on the complex letter span task, and they said that for simple verbal memory tasks working memory executive functions is not required.

Speech perception in noise requires memory (Zacks, Hasher, & Li, 2000) because it demands the ability to filter out irrelevant competing noise (Tun, O'kane, & Wingfield, 2002; Tun & Wingfield, 1999)

Ronnberg (2003) and Rönnberg, Rudner, Foo, and Lunner (2008) developed a model called the Ease of Language Understanding (ELU) model for addressing speech understanding in noise related issues which suggests the way of accounting for the role of cognition in language understanding particularly in persons with hearing impairment. The model is viewed as multisensory or multi-modal linguistic information, which is presumed to be rapid, automatic, and multi-modal. These characteristics combine to form phonological streams of information at a cognitive level. The Rapid, Automatic Multimodal Binding of Phonology (RAMBPHO) function mediates rapid and implicit unlocking of the lexicon by means of matching input with stored phonological representations in long-term memory as long as optimum condition prevails. In noisy situations, mismatch may be observed where the RAMBPHO information might have failed to activate stored representations. The compensation for mismatch may be caused the levels of language, like semantic information which is caused by the slow lexical access and less precise phonological representations in long-term memory. The authors believe that the ELU is, in general, correlated negatively with the degree of explicit involvement. This is dependent on the storage and processing capacity with which explicit functions can be carried out.

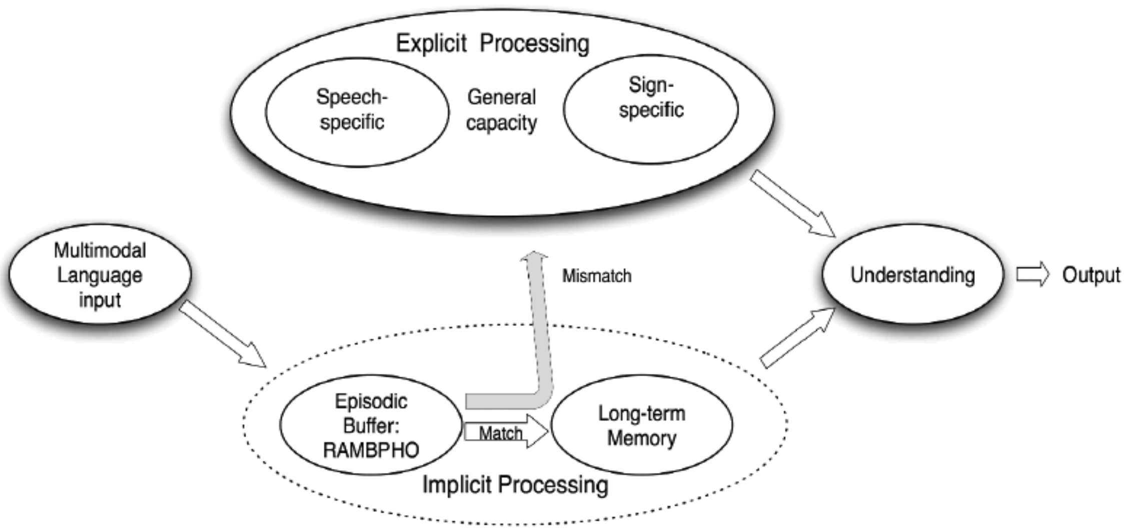


*Figure 1:* The working memory model for Ease of Language Understanding (ELU, adapted from Rönnberg et al., 2008)

Rudner et al. (2011) investigated the association between the speech perception and working memory ability for individuals with hearing impairment in unaided and aided conditions. Testing was carried out in two conditions: modulated and steady state noise with fast and slow compression release in the aided condition. 30 experienced hearing aid users with moderate hearing loss with mean age of 70 years were included in the study. The results showed under conditions of both high degradation i.e., fast acting compression, modulated noise, low signal to noise ratio that there was a significant impact of working memory during speech recognition and low degradation i.e., slow acting compression, steady state noise and high SNR. They reported that fast acting compression was best suitable for individuals with high working memory and slow acting compression was best suitable for individuals with low working memory. Hence, they concluded that the working memory is an important factor for individuals with hearing loss to perceive speech in noisy environment, irrespective of whether hearing is in aided or unaided condition.

Gordon-Salant and Cole (2016) determined speech recognition performance in noise by younger and older listeners who were further divided into two groups of high and low working memory. Twenty-eight older individuals between the age of 61 to 75 years and twenty five younger individuals between the age of 18 to 25 years with normal-hearing sensitivity participated in the study. Single-word stimuli were from the North western University Auditory Test No. 6 (NU6) (Tillman & Carhart, 1966) and the sentence stimuli were the Institute of Electrical and Electronics Engineers (IEEE) sentences were used to asses speech recognition in noise. Two tests of working memory including the listening span test and reading span tests and two tests of processing speed including Paced Auditory Serial Addition test and The Letter Digit Substitution test were used to assess the cognitive abilities. The results revealed that there was significant influence of age on the working memory capacity which was observed in the speech recognition measures in noise, which are attributed to the type of signal used. Only the sentences had main interaction between the age and working memory. Effect of age was observed for listeners in the low working memory groups only. They concluded that the disadvantage of speech recognition in noise exists in the younger and older adults with low working memory capacity and normal hearing individuals.

Calderón-Leyva et al. (2016) analyzed the association of cognitive skills in subjects with severe unilateral hearing loss versus subjects with normal hearing. The study involved 20 adults with severe unilateral sensory hearing loss and 20 adults with age matched normal hearing sensitivity individuals. Cognitive abilities were assessed with the battery Woodcock-Muñoz revised and central auditory processing was assessed with monaural psychoacoustic tests (filtered word, disyllabic word tablets and noise word) in a noise situation. The results showed that when comparing performance on tests filtered and disyllabic word tablets, statistically significant difference was found, with greater variability of response in hearing loss subjects, which also had better cognitive performance in the subtests investment of numbers, visual auditory learning, analysis and synthesis, incomplete formation of concepts and words. The hearing impaired individuals performed poorly on filtered and compressed disyllabic word, and greater ability to memory, reasoning and auditory processing. So, it is important to perform complementary tests such as auditory and cognitive skills core processes that establish strategies habilitation, rehabilitation and therapy in order to optimize and stimulate the skills of subjects with unilateral hearing loss.

From the above review, it is clear that speech perception abilities are impaired in unilateral hearing loss individuals. Also for speech recognition in noise is affected when the signal and noise are presented from the same side compared to normal hearing individuals. It also shows that accelerated speech is not being affected in unilateral hearing loss individuals. Studies have shown that in children with unilateral hearing loss working memory is affected for complex verbal tasks but not affected for simple verbal tasks compared to normal hearing group. Working memory is more affected in right ear impaired children compared to left ear impaired children. It is shown that when relationship between working memory and speech perception skills are assessed individual with low working memory has poor speech perception skills and individuals with high working memory has better speech perception skills.

## Chapter 3

## Methods

The present study aimed to compare performance of normal ear of individulas with unilateral hearing loss and any one ear of individuals with normal hearing sensitivity on a few low redundancy speech tasks. The study also investigated the effect of working memory on the low redundancy speech tasks (Speech perception in noise, low pass filtered speech and time compressed speech).

### Participants

There were 23 participants with unilateral hearing loss (Group I) and 23 participants with bilateral normal hearing sensitivity (Group II) participated in the study. The participants were in the age range of 15 to 40 years (Mean age: 26.17 years±8.33 SD). This age range was chosen as it has been reported that psycho-acoustic (Werner & Gray, 1998) and cognitive abilities (Hale, 1990) in normal listeners reach a plateau by the age of 15 years. Further, deterioration in temporal processing abilities has been reported after 40 years (Kumar & Sangamanatha, 2011). All the participants were native speakers of Kannada- a south Indian langauge. Entire study was carried out according to the ethical guidlines of the institute (Basavaraj & Venkatesan, 2009) and an informed consent was taken from each participant. A standard group comparison design was used to carry out the study. The demographic and audiological details of the participants can be seen in Table 1 and Table 2.

**Procedure for the selection of participants.** Participants in Group-I had unilateral severe to profound sensorineural hearing loss and those in Group-II had bilateral normal hearing sensitivity. A structured interview was carried out to choose the participants who met the following criteria:

- No history of external or middle ear infection evidenced by the immittance evaluation.
- No history of head trauma
- No gross neurological or cognitive dysfunction (Evaluated using Standardised Mini Mental Status Examination)

Table 1: *Demographic and audiological details of the participants having unilateral hearing loss*

| Sl.No | Age/ Gender | Duration of Hearing Loss | PTA (dBHL) | | SIS (%) | | Tympanogram (bilateral) | Acoustic Reflex (bilateral) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Right | Left | Right | Left | | Right | Left |
| 1 | 28/M | 2 months | >90 | 10 | 40 | 100 | A | Absent | Present |
| 2 | 25/M | 20 years | >90 | 15 | CNT | 100 | A | Absent | Present |
| 3 | 34/M | 7 years | >90 | 3.75 | CNT | 100 | A | Absent | Present |
| 4 | 18/F | 7 years | >90 | 5 | CNT | 100 | A | Absent | Present |
| 5 | 40/M | 25 years | >90 | 12.5 | CNT | 100 | A | Absent | Present |
| 6 | 30/M | 13 years | >90 | 15 | CNT | 100 | A | Absent | Present |
| 7 | 25/M | 10 yrs | >90 | 7.5 | CNT | 100 | A | Absent | Present |
| 8 | 40/M | 1yrs | >90 | 10 | CNT | 100 | A | Absent | Present |
| 9 | 15/F | 10 yrs | >90 | 10 | CNT | 100 | A | Absent | Present |
| 10 | 16/M | 10 yrs | >90 | 10 | CNT | 100 | A | Absent | Present |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 11 | 20/F | 20 yrs | >90 | 5 | 24 | 100 | A | Absent | Present |
| 12 | 21/M | 7 yrs | >90 | 12 | CNT | 100 | A | Absent | Present |
| 13 | 30/M | 3 yrs | >90 | 15 | CNT | 100 | A | Absent | Present |
| 14 | 15/M | 10 yrs | >90 | 12 | CNT | 100 | A | Absent | Present |
| 15 | 17/M | 10 yrs | >90 | 15 | CNT | 100 | A | Absent | Present |
| 16 | 18/M | 12 yrs | 7.5 | >90 | 100 | CNT | A | Present | Absent |
| 17 | 26/M | 3 yrs | 2.8 | >90 | 100 | CNT | A | Present | Absent |
| 18 | 40/M | 35 yrs | 10 | >90 | 100 | CNT | A | Present | Absent |
| 19 | 18/F | 18 yrs | 15 | >90 | 100 | 40 | A | Present | Absent |
| 20 | 34/M | 34 yrs | 10 | >90 | 100 | CNT | A | Present | Absent |
| 21 | 33/M | 3 yrs | 10 | >90 | 100 | CNT | A | Present | Absent |
| 22 | 33/M | 3 months | 11.5 | >90 | 100 | CNT | A | Present | Absent |
| 23 | 26/M | 2 months | 7.5 | >90 | 100 | CNT | A | Present | Absent |

Note: M = Males; F =Females; PTA=Pure-tone average, SIS=Speech identification score; CNT= could not be tested

Table 2: *Demographic and audiological details of the Normal hearing participants*

| Sl.No | Age/ Gender | PTA (dB HL) | | SIS(%) (bilateral) | Tympanogram (bilateral) | Acoustic Reflex (bilateral) |
|---|---|---|---|---|---|---|
| | | Right | Left | | | |
| 1 | 28/M | 10 | 11.25 | 100 | A | Present |
| 2 | 25/M | 7.5 | 10.5 | 100 | A | Present |
| 3 | 34/M | 10 | 12.3 | 100 | A | Present |
| 4 | 18/F | 7.5 | 13.6 | 100 | A | Present |
| 5 | 40/M | 5.5 | 8.5 | 100 | A | Present |
| 6 | 30/M | 10 | 12.6 | 100 | A | Present |
| 7 | 25/M | 5.5 | 8.5 | 100 | A | Present |
| 8 | 40 /M | 10 | 13.5 | 100 | A | Present |
| 9 | 15/F | 5.5 | 9.3 | 100 | A | Present |
| 10 | 16/M | 10 | 14.2 | 100 | A | Present |
| 11 | 20/F | 7.5 | 9.5 | 100 | A | Present |
| 12 | 21/M | 5.5 | 7.5 | 100 | A | Present |
| 13 | 30/M | 5 | 6.5 | 100 | A | Present |
| 14 | 15/M | 5.5 | 8.5 | 100 | A | Present |
| 15 | 17/M | 7.5 | 13.5 | 100 | A | Present |
| 16 | 18/M | 8.5 | 7.5 | 100 | A | Present |
| 17 | 26/M | 8.5 | 5.5 | 100 | A | Present |
| 18 | 40/M | 9.5 | 5.5 | 100 | A | Present |
| 19 | 18/F | 13.5 | 7.5 | 100 | A | Present |
| 20 | 34/M | 9.5 | 5.5 | 100 | A | Present |

| | | | | | | |
|---|---|---|---|---|---|---|
| 21 | 33/M | 12.5 | 10 | 100 | A | Present |
| 22 | 33/M | 10.5 | 7.5 | 100 | A | Present |
| 23 | 26/M | 14.5 | 10 | 100 | A | Present |

Note: Males; F =Females; PTA=Pure-tone average, SIS=Speech identification score

Prior to collection of data, detailed audiological evaluation was carried out for all the participants. Pure-tone thresholds were obtained via the modified Hughson and Westlake procedure (Carhart & Jerger, 1959), using a calibrated diagnostic audiometer for estimation of air/bone conduction pure tone thresholds. Calibrated immittance instrument was used to obtain tympanograms and acoustic reflex thresholds. Speech identification scores were obtained using a phonemically balanced word test in Kannada, developed by Yathiraj and Vijayalakshmi (2005). Bio-Logic Navigator Pro System was used to record Auditory Brainstem Response (ABR) to rule out the presence of any retrocochlear dysfunction.

**Test Environment**

The study was carried out in an acoustically treated air-conditioned room with permissible noise level as per ANSI S3.1, (1999).

**Test Procedure**

In order to obtain low redundancy speech scores, both Group I and Group II were tested using speech in noise, low pass filtered speech and time compressed speech tests. Recorded speech material was played using Adobe Audition (Version 2.0) software installed in a personal computer. The stimuli were routed through a personal computer connected to headphones where headphones were calibrated using Larson Davis Sound level meter. Speech stimuli were presented at 40 dB SL (ref: SRT). Those with bilateral normal hearing listened to the stimuli in one ear only. In order to eliminate the laterality in processing to certain auditory stimuli, testing was carried out in one particular ear (either right or left) for all the participants.The individuals were instructed to repeat what was heard and the speech identification scores were be determined. The participants were also informed that they could guess the test items in case they were not very clear. Both the participant groups were involved in both low redundancy speech perception task and working memory tasks.

**SNR-50.** In order to determine SNR-50, stimuli were taken from the recorded version of a standardized phrase test in Kannada (Shetty & Mendhakar, 2015). The material consisted of five phrase lists and each list has ten phrases. All the phrases have two words of 3–4 syllables such that entire length of phrases was made nearly equal. Each phrase in a list was mixed with a speech shaped noise at a particular signal to noise ratio (SNR) that ranged from -9 to -1 dB SNR. Speech shaped noise was derived using white noise subjected to the designed Infinite Impulse Response (IIR) filtering. The speech shaped noise and phrases were mixed using AUXVIEWER (v 1.37) software. The two signals were mixed in such a way that the added signal gives the desired SNR. The output stimulus was then RMS normalized to maintain equal loudness. For each phrase, the duration of noise was adjusted in such a way to provide sufficient duration of noise before and after the stimulus. The SNR at which 50% of the sentences were perceived was calculated using the Spearman–Kärber equation (Finney, 1952), which is as follows:

$$\text{50\% point} = I + (0.5 \times d) - d\ (\#\ \text{correct})/w$$

where,’ ‘I’ is initial presentation level (dB SNR), d is the decrement step size (attenuation), and ‘w’ is the number of words per decrement.

**Low pass filtered speech test.** Using the same phrase test (Shetty & Mendhakar, 2015) that was utilized for SNR-50 performance on low pass filtered test was evaluated. Each list was filtered using a low-pass cut-off frequency of 800 Hz at an attenuation rate of 18 dB/octave using adobe audition software. A phrase list that was not utilized to determine SNR-50 was used for this purpose and was presented in a random order. A similar procedure described above was utilized to obtain the speech identification scores. For each participant 10 phrases were presented. The numbers of correct responses were counted. The speech identification scores were calculated using the formula given below:

SIS= Obtained number of correct responsesx100/ Total number of stimuli presented

**Time compressed speech test.** The phrase list in Kannada was subjected to 60% time compression. This compression ratio was chosen based on the reports of (Prabhu, Sujan, & Rakshith, 2015) that showed , minimal effect of compression on SIS with compression less than 50%. Further, compression ratios higher than 80% resulted in severe distortion of the speech material. The phrase list was time-compressed by shortening them digitally using Pitch synchronous overlap and adds method using PRAAT software (Amsterdam, Netherlands). The presentation of phrases was randomized to eliminate any practice effect. For each participant, 10 phrases were presented and the number of correct response was counted. The speech identification scores were calculated using the formula given below:

SIS= Obtained number of correct responsesx100/ Total number of stimuli presented

**Working memory measures.** These tests were administered using "*Auditory cognitive training module*" (Smritishravan) software developed by Kumar and Sandeep (2013). The Stimuli consisted of English digits from one to nine except the digit seven. Using a staircase procedure minimum number of digits that could be recalled was assessed. The following tests were administered:

***Auditory number sequencing.*** Auditory number sequencing includes ascending and descending digit sequencing task. Participants were presented with group of numbers and depending on the task, participants were asked to repeat them in an increasing or decreasing order. For ascending task the participants are asked to rearrange the numbers in an increasing order. For e.g.: if the test stimulus is *'four, nine, six, eight'*, the response expected was 'four, six, eight, and nine'.

The complexity of the test was increased for every correct response by increasing the number of digits in the next presentation and the complexity of the test was reduced for every incorrect response. Minimum number of digits that the person can identify was noted. Similarly, the participant had to arrange the presented numbers in the decreasing order in the descending task. Thus, for the same stimulus the expected response was 'nine, eight, six, and four'. The test item start from a minimum of 2 digits and was increased till the person could repeat.

***Auditory digit span.*** This was tested by measuring forward and backward spans. The procedure was similar to auditory sequencing measures. Group of digits were presented and participants were asked to repeat them in same or reverse order as the case may be. The participants were expected to repeat the digit in the same order in forward span. For e.g.: if the stimuli are 'four, nine, six, eight', the response expected was 'four, nine, six, and eight'. The complexity of the test was increased when the participant correctly repeats the sequence and the complexity were reduced for every repetition of wrong sequence by reducing a digit. Similarly, the participants are expected to repeat the digits in reverse order in the backward digit span. Thus, for the same stimuli the expected response was 'eight, six, nine, and four'.

**Test Retest Reliability**

5% of population was involved for test retest reliability.

**Analysis**

Data obtained from individuals with unilateral hearing loss and those with normal hearing sensitivity were tabulated and analyzed using SPSS (20)

# Chapter 4

# Results

The study compared performance of normal ear of individulas with unilateral hearing loss (Group I) and any one ear of individuals with normal hearing sensitivity (Group II) on speech perception in noise, low pass filtered speech and time compressed speech. Additionally, the effect of working memory on these speech perception tasks was investigated. Descriptive statistics was carried out to obtain the mean and standard deviation of the low redundancy speech tests and working memory tests (Forward span, Backward span, Ascending span and Descending span tests) for both unilateral hearing loss and normal hearing groups. Inferential statistics and correlation analysis were also performed.

## Speech Perception in Group I and Group II

The means scores of the low pass filtered speech test for the subjects with unilateral hearing loss (UHL) was 7.43 with a standard deviation being 1.27, whereas the mean score was 8.65 for the normal hearing (NH) subjects with a standard deviation being 1.37. It is clear from the Table 3 that the normal hearing individuals had better scores compared to the individuals with unilateral hearing loss. Similarly, form the Table 3, it can be found that the scores for time compressed speech test was better in normal hearing individuals compared to those with unilateral hearing loss. Here, the mean score was 9.48 (SD 0.67) and 9.91 (SD 0.29) for those with unilateral hearing loss and normal hearing respectively. Similar findings were observed in SNR-50 where individuals with unilateral hearing loss performed better than those with normal hearing sensitivity. The mean score for the former group was -4.35 (SD 1.15) and for the latter group mean score of -4.13 (SD 1.01) was obtained.

Table 3: *The mean, and standard deviation of low pass filtered speech test, time compressed test and SNR-50 for both Unilateral hearing loss and Normal hearing group.*

| | **Group I** | | **Group II** | |
|---|---|---|---|---|
| | **Mean** | **SD** | **Mean** | **SD** |
| Low pass filtered speech test | 7.43 | 1.273 | 8.65 | 1.37 |
| Time compressed speech test | 9.48 | 0.665 | 9.91 | 0.288 |
| SNR-50 | -4.35 | 1.152 | -4.13 | 1.014 |

Group I= individulas with unilateral hearing loss; Group II= individuals with normal hearing sensitivity; Maximum score for low pass filtered speech test and time compressed speech test =10

**Working Memory in Group I and Group II**

Forward span test (Table 4) showed better performance in the normal listeners with mean score being 7.04 (SD 1.26) compared to those with unilateral hearing loss 6.48 (SD 1.12). Similar observations were found in the backward span test (Table 4) for normal listeners (5.48, SD=1.38) and those with unilateral hearing loss (5.04, SD=0.98).

Table 4: *The mean and standard deviation of Forward span test and Backward span test for both Unilateral hearing loss and Normal hearing group*

| | **Group I** | | **Group II** | |
|---|---|---|---|---|
| | **Mean** | **SD** | **Mean** | **SD** |
| **Forward Span** | 6.48 | 1.123 | 7.04 | 1.26 |
| **Backward Span** | 5.04 | 0.976 | 5.48 | 1.377 |

Group I= individulas with unilateral hearing loss; Group II= individuals with normal hearing sensitivity

Similarly, for ascending span test normal hearing group obtained a mean score of 9.39 (SD 2.25) whereas those with unilateral hearing loss obtained a mean score of 7.39 (SD 1.672). In the descending span test normal hearing group obtained a mean score of 8.13 (SD 2.82) whereas those with unilateral hearing loss mean score of 6.96 (SD 1.692) was found. It can be observed form the table 5 that control group performed better in both the test compared to the experimental group.

Table 5: *The mean and standard deviation of Ascending span test Descending span test for both Unilateral hearing loss and Normal hearing group*

| | Group I | | Group II | |
|---|---|---|---|---|
| | **Mean** | **SD** | **Mean** | **SD** |
| **Ascending Span** | 7.39 | 1.67 | 9.39 | 2.25 |
| **Descending Span** | 6.96 | 1.69 | 8.13 | 2.82 |

Group I= individulas with unilateral hearing loss; Group II= individuals with normal hearing sensitivity

**Comparison of Performance of Group I and Group II**

In order to compare the performance between unilateral hearing loss and normal hearing groups MANOVA was performed.  Scores obtained in different tests (low redundancy speech tests and working memory tests) were the dependent variables and the groups (unilateral hearing loss and normal hearing group) were independent variables. There was a significant differences between the two groups for the LPF (F (1, 17.03 = 9.756, $p<0.05$) time compressed (F (1, 2.74) =8.274, $p<0.05$), and ascending tests (F (1, 46) =11.702, $p<0.05$). In these two tasks individuals with normal hearing sensitivity performed better than those with unilateral hearing loss. This can be observed in Figure 2. However, there were no significant differences between the groups for the SNR-50 (F (1, 0.543) =0.461, $p>0.05$), Forward span (F (1, 3.67) =2.578, $>0.05$), backward span (F (1, 2.174) =1.526, $>0.05$) and descending span (F (1, 15.848) =3.93, $>0.05$). The Wilk's Lamba test showed a significant difference ($p=<0.05$) in performance between the group for LPF (F (1, 17.03 = 9.756, $p<0.05$), time compressed (F (1, 2.74) =8.274, $p<0.05$) and ascending span test (F (1, 46) =11.702, $p<0.05$)

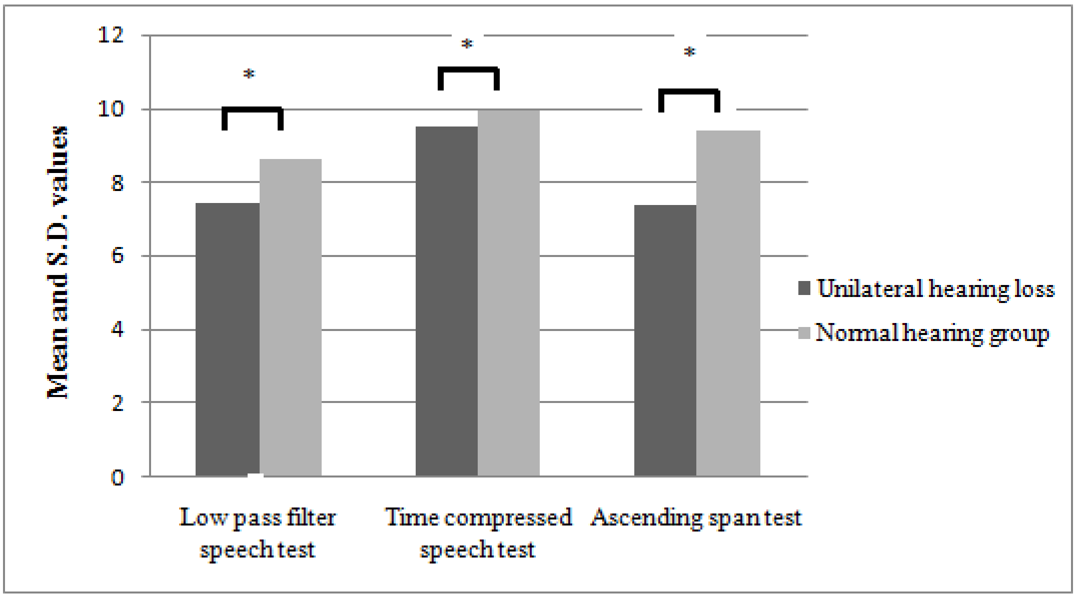


*Figure 2:* The mean scores and significant difference (*p<0.05) between Unilateral hearing loss and Normal hearing group for low pass filtered speech test, time compressed speech test and ascending span test. The error bars indicate 1 SD of error.

**Relation between Working Memory and Speech Perception**

Pearson's product moment correlation was administered to assess the relationship between low redundancy speech tests and working memory in both the groups. It was observed that there were no correlation between low redundancy speech tests and working memory tests in both the groups. These observations can be made in the table 6 and 7.

Table 6: *Results of the Pearson's correlation between subtests of working memory and low redundancy speech tests in the Unilateral Hearing Loss Group.*

| Low redundancy speech tests | Working memory tests | | | |
|---|---|---|---|---|
| | Forward span | Backward span | Ascending span | Descending span |
| | r value (p value) | r value (p value) | r value (p value) | r value (p value) |
| Low pass filter test | -0.57  (0.797) | -1.62 (0.460) | -0.105 (0.634) | 0.178 (0.416) |
| Time compressed speech test | 0.227 (0.297) | 0.177 (0.420) | 0.069 (0.753) | 0.181 (0.409) |
| SNR-50 | -3.92 (0.64) | -0.107 (0.626) | -0.162 (0.460) | -0.31 (0.887) |

*Note:* Correlation at the level of $p<0.05$.

Table 7: *Results of the Pearson's correlation between subtests of working memory and low redundancy speech tests in the Normal Hearing Group.*

| Low redundancy speech tests | Working memory tests | | | |
|---|---|---|---|---|
| | Forward span | Backward span | Ascending span | Descending span |
| | r value (p value) | r value (p value) | r value (p value) | r value (p value) |
| Low pass filter speech test | 0.246 (0.257) | 0.430 (0.41) | 0.341 (0.111) | 0.044 (0.841) |
| Time compressed speech test | 0.261 (0.229) | -0.005 (0.982) | -0.015 (0.945) | -0.120 (0.585) |
| SNR- 50 | -0.442 (0.045) | -0.442 (0.035) | -0.275 (0.203) | -0.208 (0.341) |

*Note:* Correlation at the level of <0.05

**Relation between Duration of Deafness, Speech Perception and Working Memory**

Similarly, Pearson's product moment correlation was done to check the relationship between the duration of deafness and the low redundancy speech tests as well as working memory. There was a negative correlation between duration of deafness and speech perception scores as well as working memory tasks. However, the correlation between them was weak and insignificant (Table 8).

Table 8: *Correlation between duration of deafness and low redundancy speech tests as well as working memory tests*

| **Tests** | r value (p value) |
|---|---|
| LPF | -0.325 (0.130) |
| TC | -0.243 (0.264) |
| SNR- 50 | -0.091 (0.680) |
| Forward Span | -0.148 (0.500) |
| Backward Span | -0.190 (0.385) |
| Ascending Span | -0.365 (0.087) |
| Descending Span | -0.306 (0.156) |

**Test Re-tests Reliability**

The test re-test reliability was assessed for the 5% of the participants using the Cronbach's Alpha test. It was observed that the test re-test reliability was >70% ($\alpha$>0.7) with the error value less than 30% for all the sub tests of low redundancy and working memory tests as shown in the table 9.

Table 9: *Test retest reliability of low redundancy speech tests and working memory tests for unilateral hearing loss and normal hearing group*

| | α values | |
|---|---|---|
| | Group I | Group II |
| Low pass filter test | 0.95 | 0.95 |
| Time compressed speech test | 0.91 | 0.99 |
| SNR-50 | 0.91 | 0.97 |
| Forward span test | 0.84 | 0.95 |
| Backward span test | 0.82 | 0.88 |
| Ascending span test | 0.90 | 0.97 |
| Descending span test | 0.91 | 0.94 |

Group I= individulas with unilateral hearing loss; Group II= individuals with normal hearing sensitivity

From the above results it is clear that the mean scores of low redundancy speech tests and working memory tests were greater in normal hearing group compared to unilateral hearing loss group. There was a significant difference between the normal hearing group and unilateral hearing loss group for low pass filtered speech test, time compressed speech test and ascending span test. However, there was no significant difference between normal hearing group and unilateral hearing loss group for SNR-50, forward span test and backward span test. It was found that there was no correlation between low redundancy speech tests and working memory tests in both normal hearing group and unilateral hearing loss group. Further, there was no correlation between duration of deafness and low redundancy speech tests as well as working memory tests in unilateral hearing loss group.

# Chapter 5

# Discussion

The aim of this study was to compare performance of normal ear of individulas with unilatearl hearing loss and any one ear of individuals with bilateral normal hearing sensitivity on low redundancy speech tests and working memory. The study also investigated the relation between working memory and low redundancy speech tests as well as duration of deafness and low redundancy speech tests. The low redundancy speech perception was evaluated using speech in noise (SNR-50), low pass filtered speech and time compressed speech tests. Working memory abilities were evaluated using forward and backward span test as well as ascending and descending span test.

## Low Redundancy Speech Perception in Individuals with Unilateral Hearing Loss

The results of low redundancy speech tests (SNR-50, low pass filtered speech and time compressed speech) revealed that mean scores of normal hearing group were higher than unilateral hearing loss group. However, the difference was found to be significant only for the low pass filtered speech test and time compressed speech test. Poor perception of the low pass filtered and time compressed speech can be attributed to significant deterioration in the speech signal quality that made their perception difficult for both the groups.

Studies that compared low redundancy speech perception between bilateral normal hearing group and unilateral hearing loss group showed various results. In accordance with the current study, Calderón-Leyva et al. (2016) showed poor performance in filtered word and time compressed disyllabic test in unilateral hearing loss group compared to normal hearing group, whereas there was no statistically significant difference found in speech in noise test between the two groups. Poor perception in those with unilateral hearing loss for the filtered word and time compressed syllables were attributed to cortical re-organization and activation that is different from the normal hearing group. This cortical reorganization is proven using functional magnetic resonance imaging studies (Zhang et al., 2015). They attributed the lack of significant difference in speech in noise to the presentation of signals to the normal hearing ear although it demanded more attention in those with hearing impairment.

In contrast, Welsh et al (2004) found there was no significant difference between unilateral hearing loss group and normal hearing group for 30% compressed sentences. However, there was a significant difference for speech in noise test in individuals with unilateral hearing loss compared to normal hearing group. Comparable performance for the time compressed speech between those with normal hearing and unilateral hearing loss could be attributed to a low compression ratio (30%) that did not alter the speech signal significantly. This was substantiated by Prabhu et al, (2015), reported minimal effect of compression on speech perception while using a compression ratio less than 50%.

In the current study there was no significant difference in speech perception in noise between normal hearing individuals and those with unilateral hearing loss. It is well established that understanding speech becomes much easier when both extrinsic and intrinsic redundancies are preserved (Miller, Heise, & Lichten, 1951). Normal listeners can comprehend highly degraded speech signals due to good intrinsic redundancy (Wilson & Strouse, 1999). The redundancy of the signal varies depending on whether one is listening to words in isolation, listening to sentences or participating in a conversation (Festen & Plomp, 1990). Generally, when the speech signal is embedded in noise, longer signals are much easily understood than the shorter ones. But in comparison, sentences are the easiest signal as they deliver the listener with acoustic information, semantic and contextual cues and linguistic content. Hence, these signals provide greater redundancy. In comparison to all, the most difficult signal to comprehend in the presence of background noise is monosyllabic words (Wilson & Strouse, 1999). In the present study phrases having limited extrinsic cues were used as stimuli. Hence, it would have been difficult for both the groups to comprehend phrases in the presence of noise. Additionally, monaural presentation might have reduced the extrinsic redundancy in both the groups.

In contrast to the findings of the current study, Ruscetta et al. (2005) also revealed that children with unilateral hearing loss require more advantageous listening conditions to perform equally as well as their normally hearing group on tests of speech recognition performance in-noise. They used Hearing in Noise Test-Children (HINT-C) and the Nonsense Syllable Test (NST) to study speech perception. Hall III, Grose, Buss, & Dev, 2002; Klatte, Lachmann, & Meis, 2010 studied speech perception in children with normal hearing and reported that children might require relatively more favorable signal to noise ratio compared to adults. In the current study, the participants involved were adults between the age ranges of 15-20 years and might have required lesser signal to noise ratio to perceive speech in noise.

**Working Memory in Individuals with Unilateral Hearing Loss**

The results of working memory tests showed that mean score of forward span, backward span, ascending span and descending span tests were greater in unilateral hearing loss compared to normal hearing group. However, there was a significant difference between unilateral hearing loss group and normal hearing group only for the ascending span test. The significant difference for ascending span test could be due to complexity of the task that made their perception difficult.

Ead et al. (2013) revealed that unilateral hearing loss group and normal hearing group performed identically on the simple letter span task, whereas performance of unilateral hearing loss group worsened on the complex letter span task. This they have attributed working memory executive functions that are not required for simple version of the task. So in the present study it is assumed that unilateral hearing loss group might have found ascending span test difficult and lead to deteriorated performance.

Recently, Zhang et al. (2015) showed enhanced functional connectivity in several areas in the default network mode of those with left unilateral sensorineural hearing loss. This they have attributed to a compensation for the decline of cognition. They reported that enhanced connectivity will be more in those with left unilateral sensorineural hearing loss compared those with right unilateral sensorineural hearing loss. To avoid the consequences of neurological damage and to help to maintain cognitive abilities Hawellek, Hipp, Lewis, Corbetta, and Engel (2011) reported that a plastic reorganization might have occurred. This can compensate for the impairment of cognition induced by long-term hearing loss. Such functional reorganization is manifested as enhanced functional connectivity in some brain regions in the default network mode. However, Zhang et al, (2015) found that behavioral tests did not show significant differences between the unilateral sensorineural hearing loss and the control. Hence, their results suggest that the Functional Magnetic Resonance Imaging measures might be more sensitive for observing cognitive changes in patients with hearing loss than clinical neuropsychological tests.

**Relation between Working Memory and Speech Perception Abilities**

Correlation analysis showed that there was no correlation between working memory and speech perception abilities in both unilateral hearing loss and normal hearing group.

Till date there are no studies that correlated working memory and speech perception abilities in unilateral hearing loss. However, studies have been carried out in normal hearing individuals that showed poor speech perception abilities in individuals with low working memory and better speech perception abilities in individuals with high working memory(Conway, Cowan, & Bunting, 2001; Desjardins & Doherty, 2013; Gordon-Salant & Cole, 2016; Pichora Fuller, Schneider, & Daneman, 1995).

However, in the present study, participants in both normal hearing  and unilateral hearing loss group had almost similar cognitive abilities and hence, no correlation was observed between working memory and speech perception abilities for  both the groups.

Another possible reason might be the stimuli used for assessing speech perception abilities may not have required more cognition to perceive speech in the present study. Rudner et al. (2011) reported that involvement of working memory in speech perception varies depending on the difficulty of the listening conditions. The situation becomes more cognitively demanding if the incoming signal is distorted or has limited information. In that case, the rapid access to the phonological loop, working memory capacity, selective attention, and high speed of information processing becomes more critical to understand the spoken language.

Millman and Mattys (2016) reported that speech perception in modulated maskers was related to working memory only in the least favourable SNR. They observed that the executive component of working memory was not predictive of speech perception in any conditions. Hence, in the current study administration of a simple working memory task could not establish a correlation between working memory and speech perception abilities for both the groups.

**Relation between Duration of Deafness, Speech Perception and Working Memory**

Correlation analysis revealed that there was a negative correlation between duration of deafness, speech perception abilities and working memory. However, it was weak and insignificant. This could probably due to some compensatory mechanism that helped to overcome the effect of hearing loss. Zhang et al, 2015 reported that individual with long-term hearing loss, a plastic reorganization occurs to compensate for the impairment of cognition and hence cognitive abilities won't be impaired. Since cognitive ability is not impaired in unilateral hearing loss group there was no correlation observed between duration of deafness, speech perception and working memory. Calderon-Leyva et al, (2016) assessed cognitive performance and time evolution of hearing loss in unilateral hearing loss patients. Their results showed that there was a greater variability observed in the results for unilateral hearing impaired group for cognitive tasks.

## Chapter 6

## Summary and conclusion

The present study was taken up to compare speech perception abilities as well as working memory between individuals with unilateral hearing loss and normal hearing individuals. There were two groups of participants involved in the study. Group I consisted of 23 individuals with unilateral hearing loss and Group II consisted of 23 normal hearing. The participants were in the age range of 15 to 40 years. Speech perception ability was assessed using low pass filtered speech test, time compressed speech test and SNR-50. Working memory was assessed using forward span test, backward span test, ascending span test and descending span test.

It was found that mean scores of low redundancy speech perception tests and working memory tests were greater in normal hearing group compared to unilateral hearing loss group. There was a significant difference between the normal hearing group and unilateral hearing loss group for low pass filtered speech test, time compressed speech test and ascending span test. However, there was no significant difference between normal hearing group and unilateral hearing loss group for SNR-50, forward span test and backward span test. Correlation analysis showed no correlation between low redundancy speech tests and working memory tests in both normal hearing group and unilateral hearing loss group. Further, there was no correlation between duration of deafness and low redundancy speech tests as well as working memory tests in the unilateral hearing loss group.

The difference in perception between individuals with normal hearing and unilateral hearing loss for the low pass filtered test and time compressed speech test could be due to cortical re-organization and activation in the latter group that is different from the normal hearing group. However, there was no significant difference in SNR- 50 between the two groups. This could be because of equal difficulty in the task for both the groups. The significant difference for ascending span test could be due to complexity of the task that made their perception difficult. In the present study, participants in both normal hearing and unilateral hearing loss group had almost similar cognitive abilities and hence, no correlation was observed between working memory and speech perception abilities for both the groups. No correlation between duration of deafness and low redundancy speech tests as well as working memory tests in the unilateral hearing loss group. This could probably due to some compensatory mechanism that helped to overcome the effect of hearing loss.

**Implications**

Present study will help in better understanding of cognitive abilities in individuals with unilateral hearing loss. It also helps to know the role of cognitive abilities on speech perception in adverse listening condition. Further, to counsel those with unilateral hearing loss regarding the impact of cognitive abilities on speech perception.

**Future Directions**

In the present study it was observed that there was no significant difference in working memory between unilateral hearing loss and normal hearing group except for ascending span test. Since, simple working memory tests were taken to assess the cognitive abilities these results might have been obtained. So there is a need to take up complex memory tasks to assess cognitive abilities of unilateral hearing group. There is a need to assess right ear impaired and left ear impaired individual separately for cognitive abilities to investigate the role of cerebral dominance.

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