RELATIONSHIP BETWEEN SPEECH PERCEPTION IN NOISE AND WORKING MEMORY IN INDIVIDUALS WITH NORMAL HEARING

Lavanya, S.
Register No.: 15AUD011

This Dissertation Submitted as a Part Fulfillment for the

Degree of Masters of Science

(Audiology)

University of Mysore, Mysore

ALL INDIA INSTITUTE OF SPEECH AND HEARING

Manasagangothri, Mysore – 570006

May, 2017

CERTIFICATE

This is to certify that this dissertation entitled **"Relationship between speech perception in noise and working memory in individuals with normal hearing"** is a bonafide work submitted in part fulfillment for degree of Master of Science (Audiology) of the student Registration Number: 15AUD011 This has been carried out under the guidance of faculty of the institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore
May, 2017

Prof. S. R. Savithri
Director
All India Institute of Speech and Hearing
Manasagangothri, Mysore-570006

CERTIFICATE

This is to certify that this dissertation entitled **“Relationship between speech perception in noise and working memory in individuals with normal hearing”** has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore
May, 2017

Dr. Ajith Kumar U
Guide
Reader in Audiology
Department of Audiology
All India Institute of Speech and Hearing
Manasagangothri, Mysore-570006

DECLARATION

This is to certify that this dissertation entitled **“Relationship between speech perception in noise and working memory in individuals with normal hearing”** is the result of my own study under the guidance of Dr. Ajith Kumar U, Reader in 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.

Mysore **Registration No: 15AUD011**

May, 2017

ACKNOWLEDGEMENT

"No duty is more urgent than that of returning thanks"- James Allen.

Foremost I extend my gratitude to my parents and family who gave me the freedom to pursue my interests and always supported me in all my endeavours. You have inspired me in various ways over times. Vasu, my partner in crime, thanks for being with me.

***Dr. Ajith sir**, you are the amazing teacher and an awesome guide! Thank you for all the encouragement, support and guidance you have provided.*

*I express my gratitude to **Mr. Prashanth** sir for being so approachable in clearing all my doubts regarding the software. Thank you sir!*

*I extend my gratitude to our director, **Prof S R Savithri** and HOD- Audiology **Dr. Sandeep** sir for giving me the opportunity to carry out this research.*

*Special thanks to all my lecturers for being the awesome people they are and strengthening my interest in the field. I extended my thankfulness to **Nisha** akka, **Apeksha** mam for their valuable inputs.*

*Journey of 6 years would not have been this awesome if you guys weren't there. **Shama , Meghana, Nayana, Kri, Kulli, Manisha** and **Priya** thanks for everything. **Usha** thanks for helping me out in data collection. **Jeena** cheers for all the fun. **Pavana** thanks for being so supportive.*

My most sincere gratitude to all the participants of this study. Thank you for your cooperation.

*And finally thanks to **'Gutsies'** and '**Mighty masters'** for adding the much needed zest and entertainment in the academic life. Thanks to my whole batch for being such wonderful classmates.*

Table of Contents

List of Tables

List of Figures

ABSTRACT

The present study aimed to investigate the relationship between working memory and speech perception in noise. The ability to understand speech in the presence of background noise is a major challenge for any listener, whether or not some hearing impairment exists. It is assumed that working memory plays a role when individuals with normal hearing have to process spoken language in acoustically adverse conditions. Thus, this study intended to determine the effect of working memory in perceiving nonsense words and sentences in presence of noise. For this purpose, working memory and SNR-50 tests were carried out through Smriti-Sharvan V1.0 software on hundred and thirteen normal hearing adults in the age range of 18-40 years. Working memory assessment included operation span task and reading span task. The scores of both tasks were obtained across three blocks. SNR-50 scores were obtained binaurally for bisyllabic nonsense words and for sentences at 70 dB SPL. To check the test re-test reliability all the tests were repeated on 20 participants after a gap of 30 days. Results showed that both the working memory tasks had very high reliability. SNR-50 obtained for sentences had high reliability. Working memory scores obtained across three blocks did not differ. Also working memory scores had significant correlation with SNR-50 scores of bisyllabic nonsense words. However, the correlation was not seen with SNR-50 scores of sentences. These results indicate that higher working memory capacity is required for recognizing lower redundant speech signal in presence of noise.

CHAPTER 1

INTRODUCTION

Speech is an acoustic signal in which information is transmitted by means of changes of frequency, intensity over time. The normal auditory system has the inherent ability to identify, process, and encode this information. This processing and storage of spoken information can be complicated in bad acoustic conditions such as noise, thus affecting the understanding of speech (Kjellberg, Lung & Hallman, 2008).

The ability to understand speech in the presence of background noise is a major challenge for any listener, whether or not some hearing impairment exists (Sbompato, Corteletti, Moret & Jacob, 2015). It is a complex phenomenon and is inevitable as one is faced with numerous instances of listening in the presence of noise in daily listening situations. The noise impedes normal speech perception and is likely to result in a communication breakdown. Studies have shown that noise affects auditory-perception skills, such as discrimination and recognition (Elliott, 1979; Hieber & Tillman, 1978; Gustafson & Pittman, 2011). Emerging evidence suggests that, unfavourable listening conditions have a negative effect on higher auditory perception and cognitive processes (Osman & Sullivan, 2014; Stiles, McGregor & Bentler, 2012; Valente, Plevinsky, Franco, Graham, & Lewis, 2012).

Cognition and language are highly interdependent. Cognition has been defined as the process of understanding which includes factors such as awareness, perception, conceptualization and judgement. The term cognition can be referred as higher domain which facilities information processing, understanding and communication. Cognition includes a wide range of mental structures and processes (Craik, 1991). One of the key components of cognition is working memory. Working memory is a memory system that allows on-line storage, selective attention and rehearsal of information. It is crucial for listening, speaking and for communication in general (Baddeley, 2012). The active maintenance of information and the ability to block distractors is highly interdependent features of executive attention that form the basis of working memory capacity (Coolidge & Wynn, 2005). Working memory consists of a central executive control system which monitors several components including phonological loop, visuospatial sketchpad and episodic buffer (Baddeley, 2001).

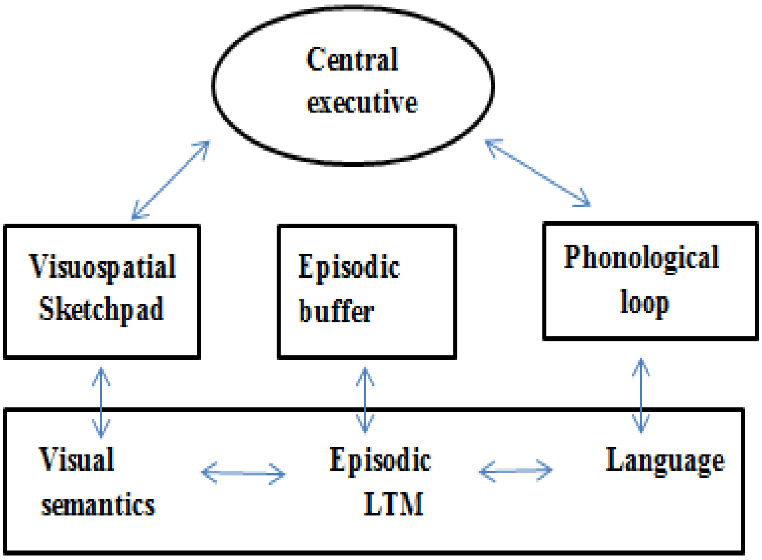

Figure 1.1 The Working Memory Model Components (Baddeley, 2000).

Figure 1.1 shows the schematic representation of working memory model proposed by Baddeley (2000). As per this model central executive controls the use of short term and long term memory stores. It serves to control and regulate the memory stores in carrying out more complex mental tasks. Phonological loop is responsible for verbal information processing whereas visuospatial sketchpad helps in maintaining visual stimuli and spatial information and episodic buffer plays major role in integrating the information perceived by different senses with that of long term memory. Ease of language understanding (ELU) model by Roennberg, Rudner, Foo, and Lunner (2008), describe working memory as a factor that connects the linguistic input with the phonological representations in semantic long-term memory.

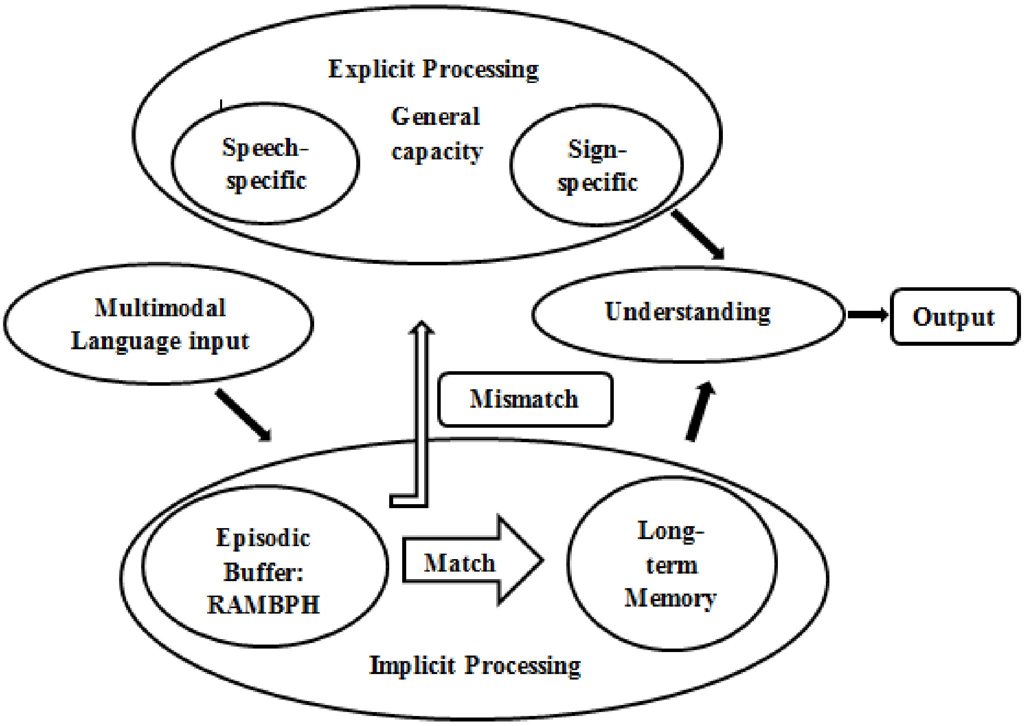

Figure 1.2 The working memory system for ELU (Roennberg, Rudner, Foo & Lunner, 2008)

Figure 1.2 shows the schematic representation of working memory model for ELU. As per this model it is assumed that working memory-based reconstruction mechanisms come into play when there is a mismatch between input and internal representation in long-term memory. Both external distortions (e.g. background noise) and internal distortions (i.e., related to the integrity of the auditory, linguistic, and cognitive systems) will contribute to the mismatch. Consequently, it is assumed that working memory plays a role when individuals with normal hearing have to process spoken language in acoustically adverse conditions.

Working memory capacity varies with individuals. The strain on working memory is assumed to be greater for people with less working memory capacity.

Individuals with lower working memory capacity have poor selective attention (Conway, Cowan, Bunting, Therriault & Minkoff, 2002) resulting, degraded performance on recall and recognition of spoken words in the presence of background noise (Green, 2007). Individuals having higher working memory capacity reportedly have better recognition of speech in the presence of background-masker (Desjardins & Doherty, 2013). It is also found that high-working memory capacity individuals were more sensitive than low-working memory capacity individuals at discriminating the longer of two temporal intervals across a range of temporal differences (Broadway & Engle, 2011) which is important in understanding speech in the presence of noise. Hence working memory is required to recognize speech in noise in every person.

Furthermore, working memory skills are important for elderly and impaired hearing listeners, since the degraded acoustic signal demands more cognition (Roberts & Allen, 2016).Once audibility has been controlled for, cognitive function is the most important predictor of speech understanding in noise (Humes, 2007). Lunner (2003) found that phonological processing speed and working memory capacity were positively correlated with aided speech perception performance. Individuals with good cognitive abilities benefited from fast release time of compression in modulated noise (Foo, Rudner, Rönnberg, & Lunner, 2007; Gatehouse, Naylor, & Elberling, 2003; Moore, 2008). However, fast compression release retained people with below average cognitive abilities at a disadvantage (Foo et al, 2007; Rudner, Rönnberg, & Lunner, 2011). Hearing aid users with good working memory capacity gain more benefit from advanced signal processing because more resources are available to overcome the extra processing of the artificial or distorted signals (Rudner et al, 2011).

1.1 Need for the study

Many communicative situations occur in environments where listening is impaired by the presence of competitive noise. One of the factors that influence speech perception in noise is the working memory (Broadway & Engle, 2011; Wong, Jin, Gunasekera, Abel, Lee, & Dhar, 2009). It was predicted that the effect of noise would be less in subjects having greater capacity of working memory (Fuller, Schneider & Daneman, 1995; Kjellberg, Ljung & Hallman, 2007). According to Daneman and Carpenter (1980) working memory in an individual is limited, and its capacity varies across individuals depending on the difficulty of the listening conditions. Earlier studies have assessed the effect of working memory using words (Pichora-Fuller, Schneider & Danemen, 1995; Conway, Cowan & Bunting, 2002; Colflesh & Conway, 2007) and sentences (Green, 2007; Desjardins & Doherty, 2013; Millman & Mattys, 2016).The present study validates the effect of working memory in understanding speech in noise using bisyllabic nonsense words and sentences and measure the relationship among working memory and speech perception in noise.

1.2 Aim of the study

To investigate the relationship between speech perception in noise and working memory in individuals with normal hearing.

1.3 Objectives of the study

1. To assess the working memory abilities using operation span task and reading span task in normal hearing individuals.
2. To measure speech perception in noise for bisyllabic nonsense words and sentences in adults with normal hearing sensitivity.
3. To find out the relationship between working memory and speech in noise in adults with normal hearing sensitivity.

CHAPTER 2

REVIEW OF LITERATURE

Understanding speech in the adverse conditions is an extremely important and challenging task for the human auditory system (Beattie, Barr, & Roup, 1997). The ability to understand speech in noise depends upon multiple factors such as characteristics of the speech signal, the signal-to-noise ratio, and the listener's degree of hearing impairment. Kjellberg, Ljung and Hallman (2007) reported that the processing and storage information can be complicated in the adverse listening conditions hence, the speech understating in the background noise depends on working memory and executive-control processes. According to Pichora-Fuller et al, (1995) speech understanding draws heavily on working memory, if listeners are not able to integrate existing information with recently processed and stored information, they would fail to arrive at a coherent interpretation of discourse.

2.1 Speech perception in noise

Every oral communication is dependent on information being appropriately received and understood. Comprehension of speech is achieved by detecting and integrating sounds, words and sentences into meaningful units. A number of distortions are present in typical listening environment which adversely affect speech recognition occasionally for normal hearing listeners (Wilson & Strouse, 1999).

Many bit of information are comprised in a Speech signal making it a redundant auditory signal (Martin, 1994). Understanding speech becomes much easier when more extrinsic and intrinsic redundancies are available (Miller, Heise & Lichten, 1951). Normal listeners can comprehend highly degraded speech signals due to speech 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. In comparison, sentences are the easiest signal to perceive as they deliver the listener with acoustic information, semantic and contextual cues and linguistic content. These signals provide greater redundancy. While participating in a conversation it is much easier to understand a known subject than the unknown one. In association to all, the most difficult signal to perceive in the presence of background noise is monosyllabic words (Wilson & Strouse, 1999) in addition nonsense syllables are the most confusing one (Carhart, 1995).

Many studies have shown about how perception differs with the stimulus in presence of noise. Beattie, Barr and Roup (1997) studied word recognition scores for monosyllabic words in quiet and noise on normal hearing individuals. Signal to noise ratios (S/Ns) of 5, 10 and 15dB were tested in Fifty-one normal hearing subjects at 50 dB HL. Monosyllabic words in a multi-talk noise were selected for testing. The mean scores noted for the subjects were 45% at the 5 dB S/N, 74% at the 10 dB S/N and 87% at the 15 dB S/N ratio. The result suggests that the normal hearing listeners were mildly disruptive to monosyllables in presence of the background noise.

To show the effect of noise in nonsense syllables, Helfer and Wilber (1990) studied the reverberation and noise effects on the perception of nonsense syllables in normal-hearing individuals in the age range of 30-35years. Nonsense Syllable Test (Resnick, Dubno, Huffnung & Levitt, 1975) were re-recorded in two different conditions, that was in quiet and in cafeteria noise at + 10 dB S/N under four levels of reverberation (0.0, 0.6, 0.9, 1.3 s). The mean group values for Nonsense Syllable Test scores in reverberation were 9% at 0.0 s, 90% at 0.6 s, 85%at 0.9 s and 80% at 1.3 s and the mean group values for Nonsense Syllable Test scores in reverberation plus noise were 80% at 0.0 s, 75% at 0.6 s, 55%at 0.9 s and 55% at 1.3 suggesting that the Nonsense Syllables were distorted by noise.

In another study, Hornsby and Ricketts (2001) studied the effect of signal-to-noise ratio on speech recognition. Nine subjects with normal hearing identified CV and VC nonsense syllables in speech shaped noise at 0 dB SNR.

Recognizing sentences in noise are comparatively easier than monosyllables or nonsense words. Kollmeier and wesselkamp (1997) found that 50% sentence scores could be obtained at a SNR of –6.1 dB. In a similar line of study, Wilson, McArdle and Smith (2007) found that, in the range of -1 to -4 dB signal-to-babble ratio, the listeners were able to identify the 50% of the stimuli presented.

In an Indian study, Avinash, meti and kumar (2010) reported that at -6.17 dB SNR, 50% sentence identification scores could be identified for normal hearing individuals. In a similar kind of study, Geetha, Kumar, Manjula and Pavan (2014) found 75% correct at –3 dB SNR, 50% correct at –5 dB SNR, and 30% correct at –7 dB SNR for sentence identification in normal hearing adults. Another study by Shetty and Mendhakar (2015), showed 50% recognition score at −5 dB SNR for phrases in normal hearing individuals.

Thus, from the above studies discussed, it can be concluded that sentences are better perceived in noise than nonsense words or monosyllables. 50% sentence identification scores could be obtained at a SNR of –6 dB, but the scores are poorer for monosyllables and for nonsense words.

Speech perception also varies depending on the type of background noise. Many studies have shown that a single competing talker or amplitude-modulated noise is a far less effective masker than multi speaker babble or speech shaped noise (Festen & Plomp, 1990).

Other factors which affect speech perception in the background noise would be age and hearing loss. Tatineni, Gilbert and Pisoni (2013) quoted that the ability of understanding speech is difficult when an individual encounter noisy background conditions, but this effect is exacerbated by hearing loss. According to Gosselin and Gagné (2011) older adults require greater effort and processing resources to understand speech. One of the reasons for the poorer speech perception in these cases can be due increased cognitive load (Roberts & Allen, 2016).

Cognition and language are highly interdependent. Cognition refers to all process by which the sensory input is transformed, elaborated, stored, recovered and used (Neisser, 1967). Cognition includes wide range of mental structure and processes (Craik, 1991). One of the components of cognition is memory. Memory is defined as serial process where in by we store whatever we have learnt, this information is retained based on the amount of rehearsals and can be recollected from the store whenever required. These processes are said to occur in different divisions of memory system, one of which is the working memory.

2.2 Working memory capacity

Working memory (WM) can be conceptualised as the cognitive system that is responsible for active maintenance of information in the face of on-going processing and/or distraction (Füllgrabe & Rosen, 2016). Baddeley and Hitch (2000) gave a dynamic model of working memory. The model had “phonological loop”, “central executive”, “visuo-spatial sketchpad”, and the “episodic buffer”. These components interact with one another to provide a comprehensive work space for the cognitive abilities. The two components “phonological” and “visuo-spatial” loops are thought to be parallel and independent. Coordination between the two loops is done by central executive.

Several studies showed that Working memory capacity (WMC) is strongly related to intelligence (Kane, Hambrick, & Conway, 2005; Oberauer, Schulze, Wilhelm, & Süß, 2005) and executive functions (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). Neuroimaging studies in humans have mapped WM-related activity to both sensory association cortices and prefrontal cortex (Linden, 2007). Neural network models have suggested that stronger frontoparietal connectivity is one potential mechanism behind higher WMC (Edin, Macoveanu, Olesen, Tegnér, & Klingberg, 2007).

WMC is generally assessed using simple span tasks (forward, backward, ascending and descending digit, visual and spatial spans) and complex span tasks (reading span, operational span, rhyme judgment, visual letter monitoring), requiring the temporary storage and simultaneous processing of information.

WMC is a cognitive process that has been positively associated with speech communication abilities (Cleary, Pisoni, & Geers, 2001). Consequently, it is assumed that it also plays a role when individuals with normal hearing have to process spoken language in acoustically adverse conditions. Mattys, Davis, Bradlow and Scott (2012) emphasised that if the implicit processes is low then the level of speech understanding will be compensated by the explicit working memory.

2.3 Role of working memory in speech perception in noise

Working memory capacity varies across individuals (Daneman & Carpenter, 1980). The involvement of working memory in speech perception varies depending on the difficulty of the listening conditions (Rudner et al., 2011). 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.

Pichora-Fuller, Schneider and Danemen (1995) led a study to note how young and old normal hearing adults listen to and remember speech in noise. Two tasks were carried out for both age groups. A working memory task and the SPIN task were done. In the SPIN task, Participants were made to listen to the sentences and then they were instructed to identify and recall the last n words from the sentences. Reading span task was carried out to measure working memory capacity. The result showed that there was no difference seen in two age groups while recalling the n words from the sentences. But, in adverse Signal to noise condition there was reduction seen in recalling the number of items in both the groups. Recalling of the words was reduced more in subjects with low working memory capacity, implying that the cognitive abilities (working memory) are important while listening in presence of noise.

Conway, Cowan and Bunting (2001) evaluated the effect of working memory in speech perception in noise. The adult participants were divided in to two groups-individuals with high working memory capacity and individuals with low working memory capacity based on Operation Span Task scores. Selective listening task was carried out using the stimuli which had an onset of the irrelevant message which began 30sec after the attended message, allowing for a brief period without distraction. Subjects were instructed to listen to the message presented to the right ear and to repeat each word as soon as it was presented, making as few errors as possible and to ignore the distractions coming to the left ear. The results revealed that the individuals with low working memory capacity performed poorly in the shadowing task as compared to the individuals with high working memory capacity. This result indicates that, higher working memory capacity is required for selective attention.

Green (2007) examined the relationship between working memory capacity and the performance of recall and recognition of orally presented text in noisy conditions. Listening span, reading span and operation span tests were done on 32 normal hearing subjects in the age-range of 20-23 years to assess the working memory capacity. The sentences were presented in two conditions: with background noise and without background noise. The subjects were supposed recall and recognize the sentences presented. The result revealed that the noise had no significant main effect on recall or recognition of spoken texts but there was a degraded performance on recall or recognition of spoken texts with people having lower working memory due to the noise exposure. Hence, people with low working memory capacity get more affected by noise.

Colflesh and Conway (2007) evaluated the individual differences in working memory capacity and divided attention in dichotic listening. The sample comprised of 118 undergraduate students. Based on operation span task and reading span task the participants were divided into two groups- individuals with high working memory capacity and individuals with low working memory capacity. In order to assess the divided attention, each participant performed two tasks: divided attention –shadow, here the participants were instructed to listen to the more relevant message which will be presented to the right ear and then they have to repeat each word and divided attention-no shadow, here the participants were instructed to press the space bar whenever they hear their name in left ear. The tasks were presented at three different SNRs: 8, 0 and +8. The results of the present study revealed that 66.7% of participants with high working memory capacity and 34.5% of participants with low working memory capacity detected their name suggesting that high working memory capacity is required to control the focus of attention. Hence, Participants with high working memory capacity are able to flexibly “zoom in” or “zoom out” depending on task demands.

Desjardins and Doherty (2013) evaluated the relationship between cognitive function, listening effort, and speech recognition for a group of younger adults with normal hearing in various types of background maskers. To objectively evaluate the listening effort a dual task paradigm was used. In the primary task, sentences were presented in three different background masker conditions: two-talker, six-talker, and speech-shaped noise (SSN) and the participants were asked to repeat sentences presented. Digital visual pursuit rotor tracking was the second task where there was a moving target around an ellipse that was displayed on the computer screen and the participant should track that moving target. Also, participants were asked to rate the sentence presented in each masker condition on scale from 0 (i.e., very difficult) to 100 (i.e., very easy). In the third task, participants were subjected to do battery of cognitive tests that measured working memory (Reading Span Test), processing speed (Digit Symbol Substitution Test), and selective attention (Stroop Test) ability. Results revealed that participants speech-recognition performance in noise were significantly related to their working memory and processing speed abilities in all three background-masker conditions. Participants rated the SSN condition to be the easiest listening condition and the two-talker condition to be the most difficult listening condition. The participants having higher working memory capacity had better word recognition, suggesting that there are association between speech recognition in fluctuating noise and working memory capacity.

Millman and Mattys (2016) assessed the relationship between components of auditory verbal working memory (AVWM) and speech perception in modulated maskers over a range of signal-to-noise ratios. Thirty normal hearing listeners in the age range of 31-67 years were included in the study. Forward digit recall, backward digit recall, and non-word repetition were used to assess AVWM. Results showed that in the least favourable SNR individual differences in the phonological component of working memory was related to the speech perception in modulated maskers. Furthermore, the executive component of working memory was not predictive of speech perception in any conditions. Hence they concluded that AVWM is predictive of the ability to benefit from temporal dips in modulated maskers which indicates that listeners with greater phonological working memory capacity were better able to correctly identify sentences in modulated noise backgrounds.

Salant and Cole (2016) studied the effect of Working Memory Capacity on Speech Recognition Performance in Noise in 25 younger (18 to 25 years) normal-hearing listeners. The participants were assigned into two groups: Individuals with high working memory and Individuals with low working memory based on the Listening Span Test. NU6 words and IEEE sentences were presented in noise using an adaptive procedure to measure the signal-to-noise ratio corresponding to 50% correct performance. Cognitive ability was evaluated with two tests of working memory (Listening Span Test and Reading Span Test) and two tests of processing speed (Paced Auditory Serial Addition Test and The Letter Digit Substitution Test). The results indicate that participants with high working memory capacity are able to capitalize on contextual cues and perform for sentence recognition. The other group with low working memory capacity was less able to adapt to distortion of speech signals caused by background noise, which requires the allocation of more processing resources to earlier processing stages.

Thus from the results of the above studies it is evident that normal listeners with low working memory capacity are at a disadvantage recognizing speech in presence of noise. However, working memory capacity varies with individuals. Earlier researches have shown the decline in working memory capacity across age and this decline exacerbated in individuals with hearing impairment. It is well known that ageing is associated with declines in both perception and cognition.

Roberts and Allen (2016) reviewed evidence for an interaction between perceptual and cognitive decline in old age.

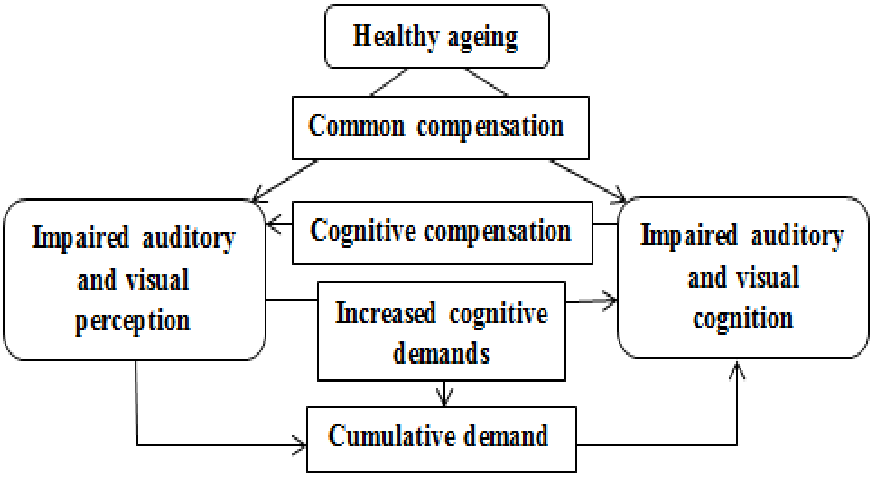

Figure 2.1: Diagram of the potential links between healthy ageing, auditory and visual perception, and auditory and visual cognition (Roberts & Allen, 2016)

Figure 2.1 shows diagram of the potential links between healthy ageing, auditory and visual perception, and auditory and visual cognition. As per the figure, the study explains how cognition is related to audition. Here they enlightened that there is a link between perception and cognition in old age. Furthermore, they quoted that there is more direct link between impaired perception and cognitive decline since, degraded input leads to a higher load on cognition, reducing resources available for cognitive processing.

A study done by Füllgrabe and Stuart (2016) revealed that WMC becomes important for speech in noise identification from middle age onward (≥40years), with the oldest listeners (≥70 years) showing the strongest correlation and differing significantly from the youngest age group.

Evidence from studies using mainly older hearing-impaired listeners indeed confirms that higher WMC is related to better unaided and aided speech-in-noise identification (Lunner 2003; Foo et al., 2007; Lunner & Sundewall-Thorén 2007; Arehart et al., 2013). In addition, high-WMC listeners were less affected by signal distortion introduced by hearing-aid processing.

Thus from the above studies, we can determine that working memory capacity plays a crucial role listening in adverse condition. The previous researches are done on how working memory capacity is related to speech perception in noise across different age groups and with hearing impaired individuals using different stimuli. However, the role of working memory in understanding nonsense words and sentences in presence of noise needs to be explored. Hence, the present study was been taken up to investigate the correlation between working memory and speech perception in noise using bisyllabic nonsense words and sentences.

CHAPTER 3

METHOD

The present study was undertaken to study the relationship between working memory and speech perception in noise. To fulfill the above aim, the following method was adopted.

3.1 Research design

A correlation research design was utilized to assess the relationship between working memory and speech in noise in normal hearing individuals.

3.2 Participants

Hundred and thirteen adults in the age range of 18-40 years (mean age = 21.85) participated in the study. Through a structured interview, it was ascertained that none of the participants had any complaint or history of ear disease, head trauma, ototoxic drug intake, and ear surgery or speech language problems. Further, it was made certain that none of the participant had any illness on the day of testing.

Detailed audiological assessment was performed for all the participants before recruiting them for the study. Selected participants had pure tone thresholds within 15 dB HL at octave frequencies between 250Hz to 8000Hz for air conduction and between 250 to 4000Hz for bone conduction. Their Speech recognition thresholds were within ±12 dB of pure tone average (average threshold of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz). Also, speech identification scores was greater than 80% at 40 dB SL (reference to SRT) on the phonetically balanced word lists in Kannada (Mayadevi, 1974). Normal functioning of middle ear were indicated by bilateral ‘A’ type of tympanogram. Acoustic reflex was (ipsilateral and contralateral) present at normal sensation levels at 500 Hz and 1000 Hz. All the participants had a formal education at least up to 10th standard and they were native listeners of Kannada. The participants considered for this study had given their informed consent.

3.3 Instrumentation

A calibrated two channel Inventis *piano* diagnostic audiometer with the TDH-39 headphone (Telephonic 815 broad hollow road, farmingdale, New York11735) and B-71 bone vibrator (Radioear, KIMMETRICS, mithbergs, MD 21783) were used to assess air conduction and bone conduction threshold respectively. GrasonStadler Inc. Tympstar system (GSI VAISYS Healthcare, Wisconsin, USA) was used to measure middle ear functioning. Working memory and speech perception in noise assessment were done using Dell Intel Core i3 laptop and Sennheisser HD449 circumaural headphones calibrated to produce 85 dB SPL output.

3.4 Test Environment

Pure tone audiometry was carried out in an acoustically and electrically shielded room where the noise levels were within the permissible limits (ANSI S3.1; 1999). All the other experiments were carried out in a quiet room with good illumination, ventilation and minimum distraction.

3.5 Stimuli and Procedure

Basic audiological evaluations were done preliminary to the actual experiment for recruiting the participants.

Basic audiological evaluations

1. Pure tone hearing thresholds were measured using modified Hughson Westlake method (Carhart & Jerger, 1959). Threshold were obtained across octave frequencies from 250 Hz to 8000 Hz for air conduction and 250 Hz to 4000 Hz for bone conduction using a calibrated two channel

Inventis *piano* diagnostic audiometer. Thresholds were tracked using modified Hughson-Westlake method (Carhart & Jerger, 1959).

2. Uncomfortable loudness level measurement for speech was done for all the clients.
3. Tympanometry was carried out with a probe tone frequency of 226Hz at 85dBSPL by varying the air pressure in the ear canal from +200dapa to -400dapa. Ipsilateral and contralateral acoustic reflexes thresholds were measured for 500, 1000, 2000 and 4000Hz.

The present study was divided into two experiments: Speech perception experiment and working memory measures.

1. Speech perception experiment

Stimuli: Signal to noise ratio required to identify 50% of the stimuli (SNR-50) presented was assessed for two types of speech materials – bisyllabic CVCV nonsense words and sentences (Avinash, Methi, & Kumar, 2010). Nineteen bisyllabic CVCV nonsense words were used. Each word had 4 syllables. The words collected were ensured to have different consonant-vowel combination (e.g:/pata/, /bata/). These words were recorded from two female speakers, who were native speakers of Kannada. A recording microphone (Ahuja, AUD-101XLR) (having a frequency response from 20 Hz to 20 kHz) was placed at 10 cm away from the speaker's mouth. Each speaker was informed to clearly articulate the nonsense words with normal vocal effort and was insisted to maintain natural intonation pattern. Adobe Audition (version 3 Syntrillium Software company, Phoenix, Arizon, United States) software was used to record the nonsense words at a sampling rate of 44.1 kHz with 24-bit resolution. All the recorded words were saved as.wav files. These nonsense words were then presented to ten normal hearing adults at their comfortable level for goodness test. Only those words that had good naturalness were selected.

All the bisyllabic nonsense words and sentences were then mixed with the speech shaped noise. This was achieved using Smriti-Sharvan V1.0 software (Kumar & Sandeep, 2013). The software was loaded on a personal laptop. Calibration of the stimulus was done using Bruel and Kjaer hand held (model no. 2270) sound level meter (SLM) mounted on a Tri-Pod (Isolation position/ or decoupler) connected to the KEMAR manikin. The output of the laptop was delivered to the KEMAR manikin through Sennheisser HD449 circumaural headphones binaurally. The volume control of the laptop was adjusted to so that reading at SLM was 70 dB SPL.

A calibrated stimulus was then presented to the participants and the SNR was varied adaptively. For both the stimuli, SNR was increased by 2 dB for every correct response and decreased by 2 dB for every incorrect response. This procedure continued till eight reversals. The mean of the mid-point of the last six reversals were calculated and considered as SNR-50. Participants were given a practice trial before the actual tests.

Procedure: Participants were made to sit comfortably in a quiet room in front of a computer monitor at a distance of 1.5 m. Stimuli were presented binaurally to participants at 70 dB SPL using Sennheisser HD449 circumaural headphones connected to Dell Intel Core i3 laptop. In case of nonsense words participants were instructed to click on the corresponding words on the computer screen after hearing the stimuli. In case of sentences participants were asked to repeat the sentences verbatim. Order of presentation and testing was randomized. Presentation of the stimuli and acquisition of the responses were controlled using Smrithi-Shravan V1.0 (Kumar & Sandeep, 2013).

2. Working memory measures

Operation span task and reading span task were carried out by adapting the tests developed by Shasthri and Kumar (2015) and Jain and Kumar (2016). Presentation of the stimuli and collection of the responses were done through Smriti-Sharvan V1.0 software (Kumar & Sandeep, 2013).

Operation span task: In operation span task, participant's ability to remember the target stimuli which was interleaved with a secondary processing task was evaluated. The secondary processing task was to verify the mathematical problem. Each element consists of a mathematical operation and a word to be remembered [e.g., $(3\times5) - 4 = 4$, yes or no? Apple]. Each element is defined as a combination of one mathematical problem and a word to be remembered. The words to be remembered will be bisyllabic. The secondary processing task, i.e., the mathematical operation to be verified had either multiplication or division for the first mathematical operation within the parenthesis. The mathematical operation outside the parenthesis had either addition or subtraction as shown in the example below:

$$(7 \times 2) - 3 = 10$$

Among total number of elements, mathematical problems were true in half of the elements and were false in the other half of the elements. Combination of a number of elements is defined as a trial. The length of the trial was varied from three to six. One trial is defined as one block. There were three blocks.

While testing, an element consisting of a mathematical problem was displayed on the computer screen followed by a word to be remembered. The participant was asked to read the mathematical equation aloud and verify whether the given answer is correct and then read the word. Soon after this, next element that is next mathematical problem and word combination was presented. After all the elements in a trial were presented, the participants were asked to repeat the words in the trial in correct serial order. Accuracy of both solving the mathematical problem as well as recalling the words in correct serial order were noted.

Reading span task*:* In reading span task, participant’s ability to remember the target stimulus which was interleaved with a secondary processing task was evaluated. The secondary processing task was verified for semantic/pragmatic correctness of a sentence in reading span task. In reading span task, which taps verbal working memory, each element consists of a sentence and a bisyllable to be remembered (e.g. “Ramu is going to school. /ka/”). Half of the sentences will make sense (or logical) (e.g. Apples are falling from an Apple tree) and other half of the sentences will not make sense (e.g. People are falling sick because of increasing flowers). The syllables to be remembered were CV in structure with combination of different consonants and vowels. Each trial consists of three to six elements (sentence-syllable combinations). One trial is defined as one block. There were three blocks. The difficulty of the items was randomized such that the number of elements was unpredictable at the outset of an item.

While testing, an element that is a sentence was displayed on the computer screen followed by a syllable to be remembered. The participant's task was to read the sentence aloud and indicate whether it made sense then read the syllable. Soon after, next element that is next sentence-syllable combination was presented. After all the elements in a trial were presented, the participant had to recall each syllable from the preceding set of sentences, in the order they appeared. The accuracy of judging the sentence and also recalling the syllables in the same order were noted.

Scoring: Both the working memory tests were scored using four different types of schemes. (i) All-or-nothing unit – in this scheme credit is given to only completely correct items. A score of 1 is given only if all the elements are recalled in correct serial order (ii) partial-credit unit – in this scheme each item is scored as proportion of correctly recalled elements per item regardless of item size (iii) All-or-nothing load – this scheme is similar to all-or-nothing unit scoring but higher weightage is given to items with higher load (iv) partial-credit load – similar to partial credit unit scoring but higher weightage is given to items with higher load.

3.6 Reliability of working memory and speech perception measures

To assess test-restest reliability between working memory measures (ANS, PCS, ANSW and PCSW) and SNR-50 scores, twenty participants were tested again after an interval of 30 days.

3.7 Statistical analyses

Working memory measures and SNR-50 scores of bisyllabic nonsense words and sentences were obtained through Smriti-Sharvan V1.0 software (Kumar & Sandeep, 2013). All these data was analysed using appropriate statistical procedures using SPSS version 20. The following statistical procedures were used to analyze the data.

i. Descriptive statistics was computed to calculate the mean and standard deviation for the working memory measures and for the SNR-50 scores.
ii. One way ANOVA was administered to compare the performance of working memory measures across three different blocks and to compare the performance between the average scores with the three blocks.
iii. Paired sample t-test was computed to assess the difference between SNR-50 scores of sentences with bisyllabic nonsense words.
iv. Reliability coefficient Cronbach's alpha was done to investigate the test/retest reliabilities of working memory measures and SNR-50 scores.

v. Karl Pearson’s Co-efficient Correlation was calculated to assess the correlation between working memory and speech perception in noise.

CHAPTER 4

RESULTS

The primary aim of the present study was to assess the effect of working memory on speech perception in noise. The study had three major objectives to be fulfilled and is given below

a. To evaluate the working memory measures using operation span task and reading span task in normal hearing individuals
b. To measure speech perception in noise for bisyllabic nonsense words and sentences in normal hearing individuals and
c. To evaluate the relationship between working memory and speech perception in noise.

In order to meet the objectives mentioned, the data of 113 participants with normal hearing sensitivity were subjected to statistical analysis. The Parameters measured were working memory measures and SNR-50 scores obtained using Smriti-Sharvan V1.0 software (Kumar & Sandeep, 2013). These data were analyzed using Statistical Package for the Social Sciences (SPSS for windows, version 20) software**.** Normal distribution of the data was ensured before proceeding with the statistical analyses using kurtosis and skewness.

4.1 Working memory measures

Operation span task (OST) and reading span task (RST) were the two working memory measures performed. Descriptive statistical analyses were performed for both the tasks to document the mean and standard deviation of all-or-nothing scores (ANS), partial credit scores (PCS), all-or-nothing scores weighted (ANSW) and partial credit scores weighted (PCSW) across three different blocks and with the average block. Average score was calculated by averaging scores obtained in three different blocks. The results of the OST analysis are shown in table 4.1 and the results of RST analysis are shown in table 4.2.

Table 4.1

Mean and standard deviation of OST measures across three blocks and average

Blocks	**OST measures**	**N**	**Mean**	**Standard deviation**
Block 1	ANS	113	0.50	0.25
	PCS	113	0.76	0.16
	ANSW	113	0.44	0.25
	PCSW	113	0.74	0.17
Block 2	ANS	113	0.49	0.26
	PCS	113	0.76	0.18
	ANSW	113	0.43	0.26
	PCSW	113	0.74	0.18
Block 3	ANS	113	0.54	0.26
	PCS	113	0.77	0.16
	ANSW	113	0.48	0.27
	PCSW	113	0.75	0.17
All average	ANS	113	0.51	0.20
	PCS	113	0.76	0.14
	ANSW	113	0.45	0.22
	PCSW	113	0.74	0.14

From table 4.1 it can be inferred that the mean scores obtained for OST measures for different parameters are similar across blocks. Also the average scores for different measures are comparable to scores obtained on individual blocks. Similar information is depicted in the figure 4.1.

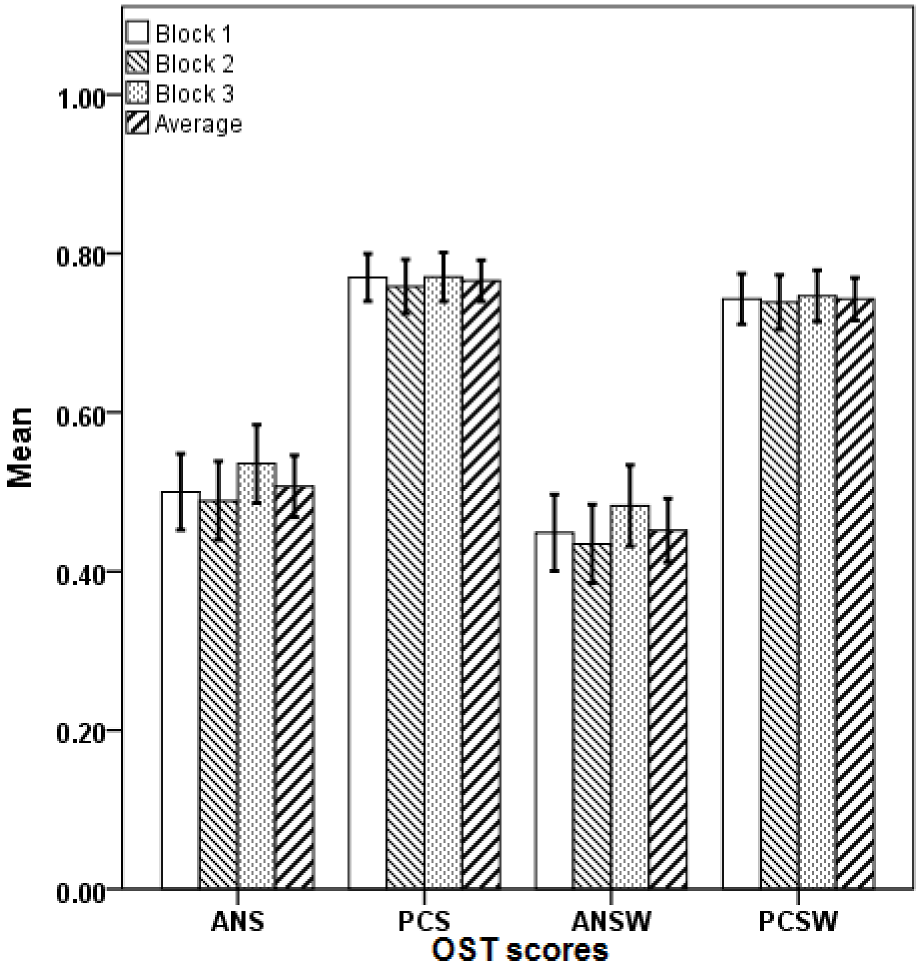

Figure 4.1 The graphical representation of mean and standard deviation of OST measures across three blocks and average.

Table 4.2

Mean and standard deviation of RST measures across three blocks and average

Blocks	**RST measures**	**N**	**Mean**	**Standard deviation**
Block 1	ANS	113	0.36	0.26
	PCS	113	0.64	0.19
	ANSW	113	0.31	0.26
	PCSW	113	0.61	0.21
Block 2	ANS	113	0.38	0.26
	PCS	113	0.68	0.21
	ANSW	113	0.34	0.26
	PCSW	113	0.65	0.22
Block 3	ANS	113	0.44	0.28
	PCS	113	0.71	0.18
	ANSW	113	0.39	0.28
	PCSW	113	0.69	0.19
All average	ANS	113	0.39	0.21
	PCS	113	0.68	0.16
	ANSW	113	0.35	0.21
	PCSW	113	0.65	0.16

It can be seen from table 4.2 that the mean scores of RST measures for the different parameters are similar across blocks. Also the average scores for different measures are comparable to scores obtained on individual blocks. The same results are depicted in the following figure (4.2).

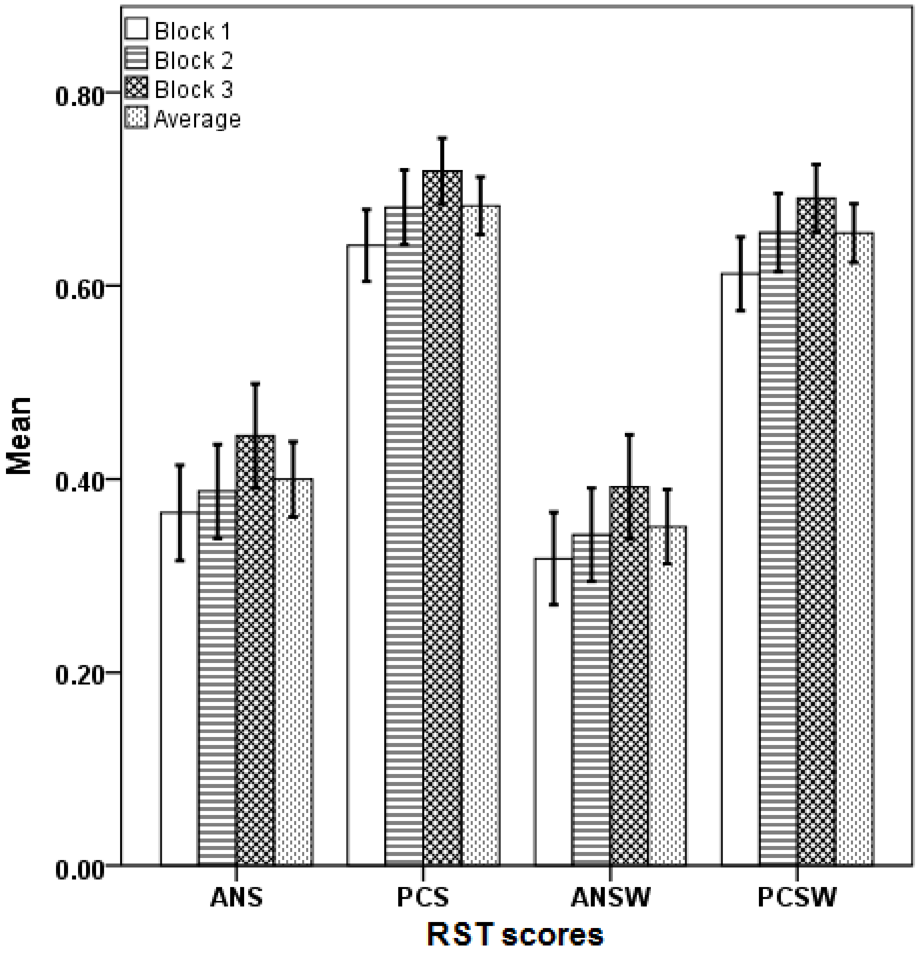

Figure 4.2 The graphical representation of mean and standard deviation of RST measures across three blocks and average.

A one way ANOVA was conducted to see if there are significant differences between average OST scores and scores obtained in three different blocks. For this purpose average score and scores obtained in three blocks were entered as factors and different types of OST scores (ANS, PCS, ANSW and PCSW) as dependent measures. Results revealed that there was no significant main effect of blocks or average score on ANS [F (3,448) = 0.717, p = 0.542], PCS [F (3,448) = 0.131, p = 0.942], ANSW [F (3,448) = 0.711, p = 0.546] and PCSW [F (3,448) = 0.042, p = 0.989]. Further, a one way ANOVA was conducted to see if there are significant differences between average RST scores and scores obtained in three different blocks. Results revealed that there was no significant main effect of blocks or average score on ANS [F (3,448) = 1.919, p = 0.126], ANSW [F (3,448) = 1.670, p = 0.173]. However, there was a significant main effects of blocks or average score on PCS [F (3,448) = 3.174, p = 0.024] and PCSW [F (3,448) = 3.046, p = 0.029]. Post hoc comparisons using the Bonferroni corrections for multiple comparison indicated that the mean score for PCS in block 1 was significantly different than the PCS block 3 score [(M = 0.77, SD = 0.24), P= 0.013] also there was a significant difference in PCSW block 1 score and the PCSW block 3 score [(M = 0.78, SD = 0.26), P= 0.016].

4.2. Speech perception assessment

SNR-50 was assessed using bisyllabic non-sense words and sentences. Descriptive statistical analyses were performed to document the mean and standard deviation of SNR-50 for bisyllabic non-sense words and sentences. The results of the analysis have been tabulated in table 4.3.

Table 4.3

Mean and standard deviation of SNR-50 scores for bisyllabic *nonsense words and sentences*.

SNR-50	N	Mean	Standard deviation
Bisyllabic nonsense words	113	-5.55	2.44
Sentences	113	-9.39	1.51

The same results have been graphically represented below (figure 4.3). From the Figure 4.3 and Table 4.3 it can be seen that SNR-50 for sentences were better compared to bisyllables.

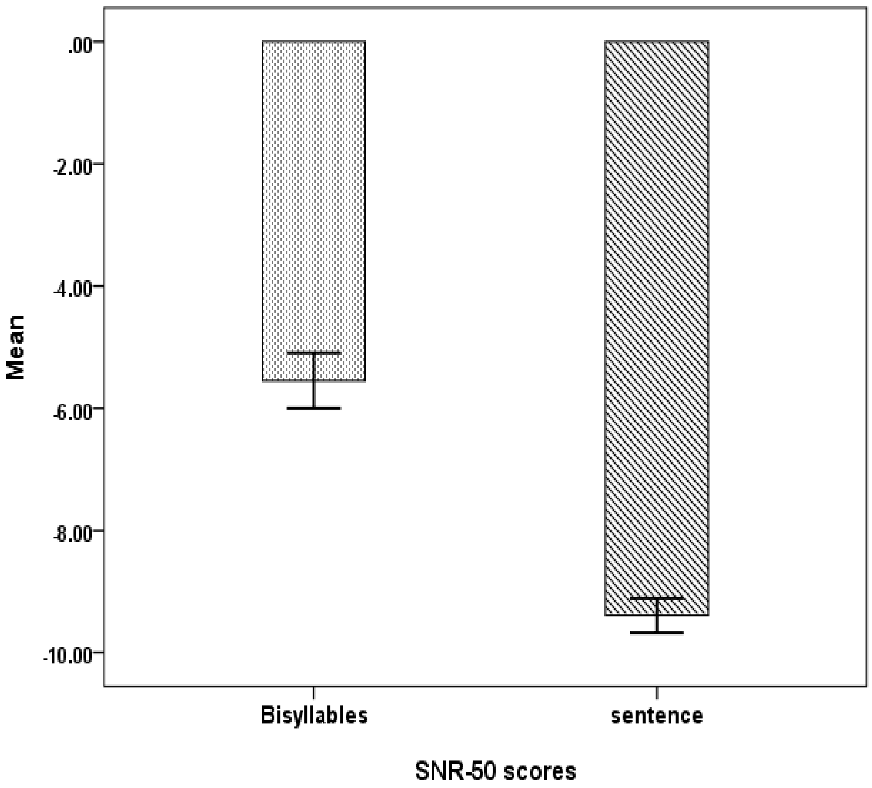

Figure 4.3 The graphical representation of mean and standard deviation of SNR-50 scores for bisyllabic nonsense words and sentences.

A paired sample t test was performed to assess the statistical significance of these differences. Results showed that the SNR-50 for sentences were significantly better compared bisyllables (t(112)=14.69, p<0.01]. These results indicate that participants were able to tolerate the higher levels of noise while listening to sentences compared to non-sense words.

4.3. Reliability of working memory and speech perception measures

To check the reliability between two recordings sessions for working memory measure (ANS, PCS, ANSW and PCSW) and SNR-50 values, Cronbach's alpha computed. Reliability measures are depicted in a table 4.4. From the table 4.4 it can be inferred that both the working memory tests had very high reliability. Reliability of SNR-50 for sentences were high but was moderate for bysyllabic nonsense words.

Table 4.4

Reliability measures for SNR-50 scores and working memory measures

TESTS	**Cronbach's alpha**
SNR-50 for bisyllabic nonsense words	0.52
SNR-50 for sentences	0.83
OST	0.93
RST	0.94

4.4. Relationship between speech perception in noise and working memory

Karl Pearson's Product-Moment correlation co-efficient was computed to evaluate the relationship between working memory and speech in noise. The scores of SNR -50 for bisyllabic nonsense words and sentences were correlated with each of working memory measures. Table 4.5 shows the correlation co-efficient between the variables for OST and Table 4.6 shows the similar information for RST. The analysis showed a significant negative correlation between all working measures with the SNR-50 scores for bisyllabic nonsense words. However, the correlation between SNR-50 of sentences and working memory measures were not significant. Figure 4.4 and Figure 4.5 shows scatter plot drawn between the variables to verify the validity of correlation. The negative correlations mean that individuals with better working memory capacity lower were able to tolerate higher levels of noise.

Table 4.5

Correlation between OST and SNR-50 scores for bisyllabic nonsense words and sentences

OST measures	SNR-50	
	Bisyllabic nonsense words	Sentences
ANS	-0.284**	-0.097
PCS	-0.281**	-0.155
ANSW	-0.282**	-0.091
PCSW	-0.281**	-0.156

**. Correlation is significant at the 0.01 level (2-tailed).

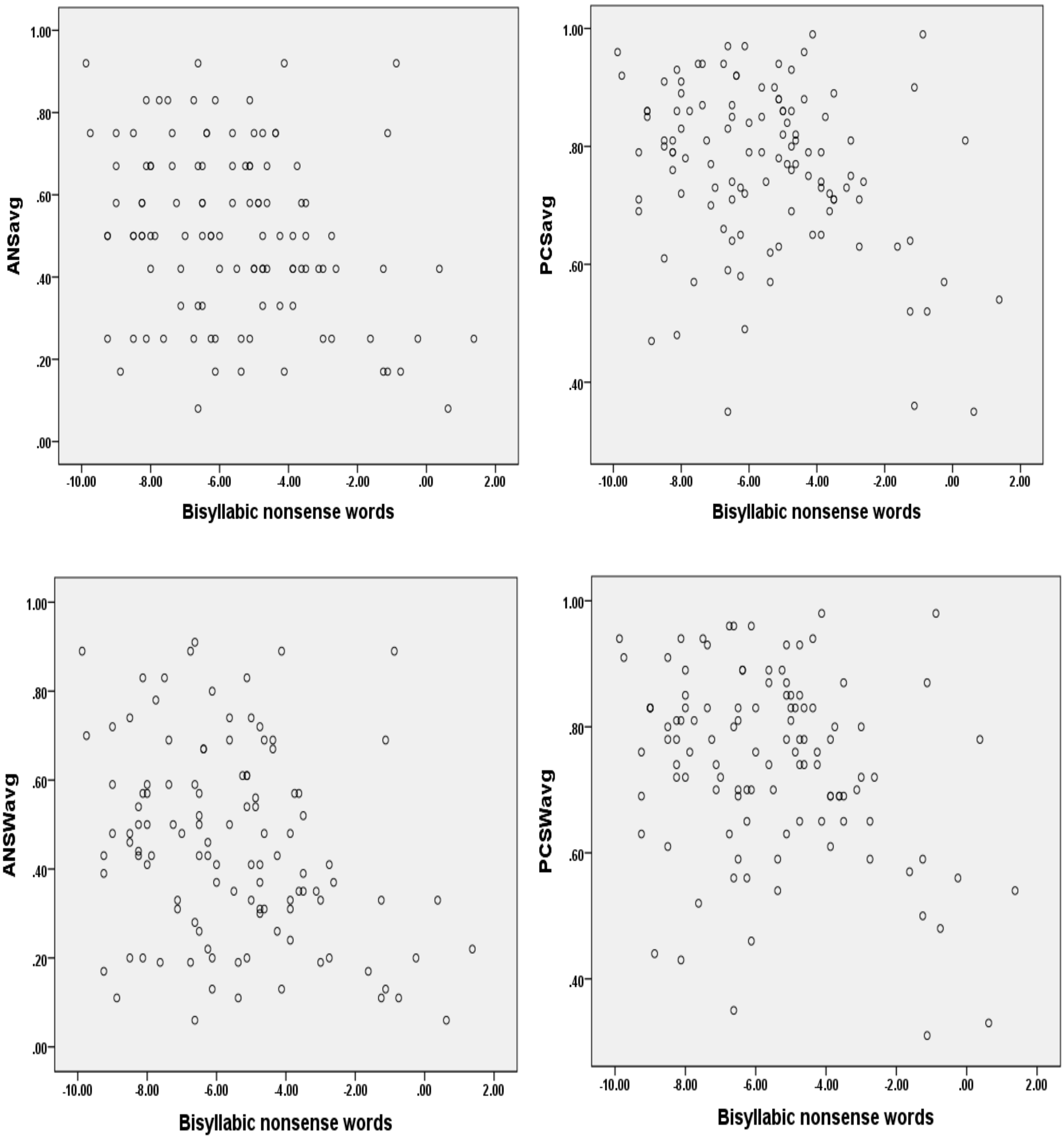

Figure 4.4: correlation matrix between OST measures and SNR-50 scores for bisyllabic nonsense words.

Table 4.6

Correlation between RST and SNR-50 scores for bysyllabic nonsense words and sentences

RST measures	SNR-50	
	Bysyllabic nonsense words	Sentences
ANS	-0.201*	-0.139
PCS	-0.226*	-0.140
ANSW	-0.196*	-0.128
PCSW	-0.231*	-0.124

*. Correlation is significant at the 0.05 level (2-tailed).

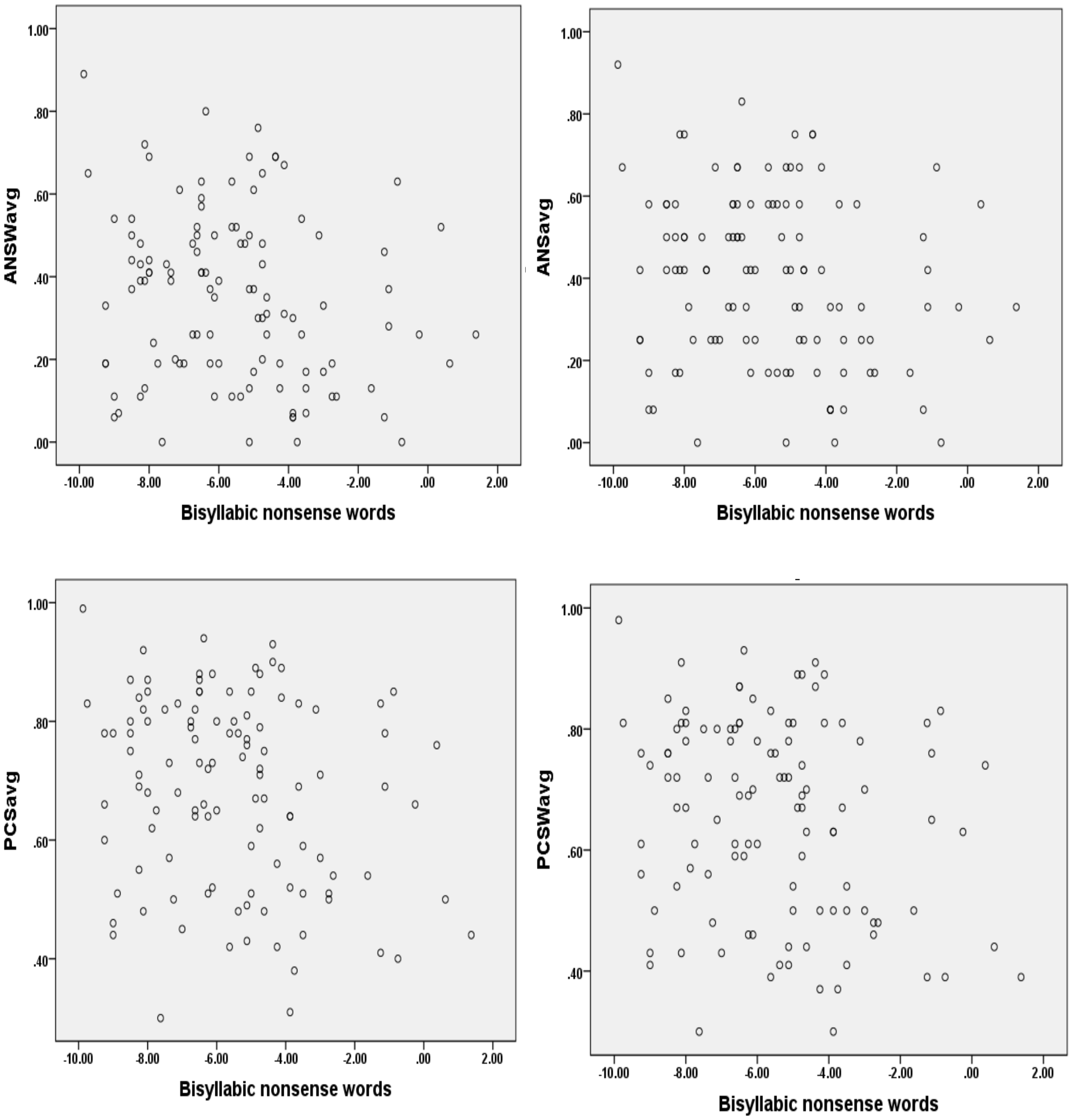

Figure 4.5: correlation matrix between RST measures and SNR-50 scores for bysyllabic nonsense words.

CHAPTER 5

DISCUSSION

The main aim of this study was to assess effect of working memory on speech perception in noise. The present study investigated working memory measures and SNR-50 scores for bisyllabic nonsense words and sentences in normal hearing individuals. This study also explored the relationship between working memory capacity and speech perception skills. Results revealed that the scores of working memory measures did not differ across three blocks and the average. However, there was significant difference seen between the SNR-50 scores for bisyllabic nonsense words and for sentences. Furthermore, the working memory measures were significantly correlated with SNR-50 score for bisyllabic nonsense words but not with the SNR-50 scores for sentences.

5.1 Working memory measures

Results revealed that the scores of working memory measures (OST and RST) did not differ across three blocks for all the parameters. However the difference was found to be significant for RST scores of PCS and PCSW in block 3. Better performance in block 3 in RST could be due to the familiarity of the sentences that made the task easier. The scores can be made comparable across the blocks by having different sentences in each block. Furthermore, both the working memory measures showed high reliability.

Reading span task and operation span task have been used in several studies. One conclusion that can be drawn from this body of research is that measures obtained from these tasks have adequate accuracy whatever it is that they actually measure. In accordance to the current study Kane, Hambrick, Tuholski, Wilhelm, Payne and Engle (2004) with the sample size of 236 observed that subjects who responded with the correct answer for one set of span stimuli in this task tended to respond with the correct answer on the others. Therefore, span scores were reliable in the sense that there was consistency in responding across items within the task at one point in time. In another study with the sample size of 6,000 Redick, Broadway, Meier, Kuriakose, Unsworth, Kane and Engle (2012) reported of high internal consistency across the tasks. Internal consistency estimates of similar magnitudes have been reported in number of studies, including Conway et al. (2002), Engle, Tuholski, Laughlin, and Conway (1999), Hambrick and Engle (2002), Miyake, Friedman, Rettinger, Shah, and Hegarty (2001), and Oberauer, Süß, Schulze, Wilhelm, and Wittmann (2000).

Evidence also suggests that working memory span tasks are reliable in the sense that the rank orders of span scores are stable across time. Similar results were obtained in the present study having test-retest correlations of 0.93 and 0.94 for operation span task and reading span task respectively. Comparable results were seen in previous studies. In adults, test–retest correlations of approximately 0.70–0.80 have been observed for operation span and reading span, over minutes (Turley-Ames & Whitfield, 2003), over weeks (Friedman & Miyake, 2004; Klein & Fiss, 1999), and even over 3 months (Klein & Fiss, 1999). Although two studies have shown less adequate test–retest reliability for the reading span task, ranging from 0.50 over weeks to 0.40–0.65 over months (MacDonald, Almor, Henderson, Kempler, & Andersen, 2001; Waters & Caplan, 1996).

5.2 Speech perception in noise

The results of SNR-50 scores for Bisyllabic nonsense words and for sentences revealed that there was a significant difference between two scores suggesting lower

SNRs are obtained for sentences. Enhanced recognition of sentences in noise can be attributed to good extrinsic redundancy. Sentences deliver the listener with acoustic information, semantic and contextual cues and linguistic content contributing for better perception (Wilson & Strouse, 1999). Whereas rhythm is the only cue for perceiving nonsense words (Nakatani & Schaffer, 1977) and those words are reported to be most confusing (Carhart, 1995).

Earlier studies have reported better SNRs for sentences than for nonsense words. 50% sentence identification scores were obtained at a SNR of -6 dB (Kollmeier & wesselkamp, 1997; Avinash, Meti & Kumar, 2010; Geetha et.,al , 2014; Shetty & Mendhakar, 2015) and 50% nonsense words identification scores were obtained at a SNR of 0 dB (Hornsby & Ricketts, 2001) and at a SNR of <6 dB (Wilson et. al., 2010).

5.3 Relationship between working memory and speech perception in noise

Correlation analysis showed that working memory had a significant correlation with the speech perception in noise. The influence of OST and RST were seen on SNR-50 scores for bisyllabic nonsense words. The SNR-50 scores for bisyllabic nonsense words showed high negative correlation with OST and RST. The negative correlations mean that individuals with better working memory capacity lower were able to tolerate higher levels of noise. Thus, the results of the present study shows that greater level of cognition is required for perception of bisyllabic nonsense syllables.

Studies have been carried out in normal hearing individuals to see the effect of working memory in speech in noise. General findings are that individuals with poor speech perception abilities will have low working memory and better speech perception abilities will have high working memory Pichora-Fuller et al, (1995);

Conway, Cowan and Bunting (2001); Desjardins and Doherty (2013); Salant and Cole (2016). Colflesh and Conway (2007) reported that the selective attention supports the notion that individuals with greater working memory capacity are better able to focus attention and avoid distraction. Conway et al. (2001) also reported that working memory is responsible for maintaining activation to relevant information and suppressing the distracting information.

In contrast to SNR-50 scores for nonsense words, SNR-50 scores for sentences did not show any significant correlation between OST and RST. This could probably due to the higher redundancy of the speech signal which strains less working memory capacity. Millman and Mattys (2016) reported that working memory was related to speech in noise only in the least favorable SNR. However, further research needs to be carried out regarding the relationship between working memory and sentence perception in noise.

SUMMARY AND CONCLUSION

The processing and storage of spoken information can be complicated in bad acoustic conditions, thus affecting the understanding of speech. In such conditions, one of the factors that influence speech perception in noise is working memory. The Present study was taken up to assess the possible relationship between working memory and speech in noise.

The objectives of the present study are as follows

1. To assess the working memory abilities using operation span and reading span in normal hearing individuals.
2. To measure speech perception in noise for bisyllabic nonsense words and sentences in adults with normal hearing sensitivity.
3. To assess the relationship between working memory and speech in noise in adults with normal hearing sensitivity

Hundred and thirteen normal hearing adults in the age range of 18-40 years recruited for the study. All the participants were native listeners of Kannada and had a formal education at least up to 10th standard. Operation span task, Reading span task and SNR-50 scores for bisyllabic nonsense words and for sentences were obtained for all the participants through Smriti-Sharvan V1.0 software. SNR-50 scores were obtained binaurally at 70 dB SPL. The scores of working memory tasks (OST and RST) were obtained across three blocks. To check the test re-test reliability all the tests were repeated on 20 participants after a gap of 30 days.

Results showed that both the working memory tasks had very high reliability. SNR-50 obtained for sentences had high reliability. Important results observed in the present study are

1. No significant difference seen in working memory scores across three blocks or in the average block except for PCS and PCSW in block three for RST.
2. Significantly lower SNR-50 scores for sentences as compared to SNR-50 scores for bisyllabic nonsense words.
3. Working memory had significant correlation with SNR-50 scores of bisyllabic nonsense words but not with the scores of sentences. This may imply that lower redundancy speech signal draws heavily on working memory capacity.

Implications of the study

1. This study has provided the normative data for OST, RST and SNR-50 using Smrithi-Shravan software

2. The study was helpful in understanding the relationship between working memory capacity and speech perception in noise.

REFERENCES

Arehart, K. H., Souza, P., Baca, R., & Kates, J. M. (2013). Working memory, age and hearing loss: Susceptibility to hearing aid distortion. *Ear and hearing*, *34*(3), 251.

Avinash, M. C., Meti, R., & Kumar, U. (2010). Development of sentences for Quick Speech-in-Noise (Quick SIN) test in Kannada. *Journal of Indian Speech and Hearing Association*, *24*(1), 59-65.

Baddeley, A. (2003). Working memory: looking back and looking forward. *Nature reviews neuroscience*, *4*(10), 829-839.

Baddeley, A. D., & Hitch, G. J. (2000). Development of working memory: Should the Pascual-Leone and the Baddeley and Hitch models be merged?. *Journal of experimental child psychology*, *77*(2), 128-137.

Baddeley, A. (2000). The episodic buffer: a new component of working memory?. *Trends in cognitive sciences*, *4*(11), 417-423.

Baddeley,A.(2012). Working memory: theories, models, and controversies. *Annual review of psychology*, *63*, 1-29.

Beattie, R. C., Barr, T., & Roup, C. (1997). Normal and hearing-impaired word recognition scores for monosyllabic words in quiet and noise. *British journal of audiology*, *31*(3), 153-164.

Broadway, J. M., & Engle, R. W. (2011). Individual differences in working memory capacity and temporal discrimination. *PLoS One*, *6*(10), e25422.

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

Cleary, M., Pisoni, D. B., & Geers, A. E. (2001). Some measures of verbal and spatial working memory in eight-and nine-year-old hearing-impaired children with cochlear implants. *Ear and hearing*, *22*(5), 395.

Colflesh, G. J., & Conway, A. R. (2007). Individual differences in working memory capacity and divided attention in dichotic listening. *Psychonomic Bulletin & Review*, *14*(4), 699-703.

Conway, A. R., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence*, *30*(2), 163-183.

Coolidge, F. L., & Wynn, T. (2005). Working memory, its executive functions, and the emergence of modern thinking. *Cambridge archaeological journal*, *15*(1), 5.

Craik (1991). Handbook of aging and cognition. Salthouse (Eds.), New Jersy.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of verbal learning and verbal behavior*, *19*(4), 450-466.

Desjardins, J. L., & Doherty, K. A. (2013). Age-related changes in listening effort for various types of masker noises. *Ear and hearing*, *34*(3), 261-272.

Edin, F., Macoveanu, J., Olesen, P., Tegnér, J., & Klingberg, T. (2007). Stronger synaptic connectivity as a mechanism behind development of working memory-related brain activity during childhood. *Journal of cognitive neuroscience*, *19*(5), 750-760.

Elliott, L. L. (1979). Performance of children aged 9 to 17 years on a test of speech intelligibility in noise using sentence material with controlled word predictability. *The Journal of the Acoustical Society of America*, *66*(3), 651-653.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. (1999). Working memory, short-term memory, and general fluid intelligence: a latent-variable approach. *Journal of experimental psychology: General*, *128*(3), 309.

Festen, J. M., & Plomp, R. (1990). Effects of fluctuating noise and interfering speech on the speech-reception threshold for impaired and normal hearing. *The Journal of the Acoustical Society of America*, *88*(4), 1725-1736.

Finitzo-Hieber, T., & Tillman, T. W. (1978). Room acoustics effects on monosyllabic word discrimination ability for normal and hearing-impaired children. *Journal of Speech, Language, and Hearing Research*, *21*(3), 440-458.

Foo, C., Rudner, M., Rönnberg, J., & Lunner, T. (2007). Recognition of speech in noise with new hearing instrument compression release settings requires explicit cognitive storage and processing capacity. *Journal of the American Academy of Audiology*, *18*(7), 618-631.

Friedman, N. P., & Miyake, A. (2004). The reading span test and its predictive power for reading comprehension ability. *Journal of memory and language*, *51*(1), 136-158.

Füllgrabe, C., & Rosen, S. (2016). Investigating the role of working memory in speech-in-noise identification for listeners with normal hearing. In *Physiology, Psychoacoustics and Cognition in Normal and Impaired Hearing* (pp. 29-36). Springer International Publishing.

Füllgrabe, C., & Rosen, S. (2016). On the (un) importance of working memory in speech-in-noise processing for listeners with normal hearing thresholds. *Frontiers in Psychology*, *7*.

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*(sup1), 77-85.

Geetha, C., Kumar, K. S., Manjula, P., & Pavan, M. (2014). Development and standardisation of the sentence identification test in the Kannada language. *J Hear Sci*, *4*(1), 18-26.

Gordon-Salant, S., & Cole, S. S. (2016). Effects of age and working memory capacity on speech recognition performance in noise among listeners with normal hearing. *Ear and hearing*, *37*(5), 593-602.

Gosselin, P. A., & Gagne, J. P. (2011). Older adults expend more listening effort than young adults recognizing speech in noise. *Journal of Speech, Language, and Hearing Research*, *54*(3), 944-958.

Green, A. M. (2007). The Interaction between Working Memory Capacity and Noise on Recall and Recognition of Orally Presented Text.

Gustafson, S. J., & Pittman, A. L. (2011). Sentence perception in listening conditions having similar speech intelligibility indices. *International journal of audiology*, *50*(1), 34-40.

Hambrick, D. Z., & Engle, R. W. (2002). Effects of domain knowledge, working memory capacity, and age on cognitive performance: An investigation of the knowledge-is-power hypothesis. *Cognitive psychology*, *44*(4), 339-387.

Helfer, K. S., & Wilber, L. A. (1990). Hearing loss, aging, and speech perception in reverberation and noise. *Journal of Speech, Language, and Hearing Research*, *33*(1), 149-155.

Hornsby, B. W., & Ricketts, T. A. (2001). The effects of compression ratio, signal-to-noise ratio, and level on speech recognition in normal-hearing listeners. *The Journal of the Acoustical Society of America*, *109*(6), 2964-2973.

Humes, L. E. (2007). The contributions of audibility and cognitive factors to the benefit provided by amplified speech to older adults. *Journal of the American Academy of Audiology*, *18*(7), 590-603.

Kane, M. J., Hambrick, D. Z., & Conway, A. R. (2005). Working memory capacity and fluid intelligence are strongly related constructs: comment on Ackerman, Beier, and Boyle (2005).

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: a latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology: General*, *133*(2), 189.

Kjellberg, A., Ljung, R., & Hallman, D. (2008). Recall of words heard in noise. *Applied Cognitive Psychology*, *22*(8), 1088-1098.

Klein, K., & Fiss, W. H. (1999). The reliability and stability of the Turner and Engle working memory task. *Behavior Research Methods, Instruments, & Computers*, *31*(3), 429-432.

Kollmeier, B., & Wesselkamp, M. (1997). Development and evaluation of a German sentence test for objective and subjective speech intelligibility assessment. *The Journal of the Acoustical Society of America*, *102*(4), 2412-2421.

Kumar, U. & Sandeep, M. (2013) Development and Test Trail of Computer Based Auditory-Cognitive Training Module for Individuals with Cochlear Hearing Loss. Departmental project. All India institute of Speech and Hearing.

Linden, D. E. (2007). The working memory networks of the human brain. *The Neuroscientist*, *13*(3), 257-267.

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

Lunner, T., & Sundewall-Thorén, E. (2007). Interactions between cognition, compression, and listening conditions: Effects on speech-in-noise performance in a two-channel hearing aid. *Journal of the American Academy of Audiology*, *18*(7), 604-617.

MacDonald, M. C., Almor, A., Henderson, V. W., Kempler, D., & Andersen, E. S. (2001). Assessing working memory and language comprehension in Alzheimer's disease. *Brain and language*, *78*(1), 17-42.

Martin, F. N. (1994). Hearing aid selection, in *Introduction to Audiology.* 256-279, Prentice Hall, Englewood Cliffs.

Mattys, S. L., Davis, M. H., Bradlow, A. R., & Scott, S. K. (2012). Speech recognition in adverse conditions: A review. *Language and Cognitive Processes*, *27*(7-8), 953-978.

Mayadevi, N. (1974). The development and standardization of a common speech discrimination test for Indians. *University of Mysore*.

McCabe, D. P., Roediger III, H. L., McDaniel, M. A., Balota, D. A., & Hambrick, D. Z. (2010). The relationship between working memory capacity and executive functioning: evidence for a common executive attention construct. *Neuropsychology*, *24*(2), 222.

Miller, G. A., Heise, G. A., & Lichten, W. (1951). The intelligibility of speech as a function of the context of the test materials. *Journal of experimental psychology*, *41*(5), 329.

Millman, R. E., & Mattys, S. (2016). Auditory verbal working memory as a predictor of speech perception in modulated maskers in normal-hearing listeners. *Journal of speech, language, and hearing research*.

Miyake, A., Friedman, N. P., Rettinger, D. A., Shah, P., & Hegarty, M. (2001). How are visuospatial working memory, executive functioning, and spatial abilities related? A latent-variable analysis. *Journal of experimental psychology: General*, *130*(4), 621.

Moore, B. C. (2008). The choice of compression speed in hearing aids: Theoretical and practical considerations and the role of individual differences. *Trends in Amplification*, *12*(2), 103-112.

Nakatani, L. H., & Schaffer, J. A. (1978). Hearing’’words’’without words: Prosodic cues for word perception. *The Journal of the Acoustical Society of America*, *63*(1), 234-245.

Neisser, U. (1967). *Cognitive psychology.* New York: Appleton-Century-Crofts

Oberauer, K., Schulze, R., Wilhelm, O., & Süß, H. M. (2005). Working memory and intelligence--their correlation and their relation: comment on Ackerman, Beier, and Boyle (2005).

Oberauer, K., Süß, H. M., Schulze, R., Wilhelm, O., & Wittmann, W. W. (2000). Working memory capacity—facets of a cognitive ability construct. *Personality and Individual Differences*, *29*(6), 1017-1045.

Osman, H., & Sullivan, J. R. (2014). Children's auditory working memory performance in degraded listening conditions. *Journal of Speech, Language, and Hearing Research*, *57*(4), 1503-1511.

Pichora-Fuller, M. K., Schneider, B. A., & Daneman, M. (1995). How young and old adults listen to and remember speech in noise. *The Journal of the Acoustical Society of America*, *97*(1), 593-608.

Redick, T. S., Broadway, J. M., Meier, M. E., Kuriakose, P. S., Unsworth, N., Kane, M. J., & Engle, R. W. (2012). Measuring working memory capacity with automated complex span tasks. *European Journal of Psychological Assessment*.

Roberts, K. L., & Allen, H. A. (2016). Perception and cognition in the ageing brain: a brief review of the short-and long-term links between perceptual and cognitive decline. *Frontiers in aging neuroscience, 8.*

Rönnberg, J., Rudner, M., Foo, C., & Lunner, T. (2008). Cognition counts: A working memory system for ease of language understanding (ELU). *International Journal of Audiology*, *47*(sup2), S99-S105.

Rönnberg, J., Rudner, M., Lunner, T., & Zekveld, A. A. (2010). When cognition kicks in: Working memory and speech understanding in noise. *Noise and Health*, *12*(49), 263.

Rudner, M., Rönnberg, J., & Lunner, T. (2011). Working memory supports listening in noise for persons with hearing impairment. *Journal of the American Academy of Audiology, 22*(3), 156-167.

Sbompato, A. F., Corteletti, L. C. B. J., Moret, A. D. L. M., & de Souza Jacob, R. T. (2015). Hearing in Noise Test Brazil: standardization for young adults with normal hearing. *Brazilian journal of otorhinolaryngology*, *81*(4), 384-388.

Shetty, H. N., & Mendhakar, A. (2015). Development of phrase recognition test in Kannada language. *Journal of Indian Speech Language & Hearing Association*, *29*(2), 21.

Stiles, D. J., McGregor, K. K., & Bentler, R. A. (2012). Vocabulary and working memory in children fit with hearing aids. *Journal of Speech, Language, and Hearing Research*, *55*(1), 154-167.

Tamati, T. N., Gilbert, J. L., & Pisoni, D. B. (2013). Some factors underlying individual differences in speech recognition on PRESTO: A first report. *Journal of the American Academy of Audiology*, *24*(7), 616-634.

Turley-Ames, K. J., & Whitfield, M. M. (2003). Strategy training and working memory task performance. *Journal of Memory and Language*, *49*(4), 446-468.

Unsworth, N., Redick, T. S., Heitz, R. P., Broadway, J. M., & Engle, R. W. (2009). Complex working memory span tasks and higher-order cognition: A latent-variable analysis of the relationship between processing and storage. *Memory*, *17*(6), 635-654.

Valente, D. L., Plevinsky, H. M., Franco, J. M., Heinrichs-Graham, E. C., & Lewis, D. E. (2012). Experimental investigation of the effects of the acoustical conditions in a simulated classroom on speech recognition and learning in children a. *The Journal of the Acoustical Society of America*, *131*(1), 232-246.

Waters, G. S. (1996). The measurement of verbal working memory capacity and its relation to reading comprehension. *The Quarterly Journal of Experimental Psychology: Section A*, *49*(1), 51-79.

Wilson, R. H., & Strouse, A. N. N. E. L. (1999). Auditory measures with speech signals. *Contemporary perspectives in hearing assessment*, *1*, 21.

Wilson, R. H., Farmer, N. M., Gandhi, A., Shelburne, E., & Weaver, J. (2010). Normative data for the Words-in-Noise Test for 6-to 12-year-old children. *Journal of Speech, Language, and Hearing Research*, *53*(5), 1111-1121.

Wilson, R. H., McArdle, R. A., & Smith, S. L. (2007). An evaluation of the BKB-SIN, HINT, QuickSIN, and WIN materials on listeners with normal hearing and listeners with hearing loss. *Journal of Speech, Language, and Hearing Research*, *50*(4), 844-856.

Wong, P. C., Jin, J. X., Gunasekera, G. M., Abel, R., Lee, E. R., & Dhar, S. (2009). Aging and cortical mechanisms of speech perception in noise. *Neuropsychology*, 47(3), 693-703.