EFFECT OF WORKING MEMORY ON HEARING AID BENEFIT IN ELDERLY

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Master of Science (Audiology)

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May, 2014

CERTIFICATE

This is to certify that the dissertation entitled "**Effect of Working Memory on Hearing Aid Benefit in Elderly"** is a bonafide work submitted in part fulfilment for the Degree of Master of Science (Audiology) of the student (Registration no. 12AUD0004). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any Universities for the award of any Degree or Diploma.

Mysore
May,2014

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CERTIFICATE

This is to certify that the dissertation entitled "**Effect of Working Memory on Hearing Aid Benefit in Elderly"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any Degree or Diploma.

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May,2014

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DECLARATION

This is to certify that this dissertation entitled “**Effect of Working Memory on Hearing Aid Benefit in Elderly”**is the result of my own study under the guidance of Dr.Ajith Kumar U, Reader, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Degree or Diploma.

Mysore
May,2014

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CHAPTER 1 - INTRODUCTION

Under normal circumstances, speech perception can be considered as involuntary as we directly recognize the spoken words with seemingly less effort (Fodor, 1983). However, speech perception becomes demanding in challenging environments such as listening to speech in noise or reverberation, (Francis & Nusbaum, 2009). Thus, understanding speech can be a serious challenge in day to day life. A number of distortions are present in typical listening environments that adversely affect speech intelligibility. These can be the external adverse factors and internal human factors. For example, the traffic noise, multiple talkers, reverberation etc. can be considered as external adverse factors. In addition to these external adverse factors, speech intelligibility can also be severely hampered by internal human factors.

Changes and challenges are seen in many areas due to ageing. These age related changes are reported to be in sensory abilities (Gordon-Salant, Frisina, Popper, & Fay, 2010), socio-emotional processes (Urry & Gross, 2010), and cognitive abilities (Craik & Salthouse, 2007). Although there are individual differences, ageing is commonly associated with declines in cognitive resources in the areas of attention (McDowd & Shaw, 2000), working memory, and executive function (Baddeley, 2002; Verhaeghen & Cerella, 2002), and mental processing speed (Salthouse, 1996). Hearing loss is prevalent in almost two thirds of adults older than 70 years of age (Fischer, Cruickshanks, Wiley, Klein, Klein, & Tweed, 2011; Chien & Lin, 2012). Word recognition for speech presented in quiet at low-to-conversational levels shows a linear decline with age of approximately 12% per decade for adults older than 60 years (Gates *et al.,* 1990). Thus, hearing loss in elderly can be considered as a type of internal human factor that adversely affect speech perception. In addition, distracting signals or noise in the environment can have adverse effects on communication. Thus in elder individuals, these speech understanding problems become even more prominent (CHABA (Committee on Hearing Bioacoustics and Biomechanics), 1988). However, whether these deficits in speech perception in elderly are due to auditory factors and/or cognitive factors is still a matter of debate. Resolving this issue is not only of scientific interest but also has practical utility in diagnosis and rehabilitation of individuals with hearing impairment.

The term “working memory” refers to a simple temporary storage of information and manipulation. 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” (Baddeley, 2000). 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. Working memory can be assessed using simple span tasks and complex span tasks. Simple span tasks include the forward, backward, ascending and descending digit, visual and spatial spans. Reading span, operational tasks, rhyme judgement, visual letter monitoring etc. constitute the complex span tasks.

Working-memory capacity is one cognitive process that is positively associated with speech-communication abilities (Cleary, Pisoni, & Geers, 2001; Pisoni & Geers, 2000). Hence, it might play a role in the speech-recognition performance of elderly hearing impaired (EHI) listeners. The situation becomes more cognitively demanding than normally when the incoming signal is distorted or has limited information due to adverse listening conditions or a hearing impairment. In the past few years, several studies have shown that hearing loss is associated with declining cognitive function. Lin (2011) demonstrated significant associations between greater hearing loss and cognitive function on both verbal and non-verbal cognitive tests. Similar studies were reported by others too (Balwin & Ash, 2011; Lunner, 2003)

Hearing aids serve as primary forms of rehabilitation in elderly individuals with hearing impairment to restore the audibility of speech. Last few decades, there have been significant advances in the design of hearing aids. Humes, Halling, and Couhlin (1996) studied the aided speech identification in elderly and reported improvement in word recognition score in aided condition compared to unaided condition. But even then, significant proportions of hearing impaired adults' complain of difficulty in understanding speech in adverse listening conditions especially, in real life. This indicates that there are deficits at higher levels other than the auditory system that may contribute to speech recognition difficulties.

Need for the study

Verbal communication often occurs in noisy backgrounds. With appropriate amplification individuals with hearing impairment in the speech range experience relatively little difficulty in understanding one talker in a quiet listening environment; however, they report difficulty understanding speech in noise and in multi-talker situations. Over the last decades, there have been significant advances in the design of hearing aids-with the incorporation of noise reduction algorithms; improved microphone and receiver technology- so on and so forth. But even then, significant proportions of hearing impaired adults' complain of difficulty in understanding speech in adverse listening conditions. Underlying mechanisms of speech perception deficits in hearing impaired individuals is unclear. These deficits probably may have a cognitive origin rather than simply auditory. In this context the present study aims to investigate the role of working memory on the benefits derived from hearing aids.

Aim of the study

To investigate the relationship between working memory on hearing aid benefit in elderly.

Objective

1. To find out the relationship between working memory tests assessing the phonological loop and hearing aid benefit in a group of elderly individuals with hearing loss.

2. To find out the relationship between working memory tests assessing the visuo-spatial skills and hearing aid benefit in a group of elderly individuals with hearing loss.

CHAPTER 2 - REVIEW OF LITERATURE

Every oral communication is dependent on information being appropriately received and understood. Detection and integration of sounds, words and sentences into meaningful units are included in this speech understanding process. However, understanding speech can be a serious challenge in day to day life. A number of distortions are present in typical listening environments that adversely affect speech intelligibility. These can be the external adverse factors and internal human factors. For example, the noise caused by the traffic and multiple talkers, or the presence of reverberation in large hallways in railway stations, churches or hospitals can be considered as external adverse factors. In addition to these external adverse factors, speech intelligibility can also be severely hampered by internal human factors.

Hearing loss, an internal human factor, is found to be third most common chronic condition reported in geriatric population (Lethbridge-Çejku, Schiller, & Bernadel, 2004). About 25% to 60% of people over 65 years of age are estimated to have hearing loss sufficient enough to impair their communication (Sangster, Gerace, & Seewald, 1991). They often complain of inability to understand speech mostly in noisy situations even when the sound levels are well above their detection thresholds. Listeners with hearing impairment tend to be more vulnerable to these external adverse factors like noise and reverberation. Large differences are observed in speech perception abilities of normal hearing and those of hearing impairment during variable background noise surroundings, (Festen & Plomp, 1990). Hence, it is necessary to know the underlying mechanisms for speech perception in noise since variable background noise surroundings are very common in day to day situations (Kramer, Kapteyn, Festen, & Tobi, 1996).

Internal human factors can be sub divided into auditory and non-auditory factors. Auditory factors are defined as factors that are related to processing in the peripheral and central auditory pathways, while non-auditory factors are related to modality-specific or general central, cognitive, or linguistic skills.

Auditory factors

Plomp (1978) describes two auditory parameters that affect speech perception. a. Increase in absolute hearing threshold, and b. hearing loss induced supra-threshold distortion (Stephans, 1976; Glasberg & Moore, 1989). These supra-threshold deficits particularly include reduced spectral and temporal auditory resolution and an abnormal auditory compression. The inter-relationship between these deficits to hearing threshold is still unclear (Ludvigsen, 1985; Oxenham & Bacon, 2003). Thus, speech perception in noise is thought to be affected as a result of reduced temporal and spectral resolution. (Glasberg & Moore, 1987; 1992; Festen & Plomp, 1990; Festen, 1993; Baer & Moore, 1993, 1994; Boothroyd, Mulhearn, Gong, & Ostroff, 1996). Pichora-Fuller, Schneider, and Daneman (1995) reported that speech understanding especially in complex listening environments worsens due to cochlear damage and age related changes in auditory processing. Nabelek and Mason (1981) also reported that the word recognition scores declined as a function of the signal to noise ratio in individuals with bilateral sensorineural hearing loss.

Non-auditory factors

Hearing aids serve the primary forms of rehabilitation in elderly individuals with hearing impairment to restore the audibility of speech. Last few decades there has been considerable improvement in design of hearing aids. But even then, significant proportions of hearing impaired adults' complain of difficulty in understanding speech in adverse listening conditions. Deficits in non-auditory processes can affect speech perception in the presence of background noise (Humes, 2005). The process of speech perception not only involves the peripheral auditory system but also depends on the central auditory pathways and cognitive functions in the areas of attention (McDowd & Shaw, 2000), working memory, executive function (Baddeley, 2002; Verhaeghen & Cerella, 2002), and general mental processing speed (Salthouse, 1996). Poorer results are observed on highly demanding working memory tasks as well as an overall decline in speed of performance (e.g. Salthouse, 1996; Wingfield & Tun, 2001). Researchers have also found deterioration in some cognitive tasks as a result of severe hearing-impairment and in hard of hearing people. More precisely, it has been proven that the phonological ability declines when auditory stimulation is reduced during a longer period (Andersson & Lyxell, 1998) for individuals with severe hearing impairment and hard of hearing.

The relative contribution of auditory and non-auditory processes to speech reception is, however, still under discussion. Thus, the speech understanding process yields not only the sensation of an auditory stimulus, but also its processing and analysis in accordance to the previous experiences. Information about how things are connected and grouped is stored in a long-term memory. Thus, hearing includes both audition and cognition. The sensory information and cognitive processing has to be available for conscious manipulation. In theoretical models (Baddeley, 2002) the working memory is responsible for the active part in language comprehension, as well as for the transfer of information into long-term memory.

Working Memory

The term “working memory” evolved from the earlier concept of short-term memory (STM), and the two are still on occasion used interchangeably. STM refers to the simple temporary storage of information, in contrast to working memory (WM), which implies a combination of storage and manipulation.

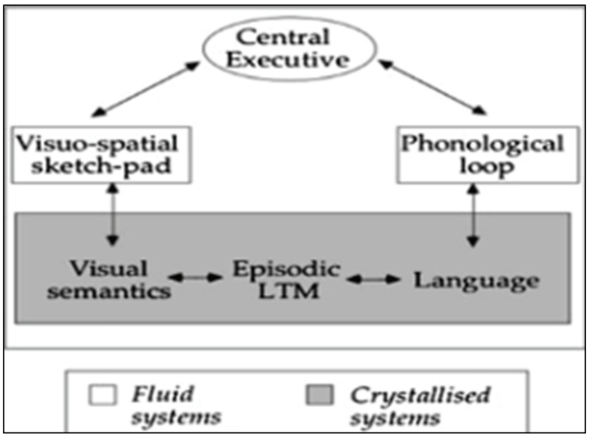


Figure 2.1. Modified Baddeley & Hitch (2012) working memory model (Adapted from “Working Memory: Theories, Models, and controversies: Alan Baddley, 2012”)

Baddeley & Hitch (1974) had split working memory model into attentional control from temporary storage. The original Baddeley & Hitch (1974) working memory model referred the verbal model as an “articulatory loop”, i.e. sub-vocal rehearsal assumed to be necessary to maintain information, and later adopted the term “phonological loop” to emphasize storage rather than rehearsal. The central controller was labelled as a “central executive” (CE). The third component the “visuo-spatial sketchpad,” constituted visual, spatial, or both. As there was no potential for storage other than the limited capacities of the visuo-spatial and phonological subsystems a fourth component, the episodic buffer (Baddeley, 2000) was added. As it can hold multidimensional representations, it can be called as a buffer store not only between the components of WM, but also linking WM to perception and long term memory (LTM) but has a limited capacity.

Working memory tests

Working memory can be assessed using simple span tasks and complex span tasks. Simple tasks include the forward, backward, ascending and descending digit, visual, spatial spans. Reading span, operational tasks, rhyme judgement, visual letter monitoring etc. constitute the complex tasks.

Simple tasks

Digits spans (also known as memory scanning) *Forward digit span:* Here, a sequence of digits is randomly presented auditorily, with an increasing level of difficulty. Each time the participant correctly repeats the sequence, the length is increased by 1 digit. If an incorrect response has occurred, the length is shortened by 1 digit. An inter-stimulus interval of usually 1 second is preferred. The participants are instructed to repeat back the numbers in the same order as presented. The scoring is based on the mean of number of digits corrected repeated by the participant for 3-5 reversals.

Backward digit span: Here, a sequence of digits is randomly presented auditorily, with an increasing level of difficulty. Each time the participant correctly repeats the sequence, the length is increased by 1 digit. If an incorrect response has occurred, the length is shortened by 1 digit. An inter-stimulus interval of usually 1 second is preferred. The participants are instructed to repeat back the numbers in the reverse order as presented. The scoring is based on the mean of number of digits corrected repeated by the participant for 3-5 reversals.

Ascending digit span: Here, a sequence of digits is randomly presented auditorily, with an increasing level of difficulty. Each time the participant correctly repeats the sequence, the length is increased by 1 digit. If an incorrect response has occurred, the length is shortened by 1 digit. An inter-stimulus interval of usually 1 second is preferred. The participants are instructed to repeat back the numbers in an ascending order as presented. The scoring is based on the mean of number of digits corrected repeated by the participant for 3-5 reversals.

Descending digit span: Here, a sequence of digits is randomly presented auditorily, with an increasing level of difficulty. Each time the participant correctly repeats the sequence, the length is increased by 1 digit. If an incorrect response has occurred, the length is shortened by 1 digit. An inter-stimulus interval of usually 1 second is preferred. The participants are instructed to repeat back the numbers in the descending order as presented. The scoring is based on the mean of number of digits corrected repeated by the participant for 3-5 reversals.

Visual tasks (also known as memory scanning) *Forward Visual task:* Here, a sequence of shapes (squares and circles) is presented visually, with an increasing level of difficulty. Shapes are randomly presented. Each shape is presented for 2 seconds followed by a 1 second gap before the onset of the next shape. Participants are instructed to direct the shapes displayed in the same order as presented. The scoring is based on mean of the number of shapes correctly identified by the participant for 3-5 reversals.

Backward Visual task: Here, a sequence of shapes (squares and circles) is presented visually, with an increasing level of difficulty. Shapes are randomly presented. Each shape is presented for 2 seconds followed by a 1 second gap before the onset of the next shape. Participants are instructed to direct the shapes displayed in the same order as presented. The scoring is based on mean of the number of shapes correctly identified by the participant for 3-5 reversals.

Complex span tasks

Reading span test: A sentence is presented word-by-word. The participant has to decide at the end if the sentence is meaningful or is a nonsense statement. After presentation of a small number of sentences, the participant has to recall the initial or last word for each of the sentences. (Daneman & Carpenter's, 1980)

Visual letter or digit monitoring

Visual letter monitoring: Letters are presented sequentially on a computer screen with an inter stimulus interval of 1 or 2 seconds. The participant has to monitor the sequence of letters and when three successive letters form a meaningful sequence, the keyboard space-bar has to be pressed. (Knuston et al., 1991)

Digit monitoring task: Digits (1-9) are presented sequentially on a computer screen with an inter stimulus interval of 1 or 2 seconds. The participant has to monitor the sequence of digits and when three successive numbers form an 'odd-even-odd' sequence, the keyboard space-bar has to be pressed. (Knuston et al., 1991)

Working memory, speech comprehension and hearing loss

Working-memory capacity is a cognitive process that has been positively associated with speech-communication abilities (Cleary, Pisoni, & Geers, 2001; Pisoni & Geers, 2000). It is reasonable to assume that working memory capacity might play a role in the speech-recognition performance of elderly hearing impaired (EHI) listeners. If the incoming signal is distorted or has limited information due to adverse listening conditions or a hearing impairment, then the situation becomes more cognitively demanding than normally. Thus, 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.

In the past few years, several studies have shown that hearing loss is associated with declining cognitive function (Hällgren, 2005; Lin, 2011). Lin (2011) demonstrated significant associations between greater hearing loss and poorer cognitive function on both verbal and nonverbal cognitive tests. He has also found that hearing aid use was associated with higher cognitive scores. Balwin and Ash (2011) found considerable decline in working memory capacity in older population as compared to the younger group. They correlated reading span task and listening span task to the speech recognition threshold. Auditory working memory scores dependent on level of presentation and hearing loss. Lower the level of presentation or more the hearing loss poorer the auditory working memory scores.

Similar studies were done by Lunner (2003) comparing the predictive values of two cognitive tests, reading span and letter monitoring, in relation to aided speech recognition in noise and he found that reading span was a strong predictor of speech recognition in noise. Daneman and Merikle (1996) reported that the measures taxing the combined processing and storage capacity of the working memory (e.g. reading span, listening span) are more sensitive measures of cognitive function than the measures that tax only the storage capacity (e.g. word span, digit span).

Era, Jokela, Qvarnberg, and Heikkinen (1986) studied the relationship between pure-tone thresholds, cognitive factors and speech understanding. Cognitive capacity was assessed with the help of three Wechsler Adult Intelligence Scale

(WAIS) sub-scales (digit span, arithmetic and block design). They correlated audiological measures to other sensory functions, psychomotor speed, cognitive functions, occupational and educational background and health. They found that the speech understandings tests correlated significantly to the pure-tone thresholds at 4000 Hz and also at the mean of 500 Hz, 1000 Hz, and 2000 Hz. Also, the speech understanding tests correlated significantly to all the tests for cognitive abilities.

Benichov, Cox, Tun, and Wingfield (2012) examined the correlation among age, hearing loss, verbal ability and cognitive function on the use of linguistic context in spoken word recognition. In cognitive function, episodic memory, working memory and processing speed was assessed. Backward digit span from the WAIS III (Weschsler, 1997) was used to assess the working memory. Results indicated that the role of peripheral hearing acuity was minimal in word recognition accuracy whereas significant variance contributed by individual differences in cognitive function and participant age.

Lunner and Sundwell-Thoren (2007) studied the interaction between cognition, compression and listening conditions in 23 experienced hearing aid users. The results indicated that subjects showing a low score in the visual monitoring task (cognitive test) performed better in unmodulated than in modulated noise while the opposite pattern were seen for subjects with high performance on cognitive tests. It was also seen that cognitive test scores were significantly correlated with the differential advantage of fast acting versus slow acting compression in conditions of modulated noise.

Rudner, Foo, Ronnberg, and Lunner (2007) conducted a study to test whether speech processing becomes difficult when there is a mismatch between speech input and phonological representations in long term memory. For this they changed compression settings in the hearing aids of 9 experienced users. New settings comprised of fast (40 ms) or slow (640 ms) compression release settings. This was followed by their training for nine weeks with the new settings followed by retesting of scores of speech recognition in modulated or unmodulated noise using Hagerman sentences and Hearing in noise test (HINT). Cognitive capacity was measured using the reading span and letter monitoring tests. Results indicated that stronger correlations were found between performances on speech recognition with the Hagerman sentences and the reading span test. Serial, accurate processing and storage is required for the letter monitoring test whereas simultaneous, accurate processing and short-term storage (dual capacity) is required for the reading span test. Thus, the dual capacity is the 'critical complex cognitive capacity' in relation to mismatch which supports for the Ease of Language Understanding (ELU) framework. The ELU predicts that mismatch occurs till the level of explicit cognitive processing and once the threshold is overdone, then the functioning worsens.

In a study by Gatehouse, Naylor, and Elberling (2003), 50 listeners were experimented with 5 different hearing aid conditions out of which two constituted of linear amplification and the other three constituted of non-linear amplification that differed in release time constants. Speech recognition score was assessed using Four Alternative Auditory Feature (FAAF) whereas visual digit monitoring and visual letter monitoring tasks were used to assess cognitive abilities. The interaction between the hearing acuity and the cognitive characteristics of listeners and the test condition under which the speech identification procedures were conducted such as presentation level, SNR, and temporal characteristics of interfering noise were investigated. Significant interactions were found between hearing aid benefit and cognitive ability, and the background noise. Specifically, it was found that individuals with greater cognitive ability derive greater benefit from temporal structure in background noise using fast time constraints which facilitates listening in the gaps.

CHAPTER 3 - METHOD

The present study aimed to investigate the effect of working memory on hearing aid benefit in elderly individuals.

Participants

A total number of 20 participants with cochlear hearing loss consisting of 17 males and 3 females ranged in age from 50-80 years (mean age of 67.65 years) participated in the study. Participants were recruited from the Audiology clinic of All India Institute of Speech and Hearing, Mysore. All the participants in the study had bilateral symmetrical hearing loss in the range of moderate to severe degree. Symmetry of hearing loss was defined as less than or equal to 15 dB difference in the hearing thresholds of the right ear and left ears (Gatehouse, Naylor, & Elberling, 2003, 2006) at corresponding frequencies. Participants selected had a word recognition score in accordance to the pure tone hearing loss (Vanaja & Jayaram, 2005). All the participants were native Kannada speakers and naïve hearing aid users. All the participants had normal middle ear functioning as indicated by normal otoscopic and immittance findings. All participants were screened for retro cochlear pathology using auditory brainstem responses. Participants were also screened for severe vision loss based on the corrected vision. None of the participants had any history or presence of neurological problems.

The present study was conducted in 3 stages

Stage I: Audiological evaluation

Stage II: Hearing aid fitting

Stage III: Working memory evaluation

Stage I

Audiological evaluation: Purpose of routine audiological evaluation was to determine the candidacy of the participants. Following audiological procedures were carried out prior to inclusion of the participants in the study.

Pure tone audiometry*:* Pure-tone thresholds were obtained using Piano Inventis dual channel audiometer using modified Hughson and Westlake procedure (Carhart & Jerger, 1959), at octave frequencies from 250 Hz to 8000 Hz for air conduction through TDH-39 headphones and from 250 Hz to 4000 Hz for bone conduction stimulation through Radio Ear B-71. Only those participants with the hearing thresholds in the range of moderate to moderately-severe (40-70 dB HL) were included for the study. Difference between air and bone conduction thresholds were within 10 dB at octave frequencies form 250 Hz to 4000 Hz in all the participants.

Speech audiometry: Speech recognition thresholds (SRT), word recognition score (WRS) and uncomfortable loudness level (UCL) were determined. SRT was obtained using the paired words in Kannada developed by Rajasekhar (1976). All the participants had SRT within 12 dB of PTA. 40 dB above SRT level, WRS was acquired using the phonemically balanced (PB) words in Kannada developed by Yathiraj and Vijayalakshmi (2005). Only those participants with WRS proportional to pure tone hearing loss (more than 70 % as per Vanaja & Jayaram, 2005) were included in the study.

Immittance evaluation: The tympanogram was obtained using GSI-Tympstar middle ear analyser by varying the air pressure in the ear canal from +200 to -400 daPa, using a 226 Hz probe-tone presented at 85 dB SPL. Using the probe-tone frequency as above, ipsilateral and contralateral acoustic reflex thresholds were acquired at octave frequencies from 500 to 4000 Hz. All the participants had 'A' type tympanogram and reflexes correlating to pure tone hearing threshold indicating normal middle ear function.

Stage II

Hearing aid fitting: A channel free Inizia 3 CP non-linear digital hearing aid was programmed bilaterally according to the degree of hearing loss using NOAH software with a Hi-Pro connected to a PC. Hearing aid was programmed using national acoustics laboratory non-linear 1 fitting formula. First fit was applied and the acclimatization level was kept at 1.The gain provided by the hearing aid was verified using Interacoustics Affinity 2.0 real-ear measurements-440 system. The probe microphone insertion depth of 28 mm was maintained for all participants. The International speech test signal was presented at 40, 60, 80 dB SPL and real ear aided response curves were obtained. Fine tuning was done wherever required to match the respective target curves. Subjective preference was also accounted during fine tuning.

Hearing aid benefit verification

SNR-50: Binaural unaided and aided SNR 50 was calculated using standardized speech perception in noise test (Methi, Avinash, & Kumar, 2009). Speech perception in noise test consisted of seven lists each contained 7 sentences mixed with the four talker speech babble noise at different signal to noise ratios (SNRs). First sentence in each list was at +8 dB SNR and in the decreasing order of -3 dB till the seventh sentence which consisted of -10 dB SNR. Each sentence had 5 key words. These sentences were presented through a personal computer (Dell Inspiron 15R-5520) at the most comfortable level (MCL) through loudspeakers connected to a calibrated audiometer. Most comfortable level was calculated using procedure given by Nabelek (2004). To avoid familiarity to the test material, three lists of sentences were presented in the unaided condition and three in the aided condition. The subjects' task was to correctly repeat the sentences presented in Kannada. For each correctly repeated key word, one point was granted from a total of 35 points for one list. The number of key words correctly identified was calculated for each SNR. The SNR 50 was determined using the Spearman-Karber equation (Finney, 1952)

SNR-50 = i + 1/2 (d) – (d) (# correct)/w

Where,

i= the initial presentation level (dB S/N)

d= the attenuation step size (decrement)

w= the number of items per decrement

= number of correctly identified words

Hearing benefit was determined by the difference between aided and unaided SNR-50

Stage III

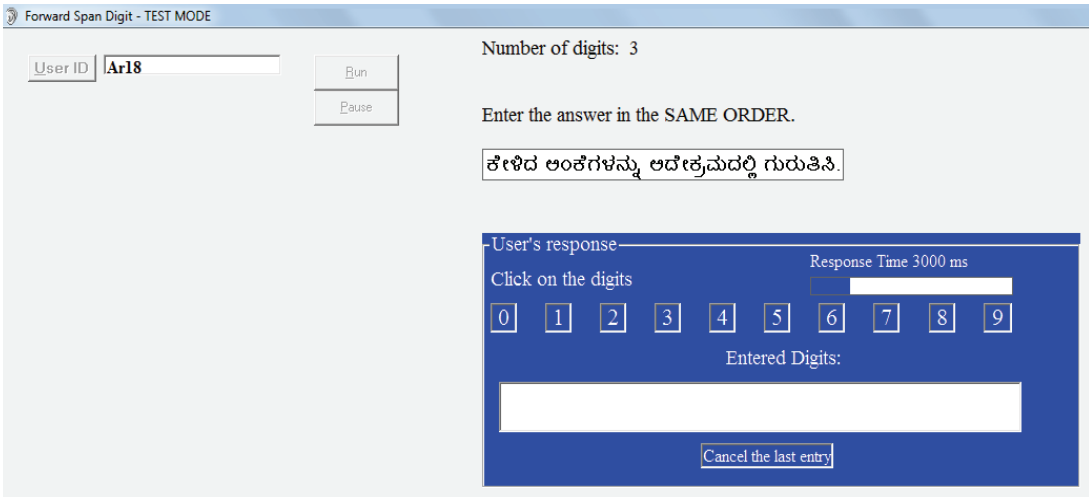
Working memory assessment: Different working memory tests that test phonological loop and visuo-spatial loop of the working memory were administered on participants. All the working memory tests were administered using computer program "auditory cognitive training module" developed by Kumar & Sandeep

(2013). The auditory working memory tests were presented through loudspeakers at a comfortable listening level.

Tests that assess phonological loop are:

Forward Span digit: Here, a sequence of digits from 0-8 was presented auditorily using the software. Bracketing method was used to measure the maximum number of digits that the person can recall. Bracketing stopped after 6 reversals and only last four reversals were considered for analyses. Digits were randomly presented. Level 1 contained 2 digits whereas level 7 contained 8 digits (Figure 3.1). An interstimulus interval of 1 second was maintained at all levels and the participants were instructed to repeat back the numbers in the same order as presented. The scoring was based on the number of digits correctly repeated by the participant.

Figure 3.1. Screenshot of Forward Span



User ID: Ar18

Number of digits: 3

Enter the answer in the SAME ORDER.

ಕೇಳಿದ ಅಂಕೆಗಳನ್ನು ಅದೇಕ್ರಮದಲ್ಲಿ ಗುರುತಿಸಿ.

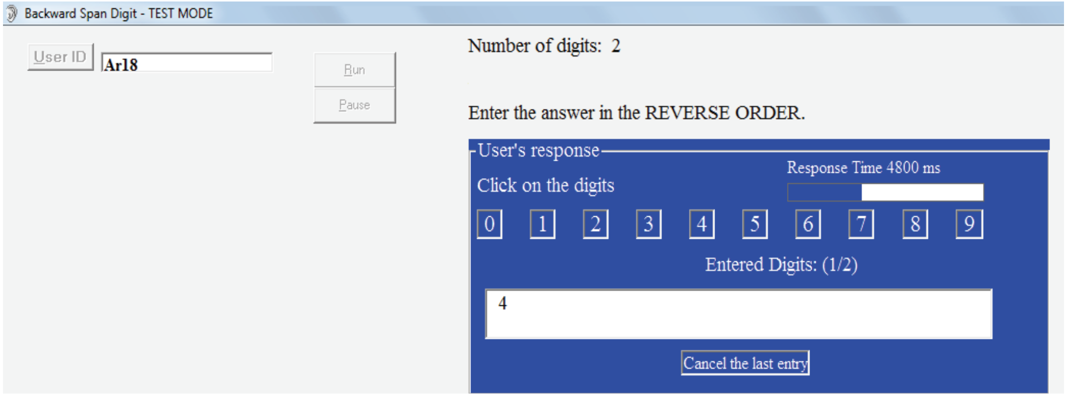
Response Time 3000 ms

Entered Digits:

Figure 3.1. Screenshot shows 3 digits are presented to the participant. Instructions are displayed on the screen in Kannada (native language) and English. Clinician has to click on the digits repeated by the participant in the same order

Backward Span digit: Here, a sequence of digits from 0-8 was presented auditorily using the software. Bracketing method was used to measure the maximum number of digits that the person can recall. Bracketing stopped after 6 reversals and only last four reversals were considered for analyses. Digits were randomly presented. Level 1 contained 2 digits whereas level 7 contained 8 digits (Figure 3.2). An interstimulus interval of 1 second was maintained at all levels and the participants were instructed to repeat the back numbers in the reverse order as presented. The scoring was based on the number of digits correctly repeated by the participant.

Figure 3.2. Screenshot of Backward Span Digit



Backward Span Digit - TEST MODE

User ID: Ar18

Number of digits: 2

Enter the answer in the REVERSE ORDER.

Response Time 4800 ms

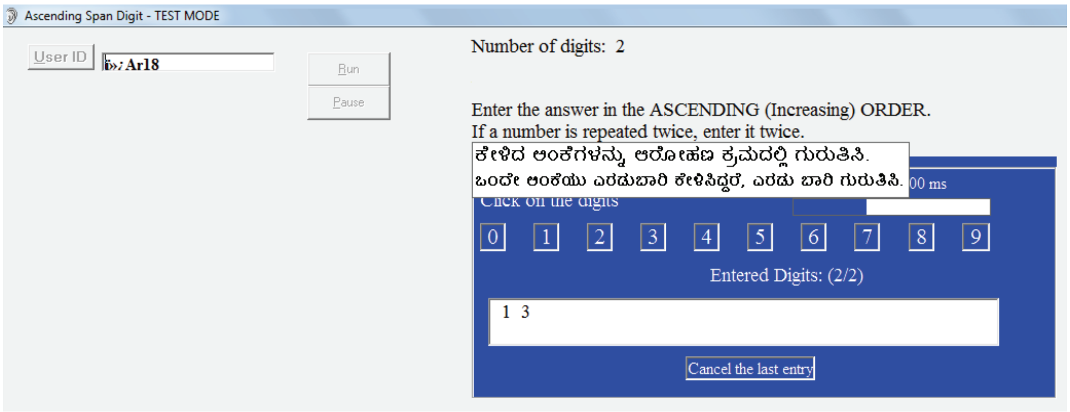
Entered Digits: (1/2)

4

Figure 3.2. Screenshot shows 2 digits are presented auditorily to the participant. Clinician has to click on the digits repeated by the participant in a reverse order.

Ascending span digit: Here, a sequence of digits from 0-8 was presented auditorily using the software. Bracketing method was used to measure the maximum number of digits that the person can recall. Bracketing stopped after 6 reversals and only last four reversals were considered for analyses. An interstimulus interval of 1 second was maintained at all levels and the participants were instructed to repeat back the numbers displayed in the ascending order (lowest-highest) as presented. The scoring was based on the number of digits correctly repeated by the participant.

Figure 3.3. Screenshot of Ascending Span Digit



User ID: ï»¿Ar18

Number of digits: 2

Enter the answer in the ASCENDING (Increasing) ORDER.
If a number is repeated twice, enter it twice.
ಕೇಳಿದ ಅಂಕೆಗಳನ್ನು ಆರೋಹಣ ಕ್ರಮದಲ್ಲಿ ಗುರುತಿಸಿ.
ಒಂದೇ ಅಂಕೆಯು ಎರಡುಬಾರಿ ಕೇಳಿಸಿದ್ದರೆ, ಎರಡು ಬಾರಿ ಗುರುತಿಸಿ.

00 ms

Click on the digits

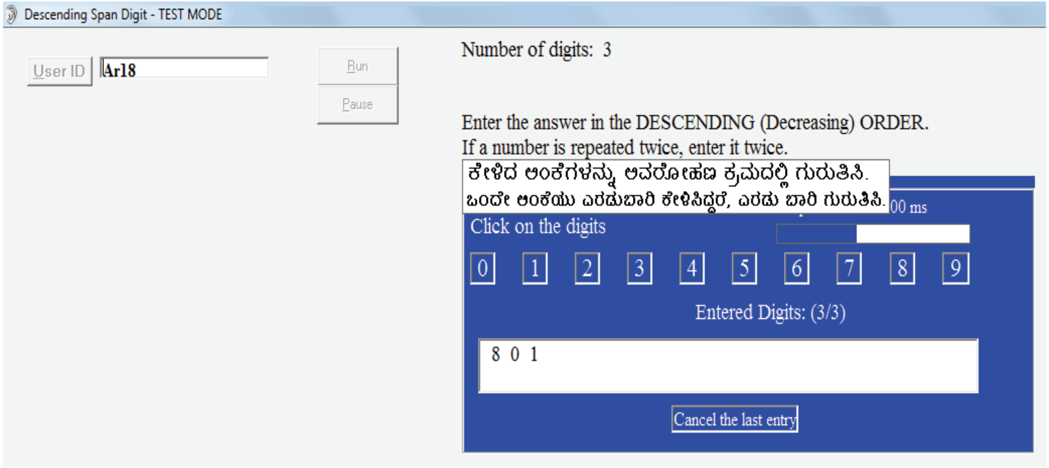
Entered Digits: (2/2)

1 3

Figure 3.3. Screenshot shows 2 digits are presented auditorily to the participant. Clinician has to click on the digits repeated by the participant in an ascending order.

Descending span digit: Here, a sequence of digits from 0-8 was presented auditorily using the software. Bracketing method was used to measure the maximum number of digits that the person can recall. Bracketing stopped after 6 reversals and only last four reversals were considered for analyses. Digits were randomly presented. Level 1 contained 2 digits whereas level 7 contained 8 digits. An interstimulus interval of 1 second was maintained at all levels and the participants were instructed to repeat back the numbers in the descending order (highest-lowest) as presented. The scoring was based on the number of digits correctly repeated by the participant.

Figure 3.4. Screenshot of Descending Span Digit



User ID: Ar18

Number of digits: 3

Enter the answer in the DESCENDING (Decreasing) ORDER.
If a number is repeated twice, enter it twice.
ಕೇಳಿದ ಅಂಕೆಗಳನ್ನು ಅವರೋಹಣ ಕ್ರಮದಲ್ಲಿ ಗುರುತಿಸಿ.
ಒಂದೇ ಅಂಕೆಯು ಎರಡುಬಾರಿ ಕೇಳಿಸಿದ್ದರೆ, ಎರಡು ಬಾರಿ ಗುರುತಿಸಿ.

00 ms

Click on the digits

Entered Digits: (3/3)

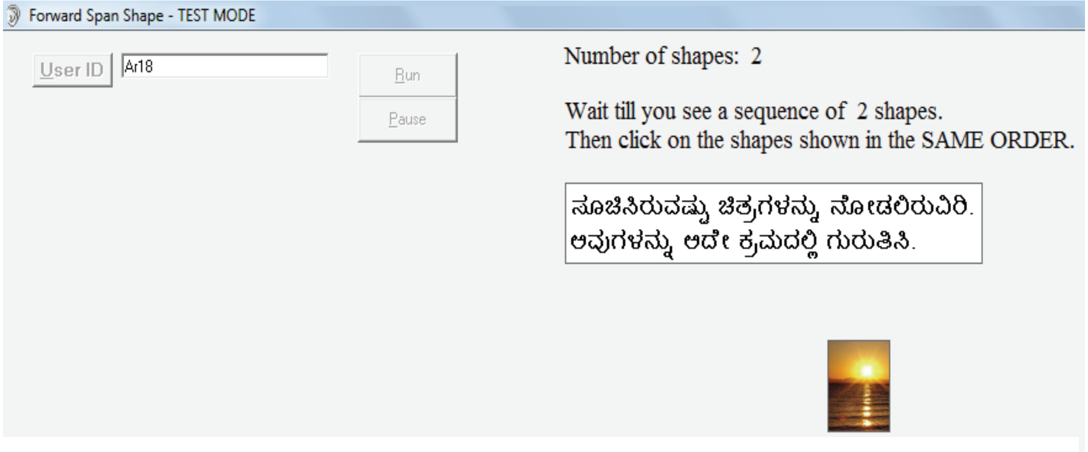
8 0 1

Figure 3.4. Screenshot shows 3 digits are presented auditorily to the participant. Clinician has to click on the digits repeated by the participant in descending order.

Tests that assess visuo-spatial loop of working memory are

Forward span Visual: Here, a sequence of shapes (squares and circles) was presented visually using the software. Bracketing method was used to measure the maximum number of shapes that the person can recall. Bracketing stopped after 6 reversals and only last four reversals were considered for analyses. Shapes were randomly presented. Level 1 contained 2 shapes whereas level 7 contained 8 shapes. Each shape was presented for 2 seconds followed by a 1 second gap (white screen) before the onset of the next shape. Participants were instructed to direct the shapes displayed in the same order as presented. The scoring was based on the number of shapes correctly identified by the participant.

Figure 3.5. Screenshot of Forward Span


Forward Span Shape - TEST MODE

User ID: Ar18

Number of shapes: 2

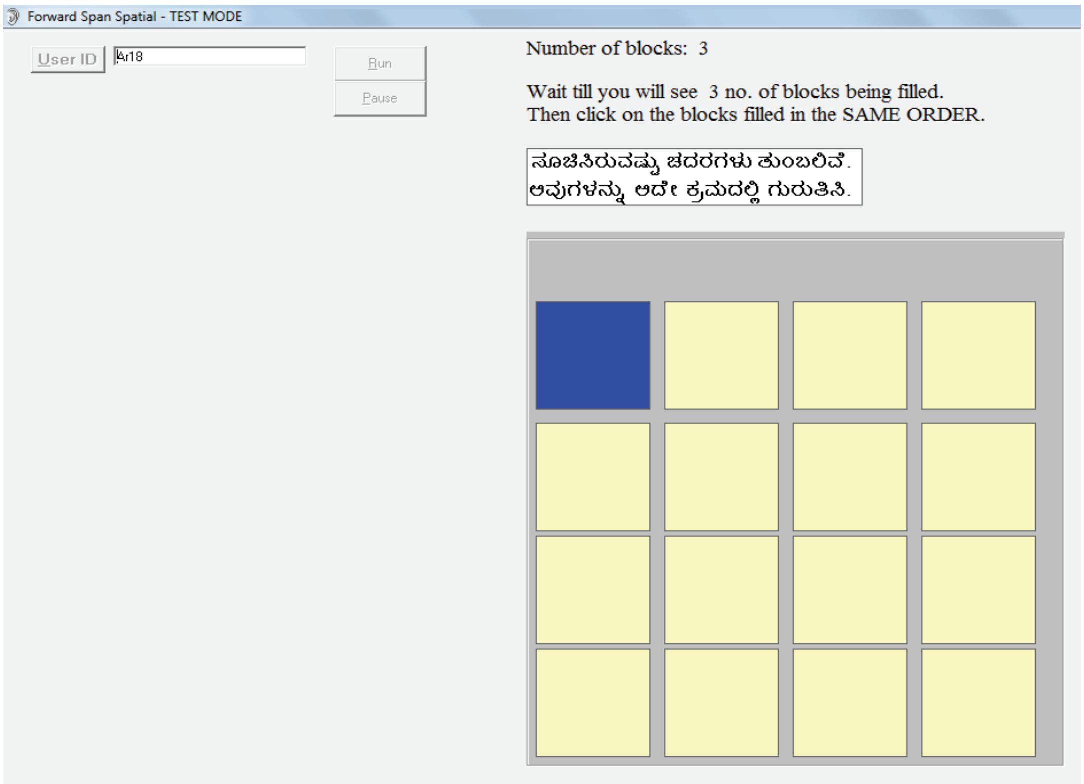
Wait till you see a sequence of 2 shapes.
Then click on the shapes shown in the SAME ORDER.

ಸೂಚಿಸಿರುವಷ್ಟು ಚಿತ್ರಗಳನ್ನು ನೋಡಲಿರುವಿರಿ.
ಅವುಗಳನ್ನು ಅದೇ ಕ್ರಮದಲ್ಲಿ ಗುರುತಿಸಿ.

Figure 3.5. Screenshot shows 2 shapes are displayed on the screen one by one. Instructions are displayed on the screen in Kannada (native language) and English. Clinician has to click on the shapes as pointed by the participant in the same order.

Forward span Spatial: Here a grid was displayed on the screen. Different blocks on the grid were highlighted sequentially using the software. Bracketing method was used to measure the maximum number of blocks that the person can recall. Bracketing stopped after 6 reversals and only last four reversals were considered for analyses. Each block was highlighted for 2 seconds followed by a 1 second gap (white screen) before the onset of the next block. Participants were instructed to show the blocks in the same order as presented. The scoring was based on the number of blocks correctly identified by the participant.

Figure 3.6. Screenshot of Forward Span Spatial



User ID: Ar18

Number of blocks: 3

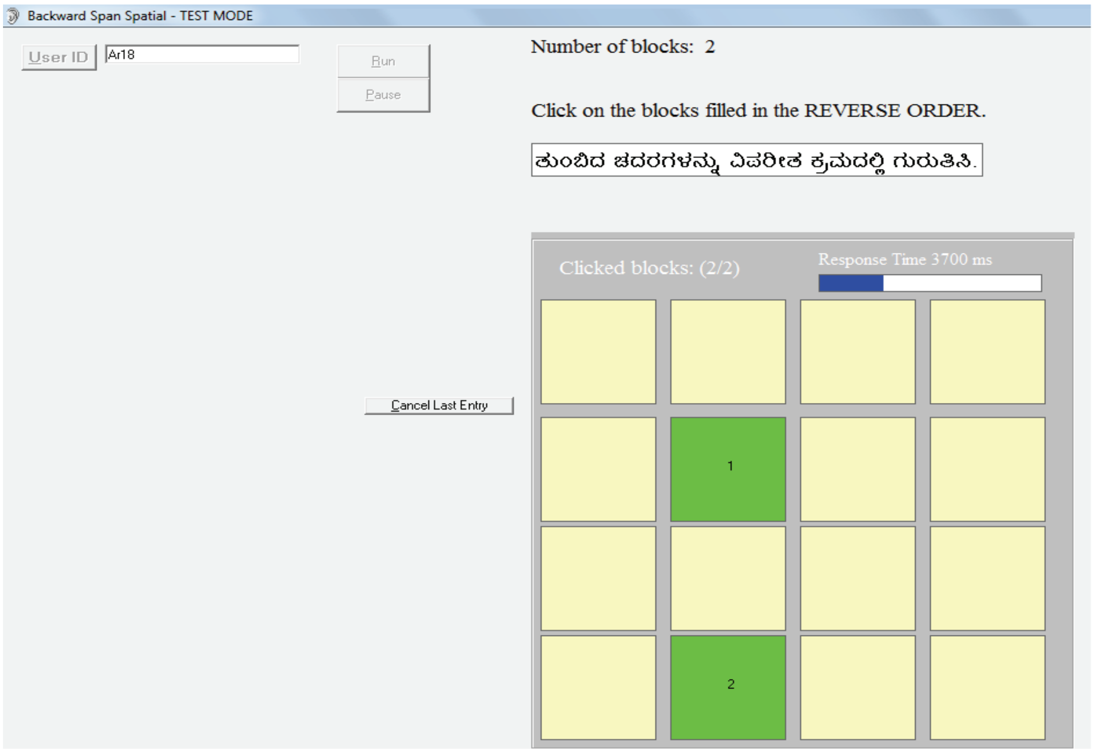
Wait till you will see 3 no. of blocks being filled.
Then click on the blocks filled in the SAME ORDER.

ಸೂಚಿಸಿರುವಷ್ಟು ಚದರಗಳು ತುಂಬಲಿವೆ.
ಅವುಗಳನ್ನು ಅದೇ ಕ್ರಮದಲ್ಲಿ ಗುರುತಿಸಿ.

Figure 3.6. Screenshot shows a block highlighted in blue which displays one by one. Instructions are displayed on the screen in Kannada (native language) and English. Clinician has to click on the block of the grid as pointed by the participant in the same order.

Backward span Spatial*:* Here a grid was displayed on the screen. Different blocks on the grid were highlighted sequentially using the software. Bracketing method was used to measure the maximum number of blocks that the person can recall. Bracketing stopped after 6 reversals and only last four reversals were considered for analyses. Each block was highlighted for 2 seconds followed by a 1 second gap (white screen) before the onset of the next block. Participants were instructed to show the blocks in the reverse order as presented. The scoring was based on the number of blocks correctly identified by the participant.

Figure 3.7. Screenshot of Backward Span Spatial



Backward Span Spatial - TEST MODE

User ID Ar18

Number of blocks: 2

Click on the blocks filled in the REVERSE ORDER.

ತುಂಬಿದ ಚದರಗಳನ್ನು ವಿಪರೀತ ಕ್ರಮದಲ್ಲಿ ಗುರುತಿಸಿ.

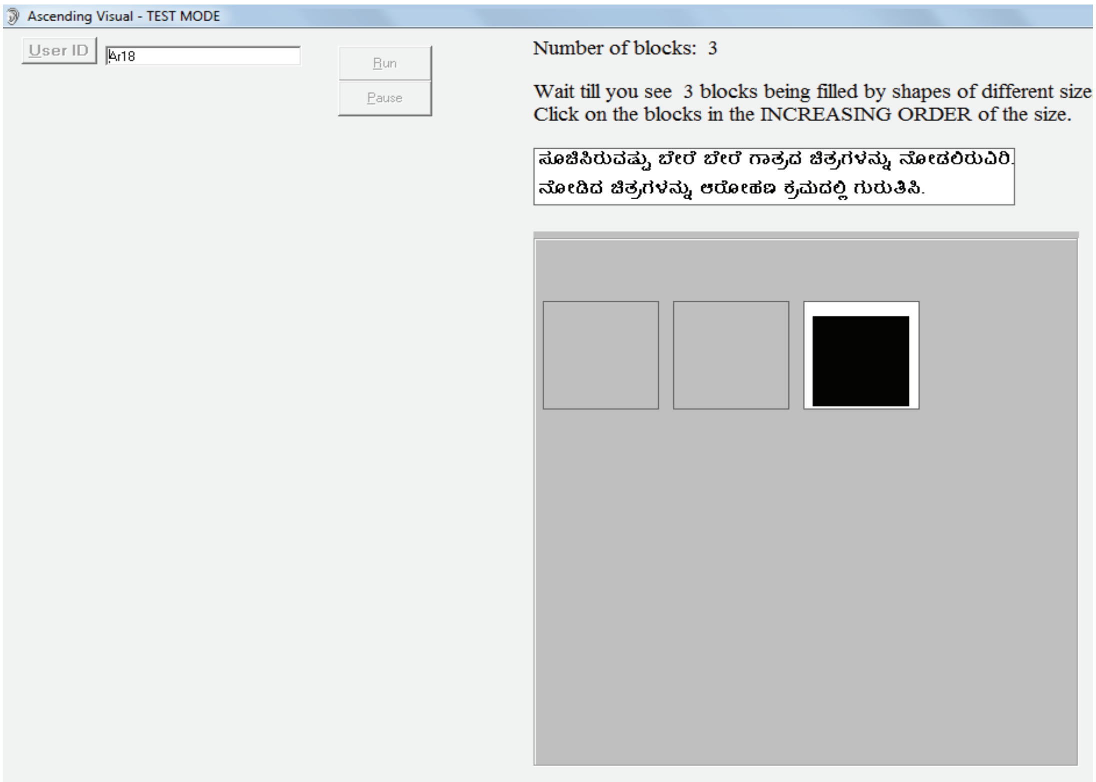
Clicked blocks: (2/2)

Response Time 3700 ms

Figure 3.7. Screenshot shows the response screen of the task. Instructions are displayed on the screen in Kannada (native language) and English. Highlighted blocks in green represent the response. Clinician has to click on the block of the grid as pointed by the participant in the reverse

Ascending visuo-spatial: Here, a grid was displayed on the screen. Each block on the grid had a shape. Bracketing method was used to measure the maximum number of blocks that the person can recall. Bracketing stopped after 6 reversals and only last four reversals were considered for analyses. A sequence of shapes was presented and the participants were instructed to indicate blocks containing shapes in the increasing order of the size or the number of sides. Each block was highlighted for 2 seconds followed by a 1 second gap (white screen) before the onset of the next block. The scoring was based on the number of blocks correctly arranged by the participant.

Figure 3.8. Screenshot of Ascending Visuo-Spatial Span



Ar18

Number of blocks: 3

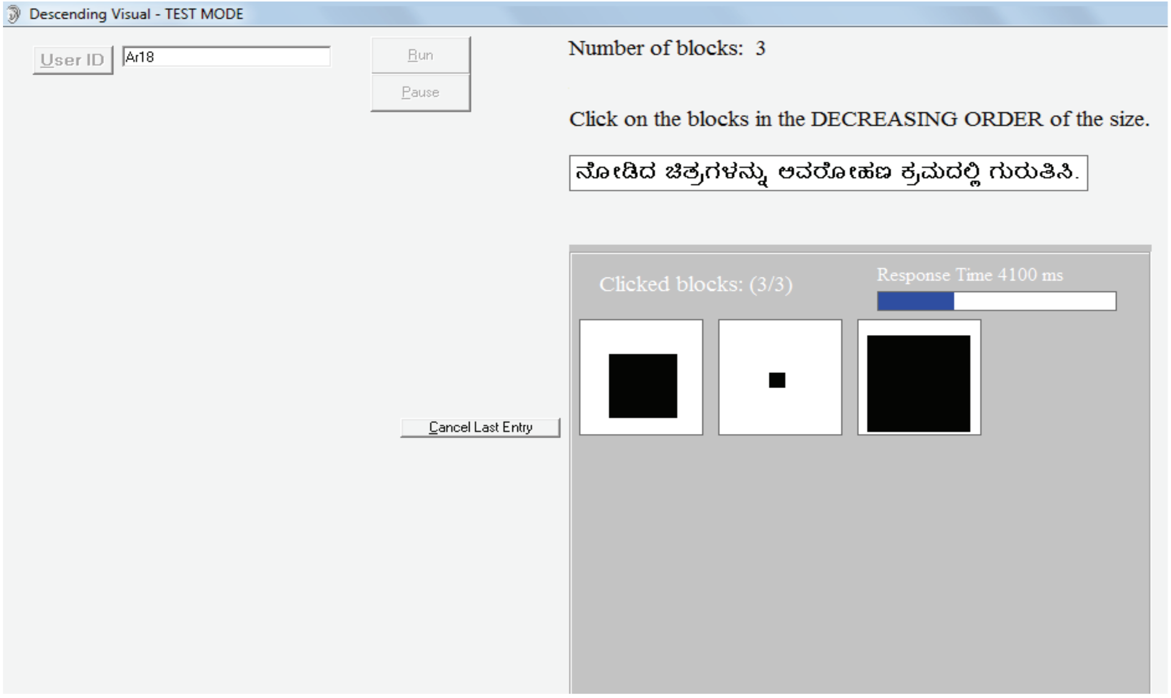
Wait till you see 3 blocks being filled by shapes of different size
Click on the blocks in the INCREASING ORDER of the size.

ಸೂಚಿಸಿರುವಷ್ಟು ಬೇರೆ ಬೇರೆ ಗಾತ್ರದ ಚಿತ್ರಗಳನ್ನು ನೋಡಲಿರುವಿರಿ.
ನೋಡಿದ ಚಿತ್ರಗಳನ್ನು ಆರೋಹಣ ಕ್ರಮದಲ್ಲಿ ಗುರುತಿಸಿ.

Figure 3.8. Screenshot shows a block highlighted with a shape. Instructions are displayed on the screen in Kannada (native language) and English. Clinician has to click on the block of the grid as pointed by the participant in the increasing order.

Descending visuo-spatial: Here, a grid was displayed on the screen. Each block on the grid had a shape. Bracketing method was used to measure the maximum number of blocks that the person can recall. Bracketing stopped after 6 reversals and only last four reversals were considered for analyses. A sequence of shapes was presented and the participants were instructed to indicate the blocks containing shapes in the decreasing order of the size or the number of sides. Each block was highlighted for 2 seconds followed by a 1 second gap (white screen) before the onset of the next block. The scoring was based on the number of blocks correctly arranged by the participant.

Figure 3.9. Screenshot of Descending Visuo-Spatial Span



User ID: Ar18

Number of blocks: 3

Click on the blocks in the DECREASING ORDER of the size.

ನೋಡಿದ ಚಿತ್ರಗಳನ್ನು ಅವರೋಹಣ ಕ್ರಮದಲ್ಲಿ ಗುರುತಿಸಿ.

Clicked blocks: (3/3)

Response Time 4100 ms

Figure 3.9. Screenshot shows the response screen of the task. Instructions are displayed on the screen in Kannada (native language) and English. Highlighted blocks in grid represent the response. Clinician has to click on the block of the grid in decreasing order of shapes as pointed by the participant.

CHAPTER 4 - RESULTS AND DISCUSSION

The objective of the present study was to find out the relationship between working memory and hearing aid benefit in the group of elderly individuals with hearing loss. Results are discussed under the heads - hearing aid benefit, working memory measures, hearing thresholds and relationship between these variables. All the statistical analyses were conducted using Statistical Package for Social Science, SPSS (version 16).

a) Hearing benefit - SNR-50 in unaided and aided conditions-: Figure 4.1. shows mean SNR-50 responses in unaided and aided condition with one standard deviation of variation. The mean scores noticeably indicate that the performance in aided condition was better when compared to the unaided condition. The mean signal to noise ratio -50 (SNR-50) in aided condition was 3.99 dB and in unaided condition was 6.05 dB. The average improvement in the SNR-50 with the hearing aid was 2.05. The variability as evidenced by the standard deviations was almost the same for both the conditions. With the hearing aid, individuals with hearing loss were able to identify 50% of the speech presented at a lower SNR compared to unaided condition. Paired t-test was performed to assess the significance of differences between the mean SNR-50 between two conditions. Results of the paired t test showed that mean SNR-50 was significantly lower in aided condition compared to unaided condition ($t=4.5$, $p<0.05$).

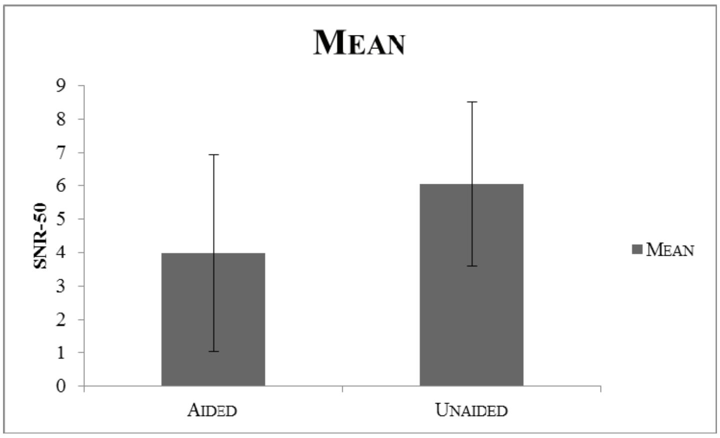


Figure 4.1. Mean SNR-50 in aided and unaided condition. The error bars indicate 1 SD of error.

Improvement in SNR-50 with the hearing aid shows the benefit derived by the hearing aid while listening to speech in presence of noise. Mean hearing aid benefit observed in the present study was 2.05 dB. This benefit observed is comparable to that reported in the literature (Grunditz & Magnusson, 2013; Hällgren, Larsby, Lyxell, & Arlinger, 2005). Grunditz and Magnusson (2013) used a monosyllabic 50-word speech-in-noise test in hearing aid fitting for comparison of speech recognition performance in the aided and unaided listening condition on one hundred and two adult hearing aid users. The speech recognition scores revealed a statistically significant hearing aid benefit for 77% of the subjects. They reported a mean hearing aid benefit of 4.4 dB. Similar results were reported by Hällgren, Larsby, Lyxell, and Arlinger (2005) who reported an improvement of 2.5 dB in noise.

b) Working memory tasks: Means of all the nine working memory tasks assessing the phonological and visuo-spatial loop along with one standard deviation of variation is depicted in Figure 4.2.

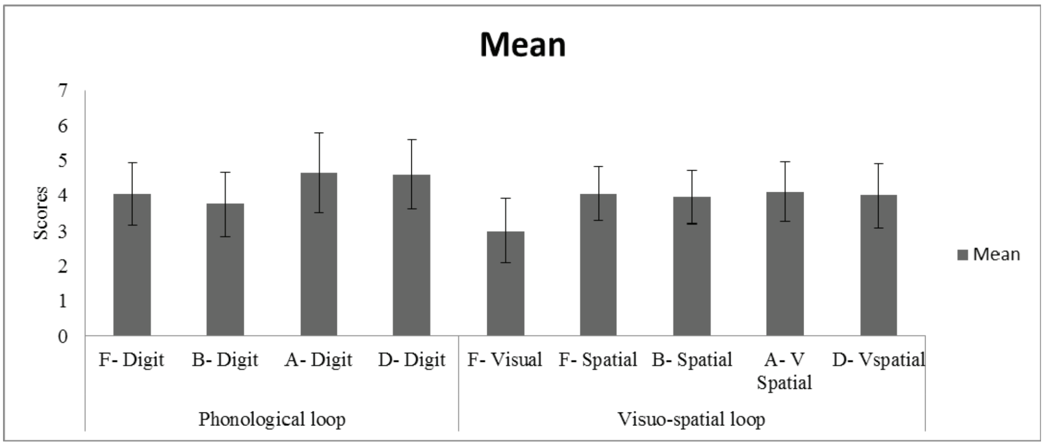


Figure 4.2. Mean scores across nine working memory measures. The error bars indicate 1SD of error.

[In the figure: F- Digit: forward digit span; B- Digit: backward digit span; A- Digit: Ascending digit span; D- Digit: Descending digit span; F- Visual: forward visual span; F- Spatial: forward spatial span; B- Spatial: backward spatial span; A- V Spatial: ascending visuo-spatial span; D-V Spatial: descending visuo-spatial span]

The mean scores obtained for forward digit span, backward digit span, ascending digit span, descending digit span were 4.05 (SD 0.88), 3.75 (SD 0.91), 4.65 (SD 1.13) and 4.6 (0.99) respectively. These scores are comparable to those reported in the literature (van Rooij & Plomp, 1989; Humes & Floyd, 2005; Humes, Lee, & Coughlin, 2006; Rishitha, 2013).van Rooij and Plomp (1989) reported that mean forward and backward digit span scores in a group of 24 elderly was 4.68 (for both spans). These scores were significantly lower when compared to young normal hearing individuals in their study. Deterioration in the score of elderly reflects ageing. Humes, Lee, and Coughlin (2006) reported an average forward span score of 5 and backward span scores of 4 in a group of elderly individuals with hearing impairment. Similar results are reported by other investigators too (Humes & Floyd, 2005). Rishitha (2013) reported slightly better digit forward and backward spans in elderly individuals without hearing loss. This may be because hearing loss can have a potential negative impact on individual's cognitive abilities. Many investigators have reported poorer cognitive functioning in individuals with hearing loss compared to individuals with normal hearing matched for age and other socio-economic status (Urry & Gross, 2010)).

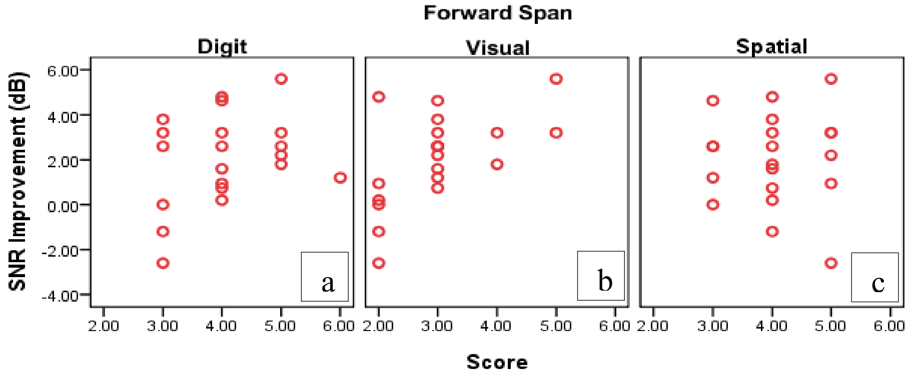
The mean scores obtained on forward visual span task were 3 (SD 0.91). Similar scores on visual span is reported by Humes and Floyd (2005) (4.66) on a group of elderly hearing impaired individuals with hearing loss. The mean scores obtained in forward spatial span, backward spatial span, ascending visuo-spatial span, descending visuo-spatial span were 4.05 (SD 0.75), 3.95 (SD 0.75), 4.1 (SD 0.85) and 4 (SD 0.91) respectively. To our knowledge till date there are no studies that have evaluated the visuo-spatial span in individuals with hearing loss.

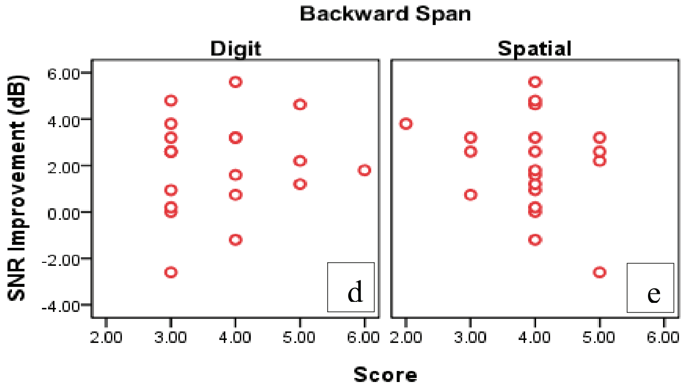
c) Relationship between working memory measures and hearing aid benefit: Pearson's Product Moment correlation analysis was done to investigate the relationship between all the nine working memory tasks and improvement in SNR-50 with the hearing aid. Table 4.1 gives the correlation coefficient 'r' across different working memory tasks and improvement in SNR 50. Figures 4.3. (a-i) show the

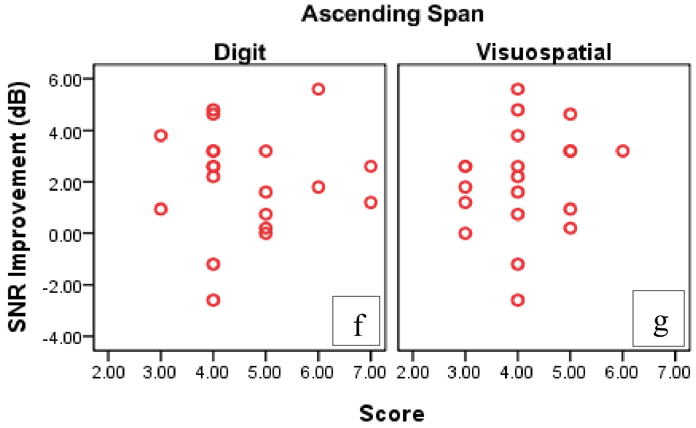
Table 4.1. Correlation coefficients for various working memory tasks

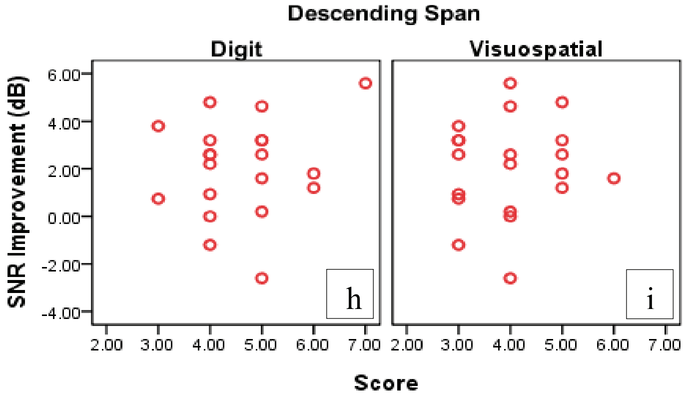
Working memory	r
Forward digit	0.290
Forward visual	0.446
Forward spatial	-0.009
Backward digit	0.107
Backward spatial	-0.222
Ascending digit	0.011
Ascending visuo-spatial	0.190
Descending digit	0.167
Descending visuo-spatial	0.089

Figures 4.3. (a-i) Scatter plot between working memory measures and hearing aid benefit (n=20).









scatter plots between the different working memory measures and improvement in SNR 50. From the Figures 4.3. (a-i) and Table 4.1., it is clear that none of the working memory measures correlated significantly with the hearing aid benefit as measured by improvement in SNR 50.

In literature, studies are equivocal regarding the relationship between working memory measures and hearing aid benefit. Humes and colleagues (2003) in a large scale study measured the contribution of various auditory and non-auditory factors on three outcome measures- speech recognition thresholds, hearing aid usage/benefit and subjective hearing benefit. Among the predictor variables they studied, cognitive ability (verbal intelligent quotient) was related to all the three outcome measures. Lunner (2003) measured speech perception thresholds for sentences in modulated noise for a group of 72 elderly hearing-impaired (mean hearing loss 45 dB). Cognitive capacity was evaluated using reading span task and the rhyme-judgement task. The results indicated significant correlations between hearing loss and speech perception (r = 0.47-0.49) and also between cognitive test and speech perception (r = 0.39-0.61). Balwin and Ash (2011) found that auditory working memory task (listening span task) correlated well with the speech recognition threshold as compared to visual working memory (reading span task) tasks which indicates that cognition ability is related to speech perception. Lunner and Sundwell-Thoren (2007) studied the interaction between cognition, compression and listening conditions in 23 experienced hearing aid users. Those with low scores on visual monitoring task (cognitive test) performed better in unmodulated than modulated noise whereas an opposite pattern was observed for subjects with high performance on cognitive tests. It was also seen that cognitive test scores significantly correlated with the differential advantage of fast acting versus slow acting compression in conditions of modulated noise. Rishitha (2013) reported a significant relationship between working memory and speech recognition thresholds.

On contrary, George, Zekveld, Kramer,Goverts, Festen, and Houtgast (2007) reported a weak relationship between speech perception and cognitive measures. They measured speech reception thresholds (SRTs) in static vs. modulated noise on 21 elderly listeners (mean loss 40 dB). They correlated the data to the text reception threshold, hearing threshold and measures of temporal resolution. Results showed that the text reception threshold gave smaller correlations with the SRT ($r = 0.34-0.42$). The amount of pure tone hearing threshold correlated best with the SRT, for both noise types ($r = 0.71-0.73$). On multiple-regression analysis, hearing thresholds formed as the first and only predictor of SRT in static noise ($R^2= 42$ %). van Rooij and Plomp (1989) also reported the poor relationship between auditory and cognitive factors. They measured the auditive (sensitivity, frequency selectivity and temporal resolution), cognitive (memory performance, processing speed and divided attention ability), and speech perception tests (at the phoneme, spondee and sentence level) in 24 elderly individuals. The results indicated that the speech perception in elderly was influenced only by the sensorimotor speed ($r = 0.52$) and the processing speed ($r = 0.58$). No other predictor variables in cognitive domain were significant. van Rooij and Plomp (1990) replicated the same study on more number of subjects (72 elderly subjects) and concluded similar findings stating only a small component of cognitive functions, (general slowing of performance and reduced memory capacity) which accounts for only one third of the systematic variance of the speech perception test.

This discrepancy in the results of the various studies may be due to differences in the cognitive/working memory tests that were used. Studies that have reported a relationship between speech perception and cognitive/working memory measures have used verbal intelligent quotient or complex working memory spans such as reading span or operation span. In the present study we used a simple span such as auditory, visual and spatial forward and backward tasks which might have resulted in poor correlation with the hearing aid benefit.

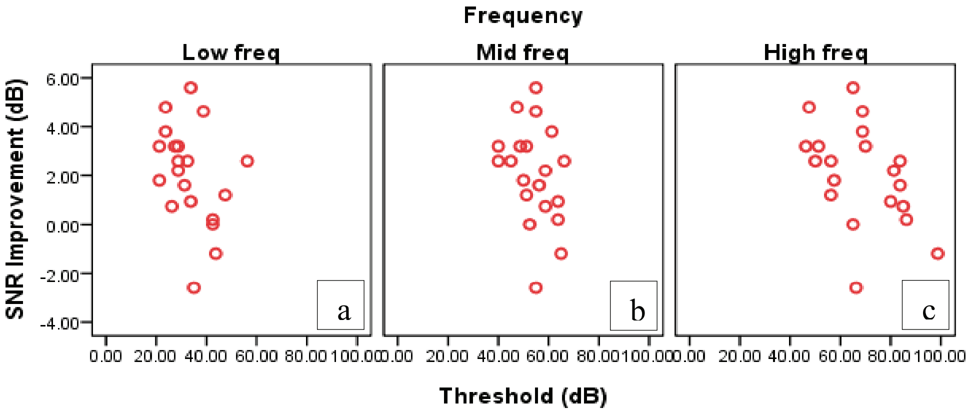
d) Relationship between average pure tone thresholds and improvement in SNR-50: Pearson's Product moment correlation analysis was done to investigate the relationship between pure tone thresholds and the SNR-50. Table 4.2. gives the correlation coefficient 'r' across average pure tone thresholds and improvement in SNR 50. Figures 4.12. (a-c) show the scatter plots between hearing thresholds and improvement observed in SNR 50 with the hearing aid. Figures 4.12. (a-c) and Table 4.2., reveal a significant negative correlation ($r = -0.45$, $p < 0.05$) between average high frequencies pure tone thresholds and to improvement in SNR-50. A negative relationship indicates that as the hearing thresholds in the high frequency region increases, benefit that could be drawn from the hearing aid decreases.

Table 4.2. Correlation of pure tone thresholds to the improvement in SNR-50

Improvement in SNR-50 to hearing threshold	r
Low-frequency average	-0.34
Mid-frequency average	-0.33
High-frequency average	-0.45*

***p<0.05**

Figure 4.4. (a-c) Correlation between hearing thresholds and hearing aid benefit (n=20).



Negative relationship between pure tone thresholds and hearing aid benefit has been reported by various investigators. For example, van Rooij and Plomp (1989) speech perception in elderly was largely determined by hearing thresholds especially at high frequencies whereas the effect for the auditive and cognitive factors was relatively small or absent. Jerger, Jerger, & Pirozzolo (1991) analysed the predictor for variation in speech audiometric score from a set of variables namely the pure tone hearing thresholds, age, and cognitive status on 200 individuals. It was observed that the degree of hearing loss bore the strongest relation to speech recognition score whereas cognitive status showed slight variance for all of these four speech audiometric scores.

Our findings of significant negative correlation between high frequency hearing thresholds and hearing aid benefits emphasize the importance of high frequencies in speech recognition. High frequencies are important for the perception of fricatives, affricates and stop transition. Inability to hear these cues will have negative impact on overall speech recognition.

CHAPTER 5 - SUMMARY AND CONCLUSIONS

Verbal communication often occurs in noisy backgrounds. With appropriate amplification individuals with hearing impairment in the speech range experience relatively little difficulty understanding one talker in a quiet listening environment; however, they report difficulty understanding speech in noise and in multi-talker situations. Over the last decades, there have been significant advances in the design of hearing aids-with the incorporation of noise reduction algorithms; improved microphone and receiver technology- so on and so forth. But even then, significant proportions of hearing impaired adults' complain of difficulty in understanding speech in adverse listening conditions. Underlying mechanisms of speech perception deficits in hearing impaired individuals is unclear. These deficits probably may have a cognitive origin rather than simply auditory. In this context the present dissertation aimed to investigate the role of working memory on the benefits derived from hearing aids.

The present study aimed to assess the effect of working memory on hearing aid benefit in elderly with following objectives

1. To correlate the findings of working memory tests assessing the phonological loop and hearing aid benefit as evaluated by speech perception in noise in the group of elderly individuals with hearing loss.

2. To correlate the findings of working memory tests assessing the visuo-spatial skills and hearing aid benefit as evaluated by speech perception in noise in the group of elderly individuals with hearing loss.

The present study included 20 participants in the age range of 50-80 years (mean age = 67.65 years). The study was conducted in three stages: audiological evaluation, hearing aid fitting and working memory evaluation. Hearing thresholds were recorded, aided and unaided SNR-50 was calculated and assessment of various working memory (auditory digit spans, visual spans, spatial spans and visuo-spatial spans) measures was carried out.

The results obtained in the study are

1. In aided condition, participants were able to identify 50% of the speech presented at a lower signal to noise ratio (SNR) compared to unaided condition.
2. There was no significant correlation between the working memory measures and hearing benefit.
3. Significant positive correlation between high-frequencies hearing thresholds and hearing aid benefit.

Lack of relationship between hearing aid benefit and working memory measures may be because in the present study working memory was evaluated using simple spans such as forward and backward. Positive relationship between high frequency thresholds and hearing aid benefit indicates the importance of high-frequencies in speech perception.

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