Comparison of Auditory Working Memory in Individuals with Blindness and Normal Sighted Individuals

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ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI, MYSURU-570 006

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CERTIFICATE

This is to certify that this dissertation entitled **'Comparison of Auditory Working Memory in Individuals with Blindness and Normal Sighted Individuals'** is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number: 18AUD029. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
July, 2020

Dr. M. Pushpavathi
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CERTIFICATE

This is to certify that this dissertation entitled **'Comparison of Auditory Working Memory in Individuals with Blindness and Normal Sighted Individuals'** has been prepared under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **'Comparison of Auditory Working Memory in Individuals with Blindness and Normal Sighted Individuals'** is the result of my own study under the guidance a faculty at All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru,
July, 2020

Registration No. 18AUD029

THIS

DISSERTATION

IS

DEDICATED

TO

MY

“TRISHA”

Acknowledgement

First, I would like to thank Dr. Sreeraj k. Sir, thank you so much. You are the coolest lecture I have come across. Since I was a fresher to AIISH and when we were asked to choose the guide for dissertation, I personally chose you as I was impressed by your lecture on auditory physiology classes in my first semester, you were calm interactive and explained our silly doubts without getting disturbed throughout the course. Sir, you used to point out small mistakes in the first slide of our presentations about the spacing, comma, full stops every minute details which most of us didn't even know its importance. As I'm a person who loves to do research you taught as the importance of it and so I think I can say that the motivation for me to do research and to think about a condition or any possible way of doing research I got it from you sir thank you so much sir.

When it comes to my dissertation, you allowed me to think about a topic. One day when I was doing my internship I was passing by the street and came across a person with blindness who was crossing the road, that moment it stuck to me that these individuals rely more on their hearing sense in day to day life, so I wanted to research such individuals, and came to you, and requested you that I want to do my dissertation on individuals with congenital blindness, without thinking much you just said "okay Rakesh we will do it" and asked me to plan a research methodology though it was not your area where you do more research work on, from this, I learned from you that as a researcher I should not only work only on one area but also to explore other paths that are related to our audiology along with my field of work in research. Thank you for boosting me, starting from encouraging me to carry out research on individuals with blindness till the end of my dissertation. In this pandemic "THE COVID-19," it was very difficult for you to guide us, but still, you regularly monitored us, helping us to finish our dissertation listening to our silly doubts. Initially, I was scared that the dissertation is going to be tough difficult to complete etc, but sir I didn't find any difficulty during my dissertation, It is just because of you sir, thank you for keeping me calm and helping me to finish my dissertation without any tension.

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Abstract

Background: *Congenital blindness refers to loss of vision early in the childhood.. Individuals with congenital blindness by nature depend more on auditory information to compensate for their loss of vision and procure a better auditory skills. Auditory working memory comprises of storage, manipulation and retrieval of auditory information. The auditory working memory can be measured using auditory digit span and auditory n back tasks.*

Aim: *The aim of this study was to assess auditory working memory performance in adults with congenital blindness and normal sighted individuals*

Method: *A total of 20 individuals with congenital blindness were taken in the age range of 18-25 years and 20 normally sighted individuals were taken along for the study. Auditory N back (Auditory two back, Auditory three back) and Auditory Digit span test (Forward digit span and Backward digit span) were compared between individuals with congenital blindness and normally sighted individuals.*

Results: *The results of Mann-Whitney U test revealed significant difference in auditory three back and auditory backward span test. There was no significant difference in auditory two back and auditory forward span test.*

Conclusion: *The higher scores in auditory three back and auditory backward span tests of working memory indicates a relatively superior auditory working memory skills in individuals with congenital blindness in comparison to normally sighted individuals.*

Key words: *Working Memory**,** Auditory Two back, Auditory Three back, Forward Digit span, Backward Digit Span.*

CHAPTER 1

Introduction

Working Memory (WM) is a cognitive mechanism that forms the underlying process to store information during complex and demanding activities. Working memory can be of visual working memory and auditory working memory. Visual working memory requires the individuals to recall visual information and auditory working memory is the ability of the individuals to recall auditory information. WM is assumed to be a temporary storage system under attentional control that underpins our capacity for complex thought (Baddely & Hitch, 1974). The WM model comprise of phonological loop, visuo-spatial sketch pad, a central executive and an episodic buffer. These components work together in order to provide a comprehensive work space for cognitive abilities.

It has been assumed that the phonological loop and the visuo-spatial sketch pad works parallel and independent to each other and the information received from these two sub systems are monitored and coordinated by the central executive system of WM. The auditory WM underpins the capacity to retrieve auditory information and manipulate them. WM has been studied extensively in various neurophysiological studies as well as in allied health science to assess the individual's ability to hold the information, manipulate it and produce in a required manner for which a task demands and is commonly measured by determining how many items a person can remember simultaneously for a short period. e.g., someone who can remember all 10 digits phone numbers and repeat them back has a greater WM capacity than someone who can only recall four.

Blindness refers to the visual acuity of less than 3/60, or a comparable visual field loss to less than 10 degree in the better eye with best possible correction (WHO, 1972). It has been reported that individuals with congenital blindness perform significantly better in tests that assess Short Term Memory (STM) tasks compared to normally sighted individuals (Withagen, Kappers, Vervloed, Knoors, & Verhoeven, 2013).

It has been reported that congenitally blind participants are known to perform significantly better to their counterparts in auditory tasks that involves temporal processing abilities, localization and cognitive abilities (Boas, Muniz, Neto, Da Silva, & Gouveia, 2011; Nilsson & Schenkman, 2016). Studies have been done that assess auditory memory using behavioral and electrophysiological test in congenitally blind adults and results shows that congenitally blind participants performed superiorly in comparison to sighted participants and also it has been shown that electrophysiological tests along with behavioral tests provides well defined knowledge about the nature and timing of mechanisms of compensatory plasticity (Röder et al., 2001).

Stankov and Spilsbury (1978) reported that when non-verbal tonal material was used to assess the short term memory, blinds performed better than sighted individuals. Hull and Mason (1995) reported that blind children perform superiorly in digit-span task compared to sighted individuals. There are very few studies that compare short term memory performance with WM. One among such studies was a research study conducted by Swanson and Luxenberg (2009) on children and reported that performance for tests that assess Short Term Memory was superior in blind children compared to normal sighted children, but this fashion was not observed in tests that assess WM.

Many tests are available to assess auditory WM, for instance, Digit Span Test (Digit Forward and Digit Backward span), listening span, and Reading span task. Nonetheless, tests like auditory listening span and reading span would be more challenging to be performed by adults with congenital blindness since it involves the display of the stimulus on the screen. Auditory n back Test which is one among the test that assesses the auditory WM would be more suitable for such population along with digit span task, also there are very few research studies that has made effort in assessing the auditory WM in adults with congenital blindness, on this account there is a need to study the auditory WM performance in such population and also to compare their performance with the normal sighted individuals.

1.1 Need for the Study

Auditory working memory is one of the brain's executive functions which refers to the capacity to maintain information for a limited time, as it aids in holding new information and use them when required. It has been observed that individuals with congenital blindness have superior temporal processing abilities compared to normally sighted individuals (Sepehrnejad et al., 2011; Stevens & Weaver, 2005) . There are very few research studies in the literature that measures the relationship between temporal processing and WM abilities; among such study is a study conducted by Fostick, Bar-El, & Ram-Tsur, (2012) who reported a correlation between temporal processing abilities and WM on their 33 individuals with dyslexia. Studies have also shown that an increase in temporal processing skills results in an improved performance on auditory memory abilities (Maggu & Yathiraj, 2011; Ramya, 2015). From the above studies, it can be hypothesized that individuals with congenital blindness possess superior auditory memory abilities compared to normally sighted individuals. Furthermore, there is a dearth of studies that assess auditory working memory performance in adults with congenital blindness.

1.2 Aim of the study

This study aims to assess auditory WM performance in adults with congenital blindness and normal sighted individuals.

1.3 Objectives

- To assess Digit Span Test and auditory n-back Test performance in adults with congenital blindness and normal sighted individuals.
- To compare Digit Span Test performance in adults with congenital blindness with normal sighted individuals.
- To compare auditory n-back Test performance in adults with congenital blindness and normal sighted individuals.

1.4 Null Hypotheses

1. There is no significant difference in Digit span Test performance between adults with congenitally blindness and normal sighted participants.
2. There is no significant difference in auditory n-back Test performance between congenitally blindness and normally sighted participants.

CHAPTER 2

Review of Literature

This chapter focuses on reviewing previous research studies for the auditory working memory under following headings

2.1 Working memory model
2.2 Auditory working memory Tests
2.3 Digit span and working memory
2.4 Auditory N back and working memory
2.5 Auditory working memory in individuals with congenital blindness

2.1. Working Memory Model

The working memory model was developed by (Baddely & Hitch, 1974) to overcome the demerits of the modal model developed by (Atkinson & Shiffrin, 1968; Sepehrnejad et al., 2011), The working memory is composed of three main components, a central executive system, a phonological loop, and a visuospatial sketch pad. The Figure 2.1 represents the modified working memory model given by Baddley and Hitch (2012).

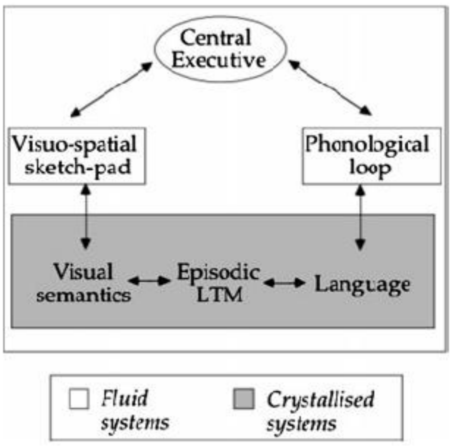

Figure 2.1 Modified Baddley and Hitch, (2012) working memory model [Adopted from “Working memory: Theories, models, and controversies” (Baddeley, 2012)]

The “central executive” system is a central unit that is involved in monitoring and coordinating the information received by the other two subsystems of working memory. The “visuospatial sketch pad” is mainly involved in processing the visual memory, for instance, recalling a visual route to a destination, or picturing a visual image, and “phonological loop” is responsible to process auditory and semantic information. A new component was introduced by Baddley in 2000 called the “episodic buffer” which is a temporary storage system that has a unique feature of holding multimodal representations and links the working memory to the long term memory with limited capacity.

2.2 Auditory Working memory Tests

Auditory Working memory tests are assessed using simple span and complex span tests. The simple span tests constitute digit forward and backward ask, ascending and descending digit task. The complex task includes operational span, reading span tasks.

2.2.1 Simple span Tests.

Forward digit span. A sequence of numbers is randomly presented to the participants through auditory mode with an increasing level of difficulty. Every correct response results in an increase in level by one digit and the incorrect response results in a decrease in level by one digit. The participants will be instructed to repeat the numbers in the same sequence as presented. The scoring is based on the mean of the number of digits correctly repeated by the participants for 3 out of 5 reversals (Kishor, 2014).

Backward digit span. A sequence of numbers is randomly presented to the participants through auditory mode with an increasing level of difficulty. Every correct response results in an increase in level by one digit and the incorrect response results in a decrease in level by one digit. The participants will be instructed to repeat the numbers in the reverse order as presented. The scoring is based on the mean of the number of digits correctly repeated by the participants for 3 out of 5 reversals (Kishor, 2014).

Ascending digit span. A sequence of numbers is randomly presented to the participants through auditory mode with an increasing level of difficulty. Every correct response results in an increase in level by one digit and the incorrect response results in a decrease in level by one digit. The participants will be instructed to repeat the numbers in the ascending sequence as presented. The scoring is based on the mean of the number of digits correctly repeated by the participants for 3 out of 5 reversals (Kishor, 2014).

Descending digit span. A sequence of numbers is randomly presented to the participants through auditory mode with an increasing level of difficulty. Every correct response results in an increase in level by one digit and the incorrect response results in a decrease in level by one digit. The participants will be instructed to repeat the numbers in the descending order as presented. The scoring is based on the mean of the number of digits correctly repeated by the participants for 3 out of 5 reversals (Kishor, 2014).

2.2.2 Complex span Tests.

Reading span. The test was originally developed by (Daneman & Carpenter, 1980). The test procedure includes the presentation of a sentence word by word. The participant's task is to listen to the sentence and has to decide if the sentence is meaningful or a non-meaningful sentence at the end, also after the presentation of a small number of sentences the participants has to recall initial or last word of each the sentence.

Operational span. The test involves the presentation of a set of words followed by a simple mathematical equation. The participant's task is to decide if the equation is correct or incorrect and simultaneously to remember the words in the same sequence presented previously. The task includes both processing and storage of information, where the participant process the first arithmetical equation, and stores the first word presented and then moves to the second equation and stores the second word and so on (Kishor, 2014).

2.3 Digit Span and Working Memory

Digit span task is one of the most commonly used tests to assess the auditory working memory in a larger number of research studies, the test is known to distinguish an individual with poor working memory from their counterpart in variety of condition where the memory aspects of the individual are compromised. For instance, individuals diagnosed with schizophrenia, a condition that involves a range of problems with cognition, behavior and emotional aspects of the individuals. It has been shown that the working memory is considerably poor in such populations which are assessed by the forward and backward digit span (Conklin, Curtis, Katsanis, & Iacono, 2000). Dobbs, Dobbs, and Kiss (2001) conducted a study on 20 subjects diagnosed with chronic fatigue syndrome, all the subjects were subjected to digit forward and digit backward tasks, the results of the study revealed that subjects performed relatively better in auditory forward digit span task when compared to the auditory backward digit span task. The authors claim that forward digits span task reflects the short term storage capacity of the individuals, while the backward digit span task is more involved in the storage, manipulation and retrieval process which targets the working memory of the individuals. It has been shown that the forward digit span task is relatively unimpaired in individuals with mild to moderate dementia of Alzheimer's type as reported by Botwinick, Storandt, and Berg (1986). Similarly, Kopelman (1985) reported similar results in their 16 patients who were diagnosed to have Korsakoff’s syndrome. Further, there are studies in the literature which shows normal performance in forward digit span task in subjects with frontal lobe damage subjects (Lezak, 1979). Giofrè, Stoppa, Ferioli, Pezzuti, and Cornoldi (2016) administered forward and backward digit span task on their 318 Italian children’s with a specific learning disability, the outcome of the study revealed that children performed poorly in digit span task especially in the forward span task compared to the backward span task, this was in opposition to the above-mentioned studies, the authors of study proclaims that such results are observed since SLD relates more to dysfunctions of the component represented through phonological short-term memory than to dysfunctions in executive working memory which was supported by Swanson (1999).

The digit span task have also been adopted to assess the working memory in individuals who were fitted with the cochlear implant, for instance, Pisoni and Geers, (2000) performed the digit span task on 43 children with pre-lingual hearing loss, all the participants underwent cochlear implant and were active implant users for more than five years. The study measured speech perception, speech intelligibility, language, and Reading abilities in addition to the forward and backward digit span. The result of the study revealed a positive correlation between the auditory digit span tasks to all other measures in the study. Gray (2003) reported the diagnostic significance, test-retest reliability of non-word repetition task and digit span task on 22 children with specific language impairment, both the tests were administered three times on the same group, scores for both the tests revealed improvement in the first and second time of administration, but there was no relative change in performance in both the tests for the third time administration, the study also proclaims acceptable test-retest reliability was achieved for digit span task, however, authors of the study put forward the need for further investigation on test-retest reliability for both the tests. The utility of digit span task also has been seen in the assessment of working memory in individuals with an auditory processing disorder, for example Lotfi, Mehrkian, Moossavi, Zadeh, and Sadjedi (2016) conducted a study aimed to assess the relationship between working memory capacity and auditory stream segregation on 15 children diagnosed with an auditory processing disorder. The auditory stream segregation was assessed using concurrent minimum audible angel, and the working memory was evaluated by employing forward and backward digit span tasks, authors reported that children with auditory processing disorder had poor scores in auditory stream segregation and working memory, also a negative correlation between the two tests was observed. Similarly, Moossavi, Mehrkian, Lotfi, and Faghihzadeh (2014) also reported poor performance on forward and backward digit span tasks in individuals with an auditory processing disorder.

2.4 Auditory N back and Working Memory

The N-Back Test is a frequently used experiment to measure WM which was introduced by Wanye in 1958. This test requires codification, temporary storage, and response, as it is necessary for the individuals to update and maintain information continuously in the WM to readily access it. The N back Test can be performed either through visual (Visual N back) or auditory (Auditory N back) mode while assessing the working memory of the individual. The test has been widely used in human neuroimaging and psychophysical studies, for instance Braver et al. (1997) reported a study on prefrontal cortex involvement for WM in human, the study was carried out on 9 individuals without any history of neurological involvement, N back was used as the cognitive test along with functional Magnetic Resonance Imaging (fMRI) to assess the area involved in WM. Specifically, the study employed 0 back, 1 back, 2 back and 3 back to measure the WM., thereby increasing the WM load from 0 back to 3 back conditions. The stimuli used by the authors were consonants and the subjects were instructed to respond to the target stimulus through pressing the button by their dominant hand and other for non-targets. Results of the fMRI revealed the activation of the middle frontal gyrus, the left inferior frontal gyrus for increasing WM load. A similar study by Callicott et al. (1999) on nine neurologically normal subjects revealed that the number of neural activation increases in the left dorsolateral prefrontal cortex as the WM load increased from 0 back to 2 back and then decreased. Studies have also been conducted by utilizing direct stimulation to dorsolateral frontal cortex through Repetitive Transcranial Magnetic Stimulation (rTMS), transcranial Direct Current Stimulation (tDCS) and revealed an increase in working memory performance (Barr et al., 2009; Berryhill & Jones, 2012). McAllister et al. (2001) conducted a study on 18 patients with Mild Traumatic Brain Injury (MTBI) and 12 healthy subjects, on whom the N back task was performed in conjugation with the fMRI. The auditory n back Test was performed with 0 back to 3 back conditions. The outcome of the study revealed no significant difference in task performance between the study group, however, the fMRI revealed that the response to increasing WM load the brain activation pattern differed between experimental and control subjects, i.e. MTBI showed varying activation during the moderate processing WM load condition, but very little increase in activation in right dorsolateral frontal cortex associated with highest processing load, from the above studies we can conclude that the dorsolateral frontal cortex is activated during WM tasks.

N back Test has also been used extensively as a tool to assess WM in various pathological conditions where the memory aspects have been compromised. Hagenhoff et al. (2013) employed N back along with Go/Nogo, and AX Continuous Performance Task (AX-CPT) to assess the executive functions in their twenty-eight subjects with a borderline personality disorder, they reported that subjects with borderline personality disorder performed similarly to the control group in Go/Nogo and AX CPT, however, in the N back Test which involves the memory component to perform the task showed higher error pattern and the poor performance in WM compare to their counterpart. Similarly, Harvey et al. (2004) performed the digit forward and backward Test, forward and backward visuospatial task N back Test on 22 individuals diagnosed with unipolar depression and 22 age and gender-matched control subjects. Their study revealed that subjects with unipolar depression performed similarly to the control subjects in short term memory tasks such as digit forward Test, forward visuo-spatial task, the performance was also comparable to normal subjects in digit backward Test but performed significantly poorer in backward visual span task. Also, for the 0 back condition, the study revealed no significant difference between the groups, however as the WM load was increased in 1 back and 2 back conditions the control subjects performed significantly poorer compare to the control group.

2.5 Auditory working memory in individuals with congenital blindness

Hull and Mason (1995) performed digit span Test on 314 blind children the results of the study revealed that children with blindness who can perceive light performed slightly better compared to the sighted children, whereas a group of blind children with more than light perception had no change in performance compared to their counterparts. Amedi et al. (2003) reported a study that included 10 participants with congenital blindness to whom verbal memory was assessed along with the fMRI, the results of the study revealed that the blinds performed significantly higher in verbal memory tasks compared to normally sighted participants. Raz, Striem, Pundak, Orlov, and Zohary (2007) study also reported that individuals with congenital blindness outer performed sighted participants on word recall tasks. Swanson and Luxenberg, (2009) conducted a study on 17 children with congenital blindness, both short term memory and working memory tests were administered, the results of the study indicated that blind children performed superiorly than sighted children in short term memory tasks but not in WM, the authors claim that congenitally blind children perform significantly better for tasks which emphasis on phonological storage and comparable performance for both the groups for tasks that tap executive system. In contrast, Withagen et al. (2013) assessed short term memory and working memory performance on 14 children with congenital blindness. The tests employed to assess short term memory composed of name learning, word span and digit forward span task, and digit backward span and listening span was used to assess the working memory. The authors reported that children with congenital blindness outperformed normally sighted children in both short term memory tasks and also in working memory tasks. The authors claim that verbal memory abilities and strategy seem to improve in the absence of sight. The authors concluded that individuals with congenital blindness possess considerable dependency on auditory-verbal information also they develop good sequential processing information thus resulting in improved performance compared to normally sighted individuals.

CHAPTER 3

Method

The study was carried out to compare auditory WM in individuals with congenital blindness and normal sighted individuals using the auditory digit span and auditory n-back task.

3.1 Selection of participants

A total of forty participants were recruited for the study. The age range of all the participants was 18 to 25 years. The study group constitutes of 20 congenitally blind participants (Group 1), and 20 age and gender-matched normally sighted participants (Group 2). Written consent was obtained from all the participants, and they were also informed regarding the complete test procedure and the approximate time needed for each test before conducting the study, which specifies the willingness of subjects/participants to participate in the study.

3.1.1 Inclusion Criteria

The participants who meet the following criteria were included for the study.

Adults with congenital Blindness.

- Visual acuity less than 3/60 or 10/200 (Snellen) in the better eye.
- Not undergone any formal musical training.
- Hearing sensitivity within normal limits <15 dB HL.
- No previous exposure to psychoacoustic tests.
- No Structural or neurological abnormalities of the ear.

Normal Sighted Individuals

- Visual acuity of 6/6 (Snellen) in both the eyes.
- Not undergone any formal musical training.
- Hearing sensitivity within normal limits <15 dB HL.
- No previous exposure to psychoacoustic tests.
- No Structural or neurological abnormalities of the ear.

3.2 Test environment

All the participants were subjected to tests in an acoustically treated room which meets the ambient noise level criteria specified by ANSI S3.1-1999 (R2008).

3.3 Test Procedure

A detail audiological evaluation was carried out to all the participants prior to the assessment of working memory tests. The details of test procedure employed for the study are given as follows

3.3.1 Preliminary investigations. All the participants were subjected to a detailed case history to rule out any pathological conditions of the auditory system. Pure Tone Audiometry where both the air conduction (250 Hz to 8000 Hz) & bone conduction threshold (250 Hz to 4000 Hz) was obtained from all the octave frequencies using modified Hughson and Westlake procedure given by Carhart & Jerger, (1959) with a dual-channel diagnostic audiometer in a sound-treated room. A criteria 15 dB HL for pure tone average of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz was employed to rule out any peripheral hearing loss: Kannada paired-word list developed at the Department of Audiology, AIISH, Mysore was used to obtain Speech Recognition Thresholds (SRT). Phonemically Balanced Kannada Word Test

(Yathiraj & Vijayalakshmi, 2005) was used to obtain Speech Identification Scores (SIS). Immittance Evaluation which includes tympanometry and acoustic reflex threshold test using a 226 Hz probe tone at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz was carried out using GSI Tympstar middle ear analyser (Grason-StadlerInc, USA) to rule out any middle ear pathology.

3.3.2 Auditory Working Memory Tests. The present study employed the digit span Test and auditory n-back Test as a tool to assess the auditory working memory. The tests were administered using software Smriti Shravan developed by Kumar and Sandeep (2013) at All India Institute of Speech and Hearing, Mysore. The software was installed to HP Notebook with Intel core i3 processor and the output of the sound card was connected to Sennheiser HDA 200 headphones with Mx 141 adapter for the presentation of all the test stimuli (at 65dB SPL).

Forward Digit Span. In forward digit span Test a sequence of numbers varying from 1 to 9 was presented binaurally under the headphones in a randomized order through the software. An Inter Stimulus Interval (ISI) of 1000 msec was maintained at all the levels. The test progressed from simple (Level 1) to complex (Level 7). Level 1 involved presentation of only 2 digits and as the participant performs the task the difficulty level increases steadily to level 8 which involved presentation of 9 digits. Three practice stimuli were provided as a default by the software to all the participants as a measure of familiarity with the test procedure. The participants were instructed to repeat the digits in the same order of presentation as shown in Figure 3.1 and the researcher will type the response in the software within 5000 msec of fixed duration to record the response of the participant. The scoring will be based on the number of digits correctly repeated by the participants in the same order for 3 out of 5 reversals and the final result of the participant will be given in terms of mean values automatically by the software.

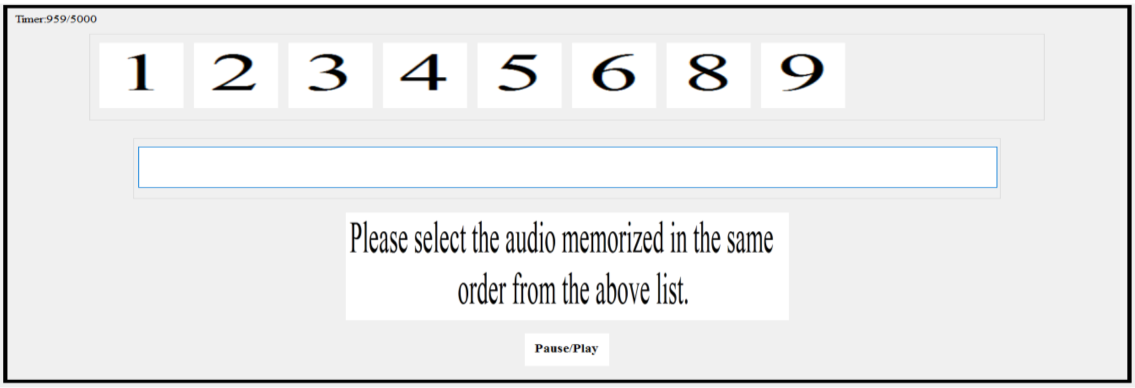

Figure 3.1 The above figure represents the screenshot taken from the software for the digit forward span test. The researcher has to click on the numbers or type the numbers repeated by the participants to record the response.

Backward Digit Span: In backward digit span test a sequence of numbers varying from 1 to 9 was presented binaurally under the headphones in a randomized order through the software. An Inter Stimulus Interval of 1000 msec was maintained at all the levels. The test progressed from simple (Level 1) to complex (Level 7). Level 1 involves presentation of only 2 digits and as the participant performs the task the difficulty level increases steadily to level 8 which involves presentation of 9 digits. Three practice stimuli will be provided as a default by the software to all the participants as a measure of familiarity with the test procedure. The participants were instructed to repeat the digits in the reverse order as shown in Figure 3.2 and the experimenter will type the response in the software within 5000 msec of fixed duration to record the response of the participant. The scoring will be based on the number of digits correctly repeated in the reverse order by the participants for 3 out of 5 reversals and the final result of the participant will be given in terms of mean values automatically by the software.

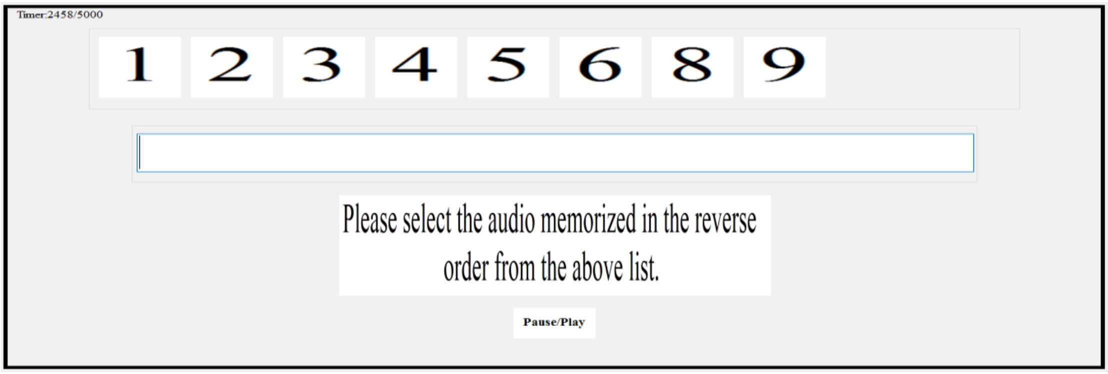

Figure 3.2. The above figure represents the screenshot taken from the software for the auditory 3 back test. The researcher has to click on the numbers or type the numbers repeated by the participants to record the response.

Auditory n-back Test. The auditory n back Test used in the present study comprised of auditory 2 back and auditory 3 back. Auditory 2-back was carried out initially as a test for familiarization and later the auditory 3 back test was presented as a tool for testing auditory WM.

Auditory 2 back. In auditory 2-back Test, the total number of trials given for each of the participants was 15 with Inter Stimulus Interval (ISI) of 1000 msec, response time was set to 5000 msec and length of the string of numbers was made to vary from 4 to 10. The test involves presenting a string of numbers in random order and requires the participants to memorize the numbers, later the participants are required to repeat the second last number from the series of numbers presented through headphones as shown in Figure 3.3 and the researcher will type the response in the software to record the response. The scoring was based on the number of responses correctly reported by the participant.

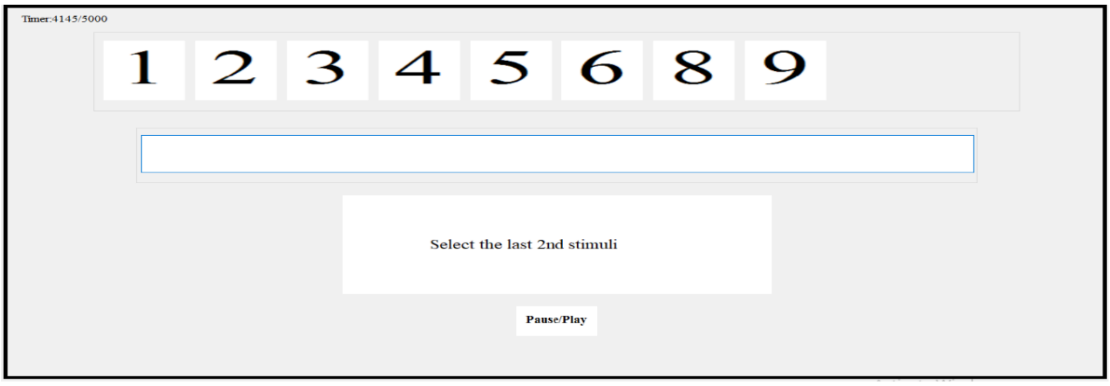

Figure 3.3. The above figure represents the screenshot taken from the software for the auditory 2 back test. The researcher has to click on the numbers or type the numbers repeated by the participants to record the response.

Auditory 3 back Test. In the auditory 3-back Test, the total number of trials given for each of the participants was 15 with Inter Stimulus Interval (ISI) of 1000 msec, response time was set to 5000 msec and length of the string of numbers was made to vary from 4 to 10. The test involves presenting a string of numbers in random order and requires the participants to memorize the numbers, later the participants are required to repeat the third last number from the series of numbers presented through headphones as shown in Figure 3.4 and the researcher will type the response in the software to record the response. The scoring was based on the number of responses correctly reported by the participant.

Figure 3.4 The above figure represents the screenshot taken from the software for the auditory 3 back test. The researcher has to click on the numbers or type the numbers repeated by the participants to record the response.

3.4 Statistical Analysis

Statistical analysis was carried out using statistical package for social sciences (SPSS) software initially. Shapiro Wilk's Test was performed to find normal distribution of the data. Mann-Whitney U Test was used to compare the performance on auditory WM in adults with congenital blindness and trained musicians. The descriptive statistics was done to assess the mean and standard deviation.

CHAPTER 4

Results

The aim of the present study was to investigate the auditory working memory performance in individuals with blindness and normal sighted individuals. The measures used for analysis was auditory n back Test which comprised of auditory 2 back and auditory 3 back, also digit forward span and digit backward span were employed to assess the auditory working memory.

Shapiro Wilk's Test of normality was administered to check whether the scores of both the working memory tests employed for the test follows the normality curve. The test revealed that the data followed the non-normal distribution curve, hence non-parametric tests were chosen for analysis. The statistical tests administered are as follows:

1. Descriptive statistics were performed to examine the central tendency and variation of the auditory working memory performance in individuals with blindness and normal sighted individuals.

2. Mann-Whitney U Test was administered to check whether there is any difference in auditory working memory performance between individuals with blindness and normal sighted individuals.

4.1 Comparison of auditory n back performance between individuals with blindness and normal sighted individuals

This section addresses the test results of auditory n back Test performance between individuals with blindness and normal sighted individuals. Descriptive statistics were done to calculate the mean, median, standard deviation, and minimum and maximum for Auditory N back Test in both the groups. The descriptive statistic results are provided in the table 4.1.

Table 4.1.

Mean, Median, Standard Deviation and Maximum and Minimum of auditory n back Test for individuals with congenital blindness and normal sighted individuals

Test	Groups	Mean	Median	Standard Deviation	Maximum	Minimum
Aud_2 back	Group 1	13.9500	14.0000	1.27	11.00	15.00
	Group 2	14.4500	15.0000	0.88	12.00	15.00
Aud_3 back	Group 1	9.4000	9.0000	2.03	6.00	14.00
	Group 2	12.7500	13.0000	1.11	10.00	15.00

Note: Group 1: Control Group, Group 2; Individuals with congenital blindness.
Aud_2 back; Auditory 2 back, Aud_3 back; Auditory 3 back

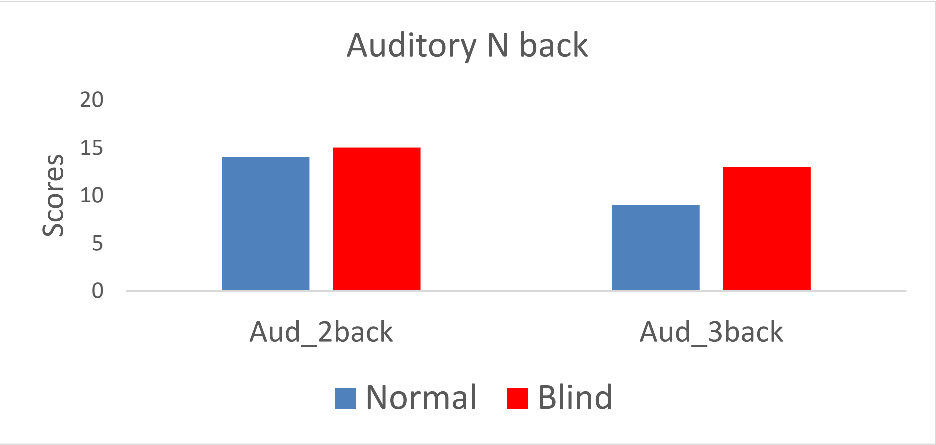

Figure 4.1: Median scores of Auditory N Back (on y axis) of individuals with congenital blindness and normally sighted individuals. Note: Aud_2 Back: Auditory 2 Back, Aud_3 Back: Auditory 3 back.

The inferential statistics, Mann-Whitney U Test was performed on this data to find any difference between individuals with blindness and normally sighted individuals. The test results revealed that there was no significant difference ($p > 0.05$) between the two groups for auditory 2 back Test. However, a significant difference was observed in auditory 3 back Test ($p < 0.05$) between individuals with blindness and normally sighted individuals. The effect size for auditory 2 back was r=0.21, and effect size for auditory 3 back was r=0.62.

Table 4.2.
Results of Mann Whitney U Test auditory n back task

	Z	*P Value*
Aud_2 back	-1.347	.178
Aud_3 back	-4.313	.000

Note: Aud_2 back; Auditory 2 back Test, Aud_3 back; Auditory 3 back Test.

4.2 Comparison of auditory digit span Test performance between individuals with blindness and normal sighted individuals

This section addresses the test results of auditory digit span Test performance between individuals with blindness and normal sighted individuals. Descriptive statistics were done to calculate the mean, median, standard deviation, and minimum and maximum for auditory digit span back Test in both the groups. The descriptive statistic results are provided in the table 4.3.

Table 4.3.
Mean, Median, Standard Deviation and Maximum and Minimum of auditory digit span Test for individuals with congenital blindness and normal sighted individuals.

Test	Groups	Mean	Median	Standard Deviation	Maximum	Minimum
FDS	Group 1	4.4650	4.8000	0.93	1.60	5.10
	Group 2	4.5700	4.5500	0.47	3.20	5.00
BDS	Group 1	2.2200	1.8000	0.72	1.40	3.50
	Group 2	4.9050	4.8000	0.54	3.50	5.80

Note: Group 1: Control Group, Group 2; Individuals with congenital blindness. FDS; Forward Digit span, BDS; Backward Digit Span

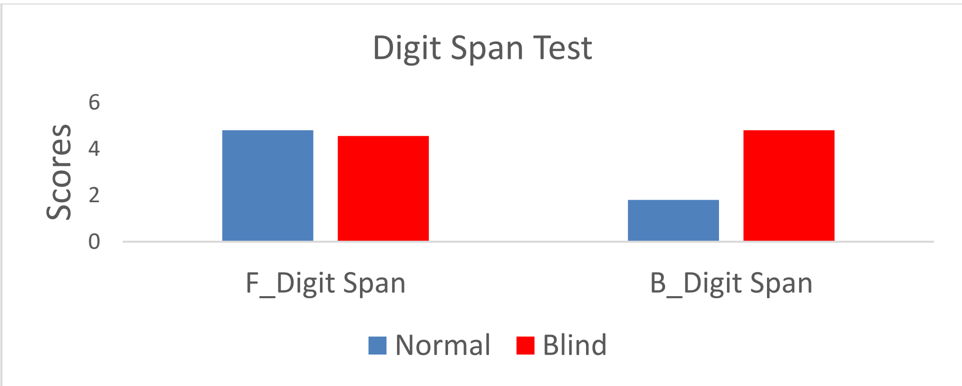

Figure 4.2: Median scores of auditory digit span Test (on y axis) for individuals with congenital blindness and normally sighted individuals. Note: F_Digit span; Forward Digit Span, B_Digit span; Backward Digit Span.

The inferential statistics, Mann-Whitney U Test was performed on this data to find any difference between individuals with blindness and normally sighted individuals. The test results revealed that there was no significant difference ($p > 0.05$) between the two groups for auditory digit forward span Test. However, a significant difference was observed in auditory digit backward span Test ($p < 0.05$) between individuals with blindness and normally sighted individuals. The effect size for auditory forward digit span was r = 0.10, and effect size for auditory backward digit span was r=3.35.

Table 4.4.
Results of Mann-Whitney U test auditory digit span Test.

	Z	*p Value*
Aud_FD Span	-.911	.362
Aud_BD Span	-5.424	.000

Note: Aud_FD Span: Auditory Forward Digit Span, Aud_BD Span: Auditory Backward Digit Span.

In the present study individuals with congenital blindness and normal sighted participants had similar performance in the auditory 2 back and auditory forward digit span Test, however individuals with congenital blindness outer performed normal sighted individuals in auditory 3 back and auditory backward digit span Test, however the performance on auditory 2 back and auditory forward digit.

CHAPTER 5

Discussion

The study aimed to assess the auditory working memory performance in individuals with congenital blindness and normally sighted individuals. The results of the study revealed that there was no significant difference in auditory two back and auditory digit forward span tests. However, a significant difference was observed in the auditory three back and auditory-digit backward span Tests between individuals with congenital blindness and normally sighted individuals.

The results of the forward digit span Test are incongruent to previous studies which describe that the forward digit span tends to less effective compared to backward digit span as it does not taps the working memory rather it reflects the short term storage capacity of the individuals (Botwinick et al., 1986; Dobbs et al., 2001; Kopelman, 1985), thus explaining superior performance in digit forward span in both individuals with congenital blindness and normally sighted individuals. The backward digit span requires storage, manipulation and retrieval of the information thus assess the working memory; and the present study reveals that individuals with congenital blindness performed significantly higher in the backward digit span Test in comparison to normally sighted individuals, such difference in performance are observed as the individuals with congenital blindness develop superior auditory skills and memory span to compensate their loss of vision.

In the present study, the auditory two back tasks were performed as a test of familiarization as the task was less complicated and easier to perform, thus explaining significantly higher performance in both the groups under the study. However, a significant difference was noted in the auditory three back task which reflects that individuals with congenital blindness procure higher working memory capacity in comparison to normally sighted individuals. Such superior performance in auditory 3 back task in individuals with congenital blindness can be either due to superior working memory skills or due to the practice sessions of auditory two back, as the individuals with congenital blindness might develop serial strategies in order to compensate for the lack of immediate visual information. It has been reported in literature studies that individuals with blindness outperform sighted participants in various auditory tasks, auditory localization, and temporal processing skills (Nilsson & Schenkman, 2016).

Muchnik et al., (1991) reported that individuals with blinds possess superior central auditory skills in comparison to normal sighted individuals. These researches conclude that individuals with blindness develop better directional hearing than sighted individuals which helps them to perform higher in localization skills, and there dependency on audition as a primary source of obtaining information makes them naturally to develop better auditory discrimination skills especially in adverse listening condition. Röder et al. (2001) reported that individuals with congenital blindness have superior localization abilities compared to sighted individuals. The authors reasoned that all the human new born possess auditory orientation of sound abilities even before visual orientation is developed, when the visual information is absent in human development, the auditory representations continues to develop which could result in gaining such advantage in localization skills. Furthermore, there are research studies which claims that individuals with congenital blindness also possess higher auditory discrimination skills than sighted participants, as the auditory mechanisms develops stronger to compensate the loss of vision in individuals with congenital blindness (Gougoux et al., 2004).

Along with these auditory skills, it has been well documented in the literature that individuals with congenital blindness are also known to perform superiorly in cognitive skills. Hull and Mason (1995) reported that blinds perform significantly higher in working memory tasks compared to their counterpart, the authors concluded that such superior performance in blinds are observed as they develop better memory span to compensate for the lack of vision, similar observations on higher cognitive skills in blinds has been reported in various research studies (Withagen et al., 2013; Amedi et al., 2003; Raz et al., 2007).

In the present study individuals with congenital blindness performed superiorly in auditory 3 back and auditory backward digit span Test. These tests taps the working memory aspects rather than short term memory. The results of the present study are in congruent to previous studies on working memory in individuals with congenital blindness. It is assumed that such superior performance by blinds can be due to development of higher auditory skills from the early age which helps not only to better localize a sound source, better auditory discrimination abilities but also help in improving their auditory working memory.

CHAPTER 6

Summary and Conclusion

Individuals with blindness relay more on the auditory information to compensate for the loss of vision which helps them to better navigate in the street, localize a sound source and also because of the loss of vision they train themselves by nature to develop a strong auditory memory. However, it is important to note that development of such auditory skills cannot be generalized to all individuals with blindness; rather individuals who lost their vision early in the age also known as congenitally blind are known to develop such auditory skills at a higher rate in comparison to those individuals with who develop blindness later in the age.

This study was taken up to compare the auditory working memory in individuals with congenital blindness and normally sighted individuals. Forty adults were divided into two groups of twenty individuals each. Individuals aged 18 to 25 years without any complaint of vision formed Group 2 (N=20) and individuals with congenital blindness constituted Group 1 (N=20). The auditory working memory was studied in both the groups using Digit span Test (Forward Digit Span, Backward Digit Span) and Auditory N back Test (Auditory two back, and auditory three back). The tests were administered using software Smriti Shravan developed by Kumar and Sandeep (2013) at All India Institute of Speech and Hearing, Mysore. The software was installed to HP Notebook with Intel i3 processor, and the stimulus was presented through Sennheiser HDA 200 headphones at 65 dB SPL. The results of the study indicated a significant difference in auditory 3 back and digit backward span Test. There was no significant difference in auditory 2 back and digit forward span Test which could be because the auditory 2 back task was easier and less complex to perform and digit forward span task assess more of short term memory rather than the working memory.

Hence, from the study it can be concluded that individuals with blindness possess superior working memory than the sighted individuals and perform significantly higher as the working memory load is increased.

6.1 Implications of the study

1. Better understanding about working memory in adults with congenital blindness.
2. Normative on working memory in adults with congenital blindness is obtained as the outcome of the study.

6.2 Future Directions

1. To carry out the study in individuals with partial blindness and comparing the obtained results with the present study, for better generalization of the results.
2. To carry out the study in children with congenital blindness to see if there is a difference that exists between adults with congenital blindness.
3. To carry out electrophysiological tests to support the obtained behavioural test results on working memory.

6.3 Limitations of the study

The number of participants in the study was limited to 20, to generalize the findings a larger sample size would have been appropriate.

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