ASSESSMENT OF AUDITORY WORKING MEMORY AND ATTENTION IN CHILDREN WITH COCHLEAR IMPLANTS

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September 2023

CERTIFICATE

This is to certify that this dissertation entitled '**Assessment of auditory working memory and attention in children with cochlear implants'** is a bonafide work submitted as a part for the fulfilment for the degree of Master of Science (Audiology) of the student Registration Number: P01II21S0063. This has been carried out under the guidance of the faculty of the institute and has not been submitted earlier to any other university for the award of any other diploma or degree.

Mysuru

September 2023

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DECLARATION

This is to certify that this dissertation entitled '**Assessment of auditory working memory and attention in children with cochlear implants'** is the result of my own study under the guidance of Dr. Geetha C., Associate Professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru and has not been submitted to any other University for the award of any Diploma or Degree.

Mysuru **Registration Number:** P01II21S0063

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I dedicate this dissertation to my loving parents,

***Mummy and Papa**,*

whose unwavering support, boundless love, and constant encouragement

have been my guiding light throughout this academic journey.

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Abstract

Background: *The most effective treatment method for children with severe to profound sensorineural hearing loss is a cochlear implant. However, children with cochlear implants (CI) could might have poorer performance on working memory and attention tests when compared with their normal hearing (NH) peers. Since the socio-cultural background could influence the performance on cognitive tasks, it is imperative to assess cognitive aspects of children using cochlear implant in India.* ***Aim:*** *The study aimed to compare the working memory and attention performances of children with cochlear implants with that of normal hearing peers.* ***Method:*** *The study involved two groups (Group I included CI and Group II included NH children), each consisting of 25 participants in the age range of 8 to 15 years. Digit span forward, digit span backward and sound count test from CLAP-C for attention were performed on all the participants and the scores were compared between the two groups.* ***Results:*** *The results of Mann-Whitney U test revealed significant group differences in the digit span forward test, digit span backward test and attention test of sound count.* ***Conclusion:*** *Children with CI had poorer performance in working memory and attention tests when compared with the age-matched NH peers. Training is required to improve the cognitive abilities of children with CI.*

Keywords: *Cochlear implant, working memory, attention.*

CHAPTER 1

INTRODUCTION

Cochlear implants (CI) are devices which are designed to provide a sense of hearing to individuals having severe to profound hearing loss. CI proves especially beneficial for those who do not experience significant improvements with conventional hearing aids, often due to the extent of their hearing loss (Deep et al., 2019; Tanamati et al., 2011). Over the past two decades, millions of children have undergone cochlear implantation. However, because of an early period of deafness followed by limited auditory input from the cochlear implant, many children with CI still face challenges, including delays in speech-language development and other neurocognitive areas (Pisoni et al., 2008; Ullman et al., 2005). Consequently, outcomes with respect to speech perception, speech production, and language skills in the CI population exhibit a wide range, with some children functioning nearly normal in quiet listening environments. In contrast, others struggle with fundamental speech-language abilities (Marschark & Hauser, 2008; Schorr et al., 2017; Soleymani et al., 2016).

Despite the increase in the success of spoken language results, long-term users of CI are subjected to complex cognitive capacity impairments, including delays observed in scores of verbal short-term memory and tests for working memory even after years of implantation (AuBuchon et al., 2015; Dawson et al., 2002; Lyxell et al. 2008; Kronenberger et al. 2013; Marschark et al., 2007). Working memory issues in preschool-aged children lead to having trouble following instructions with several steps, finishing tasks, and forgetting what to do during an activity. These issues significantly affect early learning (Gioia et al., 2003).

Bharadwaj et al. (2015) administered subtests of the Woodcock-Johnson III Tests of Cognitive Abilities, Normative Update (WJ III COG NU). Ford et al. (2010) assessed visual working memory (Spatial Span) using subtests from the Wechsler Intelligence Scale for Children-IV Integrated (WISC-IV) (McCloskey & Maerlender, 2005), short-term memory subtests (Lichtenberger & Kaufman, 2017) on children using cochlear implant. For visual working memory tasks, children with CI performed about average, and below average performance was observed on auditory working memory tests. While the mean standard scores for short term memory tests involving auditory modality (word order and numerical recall) were below average, the mean standard scores for short term memory tests involving hand motions (visual-motor) were well within the average range.

Studies have reported differences in digit span between deaf children using cochlear implants and children with normal hearing. Cochlear implant users had shorter digit spans than their age-matched peers with normal hearing. The above observation indicates that the development of short-term working memory capacity follows an atypical trajectory in children with cochlear implants (Pisoni & Cleary, 2003).

Apart from the work memory deficits, CI input prompts the allocation of limited-capacity central resources to focus on processing the diminished input, potentially resulting in attention deficits (Gianvecchio & French, 2002). Several researchers have assessed the attention abilities of children with cochlear implants using different test procedures in auditory and visual modalities. Irrespective of the test procedures, the findings of the studies reported that children with CI have shorter attention spans and their performance is poorer on the attention tests (Chen et al., 2019; Houston, 2009; Nicastri et al., 2023; Tharpe et al., 2002).

Further, cognitive abilities become essential as the predictors of many developmental skills such as language, phonology, vocabulary, etc. Verbal short term memory (digit span forward test scores) correlate with the rate of development of language and vocabulary comprehension abilities throughout time. Digit span backward scores exhibiting various patterns of verbal working memory development correlate with the rate of expansion of vocabulary and spoken word recognition proficiency improvement over time (Kronenberger et al., 2013). Similarly, the development and perception of language and speech, reading comprehension, and academic success are all positively correlated with auditory working memory (Gathercole et al., 2006; Ingvalson et al., 2014; Vuontela et al., 2003). Differences in working memory capabilities and their relationship to early learning abilities are significant (Spencer, 2020). Attention also plays a major role in development of speech and language abilities. Shorter attention spans are commonly found in children with speech and language developmental delays (Galassi et al., 2021; Smolak et al., 2020). Hence, to predict these outcomes, good auditory working memory and attention are mandatory.

1.1 Need of the study

The technology of cochlear implants has significantly advanced during the last few decades. Even then children with CI exhibited working memory and attention deficits compared to their normal hearing counterparts on serial recall measures. (Bharadwaj et al., 2015; Burkholder & Pisoni, 2003; Kronenberger et al., 2013; Lichtenberger & Kaufman, 2017; D. B. Pisoni & Cleary, 2003; Stiles et al., 2012).

Studies have compared the differences in attention and auditory working memory performances of children with CI compared to their age-matched normal-hearing peers in the western population. The cultural variations and socio-economic status of the cochlear implant recipients can significantly affect the performance of children having cochlear implants. Studies have indicated that the level of parental education can have an impact on cognitive skills and working memory abilities (Jefferson et al., 2011). Children belonging to lower socioeconomic backgrounds achieved notably lower scores in expressive and receptive vocabulary assessments compared to their peers from higher-income families. However, there were no statistically significant differences observed in between the two groups in terms of working memory performance (Engel et al., 2008). Socioeconomic disparities are commonly linked with differences that are observed in cognitive development. Most prominent differences are observed in supporting language, reading, executive functions, spatial skills and neurocognitive abilities (Noble et al., 2015).

The majority of children in India get implanted under the schemes provided by the government. Hence, the recipients of CI typically belong to a lower socioeconomic background. Socioeconomic status is a pervasive predictor of child development and can influence various developmental aspects in the childhood(Hoff & Laursen, 2019). Hence, there is a need to conduct a study to evaluate the working memory and attention abilities of children with CI in the Indian population to see if any differences may exist due to the above-described factors.

1.2 Aim of the study

The present study aimed to assess the working memory and attention performances of children with cochlear implants and compare the same with those of normal hearing peers.

1.3 Objectives of the study

The objectives of the study are-

1. to compare working memory scores using digit span tests between children with a cochlear implant and age-matched peers with normal hearing sensitivity.
2. to compare the attention scores between children with a cochlear implant and the age-matched peers with normal hearing sensitivity.

CHAPTER 2

REVIEW OF LITERATURE

Cognition contains elements like awareness, perception, conceptualization, and judgment. The term "cognition" refers to a higher domain that facilitates communication, understanding, and the processing of information (Craik, 1991). Cognitive function is the most significant predictor of various aspects like spoken language development (Gathercole & Baddeley, 1990; Pisoni & Cleary, 2004; Schorr et al., 2017), academic performance (Alloway & Alloway, 2010) and speech understanding in noise (Humes, 2007).

Children born with hearing impairment may have prolonged periods of auditory deprivation until they undergo cochlear implantation. Hence, reduced auditory perception might lead to a deterioration in cognitive abilities even when the hearing devices are fitted (Baltes et al., 1997; Pisoni et al., 2003.; Ullman et al., 2005). Further, working memory significantly affects a person's capacity to carry out essential tasks, including reading, word learning, language acquisition, arithmetic processing, and reasoning (Alloway et al., 2006; Bayliss et al., 2005). Even a mild hearing loss might lead to reduced performance in cognitive tasks because of higher-level comprehension, such as retention of auditory information into memory, has to be used for decoding and perceiving the speech signal accurately (Besser et al., 2013; Tun et al., 2009). Therefore, assessing cognitive abilities in individuals with hearing impairment is essential. The present aimed to assess working memory and cognition in children with CI. Therefore, the literature is reviewed on auditory working memory and attention tests in children with CI.

2.1 Memory and its types

Memory is the cognitive process of encompassing the storage, retention, and retrieval of information or past experiences, and it holds significant importance in our daily lives (Adams et al., 2018; Gathercole, 1998; Klein, 2015). It comprises various types and stages, playing a pivotal role in activities day to day activities. Memory can be categorized into three primary divisions: sensory memory, short-term memory, and long-term memory. Sensory memory typically lasts for a very brief duration, spanning from 200 to 500 milliseconds (Izquierdo et al., 1999). Short-term memory forms an active component within the memory system and lasts for a few seconds to few minutes (Izquierdo et al., 1999). It aids in processes such as rehearsal, information aggregation and facilitates the transfer of data into long-term memory. Long-term memory, the final division, allows for the storage of information for extended periods, often spanning a lifetime (Awh et al., 1996). Working memory is a form of short-term memory temporarily holding and manipulating information especially for cognitive tasks (Baddeley & Hitch, 2000).

2.2 Working memory

Miller et al. (1960) proposed the term 'working memory '. It is regarded as one of the important mental faculties, playing a crucial role in cognitive activities such as planning, problem solving and reasoning. Working memory is part of the cognitive system that temporarily holds and then manipulates information necessary for various cognitive tasks. It is often described as a mental workspace where information is actively processed, allowing individuals to perform complex cognitive activities such as problem-solving, reasoning, comprehension, and learning (Baddeley, 1992).

Children having poor working memory abilities perform poorly on all working memory tests, irrespective of whether they involve verbal or visuo-spatial material as they cannot hold sufficient information to allow them to complete the task (Cleary et al., 2001; Pisoni & Cleary, 2003, 2004). There are various tests available in cognition test modules to test auditory working memory in children. Some of the batteries that include auditory working memory are Wechsler Intelligence Scale for Children-III, Forward Digit Span and Backward Digit Span, Illinois test of psycholinguistic skills, Woodcock-Johnson III Tests of Cognitive Abilities, Working Memory Test Battery for Children etc.

2.3 Auditory working memory tests

Auditory working memory is a process in which auditory stimulus will be temporarily retained in the brain's working memory and used to carry out tasks when the stimulus is not present (Roy, 2018). Auditory working memory can be evaluated using different forms of tests. These tests may include the simple span task (Forward digit, backward digit, ascending digit and descending digit) and complex span tasks (reading span, operational tasks, rhyme judgements: visual letter monitoring and n-back task). Digit recall, word recall and nonword repetition are some of the commonly used tasks to assess working memory and have been used extensively in the past (A. Adams et al., 1995; Bayliss et al., 2005). Some of the commonly used working memory tests and their procedures are as given in the following sections.

2.3.1 Simple span Tests

Forward and Backward digit span tests:

Sir Francis Galton invented the forward digit span test in the late 19^{th} century. The forward digit span test evaluates attention and short-term memory. In this test, numbers are presented sequentially through the auditory mode in a random order. The level of presentation increases in difficulty with each correct response. After each correct response, the difficulty level of the next sequence increases by one digit.

Similarly, after each incorrect response, the next sequence decreases by one digit. The subject's task is to repeat the digits in the same order as presented (Blackburn & Benton, 1957; Kishor, 2014; Schulze et al., 2018). Blackburn and Benton developed the backward digit span test in 1950s which also measures working memory. In this test numbers are presented sequentially through the auditory mode in a random order. The sequence increases in difficulty with each correct response. After each correct response, the next sequence increases by one digit. Similarly, after each incorrect response, the level of presentation decreases by one digit. The subject is instructed to repeat the numbers in the reverse order as presented (Blackburn & Benton, 1957; Kishor, 2014; Schulze et al., 2018).

Ascending and Descending digit span tests:

In the ascending span test, numbers are presented sequentially through the auditory mode in a random order. The level of presentation goes on increasing in difficulty with each correct response. After each correct response, the level of difficulty increases by one digit. Similarly, after each incorrect response, the number of digits decreases by one digit. The participant is instructed to arrange the numbers presented in ascending order and then respond (Case et al., 1982; Chincotta & Hoosain, 2007; Kishor, 2014)**.** In descending test, numbers are presented sequentially through the auditory mode in a random order. The difficulty level increases in difficulty with each correct response. After each correct response, the level of the next presentation increases by one digit. Similarly, after each incorrect response the difficulty level decreases by one digit. The participant is instructed to arrange the numbers presented in descending order and then respond (Case et al., 1982; Chincotta & Hoosain, 2007; Kishor, 2014).

2.3.2 Complex span tests

Reading span test:

This test was given by Daneman & Carpenter, 1980. The test involves presentation of a sentence word by word. The participant's task is to decide whether the sentence was meaning-full or non-meaningful. Also, the listener has to either repeat the first or the last word of the sentence depending on the instructions (Friedman & Miyake, 2004, 2005; Robert et al., 2009).The reading span task involves participants in a dual cognitive challenge: firstly, they must read a sequence of sentences aloud while simultaneously assessing the semantic acceptability of each sentence; secondly, they must remember the last word of each sentence for future recall. Significantly, success in the reading span task has been observed to foretell the proficiency in complex cognitive processes, including comprehension, problem-solving, and reasoning—tasks that hinge on the deployment of executive attention (Geers et al., 2013).

Operational span:

Measures used for operation span task were adapted from the versions of (Conway et al., 2005) and (Kane et al., 2004). The listener's task is to say if the mathematical equation is correct or not, and along with that, the participant has to repeat the words that were presented before in the same order (Case et al., 1982; Kishor, 2014; Towse et al., 2000; Unsworth et al., 2005)

2.4 Attention and its types.

Attention refers to an individual's capacity to actively process particular information in their surroundings while disregarding irrelevant details. It is crucial to recognize that attention has constraints in terms of both its capacity and duration (Driver, 2001; Friedman & Miyake, 2004). Therefore, it becomes essential to employ effective strategies for managing the limited attentional resources at our disposal, enabling us to better comprehend the world around us.

There are many different types of attention used by people. Sustained attention is also known as concentration. It is the ability of an individual to focus on one thing for a longer period. It focuses on the task a person is handling and continue to engage in the same behaviour till the time task is complete or a certain period of time has elapsed (Driver, 2001). Alternating attention involves effortlessly shifting attention between two or more things with different cognitive demands (Brain, 2000). Selective attention is the type of attention which entails the ability to make choices and focus attention selectively on specific stimuli in the environment while simultaneously ignoring other stimuli (Driver, 2001; Duncan, 1984). Focused attention involves being able to suddenly drawn to a specific visual, auditory, or tactile stimuli such as a loud noise or a flash of light (Gabriel & Chua, 2006). Limited attention is also known as divided attention. It is a form of attention which also involves multitasking (Lindsay, 2020; Scalf et al., 2013).

2.5 Working memory and attention deficits in children with CI.

With the emergence of CI, a new realization regarding the interaction of sensory and cognitive systems emerged. Sensory experiences can fundamentally affect cognitive operations (Bush et al., 2005). More specifically, the quantity and characteristics of auditory input following the adoption of a CI play a pivotal role in shaping the encoding and processing of verbal content in working memory, with a particular emphasis on its impact on children (Burkholder & Pisoni, 2003; Pisoni & Cleary, 2004). Children who undergo cochlear implantation tend to exhibit reduced working memory capabilities when compared to their counterparts with normal hearing (Bharadwaj et al., 2015; Burkholder & Pisoni, 2003b; Kronenberger et al., 2013; Lichtenberger & Kaufman, 2017; Pisoni & Cleary, 2003; Stiles et al., 2012). Furthermore, these decreased working memory capacities seem to have repercussions on other cognitive functions (Pisoni et al., 2005).

Pisoni and Cleary (2003) used the Wechsler Memory, Verbal Rehearsal, and Scanning 333 Intelligence Scale for Children's auditory digit span exercise, which gave scores of working memory capacity. They administered the test on 8-9-year-old CI users. Live voice presentation of digits and visual cues for stimuli presentation were used. There was evidence of decreased memory spans in hearing-impaired children utilizing CI compared to the normal hearing children.

Shorter verbal memory spans and deficits in digit span and non-word repetition measures in children implanted with CI have been observed through various studies (Cleary et al., 2001; Watson et al., 2007). Comparing the cognitive functions in children with hearing impairment using CI to age-equivalent normal-hearing children, the performance of normal-hearing peers was superior to children with CI on a digit span test. As in normal-hearing children, a high correlation between digit span to reading and language has been observed in children using CI (Pisoni & Geers, 2000). Preschool-aged children with CI performed significantly poorer on inhibition-concentration and working memory tests when compared with age-matched NH peers and with national norms (Beer et al., 2014).

Using digit span tests, Pisoni and Cleary (2003a) measured the working memory capacity. It was found that even individual variations in performance could contribute to variations in outcome measures of speech and language performance in children with CI. Simple forward digit span measures of verbal working memory were significantly correlated with spoken word recognition scores (Burkholder & Pisoni, 2003). In children with typical development, the scores of working memory tasks influence reading abilities independent of measures of their phonological skills (Jefferson et al., 2011). Working memory is also linked to math outcomes. Children having low working memory scores can be related to their poor performance on arithmetic word problems and computational skills (Swanson & Sachse-Lee, 2001). Hence, auditory attention and working memory performance can play an essential role in predicting these outcomes related to academic performance and the development of spoken language abilities. Therefore, assessing the attention and working memory performance in children with cochlear implants is vital.

A research investigation aimed to assess whether children who utilized cochlear implants exhibited divergent performance compared to age- and gender-matched peers using hearing aids across eight neuropsychological assessments that gauged aspects of visual memory, attention, and executive functioning. The findings suggested that disparities in visual memory abilities might contribute to the variation in language skills between children with implants and hearing aids (Surowiecki et al., 2002).

Many researchers have investigated children's attention abilities using different test procedures, such as use of visual distractors along with auditory stimuli, syllable and digit count tasks, dichotic presentations, etc. Irrespective of the test procedures used, the studies have reported deficits in the attention spans of children using CI in comparison with their age-matched normal hearing peers (Chen et al., 2019; Houston, 2009; Nicastri et al., 2023; Tharpe et al., 2002). Infants with CI have a reduced span of attention to speech compared to normal-hearing infants, and the speech input available to the CI infants differs from available input to infants with normal hearing (Houston & Bergeson, 2014).

Cognitive abilities play an important role when it comes to the development of various childhood aspects such as language, phonology, vocabulary, etc. (Kronenberger et al., 2013). Similarly, there is evidence of the relationship between working memory and children's academic performance (Alloway & Alloway, 2010). The development and perception of spoken language, reading comprehension, and other academic aspects positively correlate with auditory working memory performance. The cognitive abilities and attention aspects can predict education and affect academic performance (Gathercole et al., 2006; Ingvalson et al., 2014; Vuontela et al., 2003).

CHAPTER 3

METHOD

The present study employed a quasi-experimental research design. Purposive sampling was used to enrol the participants.

3.1 Participants.

The study included 50 school-going children in the age range of 8 to 15 years. These 50 participants were further divided into two subgroups. Group I included 25 normal children with a hearing threshold of less than 10 to 15 dB HL served as controls. The mean age of participants in this group was 10.64 (SD = 1.69) Group II included 25 children with bimodal cochlear implantation with bilateral severe to profound hearing loss. The mean age of participants in this group was 10.92 (SD = 2.19).

Group I had a mean PTA of 10.93 dB HL (SD = 2.35) in the right ear and 10.5 (SD = 2.12) in the left ear, and Group II had a mean PTA of 104.69 dB HL (SD = 5.67) in the right ear and 109.19 (SD = 6.22) in the left ear. An attempt was made to match the age, gender, and listening environment between the two groups. The inclusion and exclusion criteria used to select the participants are given below:

3.2 Inclusion criteria:

Group I

1. Participants with normal hearing sensitivity were in both ears (≤ 15 dB HL) for both air conduction (0.25 Hz to 8 kHz) and bone conduction thresholds (0.25 Hz to 4 kHz), the air-bone gap is less than 10 dB HL.
2. Participants had speech identification scores of 100%.
3. Children with normal otoscopic findings in both ears were selected as a control group.
4. Participants with age-adequate language skills (based on informal language screening) were included.

Group II

1. Participants with a CI in one ear and a hearing aid in the opposite ear, i.e, bimodal users.
2. Participants had used CI for at least three years.
3. All participants had immittance findings of “A” type or “As” type.
4. Aided speech identification scores were above 80% for all the participants.
5. The implanted ear's aided threshold in the upper range of spectrum for all the participants.
6. Participants with adequate language to perform the tasks were selected. (Informal assessment was done using verbal questions, including reasoning and picture description).

3.3 Exclusion criteria

1. Participants with unilateral hearing loss were not selected in Group II.
2. Participants with poor word recognition scores were excluded from the study.
3. Participate with inadequate language were excluded from the study.
4. Participants with additional disabilities and anomalies such as middle ear infections, visual impairment, and borderline intellectual disabilities were excluded.

The demographic and audiological details of all the participants are in Table 3.1. and Table 3.2 for two groups. The details about the cochlear implant used are also given in Table 3.2.

Table 3.1.

The demographic and audiological details of the participants with normal hearing in Group I.

SI.no	Age (years)/ gender	PTA (dB HL)		SIS (%)
		Right ear	Left Ear	Both ears (R/L)
1.	9/M	12.5	12.5	100
2.	9/F	10	8.75	100
3.	10/M	13.75	12.5	100
4.	10/F	11.25	8.75	100
5.	8/M	5	6.25	100
6.	12/F	12.5	8.75	100
7.	9/M	12.5	13.75	100
8.	12/M	11.25	10.5	100
9.	11/M	8.75	10	100
10.	8/M	12.5	11.25	100
11.	9/M	10.5	12.5	100
12.	13/M	10	8.75	100
13.	13/F	13.75	12.5	100
14.	13/F	8.5	10.5	100
15.	14/F	12.5	12.5	100
16.	11/F	10	8.75	100
17.	14/F	13.75	12.5	100
18.	8/F	11.25	8.75	100
19.	12/F	5	6.25	100
20.	11/M	12.5	8.75	100
21.	11/M	12.5	13.75	100
22.	14/M	11.25	10.5	100
23.	9/M	8.75	10	100
24.	11/M	12.5	11.25	100
25.	8/M	10.5	12.5	100

Note: PTA- Puretone average thresholds at 500 Hz, 1 kHz, 2 kHz, 4 kHz; SIS-speech identification scores.

Table 3.2.

The demographic and audiological details of participants with details of cochlear implants in CI group.

SI. No	Age / gender	PTA (dB HL)		SIS Aided (%)	Model of implant		Model of hearing aid
		Right ear	Left ear		Model of CI	Model of speech processor	
1.	12Y/M	106.5	110	88	Freedom ST	CP802	Phonak Naida P30 UP
2.	8Y/M	110	115	92	Freedom ST	CP802	Beltone boost 695
3.	8Y/M	100	98.75	88	Medel Sonata	Opus 2	Verunio XTM XP BTE
4.	12Y/M	96.25	102.5	84	Freedom	CP 802	Siemens Lotus
5.	9Y/F	113.5	103.5	88	Freedom	CP802	Enzo 598 BTE
6.	9Y/M	97.5	116.2	88	Medel sonata	Opus 2	Logar 598 BTE
7.	9Y/M	100	106.5	88	CI24RE(ST)	CP802	Danavox LG 290
8.	8Y/M	110	113.5	84	CI22	CP1002NFS	Beltone boost
9.	11Y/M	102.5	115	92	CI24RE(ST)	CP802	Danavox logar 598
10.	12Y/F	106.5	110	96	Freedom	CP802	Danavox logar 598
11.	9Y/M	106.5	115	84	Freedom	CP802	Beltone boost 695
12.	11Y/F	100	103.5	92	Medel Sonata	Opus 2	Danavox logar 440
13.	12Y/M	97.5	115	92	Freedom	CP802	Starkey Aries pro
14.	13Y/M	102.5	110	92	Medel Sonata	Opus 2	Beltone boost 695
15.	14Y/M	111.25	117.5	96	Freedom	CP802	Audio service volta HP
16.	11Y/M	106.5	112.5	96	Medel Sonata	Opus 2	Danavox Klar 388 DW SP BTE
17.	9Y/F	100	106.5	92	Medel Sonata	Opus 2	Starkey Aries pro
18.	12Y/F	113.5	115	88	CI24RE(ST)	CP802	Phonak Naida P30 UP
19.	11Y/M	98.75	103.5	92	Freedom	CP802	Rely 395 DW SP BTE
20.	13Y/F	106.5	102.5	92	Freedom	CP802	Audio service volta HP
21.	10Y/F	106.5	102.5	88	Freedom	CP802	Beltone boost 695
22.	11Y/F	113.5	103.5	96	Medel Sonata	Opus 2	Danavox Klar 388 DW SP BTE
23.	10Y/M	115	97.5	96	CI24RE(ST)	CP802	Rely 395 DW SP BTE
24.	12Y/F	100	106.5	92	Medel Sonata	Opus 2	Starkey Aries pro
25.	11Y/F	106.5	103.5	88	Freedom	CP802	Danavox Klar 388 DW SP BTE

Note: PTA- Puretone average thresholds at 500 Hz, 1 kHz, 2 kHz, 4 kHz; SIS- speech identification scores.

3.3 Test environment

Testing was done in a sound-treated room with ambient noise levels within the specified ranges per ANSI S3.1 (1991). The test room was comfortable enough for the children with reference to temperature and light.

3.4 Stimuli and material

- Smrithi Shravan V 1.0 (Kumar et al., 2012) installed in laptop was used to present the stimuli for digit span tests. The signal was routed through an audiometer and presented through a loudspeaker. The stimuli consisted of Kannada numbers from 1 to 7.
- The sound count subtest of CLAP-C (Anuroopa, 2006) was used to assess attention. It had 5 level. Each level had increasing number of syllables.

3.5 Ethical consideration

All the testing procedures in the present study were performed using a non-invasive approach. The test procedures were explained to the parents of the participants before the testing clearly, and written informed consent was taken from the parents / caretakers of the participants.

3.6 Instrumentation

- An otoscopic examination was done using a clinical otoscope to rule out tympanic membrane abnormalities and to check for the status of the external ear abnormalities.
- The two-channel calibrated clinical audiometer (Piano plus Inventis) with an option for speech audiometry was used to perform threshold estimation at the octave frequencies and to carry out speech audiometry. The pure tone audiometry for air conduction threshold estimation was obtained using

calibrated TDH 39 headphones from 250 Hz to 8000 Hz at octave frequencies. The output of the audiometer was routed to a loudspeaker, placed 1 meter away from where the child was seated, at 45° Azimuth.

- Calibrated GSI Tympstar Pro Immittance meter was used to perform tympanometry and the acoustic reflex threshold measurements with the probe tone frequency of 226 Hz. Ipsilateral and contralateral acoustic reflexes were measured at 500, 1 kHz, 2 kHz, and 4 kHz**.**

3.4 Procedure

3.4.1 Routine audiological evaluation

All participants initially underwent a standard audiological assessment comprising pure-tone audiometry using Modified Hughson & Westlake method (Carhart & Jerger, 1959) at octave frequency range from 0.25 to 8 kHz with speech audiometry including speech recognition threshold, speech identification scores, and uncomfortable loudness level. Tympanometry with reflex measurement was carried out. The pure tone average threshold was calculated by taking average of thresholds at 500 Hz, 1 kHz, 2 kHz and 4 kHz for all the participants. Kannada spondee words were used for the measurement of speech recognition threshold. Kannada monosyllabic words were used for measurement of speech identification sores. A total of 25 words were presented to each ear and number of correct words repeated were taken for calculating the speech identification scores. Immittance testing was done for all the participants. All the CI participants were wearing CI in one ear and hearing aid in opposite. The hearing aids and CI were mapped and programmed by a qualified audiologist. The aided performance assessment was carried out for a frequency range from 0.25 to 8 kHz towards the CI side. Additionally, a behavioural listening check with ling six sound test. Also, the aided speech recognition scores were calculated where the Kannada monosyllabic words were presented through the loudspeakers. A total of 25 words were presented and the number of correctly repeated words were used for calculating the speech recognition scores.

3.4.2 Assessment of auditory working memory

Auditory working memory scores were assessed for children using CI and children having normal hearing sensitivity. CI children had both cochlear implants and hearing aids switched-on during the testing. The CI had stabilized maps and the hearing aids had maximum gain. Using the Smriti-Shravan testing software, the auditory working memory was evaluated. The evaluation of auditory working memory was performed using an auditory cognitive module, having digit span tasks. The stimuli were presented using a loudspeaker placed at a one-meter distance at an angle of 45^o routed through a calibrated audiometer. The stimuli were presented at 45 dB HL. Digit span tasks included two tasks, namely forward digit span and back word digit span.

The task began with an initial presentation of 2 digits, and a trial for the same was included before the evaluation task. Kannada numbers were used as stimuli for both the digit span tasks. Single digit numbers including- 1,2,3,4,5,6,7 and 8 were used for presentation. Three trials were provided before the actual presentation of the test stimuli.

The tests began with the presentation of 2 digits. The number of digits in a cluster either increased or decreased based on the correct or incorrect response. One up-one-down procedure was used for the presentation of subsequent stimuli. This was done for ease of administration and to avoid subject fatigue. The participants had to memorize the digits and repeat them in the same order for the forward digit span task and repeat in the opposite order for the backward digit span task. The participants had to repeat the digits in the same order for the forward digit span task and repeat in the reverse order in backward digit span. Written stimuli were also provided for practice to few cases of children with CI where they had difficulty in understanding the verbal instructions.

The clinician listened to the responses repeated by the child and then used the keyboard to type the responses. For both the forward and backward digit span tasks the Inter Stimulus Interval between the subsequent stimuli was 1100 msec. Number of reversals used calculation of the scores were '5' and two reversals were discarded. The responses were analysed for scoring by the software. The responses were measured by taking the midpoint of four best reversals out of six and were averaged. The max value and the mid-point scores were used for the analysis.

3.4.3 Assessment of attention

Attention scores were evaluated using "Cognitive-linguistic assessment protocol for children" (CLAP-C) (Anuroopa, 2006). The subtest of *sound test count* was used from the auditory domain, where the participant had to count the number of times a sound was heard in a sequence of sounds. This test required sustained and selective attention to complete it. There are five levels in which complexity increases from level one to level five. The stimulus was presented using a loudspeaker placed at a one-meter distance at an angle of 45^o routed through a calibrated audiometer. The stimuli were presented at 45 dB HL. Stimuli for this test was presented with live voice through the microphone. The children were instructed to count the number of times the target sound /b/ appears from the set of other syllables presented by the clinician. Written stimulus was used for explaining about the task procedure in case the child had difficulty in following the verbal instructions for completion of the task. For every correct answer, child was scored ‘1’, and if the answer is incorrect or even if the child misses one sound, the score will be considered as ‘0’. The 5 levels of stimuli used in the test were:

Level 1- ma, ba, ta

Level 2- sa, la, ba, ra, sa

Level 3- ba, ja, la, ba, pa, ba, ha

Level 4- ta, ka, pa, pa, ba, na, la, ra, sa

Level 5- na, ta, pa, ba, ha, na, ba, cha, la

3.5 Statistical Analysis

The collected data were analysed using Statistical Package for Social Sciences (SPSS for Windows, Statistical Version 26) software. The Shapiro-Wilk normality test was carried out to determine the data distribution. descriptive statistics were performed to summarize the data. Mann-Whitney U test was conducted to compare the variables between groups.

CHAPTER 4

RESULTS

The primary aim of the study was to compare working memory scores and the attention scores between children with a cochlear implant and the age-matched peers with normal hearing sensitivity. Statistical analysis was done using the software Statistical Package for Social Sciences (SPSS) version 26.0. The data was analysed for normality using Shapiro-Wilk's test, the results of scores obtained in working memory and attention tests did not follow the normal distribution ($p < 0.05$). Hence, the data were subjected to non-parametric tests. The overall mean, median and standard deviation for the scores of the forward span test, backward span test and attention obtained in normal hearing children and children with CI is shown in Table 4.1.

Table 4.1

Mean, median and standard deviation (SD) of the scores obtained by children with CI and normal hearing children.

		Tests				
Group		**dfmid**	**dfmax**	**dbmid**	**dbmax**	**attention**
Normal	Mean	3.94	5.12	2.50	3.54	4.88
	Median	3.83	5.00	2.33	4.00	5.00
	SD	0.99	1.13	0.65	0.82	0.33
CI	Mean	2.57	3.64	1.40	2.40	3.60
	Median	2.33	4.00	1.50	2.00	4.00
	SD	0.78	1.03	0.96	1.11	1.28

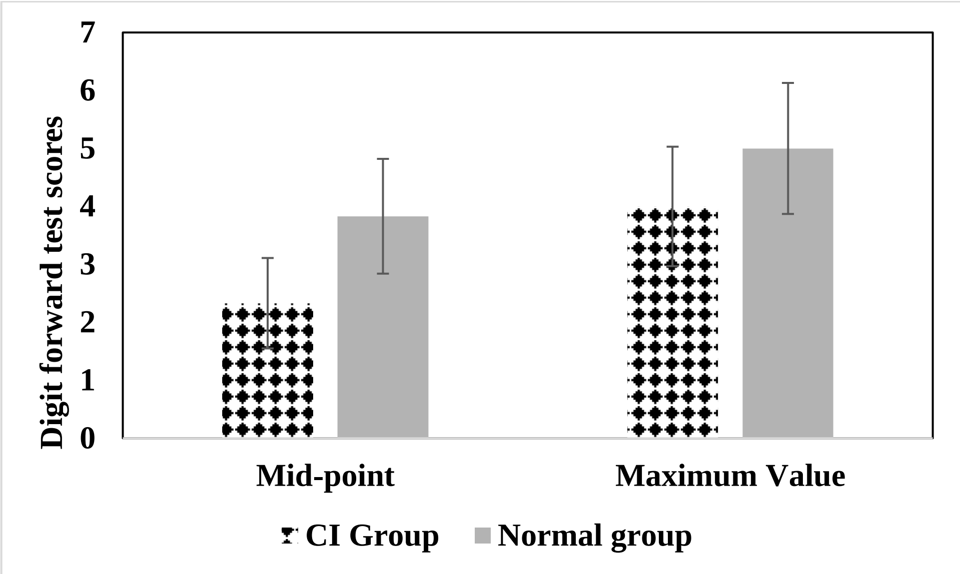
Note: dfmid- digit forward midpoint, dfmax- digit forward maximum value, dbmid- digit backward midpoint, dbmax- digit backward maximum value, CI – Cochlear implant.

4.1. Comparison of digit span forward test between normal hearing children and children with CI

The mid-point and the maximum value scores obtained for the digit span forward test were analysed between the two groups. The median value and standard deviation of mid-point scores and the maximum value for digit forward test of the two groups are represented graphically in the Figure 4.1. The graph indicates that for both mid-point and maximum value of digit forward test the CI group has performed poorer than the normal hearing group.

Figure 4.1

Graphical representation of median values and standard deviation of scores for the mid-point and maximum value for digit forward test.



Note: CI - Cochlear Implant.

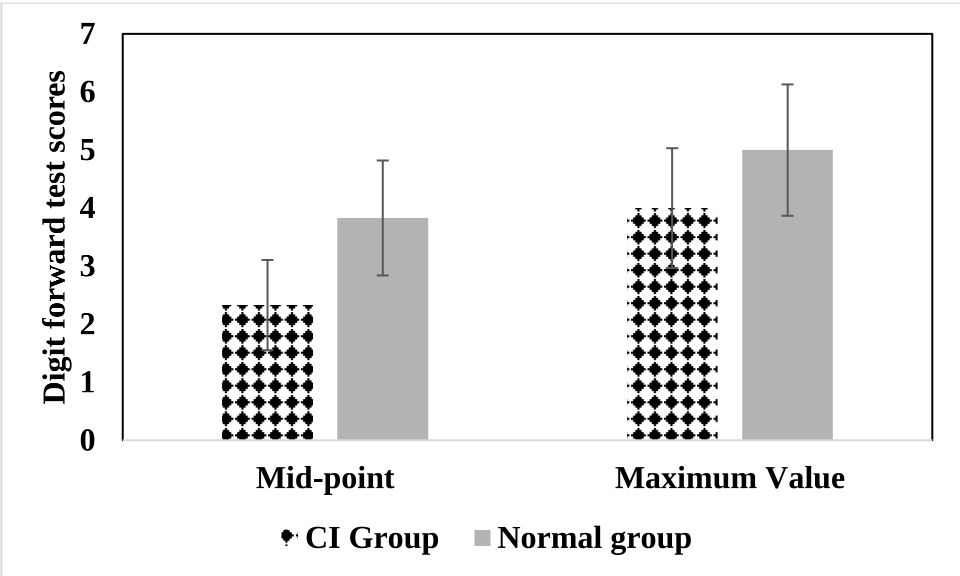
Mann Whitney U test was administered to compare the scores obtained by normal hearing children and children with CI in the digit span forward test. Results revealed a significant difference between the scores of the two groups for the digit forward recall test. Significant differences were found for both the digit forward mid-point *($|Z| = 4.250, p < 0.01$)* and the maximum value for digit forward recall *($|Z| = 3.99, p < 0.01$)*.

4.2. Comparison of digit span backward recall between normal hearing children and children with CI

The mid-point and the maximum value scores obtained for the digit span backward test were analysed between the two groups. The median value and standard deviation of mid-point scores and the maximum value for digit backward test of the two groups are represented graphically in the Figure 4.2. The graph indicates that for both mid-point and maximum value of digit backward test the CI group has performed poorer than the normal hearing group.

Figure 4.2

Graphical representation of median values and standard deviation of scores for the mid-point and maximum value for digit backward test.



Note: CI - Cochlear Implant.

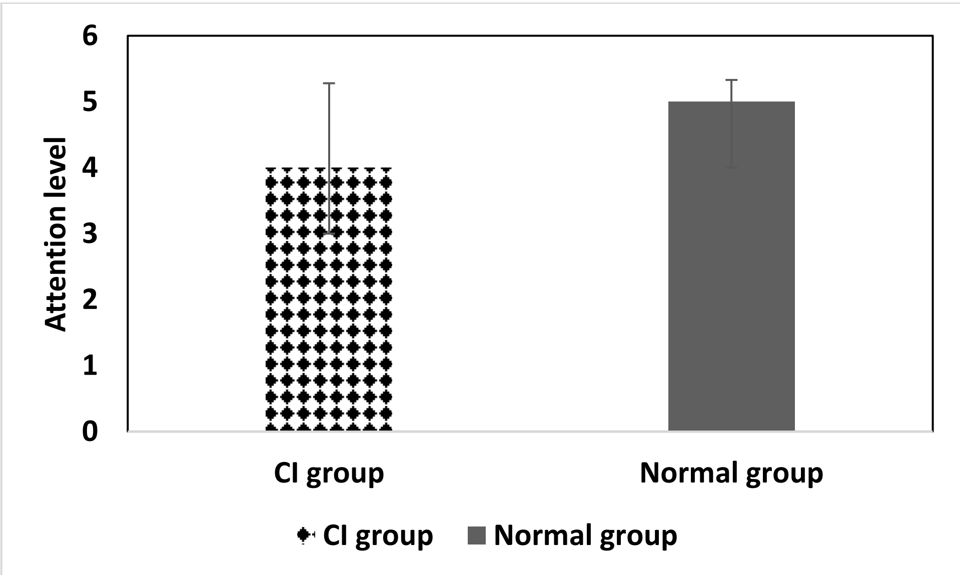
Mann Whitney U test was administered to compare the scores obtained by normal hearing children and children with CI in the digit span backward test. Results revealed a significant difference between the scores of the two groups for the digit backward recall test. Significant differences were found for both the digit backward mid-point *($|Z|= 3.96, p < 0.01$)* and the maximum value for digit backward recall *($|Z|= 33.63, p < 0.01$).*

4.3. Comparison of attention scores between normal hearing children and children with CI

The attention levels obtained for participants in each group were analysed to compare performance between children with CI and children with normal hearing. The median value and standard deviation of attention levels obtained by the two groups are represented graphically in the Figure 4.3. The graph indicates that the median level of attention obtained for the CI group has poorer than the median level of attention obtained normal hearing group.

Figure 4.3

Graphical representation of median values and standard deviation of scores for the attention test.



Note: CI- Cochlear Implant.

Mann Whitney U test was administered to compare the scores obtained by normal hearing children and children with CI in the syllable count test of attention. Results revealed a significant difference between the scores of the two groups for the syllable count test of attention *(*$|Z| = 4.18$ *and* $p < 0.01$*).*

CHAPTER 5

DISCUSSION

The present study aimed to assess the auditory working memory and attention of individuals with normal hearing sensitivity and individuals having cochlear implants. The results of the study revealed significant differences between the two groups on working memory tests. Likewise, there was a significant difference in attention level measured using subtest of sound test count from the Cognitive-linguistic assessment protocol for children (CLAP-C) between the two groups. The above results are discussed below.

5.1 Comparison of Digit span test recall in children with normal hearing sensitivity and children with CI.

There existed a significant difference in the scores of digit forward and digit backward tests between the children with normal hearing and children with CI. This finding is in consensus with many earlier research study findings (Bharadwaj et al., 2015; Burkholder & Pisoni, 2003; Kronenberger et al., 2013; Lichtenberger & Kaufman, 2017; Pisoni & Cleary, 2003; Stiles et al., 2012). Conditions involving degraded or absent auditory input, such as deafness and hearing impairment are associated with differences in comparison to the normal hearing individuals on several types of cognitive tasks. Cochlear implants (CIs) can partially reinstate auditory capabilities in deaf children, fostering the acquisition of speech and language skills in numerous instances (Ullman et al., 2005). Nonetheless, the combination of an initial phase of deafness followed by the constraints of auditory input provided by CIs continues to exert a lasting influence on the development of speech, language, and other aspects of neurocognitive development in many CI children (Pisoni et al., 2008).

In the present study, the median number of digits forward recalled is denoted by the terms digit forward max (dfmax) for the maximum value for forward span digit recall test and digit backward maximum (dbmax) for the maximum value for digit backward recall test. In the present study, the median dfmax value was 5.00 for children with NH and the median dfmax value was 4.00 for the children with CI. The present study findings of children with normal hearing are similar to that of children without abacus training in a study by Roy et al. (2020). The results of the present study support the findings of the earlier studies which reveal that the working memory test scores for children with CI are lesser when compared with the scores of normal hearing children (Burkholder & Pisoni, 2003b; Geers et al., 2013; Kronenberger et al., 2011; Pisoni et al., 2011). However, the overall median maximum digit span scores for both digit forward and digit backward tests in the present study are found to be lesser than the maximum recall values obtained for the respective tests in the study by Kronenberger et al. (2011) in the screening and the pre-training assessment. The maximum scores obtained in the present study are in consensus with study by Geers et al. (2013) and Pisoni et al. (2011) but the median maximum values are lesser in comparison to their study.

The reason for the discrepancies could be the differences in the method. In the present study, the stimuli used for digit span tests was routed through a laptop and presented through loudspeakers from a distance of 5 feet. In contrast, most of the studies that have used live voice for presentation of the numbers and numbers were presented from a distance of 3 feet. Additionally, visual cues were used along with auditory cues for carrying out the task (Burkholder & Pisoni, 2003; Geers et al., 2013; Pisoni et al., 2011). These differences in the mode of test administration could have contributed to the disparity between the scores obtained for the working memory tests. Further, socio-economic status might also have had influence on the reduced performance as most cases included in the present study had undergone cochlear implantation through free schemes. However, this hypothesis needs to be tested by analysing the socioeconomic status and performance on cognitive tests.

Though children with cochlear implants, in the present study, have used the device for several years and have undergone intensive listening training in the initial years on different domains including cognition, there tends to be working memory deficit. These findings mandate the need for additional training in these children. Kronenberger et al. (2011) investigated the efficacy and feasibility of a working memory training program for improving memory and language skills in children with CI in the age range of 7 to 15 years. All the children were given a home-based working memory training program for a duration of 5 weeks. A significant difference existed between the working memory scores pre and post the training program. Hence, working memory training could be effective for improving the working memory test scores and hence, may be recommended for school going children.

5.2 Attention in children with normal hearing sensitivity and children with CI.

In the present study a significant difference was noted in between two groups for attention scores on the sound count subtest of CLAP-C. The CI group performed significantly poorer when their performance was compared with that of the normal hearing group. The findings of the study are in support of the previous study findings which have assessed auditory based attention in children with CI (Chen et al., 2019; Houston, 2009; Nicastri et al., 2023; Tharpe et al., 2002). Previous studies suggest that a prolonged period of deafness and lack of auditory inputs result in deficits in the cognitive functioning (Pisoni et al., 2005; Ullman et al., 2008). Hence, the children with CI have poorer attention in comparison with their age-matched normal hearing peers.

Nicastri et al. (2023) studied the influence of auditory attention on linguistic outcomes in children with cochlear implants in the age range of 8 to 13 yrs. A dichotic listening task was used to assess the attention of children. The Performances of the CI group differed significantly for cognitive workload when compared with the normative data. Houston (2009) and Tharpe et al. (2002) have studied the attention in children with CI and their normal hearing peers. A significant difference was noted in the performance of the two groups for visual and auditory attention tests. The CI group's performance was significantly poorer than the normal hearing group.

Chen et al. (2019) assessed the effect of visual distractor on attention in children with CI. The auditory target stimulus was the digit "3" and the nontarget stimuli consisted of all other digits from 0 to 9. The stimulus was presented using a loudspeaker placed at 1m distance. The distractor visual stimuli employed cartoon figures which were presented simultaneously with the target stimuli. The results of the study revealed that the children with CI were distracted greater than the children with normal hearing. It was found in their study that children with normal hearing responded at a faster rate to auditory stimuli when compared with children with CIs. This indicates that there could in impairment in selective attention to auditory stimuli in CI users.

Further, it can be observed that different studies have used different tests to assess the attention in children with hearing loss such as digit count, syllable count, dichotic presentation or use of visual distractors. All the studies have concluded that the children with CI have poorer attention abilities. The results obtained using sound count test of CLAP-C, in the current study, is in consensus with the previous study findings. Hence, CLAP-C is a sensitive test in tapping the attention abilities of children with CI.

Studies have assessed effects of training on children having attention deficits and have found improvement in the attention span (Daly et al., 2007; Lange et al., 2012; Lim et al., 2023). Lim et al. (2023) used a 3D computer-based training activity for children with attention deficit hyperactivity disorder and found that the attention performance improved with training. No such training studies have been caried out for children with CI and hence, there is a need for studies to check if children with CI subjected to attention training improve their level of attention or not.

CHAPTER 6

SUMMARY AND CONCLUSION

Working memory refers to the ability of a person to manipulate and store information for brief periods of time, and it is the ability to pay attention and process new information. It is a prerequisite for various abilities such as reading, writing, speech and language development. Attention is the ability of an individual to process specific information in the environment actively while ignoring other irrelevant details.

The present study's objectives were to compare the working memory and attention performances of children with cochlear implants with that of normal hearing peers in the age range of 8-15 years of age. The participants of the current study were divided into two groups- clinical group and control group. Both the groups consisted of 25 participants each in the age range of 8-15 years. All the participants underwent the routine evaluation. The participants underwent digit span forward test and digit span backward working memory tests and the sound count test which is a subtest of CLAP-C for assessing attention. The data obtained for the three tests was analysed using SPPS version 26.0. The results revealed a statistically significant difference between the two groups for the working memory tests, and on the sound count test of attention. Though children with cochlear implants, in the present study, have used the device for several years and have undergone intensive listening training in the initial years on different domains including cognition, there tends to be working memory deficit.

6.1 Conclusion

It can be concluded that the children with CI had poorer performance in working memory and attention tests in comparison with the age-matched normal-hearing peers.

The findings of the present study mandate the need for additional training on cognitive abilities in school-going children.

6.2 Implications of the study:

- The study has given insights on the working memory abilities and attention span in children with CI.
- The study implies that the children with CI have poorer working memory and attention and training is required to improve their performance.

6.3 Limitations of the study:

- The participants in the clinical group were not divided based on the models of the CI.
- Complex tests evaluating working memory are not done because of the subject limitations.

6.4 Future directions:

- Future research can be carried out in a broader age range by dividing the participants into smaller age groups.
- Future research can be carried out in older group of participants in which many other working memory tests can be done.
- In future studies, the participants can be grouped bases on the models of the CI and hearing aids.

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