AUDITORY WORKING MEMORY MEASURES IN CHILDREN WITH HEARING IMPAIRMENT – A SYSTEMATIC REVIEW

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This Dissertation is submitted as part

fulfilment for the Degree of Master of Science in Audiology

University of Mysore, Mysuru

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August 2022

CERTIFICATE

This is to certify that this dissertation entitled **'Auditory Working Memory Measures in Children with Hearing Impairment – A Systematic Review'** is a bonafide work submitted as a part for the fulfilment for the degree of Master of Science (Audiology) of the student Registration Number: 20AUD017. This has been carried out under the guidance of the faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

August 2022

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DECLARATION

This is to certify that this dissertation entitled **'Auditory Working Memory Measures in Children with Hearing Impairment – A Systematic Review'** is the result of my own study under the guidance of Dr. Devi N, Associate Professor, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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August 2022

This Dissertation is

dedicated to

My Family

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Auditory working memory (AWM) is the process by which information is held in the brain for a briefer duration of time until either it is employed to complete a task, deleted after a short period of time, or transferred to long-term memory. AWM deficits have been noticed even in children with a milder hearing impairment. It is essential to incorporate AWM assessment as a part of the standard audiological battery to minimize the detrimental effects of working memory deficits. The present study systematically reviews the articles published in the past ten years (2011-2021) regarding test tools available to assess the AWM in children with hearing impairment and the efficiency of the same.

An overview of the auditory working measures such as the forward and backward digit span test; digit span subtests of Wechsler Intelligence Scale for Children-III; non-word repetition; Illinois test of psycholinguistic skills -Forward Digit Span; Numbers reversed subtest from Woodcock-Johnson III Tests of Cognitive Abilities; and Word & non-word recall subtests of Working Memory Test Battery -Children; Number recall, and Word order task from Kaufman Assessment Battery for Children II are provided in detail. The present systematic review also provides an overview of the efficiency of the assessment tools by discussing the correlation between the findings obtained in memory tasks with other auditory, verbal, and visual measures. The working memory performance in children with hearing impairment using a hearing aid or cochlear implant has been highlighted in this study.

CHAPTER 1

INTRODUCTION

Hearing loss affects around 466 million individuals worldwide, among which 34 million are found to be children (Kushalnagar, 2019). Unaddressed hearing loss has an adverse effect on language development, performance in school, employment opportunities, psychosocial well-being, and aspects of family life. The performance in the presence of noise in the background or an acoustic signal that is distorted is affected even with hearing aids and cochlear implants (Yumba, 2017). Hearing loss reduces the capacity of certain brain parts, which provides speech processing resources and skills. Working memory is one of them, and it is critical for perception, particularly in noisy and difficult auditory situations (Baddeley, 2003). Hearing loss can affect auditory processing and working memory due to its effect on the neuronal organization and brain plasticity (Caldwell & Nittrouer, 2013; Pisoni, 2000).

A small amount of information that is held in mind and used in executing cognitive tasks is known as the working memory (WM) (Baddeley & Hitch, 1974). When stating the working memory, it refers to either abstract (can be contemplated) or concrete (can be counted). Similarly, auditory working memory (AWM) is a process in which an auditory stimulus will be stored in the brain for a brief duration in the absence of the stimulus and used to execute tasks (Roy, 2018). WM acts as a connection between short-term memory (STM) and long-term memory (LTM), wherein it retains the information and uses it for a brief duration. WM is required for various cognitive functions, including learning, reading, and comprehension (Baddeley, 2003). Encoding - information processing and loading them into the memory storage; maintenance - the active rehearsal and retention of this knowledge for use in the future; and retrieval - the recall or use of the information that was stored, are the three phases of working memory (Heinrichs-Graham et al., 2022).

Simple or complex tasks can be employed to evaluate AWM. Only information storage is required for simple tasks, whereas storage and information processing are required for performing complex tasks (Engle et al., 1999). The phonological loop's integrity and verbal short-term memory functioning are most frequently measured using the non-word repetition test. Non-word Repetition Test (Dollaghan & Campbell, 1998), and Children's Test of Non-word Repetition (Gathercole & Baddeley, 1996) are the most often used non-word repetition tests. The stimulus (nonsense words) presented through audition mode will be asked to be repeated by the listeners in these tests, with the lengthening of syllables. In early childhood, failing to appropriately repeat multi-syllabic nonsensical words with greater than or equal to three syllables is a reliable indicator of impaired language (Botting & Conti-Ramsden, 2001).

Weschler Intelligence Scale for Children (Weschler, 1991) gives verbal, non-verbal, and full-scale IQ. The Digit span test is a supplementary test in the verbal scale of WISC-III, which assesses the working memory span of the individual. Woodcock-Johnson III Tests of Cognitive Abilities (Woodcock, McGrew, & Mather, 2001, 2007) comprises 31 tests for measuring general and specific cognitive abilities, which can be used for individuals between 5-95 years of age. Among the subtests, numbers reversed, memory for words, AWM, and memory for sentences are the tests that tap on the STM and WM. The Working Memory Test Battery for Children (Pickering & Gathercole, 2001) is an evaluation tool that measures visual as well as verbal WM and STM in children aged 5-15. Among the nine subtests in WMTB-C, three subtests - listening recall, counting recall, and backward digit recall tests - assess the WM. The subtests also evaluate the phonological loop, central executive function, visual-spatial sketch pad, and integrity. Digit span recall is a test for assessing the capability of an individual's auditory working memory. The forward digit span evaluates quick phonological coding ability with minimal cognitive work, and the backward digit span necessitates a more significant memory load (Marschark & Hauser, 2008).

The normal hearing (NH) children and children with hearing impairment (HI) exhibit variances in the domain of auditory experience in terms of quality and the quantity of the acoustic information affected in children with hearing impairment. This difference might impact the cognitive and linguistic development of HI children (Stiles et al., 2012). Studies state that the neural networks involved in specific aspects of cognition are affected due to auditory deprivation caused by hearing loss that remains untreated (Roy, 2018; Wong et al., 2010). Mild/moderate hearing loss in children has also been linked to a lack of auditory skills (Hall et al., 2012). Reduced auditory perception might lead to a permanent deterioration in cognition (Baltes & Lindenberger, 1997). Even a mild hearing loss might lead to reduced performance in related cognitive tasks since the resources used for higher-level comprehensions, such as retention of auditory information into memory, has to be used for decoding and perceiving the speech signal accurately (Gosselin & Gagné, 2011; Tun et al., 2009; Desjardins, 2016; Desjardins & Doherty, 2013).

A significant difference in working memory and working span has been noted across individuals. This capacity growth across childhood has been marked with a noticeable increase between the 5 and 11 years of age and a slighter increase until 15 years of age. In this span of time, almost most children develop adult-like working memory. Exploring intraindividual differences under varied listening conditions using the auditory mode to determine the allocation of working memory resources amid encoding and storing in a person's limited capability has to be performed across listening tasks (Pichora-Fuller, 2003; Pichora-Fuller & Singh, 2006). Osman and Sullivan (2014) found that the performance in AWM tasks of typically developing children was better in quiet listening conditions than in the presence of noise (Osman & Sullivan, 2014).

Individuals with cochlear implants (CI) exhibited WM deficits compared to their NH counterparts on serial recall measures (Burkholder & Pisoni, 2003). The deficits noted in WM can be attributed to hearing loss. 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 loss using CI to their NH peers, the performance of normal-hearing peers were superior to children with CI when administered with a digit span test. As in NH children, a high correlation between digit span to reading and language has been observed in children using CI (Pisoni & Geers, 2000). Children with CI with increased serial recall on the digit span were found to have improved speech recognition (Pisoni & Cleary, 2003). With the increasing need for research in this area, it is required to systematically evaluate the available tests for assessing auditory working memory.

Need for the Study

Auditory working memory is associated with various processes such as the acquisition of language and learning sound patterns (Baddeley et al., 1998; Gathercole et al., 1992; Gathercole & Pickering, 2000), and communicating in noisy situations (Parbery-Clark et al., 2009). It is also thought to be a good predictor of successful communication and success in school (Daneman & Merikle, 1996). Children with even a mild degree of hearing loss scored worse than those with minimal hearing loss in reading and WM tasks (in digit span) (Moore et al., 2020). According to Cowan (1998), retrieval from STM and subvocal rehearsal of phonological information are interdependent skills in typically developing children. The oral and aural activities are essential for speech and language development as they support phonological encoding and spoken language skills. Despite having indications of verbal encoding and rehearsal in auditory memory in CI children, they are recognized to have abnormal phonological memory skills and shorter digit spans (Burkholder & Pisoni, 2003). Disruptions in WM could compromise parts of sustaining perceptual mechanisms. Also, any changes to WM could propagate to the information processing system and can impact learning and reading as well as other cognitive activities and the distribution of attentional resources (Fry & Hale, 2000).

These findings suggest that AWM deficits can have deleterious effects across different processes despite being fitted with hearing aids or cochlear implants. AWM abilities are often overlooked, undermining audiological assessment's efficacy in individuals with hearing impairment. Various tests developed in the recent past to assess this ability have to be included in the test battery to prevent long-term deficits. Hence, an update on the tests available for evaluating the auditory working memory in children from the literature is required.

Aim of the Study

The current study aims at reviewing the significant studies conducted on various tests used to assess the auditory working memory abilities in children with hearing impairment.

Objectives of the Study

Research questions: To identify

1. What are the various tests used to assess the auditory working memory abilities in children with hearing impairment?

2. What is the efficiency of these tests in assessing the auditory working memory in children with hearing impairment?

CHAPTER 2

METHODS

The systemic review was conducted based on the Preferred Reporting Items for Systematic Review and Meta-analyses statement (PRISMA statement) (Page et al., 2021). A systematic literature search was carried out for peer-reviewed articles published from 2011 to 2021.

2.1 Information sources

The following databases were extensively searched for studies on AWM measures in children with hearing impairment: PubMed/Medline, Google Scholar, and Science Direct. Lists of references and citations were searched manually for further relevant studies.

2.2 Search strategy

The search was carried out using key terms, related search phrases, derivatives, and MeSH words relevant to the study combined with Boolean operators such as 'AND,' 'OR,' 'NOT.

"Working memory" OR "Auditory working memory" OR "Verbal working memory" AND "Assessment" OR "Measures" OR "Recall tests" OR "Digit Span Test" OR "Word Repetition test" OR "Non-word repetition test" OR "Test battery" AND "Children" NOT Auditory Processing Disorders NOT Co-morbid conditions NOT "Adults" were used as the key terms for searching studies.

2.3 Study selection

The specific inclusion criteria and exclusion criteria for the selection of studies were as follows:

2.3.1 Inclusion Criteria:

The articles fulfilling the following criteria were included.

- Original articles with human participants, appropriate samples, assessment approaches, and statistics.
- Articles focused majorly on the assessment of auditory working memory.
- The articles focus on individuals with hearing impairment with or without the usage of hearing aid/ cochlear implants.
- The selection criteria were based on PECO criteria
    - Participant – Children with hearing impairment
    - Exposure - Auditory working memory tests
    - Comparators – Children with normal hearing status and typical development
    - Outcomes - Results of auditory working memory tests and their co-relation

2.3.2 Exclusion Criteria:

The articles fulfilling the following criteria were excluded.

- Articles with lower quality methodology and language aside from English.
- Assessment of individuals with an auditory processing disorder.

- Assessment of individuals with other co-morbid conditions.
- Case reports, letters to editors, and editorials.

2.4 Data extraction

The search results were combined using the Rayyan QCRI (Qatar Computing Research Institute) and Mendeley desktop reference manager system, and the duplicatestudies were eliminated. The studies that met the inclusion criteria were identified by screening the titles and abstracts retrieved from the search strategies. Later, the full text of the potential studies was retrieved and matched to see if they were eligible.The extracted data included: article title, author details with their affiliation, year of publication, research design, study population, sample size, age group, comparison group, method of outcome measures, and keywords specific to assessing working memory in children.

2.5 Quality assessment:

The CASP (Critical Appraisal Skills Programme, 2018) was used to conduct a methodological quality assessment of the included studies. The finding has been shown in the result section in detail.

Chapter 3

RESULTS

A total of 17600 articles were identified using database searches, with 14 duplicates eliminated. A total of 17586 articles were included in the title/abstract screening. Following the title and abstract review, 27 articles were selected for the full-length article screening. 10 articles matched the inclusion criteria in the study. The remaining 17 articles were excluded mainly because of the study design (pilot study) and irrelevant study population (study population had comorbidity like auditory processing disorder; the population included adult participants). Adetailed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart for the selection of the study is shown in Figure 3.1

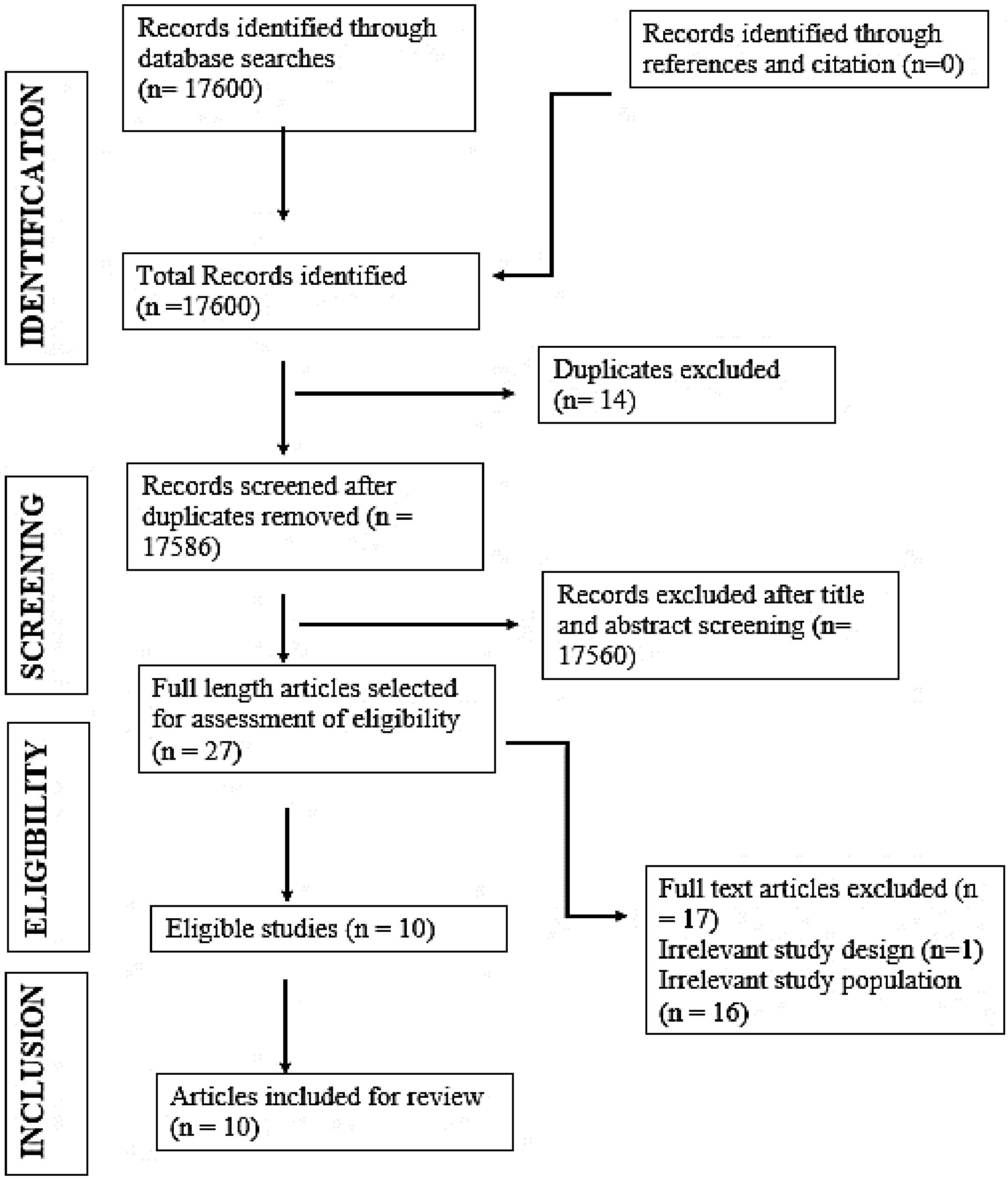

Figure 3.1: PRISMA flowchart for the selection process of articles included in the review.

3.1 Study Characteristics

Population: The study population included children with hearing impairment with or without the usage of hearing aid and cochlear implants. 8/10 studies included participants using cochlear implants, while the remaining 2 studies included children using hearing aids. Participants with any co-morbid conditions (such as auditory processing disorder, autism spectrum disorders, intellectual disability, etc), and poor performance in IQ tests were excluded from all the studies.

Exposure: The exposure of interest in this study was auditory working memory assessment tests for children. The selected articles assessed AWM abilities directly or using verbal working memory in audition mode. Wechsler Intelligence Scale for Children-III in 2 studies (AuBuchon et al., 2015; Harris et al., 2013), Forward Digit Span and Backward Digit Span in 4 studies (Javanbakht et al., 2021; Soleymani et al., 2014; Stiles et al., 2012; Tao et al., 2014), ITPA-FDS (Torppa et al., 2014), Non-Word Repetition in 2 studies (Javanbakht et al., 2021; Soleymani et al., 2014), Woodcock-Johnson III Tests of Cognitive Abilities in 1 study (Bharadwaj et al., 2015), Working Memory Test Battery for children in 2 studies (Talebi & Arjmandnia, 2016; Willis et al., 2014) and Kaufman Assessment Battery for Children II in 1 study (Bharadwaj et al., 2015) were used to assess AWM.

Comparators: Typically developing normal hearing children were selected as the control group in 6/10 studies (AuBuchon et al., 2015; Soleymani et al., 2014; Stiles et al., 2012; Talebi & Arjmandnia, 2016; Tao et al., 2014; Torppa et al., 2014) and 4/10 of the included studies had no control group (Bharadwaj et al., 2015; Harris et al., 2013; Javanbakht et al., 2021; Willis et al., 2014)

Outcomes: The outcomes of all the selected articles included the Auditory working memory test findings.

Table 3.1 summarizes the study's objective, study design, study population details, assessment approaches, and their procedure in-depth, and study outcomes focusing on auditory working memory in children.

Table 3.1 Study characteristics of the selected articles

Author and Year	Study design	The objective of the study	Population type	Tests used	Test Procedure	Results	Discussion
Stiles et al. (2012)	Comparative study	To study the disturbances in WM, and its relation to the receptive vocabularies in mild to moderately severe SNHL children.	**Experimental group:** 16 children (mild to severe SNHL) fitted with bilateral hearing aids. Mean age - 3;92 [years; months]) **Control group:** 24 normal-hearing children (13 boys, 11 girls) Mean age - 9;94 [years;months)	FDS BDS	**FDS task** – Children had to repeat the digits in the same order as presented. Numbers were presented in every one-second interval. The digits were not repeated within the series. Additionally, "7" was omitted from the presentation to make all of them monosyllabic. Children repeated two strings at	HI children and CNH showed an auditory advantage in forward span. Children with HI showed a similar memory span as that of CNH. The presence of background noise did not affect performance in either group.	Children with moderate to moderately severe HL displayed a resilient WM system. Relationships between WM and vocabulary were observed for all children; those with poor WM demonstrated a

					each length. The three-digit sequence was tested first. The number of digits per sequence increased by one digit if any of the 3-digit strings could be correctly repeated. This gradual lengthening of the sequence persisted until the children reached the string limit of 8 digits, the examiner stopped the process, or both strings of a single length were wrongly repeated back. **BDS task** –		smaller vocabulary size. The presence of noise did not affect the performance of the digit task. This could be explained by the fact that either the background noise wasn't distracting enough to need a change in the executive resource allocation for the WM activities, or

					Children had to repeat the digits in reverse order of presentation. Except for starting with strings of two digits rather than three, test administration was the same as for FDS. The BDS task was administered similarly to the FDS task. Four different conditions were used to administer the FDS and BDS: auditory quiet, auditory noise, visual quiet, and visual noise		the resources required to decode the signal in noise are unrelated to those used for WM tasks.

Harris et al. (2013)	Longitudinal study	To investigate how verbal STM and WM function as a developmentally-limiting source of variability in children's speech and language outcomes longitudinally following CI.	**Experimental group:** 66 children with CI Age range: 7-15 years (Mean/SD not specified)	WISC—III Edition	The test involves the child repeating progressively larger lists of digits presented by the experimenter using live voice. Roughly one digit per second was presented. There are two recall conditions in the task: • DSF • DSB In order to complete the DSF task, participants must repeat a series of random digits, starting with a two-digit sequence and going in	Compared with the normative mean scores (Population means – 10; SD – 3), the CI children's scores were 1 SD below the normative in 50.5% in DSF and 44.0% in DSB across all ages. However, the DSF and DSB performance slopes in the CI group that	Variation in STM/WM is one of the fundamental neurocognitive-related factors that underlie all behavioral measures of S/L performance.

					order from 1 to 9 (inclusive). For each sequence length, two things are presented, and if the subject reproduces at least one of them correctly, the sequence length is increased by one. This process continues until the participant repeats both of the wrong items at the same sequence length. The only difference between the DSB and DSF tasks is that subjects must reproduce the	represented the development of verbal STM/WM capacity were comparable in magnitude to values found in a sample of people with normal hearing using WISC-III cross-sectional norms.	

					sequences in reverse order.		
Soleymani et al. (2014)	Cross-sectional study	To investigate WM as cognitive ability in children with ND and CI.	**Experimental group:** 50 children with CI. Age range- 5–7 years Mean – 6.16 SD – 0.79 **Control group:** 50 children with ND. Age range – 5-7 years Mean – 6.16 SD – 0.79	NWR FDS BDS	**Non-word repetition task** Two practice non-words were given to the children before moving on to the actual testing. Children were presented with the original target non-words, which they had to repeat. They received a score of 1 if they repeated the target non-word perfectly; else, they received a score of 0. The total	**Mean and SD** • **FDS** NH- 5.42 (1.63) CI - 2.30(1.43) • **BDS** NH- 3(1.95) CI – 0.84(0.84) • **NWR** NH- 22.78(1.59) CI – 12.28(1.82) The NWR scores of the CI children showed	The working memory of children with CI has been compromised. The differences between ND and CI children suggested that early exposure to sound had a significant impact on the part of the brain that stores and retains phonological information in

					score for this task was 25. **FDS and BDS tasks** The child was told to repeat seven sets of numbers, 3–9 for FDS and 2–8 for BDS. In FDS, children were tasked with repeating the numbers in the same sequence as before. Children should just tell numerals in reverse order in BDS, though. Each number in the series was stated with a one-second interval. Every group of	a strong relationship with the FDS and BDS. Also, FDS and BDS are strongly associated. Although FDS and BDS were substantially correlated, the NWR scores of the ND children were shown to be only modestly related to them.	STM. Children with CI were found to have a similar developmental pattern. There was no discernible difference between preschool and first grade in the BDS. Children with CIs may not perform as well on BDS in the early stages of development as with ND since it is a test designed

					numbers is repeated twice. Each response was worth one point when it was correct. The task was concluded after two attempts at each sequence failed. The maximum score for each task was 14. The FDS was finished before the BDS.		to evaluate complex memory span.
Tao et al. (2014)	Correlational study	To study the relationship between AWM and speech perception performance in Mandarin-	**Experimental group:** 32 CI users (21 - pre-lingual HI 11- post-lingual HI)	Auditory digit span test	An adaptive (1-up/1-down) approach was used to test auditory digit span recall in both the forward and backward directions. The stimuli featured a	**The mean score** CI group: BDS - 4.72 (SE=0.33) FDS - 6.10 (SE=0.35) for.	Compared to NH participants, CI individuals' scores on the forward and backward digit span were

		speaking CI children. .	Age Range - 6.0–26.0 years Mean – 13.0 SD – 4.0 **Control group:** 21 Normal hearing children Age range: 8–14 years Mean – 11.0 SD – 1.6		single-man talker uttering the numbers 0 through 9. Numbers were chosen and delivered at random order (no visual cues). Children replied by clicking on the response boxes on a computer screen in the order of the sequence of digits they heard. Three digits made up the first series. The number of digits provided increased or decreased depending on how	NH group: BDS - 5.96 (SE=0.30) FDS - 7.39 (SE=0.21) Performance ranged from 1.8 to 11 for FDS and from 2.1 to 9.7 for backward digit span, indicating a significant inter-subject variability. Only sentence recognition in quiet	significantly lower. Despite some similarity in the distributions of digit span scores, Mandarin-speaking CI individuals may be less capable and efficient at processing phonological information than NH participants, which would show up in their digit span. The connection between WM and

					accurately the response was given.	environments showed a significant correlation with AWM efficiency. The relationship between WM and lexical tone recognition was not observed.	speech performance was unaffected by pitch cues.
Torppa et al. (2014)	Longitudinal study	To investigate the effects of musical experience, auditory working memory, and F0 auditory	**Experimental group:** 21 unilaterally implanted children (CIm and CIn group) **Control group:**	FDS	ITPA FDS task was employed. In the analysis, raw scores were employed; these don't necessarily	**Mean scores and SD in FDS task:** NH-T1= 22.43 (7.10)	Children with CIs who have musical practice do better on the FDS than children without musical

		discrimination in the CI group.	21 normal-hearing children. All the children were aged 4 – 13 years		indicate how many digits are repeated.	NH –T2 = 25.43 (7.72) CIm-T1= 20.38 (7.61) CIm-T2= 24.38 (9.52) CIn - T1= 15.69 (5.30) CIn-T2= 16.77 (5.83) FDS in Cim and NH groups were similar, but the CIn group performed more poorly.	experience. Digit span and intensity perception were correlated to prosodic perception.

						Similar findings were seen with respect to F0 discrimination and prosodic perception.	
Willis et al. (2014)	Longitudinal study	To compare verbal and visual WM of six children with congenital HI.	**Experimental group:** 6children/adolescents with a unilateral cochlear implant Age range: 8 and 15 years	Subtests of WMTB-C	Children are asked to recall words in the same order as presented in the word recall subtest. The NWR followed the same procedure, and the items followed a similar CVC structure as the "real" word. The children must correctly recall four targets. The	**Mean Standard Scores:** **First-year of study** Word recall – 81.67 (SD – 12.48) Non-word recall – 110 (SD - 10.66)	For two years, all the children displayed the same pattern of verbal working memory. It was found that the children had more trouble with non-word memory than with word recall.

					difficulty of the tasks increases for each subgroup, starting at two, three, or four. The subtest is terminated when a child cannot correctly reproduce four targets from a subset.	**Second-year of study** Word recall – 80 (SD – 13.19) Non-word recall – 108 (SD – 11.28) Performance in non-word recall was better than word recall at both points of measurement.	Children with HI may not have appropriate phonological representations in their STM, making storing and retrieving information more challenging. Visual WM was comparable to that of peers with average hearing.
AuBuchon et al. (2015)	Longitudinal study	To study whether early-implanted, long-term CI users exhibit	**Experimental group:** 23 CI users	WISC – III subsets	Lists of the set of digits were presented using live voice as per the instructions for the	**Forward span measures:**	The performance on ADS-F had a strong positive correlation with a

		delays in verbal STM and WM capacity when audibility and speech production processes are excluded.	The age range at initial testing-7.8–15.3 years (Mean – 11.8; SD – 1.9) Age at follow-up – 10.1 – 17.1 years (Mean – 14.0; SD-2.4) **Control group:** 23 NH controls The age range at initial testing -8.2–15.3 years (Mean – 12.5; SD – 2.2) Age range at follow up – 10.1-16.6 years (Mean-14.0; SD-2.1)		forward and backward span subtests of the WISCIII. The lists were to be repeated aloud by the participants in either forward or reverse order.	A significant effect of hearing status was seen across forward span measures. CI group mean – 6.47 (SD – 2.72) NH group mean – 8.3 (SD – 3.25) Significant effects on task were also seen. ADS-F mean - 8.25, SD - 2.76	visual and computerized version of the digit span-forward task (no auditory stimuli were given) in long-term CI users. While ADS-B did not correlate with the other 2 tasks, also, the performance in ADS-B did not vary between NH and CI groups as there was an increase in

						No interaction between hearing status and task. NH group had a superior performance than CI users on all forward tasks. **Backward span measures:** No effect on hearing status was seen Effect of the task was seen	demand for processing the instructions.

						ADS-B mean - 5.18, SD - 2.14 No interaction between hearing status and tasks.	
Bharadwaj et al. (2015)	Cross - Correlational study	To study the WM and STM skills in the auditory and visual modalities in school-going CI children. Study the relationship between verbal and visual	**Experimental group:** 10 children Age - 7 to 11 years (Mean/SD not specified) CI users	WJ III COG NU KABC - II	In the Numbers Reversed task, the test subject responds to a series of numbers before repeating them in a reverse manner. AWM is a task that assesses a person's capacity to hold a list of words and numbers in immediate awareness and then	The mean, standard scores on WJ III COG NU (numbers reversed and AWM) were less than the average SD (scores were <85 in both numbers reversed and AWM).	All CI children exhibited less than average performance in tasks related to verbal knowledge (number recall, word order) in KABC II. The outcomes are consistent with the idea that

		WM/STM measures versus reading.			reorganize the information so that the words are remembered first and subsequently the numbers. The Number Recall task tests a subject's ability to retain short-term auditory information by listening to a set of numbers before having them repeated in the same order. The Word order task requires the participant to touch the object's silhouettes after hearing their	Reading measures and the number recall test showed a strong positive association (Except for passage comprehension and oral reading).	early-onset hearing loss impacts capacities like memory and creating sequential information due to sensory deprivation. The abilities were related to the following: Word reading abilities – Auditory STM Passage comprehension

					names in the same order.		abilities – Visual and Auditory WM.
Talebi, S., & Arjmandnia, A. A. (2016)	Nonexperimental, correlational and causal-comparative study.	To study the interaction between WM and STM performance and their impact on CI outcomes	**Experimental group:** 31 children with CI Mean age – 121.52 months; SD – 19.946 **Control group:** 31 children with NH Mean age = 120.68 months; SD =18.137	WMTB-C	Not explained in detail.	**Working memory scores (Mean (SD)):** NH – 68.9 (10.67) HI – 57.13 (8.64) **Working memory span:** NH – 4.09 (0.65) HI – 3.61 (0.48)	Children with and without cochlear implants were found to have WM and STM that interacted well with each other. Working and short-term memories are enhanced in people

						Short-term memory score NH – 56.13(6.96) HI – 47.10 (6.57) **Short-term memory span:** NH – 4.63 (0.62) HI – 3.87 (0.55) WM efficiency was significantly and positively correlated with CI results. In addition, the	implanted at younger ages. There is a substantial correlation between AWM and STM, as well as between AWM, STM, and speech intelligibility.

						children with cochlear implants performed worse than their counterparts with normal hearing.	
Javanbakht et al. (2021)	Cross-sectional study	To compare the memory abilities of two groups of children who used hearing aids in both ears and only differed in their capacity to understand speech in noisy environments.	**Experimental group:** 31 hearing aid user students Participants were split into 2 groups: • HP- BKB SIN score Less than or equal to 7 • LP- BKBSIN	FDS BDS NWR (Persian version)	**FDS**: The number series started out with two digits and eventually progressed to seven digits. The number of correctly memorized series is how the performance is measured. The exam was terminated after	**Mean WM scores:** **FDS**: HP-2.00 (±0.50) LP-1.52 (±0.65) **BDS**: HP-2.00 (±0.50) LP-1.52 (±0.68)	Speech in noise tests was significantly correlated with all the WM measures. This correlation was higher for NWR than FDS and BDS.

			score greater than 7 Age range - 8–12 years were selected **Mean and SD – 9.13 ± 0.17**		the child stated two wrong series. **BDS**: Similar to FDS, except the subject must repeat the numbers backward. **Non-word repetition test:** 40 nonsense syllable words. Each non-word contained 2, 3, or 4 syllables, and the interval between each presentation was 10 seconds or shorter, depending on how quickly the participant repeated each item.	**NWR**: HP-28.77 (±5.04) LP-22.33 (±4.21) The LP group had poor scores on FDS, BDS, and NWR tests.	

					The test was carried out with a human voice and was based on the phonetically transcribed non-words that were accessible. The child hears the nonsense words read aloud, and it has to be repeated. The number of correctly repeated non-words is used to grade performance.		

Note. HI – Hearing Impaired, CI – Cochlear implant, NH – Normal Hearing, ND – Children with Normal Development, WISC—III - Wechsler Intelligence Scale for Children-III, DSF/FDS – Digit Span Forward, DSB/FDB – Digit Span Backward, NWR – Nonword Repetition, WJ III COG NU - Woodcock-Johnson III Tests of Cognitive Abilities, KABC – II - Kaufman Assessment Battery for Children II, ITPA - Illinois test of psycholinguistic abilities, CIm – CI with musical experience, CIn – CI without musical experience, T1- the first measured time point, T2 – the second measured time point, WMTB-C - Working Memory Test Battery for children, WM – Working Memory, AWM – Auditory Working

Memory, STM – Short Term Memory, LP – Low Performance, HP – High Performance, BKBSIN - Persian version of Bamford-Kowal-Bench Speech In Noise test, SNHL- Sensorineural Hearing Loss.

3.2 Quality Assessment

The quality of the studies was assessed using The Critical Appraisals Skills Programme for Diagnostic Test Study (CASP). It is a generic tool for appraising the strengths and limitations of any qualitative research methodology. It consists of 12 questions to assess the article in depth across each section to reduce bias. The questions in the tool are marked as "Yes', 'No' or "Can't tell," depending on the question's requirement.

The results of the following questions forall selected studies are provided in Table 3.2.

Section A: Are the results of the trial valid?

Q1. Was there a clear question for the study to address?

Q2. Was there a comparison with an appropriate reference standard?

Q3. Did all patients get the diagnostic test and reference standard?

Q4. Could the results of the test have been influenced by the results of the reference standard?

Q5. Is the disease status of the tested population clearly described?

Q6. Were the methods for performing the test described in sufficient detail?

Section B: What are the results?

Q7. What are the results?

Q7a. Are the sensitivity and specificity and/or likelihood ratios presented?

Q7b. Are the results presented in such a way that we can work them out?

Q8. How sure are we about the results? Consequences and cost of alternatives performed?

Q8a. The results have not occurred by chance

Q8b. Are there confidence limits?

Section C: Will the results help locally?

Q9. Can the results be applied to your patients/the population of interest?

Q10. Can the test be applied to your patient or population of interest?

Q11. Were all outcomes important to the individual or population considered?

Table 3.2. Results of the quality assessment for all of the selected studies.

AUTHOR AND YEAR	QUESTIONS												
	Section A: Are the results of the trial valid?						Section B: What are the results?				Section C: Will the results help locally?		
	Q1	Q2	Q3	Q4	Q5	Q6	Q7		Q8		Q9	Q10	Q11
							Q7a	Q7b	Q8a	Q8b			
Stiles et al. (2012)													
Harris et al. (2013)													
Soleymani et al. (2014)													
Tao et al. (2014)													
Torppa et al. (2014)													
Willis et al. (2014)													
AuBuchon et al. (2015)													
Bharadwaj et al. (2015)													

Talebi & Arjmandnia (2016)													
Javanbakht et al. (2021)													
Total of Yes %	100%	100%	90%	0	100%	90%	0	80%	100%	80%	0	100%	100%

CASP Checklist - Diagnostic Test Study

Yes No Can't tell

On analysis, as depicted in Table 3.2, it was found that all the studies were of good quality. The research questions were addressed, and there was a comparison with the reference standard in all the studies. The status of the test population was provided in detail in all 10 studies included. All the patients received the diagnostic and reference standard tests in 10/10 studies (100%). The test procedure was explained in detail in 9/10 studies (90%).

On the contrary, the procedure was not justified in 1 of the study. All the tests used in the study can also be used for the local population. The results of 9/10 studies are explained so they can be calculated and worked out. The sensitivity and specificity of the tests were not provided in any of the studies. At the same time, the confidence limits have been provided in 8/10 studies for individual tasks.

CHAPTER 4

DISCUSSION

This systematic review focused on the various test measures available for assessing the auditory working memory in children with hearing impairment.

4.1 Assessment procedures

The different assessment procedures included in this review are as follows:

- Wechsler Intelligence Scale for Children-III
- Forward Digit Span and Backward Digit Span
- Illinois test of psycholinguistic skills -FDS
- Woodcock-Johnson III Tests of Cognitive Abilities
- Working Memory Test Battery for Children
- Kaufman Assessment Battery for Children II
- Non-Word Repetition

4.1.1 Wechsler Intelligence Scale for Children-III

The WISC-III measures cognitive functioning designed for children aged 6-16 years. The WISC-III Digit span subtest involves the child repeating progressively larger lists of digits spoken live voice by the test administrator at a rate of roughly one digit per second (Wechsler 1991). In the present review, two studies (AuBuchon et al., 2015; Harris et al., 2013) used the digit span subtest from WISC-III.

Harris et al. (2013) used two recall conditions—Digit Span Forward (DSF) and Digit Span Backward (DSB). The DSF task requires participants to repeatedly say a list of random digits starting with a two-digit sequence ranging from 1 to 9 (inclusive). There are two items to be repeated for each sequence length, and if the subject repeats at least one of them correctly, the sequence length is increased by one until the participant repeats both of them erroneously at the same sequence length. Except for the change in order (reverse order), the DSB task is the same as the DSF task. Aubuchon et al. (2015) used the same procedure in their study. The raw scores obtained from the individuals with hearing impairment were compared with WISC-III norms (population means – 10 and SD – 3; normative are available only for the total score).

4.1.2 Forward Digit Span and Backward Digit Span

Javanbakht et al.(2021) used forward and backward working memory to assess working memory. In the forward digit span test, the child was instructed to repeat a series of single-digit numbers in order after they were randomly read. The test ends when the child says two incorrect series. The number series started with two digits and expanded gradually to seven digits. The number of series accurately memorized is used to grade performance. The backward digit span test is administered in the same way as the forward one, except the individual is required to repeat the numbers backward. Testing was carried out at a comfortable intensity level, and scoring was done in binaural mode.

Soleymani et al. (2014) used a set of seven numbers, i.e., 3-9 for forward and 2-8 for backward digit span test. There was a one-second pause between each number in the said series. Every set of numbers appeared twice, and there were no repeated digits in a string. Each correct response was worth one point, with the maximum score being 14. The task terminated after two repetitions of each sequence failed.

Stiles et al.(2012) performed the forward and backward digit span tests in quiet and noise conditions. The digits were presented at 65dB SPL in the auditory mode through a monitor-mounted speaker at an angle of 0° and 0.5 m distance in the quiet scenario. In the noisy conditions, the background noise was given from two speakers at ±110° azimuth at a 1 m distance. However, the authors did not explain the reason for the speaker's location. In noisy conditions, the stimuli were presented at +15 dB SNR as this level was considered a good SNR for classrooms according to ANSI (2002). Each item in a trial is worth 0.5 points. The scoring procedure was adopted from WISC- III. The FDS score was calculated using the formula – 2 + 0.5 * (number of correct responses), while the BDS score was calculated using the formula – 1 + 0.5*(number of correct responses).

Tao et al.(2014) used digits 0-9 in auditory only mode using an adaptive approach (1-up/1-down) to test auditory digit span recall in both the forward and backward directions. The test began with 3 digits initially, and the sequence length was increased based on the number of correct repetitions. The first two trials were adjusted by 2 digits, while the remaining sequences were adjusted by 1 digit. 25 trials were carried out in each run. The digit span score is the mean score of all trials except for the first two trials.

4.1.3 Illinois test of psycholinguistic skills -FDS

ITPA is used for children aged 4-8 years to assess the capability to acquire and use language. Torppa et al.(2014) used the forward digit span subtest of the ITPA to assess the working memory. The analysis employed raw scores, which do not accurately reflect the number of repeated digits. The FDS was conducted using the live voice of the experimenter in a face-to-face setting.

4.1.4 Non-Word Repetition

In the present review, two studies (Javanbakht et al., 2021; Soleymani et al., 2014) used the Non-Word repetition test. Soleymani et al. (2014) developed their study's material for the NWR test. Sixty words spanned every syllable structure in Farsi were chosen to create the list of non-words. Six children between the ages of 3-6 had used these 1-4 syllable terms in their free speech. Each word's one or two phonemes were altered, turning it into a non-word with no Farsi-language meaning. As a result, Farsi possessed phonotactic rules for non-words. A team of experts made up of five speech-language pathologists, and five linguists were assembled to choose appropriate non-words from the list. The non-words had to agree to 90% of the criteria to be accepted. Twenty-five non-words met the 90% threshold.

Javanbakht et al.(2021) used the Persian version of the non-word repetition test. This test contains 40 words (nonsense syllable words), and each non-word had 2, 3, or 4 syllables. Based on the subject's repetition speed following each item presentation, the interval between each item presentation was around 10 seconds or shorter. Live voice presentation was used in the test. The child had to listen to the nonsense words, and they had to repeat them exactly. The number of non-words repeated correctly was used to grade performance.

4.1.5 Woodcock-Johnson III Tests of Cognitive Abilities

It is a test to assess the cognitive ability and cognitive assessments in children above age 2 through adulthood. Bharadwaj et al. (2015) used the task known as "Numbers Reversed" and "AWM" tasks from this tool. The auditory working memory range or capability measures include the ability to reverse numbers and auditory working memory. The numbers presented have to be repeated in reverse order in the numbers reversed task. In the AWM task, the participant is presented with a list of words and numbers, which the participant has to hold in memory and reorder the information by recalling the words and then the numbers.

4.1.6 Working Memory Test Battery for Children

The working memory of children between the ages of 5 and 15 can be tested using Working Memory Test Battery for Children (WMTB-C). The word recall and non-word recall subtests of the WMTB-C assess the efficiency of the phonological loop. In the word recall subtest, children must correctly recall single-syllable words in the order they were given. Word structure is consonant-vowel-consonant (CVC). The non-word recall subtest follows the same procedure, and the items follow the same CVC structure as the "real" words. Every one of these tests is administered in its entirety before going on to the next one. Both of the subtests prohibit repeated attempts. Children were asked to repeat single-syllable and CVC nonsense words rather than multi-syllabic nonsense words in the non-word recall task, which attempts to account for the oro-motor deficit as a potential confounding factor. In this review, two studies (Talebi & Arjmandnia, 2016; Willis et al., 2014) used WMTB-C to assess working memory wherein the above-described procedure was used.

4.1.7 Kaufman Assessment Battery for Children II

In this review, one study (Bharadwaj et al., 2015) used the KABC-II to assess working memory. KABC-II is a test employed for children between 2.5–12.5 years, which offers a global intelligence assessment. Bharadwaj et al.(2015) used the subtests such as the Number Recall task to evaluate auditory short-term memory capacity and the Word Order task, to test auditory short-term memory.

The number recall test involves listening to a set of numbers and repeating in the same order, and word order involves touching the silhouettes of those objects when heard.

4.2 The efficiency of the measures of auditory working memory:

The articles reviewed in this study compared the differences in performance of auditory working memory tasks between normal hearing and children with hearing impairment. The efficiency of the test used had been explained through the correlation of the auditory working memory performances with auditory, visual, and verbal measures.

Stiles et al. (2012) examined the vocabulary and working memory in children with mild to moderately severe hearing loss. This study provides a unique finding, unlike the results observed in profoundly HI children. Phonological bias and auditory advantage were found in children with hearing loss. Children with hearing impairment could recite longer strings of the stimulus presented. This ability was found to be better in auditory modality than in visual modality in HI children suggesting the underlying mechanism for auditory advantage is actively present in these children. The articulation rate in HI children was comparatively slower than in NH children suggesting the reduced efficiency in the subvocal articulatory system in the WM. The Corsi span used to assess the visuospatial STM was similar between NH children and HI children with high executive function. In contrast, it was shorter in HI children with low executive function.

In the Corsi and Digit span tests, there was no discernible difference between the quiet and noisy circumstances because the background noise was not intrusive enough to reallocate the executive resources in the working memory tasks. A quicker rate of articulation was observed in children with greater vocabularies. In the auditory-quiet condition, they did better on the digit span, while in the noisy condition, they did better on the Corsi span. The authors concluded that in children with HI working memory under challenging situations could be best administered with less predictable sentences and speech-like noise as the background noise.

Harris et al. (2013) examined the influence of verbal STM and WM capacity as a factor on children's speech and language results following cochlear implantation. This study found that verbal STM and WM capacity process assessments accurately predicted long-term speech and language outcomes following cochlear implantation and a major percentage of the previously unexplained individual differences in S/L outcomes. Compared to normative data from age-matched peers with normal hearing, these abilities' maturation speed is slower than that of verbal STM/WM. In the long term, the baseline data showed a stronger association with speech and language outcomes than the measures at further visits on the digit span.

Soleymani et al. (2014) investigated the working memory in normally developed children and children using CI between 5-7 years of age. The outcomes of the current. According to this study, some working memory components are impaired in CI children. CI children with early exposure to sound significantly impacted the human memory system employed for phonological information stored and retained in short-term memory.

This study indicated that children implanted later in life had lower NWR, FDS, and BDS scores than early implanted children. Also, children did better on all tasks as the length of CI usage increased. These findings suggested that exposure to auditory input improves a child's performance on phonological processing tasks such as digit span and NWR.

The development of NWR, BDS, and FDS in typically developing children ages 5-7 who attended preschool, first, and second grades showed significant variations between groups in NWR, FDS, and BDS. Children with CIs in NWR and FDS were found to have a similar developmental trend. There was no obvious distinction between preschool and first grade in the BDS. As the child became older and was exposed to more auditory stimuli, primarily spoken language, this skill got stronger.

Tao et al. (2014) investigated the relationship between auditory working memory and speech perception in Mandarin-speaking children with the cochlear implant. For all speech parameters (Word in sentence recognition (quiet and noise), Chinese disyllable recognition, and Chinese lexical tone recognition), CI users dramatically underperformed NH listeners regarding speech performance. The worst CI performance was for noisy sentence identification.

Despite the considerable overlap in digit span score distributions, CI individuals' forward and backward digit span scores were considerably worse than those of normal hearing participants. Additionally, CI participants' articulation rate was substantially slower than their counterparts with normal hearing. These findings of AWM imply that CI users may handle auditory information less effectively and well than normal hearing listeners when taken as a whole. In both CI and NH subjects, there was a strong correlation between the forward and backward digit span scores and between the articulation rate and digit span scores. However, WM tests did not significantly correlate with CI users' ability to recognize sentences in noise. The primary conclusions from this investigation were similar to earlier research on English populations.

Torppa et al. (2014) used ITPA- forward digit span subtest to assess the auditory working memory in children. It was found that AWM interfered with pitch perception, wherein the CI children with music exposure had comparable performance to the control group. In contrast, the CI children with no exposure to music had poorer performance than the control group. Longer forward digit spans improved performance on both prosodic measures. Similar to F0 discrimination, forward digit span development with age followed the same pattern and progressed in all three groups at the same rate.

Willis et al. (2014) used the word and non-word recall subtest from WMTB-C to assess the verbal memory and the odd one out subtest from the Automated Working Memory Assessment. Findings indicate that despite long-term usage of their cochlear implants or hearing aids, the population of children with HI have extremely low spoken language outcomes. All six study participants outperformed the control group when challenged to recite lists of non-words rather than actual words. It has not been demonstrated that the children with HI repeat non-words better than their hearing classmates in imitating multi-syllabic nonsense words. The results of the current study suggest that these children may struggle to access their lexicon and retrieve words because they had a tougher time repeating words than non-words. It has been suggested that children with HI might not have enough phonological representations in their STM, making storing and retrieving knowledge more difficult. Users of CIs had visual memory abilities on par with those of their hearing peers.

AuBuchon et al. (2015) used auditory, visual and computerized (auditory digit span task using visual representation) digit span tasks wherein the instructions were derived from WISC-III for ADS and CDS and WISC-IV for VDS. Higher receptive vocabulary, nonverbal IQ scores, and an earlier age of deafness onset were all associated with ADS-F for CI users. In contrast, CDS-F was strongly connected to receptive vocabulary and the length of CI use, while VDS-F was significantly related to solely receptive vocabulary. The duration of CI use was likewise highly correlated with both backward span tasks. Additionally, ADS-B and CDS-B correlated with nonverbal IQ and receptive vocabulary, respectively.

If audibility had affected performance on the ADS-F, we would have anticipated a decline in the deficits of CI users in the VDS-F and CDS-F since poor audibility leads to underspecified and sparsely coded phonological representations in the long-term memory, which provides less support for reactivation and recovery within the short-term memory store. Similarly, CDS-F should have performed better, given it had no audio stimulation if speech-motor commands hindered the performance of CI users in ADS-F and VDS-F. However, the underperformance of CI users in all three-digit spread tasks remained consistent. This observation points to the fundamental cognitive processes that underlie STM to be impaired rather than problems with speech production or audibility in long-term CI users. Average delays were longer for CI users, providing them more time to take advantage of age-related memory performance increases. Despite having substantially more time than the NH controls for developmental changes to occur, no equivalent rise in digit span was seen.

The little effect of the group on the backward tasks most likely reflects the extra processing needed to follow the directions to reverse the list for recall. The test becomes more challenging for both groups when the list's digits are reversed. Still, the normal-hearing controls suffer the most because it prevents them from initiating lexical processing methods, making the two groups' performance on backward span tasks more comparable.

Bharadwaj et al. (2015) examined the auditory and visual WM and STM in children using CI. The KABC-II, WISC-IV Integrated, and the WC III COG NU were used to measure verbal knowledge, auditory and visual STM and WM, and verbal knowledge in general. The Woodcock Reading Mastery Test III was used to evaluate reading performance.

The results of this study show that CI users' performance on the auditory STM measures was below average when compared to age-based norms, in contrast to STM tasks involving the visual modality. This is consistent with the idea that WM ability in young children with early-onset hearing loss is modality-specific. The advantages of visual WM tests and the difficulties of auditory WM tasks suggest the existence of these various modality-specific subsystems. The auditory scaffolding hypothesis, which contends that cognitive capacities like memory and creating sequential information are impacted by sensory deprivation brought on by early-onset hearing loss, is further supported by the difficulty observed on both the auditory STM and WM tests. The auditory scaffolding hypothesis, which contends that cognitive capacities like memory and creating sequential information are impacted by sensory deprivation brought on by early-onset hearing loss, is further supported by the difficulty observed on both the auditory STM and WM tests.

Furthermore, results on all verbal knowledge tests were below average. Children with CI performed below average on reading evaluations for listening and passage comprehension. These measures were related positively to visual short-term memory, visual working memory, and auditory short-term memory. The auditory working memory subtests did not match performance on reading or language tests.

Talebi et al. (2016) investigated how working and short-term memories interact with auditory perception and speech understanding in children with CI. A further objective of this study was to compare the working and short-term memories' current state in relation to children with cochlear implants and their normal-hearing counterparts. WMTB-C was used to assess the memory performance, Categories of Auditory Performance was used to assess auditory perception, and Speech Intelligibility Rating to evaluate the speech production of the participants. According to this study, children using CI performed poorer than their normal-hearing peers in WM and STM. Children with and without CI were found to have similar levels of working memory and short-term memory. The children with CI cannot, however, be compared to typical children due to the age of their implants and continuing usage of their hearing senses. Earlier implantation enhances short-term memory in individuals without implantation. The results of the present investigation showed a positive and substantial relationship between the working and short-term memories of children with cochlear implants and their auditory perception. Additionally, there was a significantly positive association among children with cochlear implants between WM and STM and speech understandability.

Javanbakht et al.(2021) compared the WM capacity as a factor influencing speech in noise performance in children with normal hearing and hearing aid users. This study's working memory tests were compared to the results of the speech-in-noise perception test. It became clear that there was a strong relationship between the results of all three working memory tests and the children with hearing loss' speech-in-noise perception scores.

NWR is more difficult and consists of nonsensical pseudo-words with a variety of syllables when compared to the tests for determining the forward and backward digit spread. Hearing and repeating a word is necessary for proper word acquisition. In challenging auditory and learning environments like kindergarten, preschool, and school, predicting a child's score better on the non-word repetition test is logical. Children with hearing aids who received early hearing rehabilitation services with increased emphasis on activities like poetry reading, storytelling, and music therapy exhibited improved WM results and speech comprehension scores, which may indicate the effects of these pursuits on improving speech in noise comprehension through improving working memory.

Chapter 5

SUMMARY AND CONCLUSION

There is a lack of importance given to the working memory assessment, outcomes, and the impact of the deficits on other cognitive and linguistic abilities. Hence, this study reviewed the assessment tools available to evaluate auditory working memory.

This systematic review has described the working memory measures available and the results in children with hearing impairment. The assessment tools focused chiefly on the auditory (and verbal) working memory and short-term memory. The present study shows that the digit span task, though used to assess the working memory, focuses on the memory span rather than the working memory itself. Yet, it is the most commonly used form of working memory measure. Apart from the digit span tasks, word and non-word recall, number reversing, and non-word repetition are the most frequently employed measures to assess working memory.

The most common and standard immediate memory assessments, such as forward and backward digit spans, are important clinical tools for assessing verbal short-term and working memory in CI users. Still, they fail to provide comprehensive knowledge of basic memory mechanisms. According to the present review study report, the forward digit span task is more sensitive than the backward digit span task. Because it requires more effort to comprehend the backward digit span task's instructions. As a result, it highlights the necessity of reviewing WM literature in search of novel experimental strategies and behavioral tasks that can more precisely detect weaknesses in phonological storage and lexical processing. Furthermore, it is necessary to describe the verbal, and linguistic processing abilities used by children with hearing loss.

Compared to the tests for detecting the forward and backward digit span, the non-word repetition test is more complex as it consists of meaningless pseudo-words with various syllables. Also, using monosyllabic non-words overcomes the potential disadvantage of perceptual difficulties seen while using non-meaningful multi-syllable in the pediatric population. It is also indicated that children with severe to profound hearing loss have poorer performance in all the working memory tasks despite being fitted with amplification devices (hearing aid/CI). In contrast, children with mild to moderately severe hearing loss demonstrated performance similar to their peers in digit span tasks in quiet and noise conditions. As a future direction, focus on developing deficit-specific assessment measures of auditory working memory, and the normative data for the same has to be considered.

5.1 Clinical implication:

- This review explains the variations in working memory across different hearing loss degrees.
- This review's outcomes help us understand the impact of working memory deficit on speech and language acquisition, literacy outcomes, speech perception in quiet and noise, and pitch perception, henceforth explaining the importance of inclusion of working memory assessment.
- Assessment of the working memory emphasizes the need to intervene in working memory to improve the overall performance of children with hearing impairment post-amplification.

5.2 Limitations

- More number of studies included participants with cochlear implants, and very few studies had hearing aid users. Therefore, the precise information about auditory working memory outcomes in hearing aid users could not be explained.

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