

# LANGUAGE COMPREHENSION AND COGNITIVE ABILITIES IN CHILDREN WITH COCHLEAR IMPLANTS

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**Abstract:** *Despite early intervention with cochlear implants, children with hearing impairment often show poorer language performance than their hearing peers. Previous research has focussed primarily on language outcomes, while data on the relationship between language and cognitive function is limited. The aim of this study was to investigate and compare receptive language skills and the components of verbal working memory (storage and processing of information) in children with cochlear implants and their hearing peers, as well as to investigate the relationships between these skills within and between groups.*

*The study involved 35 children with cochlear implants and 23 hearing children, aged 6 to 15 years, who were matched for gender and chronological age. They were assessed using the Croatian versions of the Peabody Picture Vocabulary Test (PPVT-III-HR) and the Test for Reception of Grammar (TROG-2:HR), while verbal working memory was assessed using the Digit-Span task.*

*The results showed that children with cochlear implants had significantly lower scores in vocabulary and grammar comprehension, as well as lower verbal working memory capacity. Stronger correlations between language and cognitive variables were observed in the group of children with cochlear implants than in the hearing group. These results emphasise the importance of integrated assessment and intervention targeting both language and cognitive skills.*

**Keywords:** *cochlear implant, language comprehension, vocabulary, working memory, children with hearing impairment*

## INTRODUCTION

Hearing impairment in children represents a fundamental obstacle to the development of functional communication and language skills, since it has a significant impact on the language acquisition process (Wilson et al., 2024). Most children with severe hearing loss or deafness are born to hearing parents who want their child to communicate using spoken language (Hoff, 2013) and therefore, opt for cochlear implantation. Cochlear implant technology is constantly evolving, and the most advanced devices that are currently available provide access to the full speech spectrum (Velandia et al., 2020). Combined with protocols for early detection of hearing loss, this offers children with congenital profound hearing loss or deafness a great opportunity for the development of communication, auditory, language, speech, and socio-emotional skills, as well as literacy and academic development within expected

milestones (Cole & Flexer, 2019; Wieringen & Wouters, 2014).

However, despite sophisticated cochlear implant technology, these devices do not transmit all relevant speech features due to limitations in spectral and temporal resolution, which further impedes speech understanding (Wilson et al., 2024). Language development in congenitally deaf children who use cochlear implants (CIs) is a complex and multidimensional process involving the interplay of sensory stimulation, cognitive function, and language exposure. Most studies on the language outcomes of children with CIs have focussed on vocabulary development, as intervention for congenital hearing loss can begin very early and vocabulary is one of the most accessible indicators of language progress in the early stages of intervention. The area of research that has been extensively studied is receptive vocabulary, which is usually measured using the Peabody Picture

Vocabulary Test (PPVT; Dunn & Dunn, 1997). Previous studies have shown that children with CIs show significantly poorer receptive vocabulary, which can be one to two standard deviations lower than their hearing peers (see overview in

Table 1) (AuBuchon et al., 2015; Blomquist et al., 2021; Conway et al., 2011; Davidson et al., 2014; Dettman et al., 2016; Fitzpatrick et al., 2012; Hrastinski et al., 2019; Kronenberger & Pisoni, 2019; Kronenberger et al., 2021).

**Table 1.** Research findings on receptive and expressive vocabulary in school-aged children with cochlear implants

Author (year)	Participants	Age (years)	Test used	Standard scores (M = 100, SD = 15)
Conway et al. (2011)	23 CI 26 TH	5–10	PPVT	TH = 114 CI = 86
Fitzpatrick et al. (2012)	21 CI Norms	10	PPVT	CI = 77
Davidson et al. (2014)	101 CI 47 TH	9	PPVT	TH = 114 CI - good = 102 CI - poor = 86
Dettman et al. (2016)	207 CI Norms	5.6	PPVT	CI = 75.5
Hrastinski et al. (2019)	10 CI Norms	11.9	PPVT	CI = 74
AuBuchon et al. (2015)	23 CI 23 TH	12	PPVT	TH = 112 CI = 90
Kronenberger & Pisoni (2019)	53 CI 60 TH	9–29	PPVT	TH = 112 CI = 91
Blomquist et al. (2021)	24 CI 24 TH	5–10	PPVT	TH = 122 CI = 96
Kronenberger et al. (2021)	28 CI 26 TH	9–22	PPVT	TH = 115 CI = 95

*Note:* PPVT, Peabody Picture Vocabulary Test; TH, typical hearing peers; CI, children with cochlear implants

Vocabulary assessments alone cannot provide a comprehensive picture of language development in children with CIs, as they do not provide information about language structuring and the effectiveness of its use, such as assessments of morphology, syntax, or pragmatics. Receptive and expressive morphosyntactic abilities refer to a child's ability to understand and express grammatical relationships between words. Receptive language skills include understanding the meaning derived from the grammatical structure of a sentence, while expressive language skills include the correct formation of sentences and the use of grammatical markers in language (Wilson et al., 2024).

Despite their importance, studies on morphosyntactic skills in children with CIs are relatively rare. Instruments that have been frequently used for this purpose are the Test for Reception of

Grammar (TROG; Bishop, 1989) and the Clinical Evaluation of Language Fundamentals (CELF; Semel et al., 2013). Studies using the TROG have shown that morphosyntactic acquisition progresses more slowly in children with CIs than in their hearing peers (Wilstedt-Svensson et al., 2004). However, these children show significant improvement over time, especially if implantation is performed before the age of 4 years (Nikolopoulos et al., 2004), while the best results are achieved if implantation is performed before 12 months of age (Colletti et al. 2011). Studies using the CELF test show that school-aged children with CIs are, on average, one standard deviation below the normative mean in language comprehension (Geers & Nicholas, 2013; Dettman et al. 2016; Kronenberger & Pisoni, 2019).

Cochlear implantation not only affects speech perception and language skills, but also influences

neurocognitive functions, as the brain systems do not develop in isolation. Early sensory experiences and the function of one part of the brain can influence the development of other neurocognitive capacities (Kral et al., 2016). Language serves as the basis for the development of cognitive functions such as short-term memory, reasoning, and executive functions. At the same time, working memory supports language processes by enabling the temporary storage and processing of phonological information, which is essential for both speech comprehension and language production (Baddeley, 2003).

According to the theory of a bidirectional relationship between language and working memory, language development contributes to more efficient processing and control of phonological information, while a well-developed working memory accelerates the acquisition of complex language skills (Gathercole & Baddeley, 2014). This relationship is particularly important in children with CIs, since both processes occur in the context of adaptation to an artificial auditory input.

In children with CIs, phonological representations are often altered due to insufficiently clear sensory input, which requires additional cognitive effort for verbal processing. This places a greater demand on the working memory compared to children with typical hearing (Kronenberger et al., 2014). The capacity of the working memory has a significant effect on language comprehension - children with a higher working memory capacity also show better language skills (Nittrouer et al., 2013). Verbal working memory is commonly assessed using digit span tasks: forward digit span assesses storage, while backward digit span assesses processing of verbal information (Donolato et al., 2017). These tasks have been widely used in research on children with CIs (AuBuchon et al., 2015; Davidson et al., 2019; Geers et al., 2014; Harris & Terlektsi, 2011; Kronenberger et al., 2021), showing that children with CIs often have a lower capacity of verbal working memory than their hearing peers. This can be a significant predictor of delays in speech perception and language development (Nittrouer et al., 2013).

Despite the significant technological advances in CIs and the increasingly early inclusion of children with congenital severe hearing loss in habilitation and educational programmes, many children with CIs still have poor language skills compared to their hearing peers. Receptive vocabulary remains the most extensively studied area of language, while receptive morphosyntactic skills and their relationship to working memory have been less explored. As verbal working memory plays a key role in the development and processing of language, it is particularly important to investigate how this cognitive ability contributes to language outcomes in children with CIs.

### **Aims and hypotheses**

The questions outlined above led to the four main objectives of this study. Firstly, the study aimed to investigate and compare the vocabulary and grammar comprehension of school-aged children with CIs and their hearing peers. Secondly, the study compared vocabulary and grammar comprehension within the group of children with CIs, and thirdly, went on to assess and compare verbal information storage and processing skills. Fourth, the study investigated the relationships between cognitive and language skills within each group in order to determine whether patterns of associations differed between groups.

It was hypothesised that children with CIs would have significantly weaker language skills - namely vocabulary and grammatical understanding - compared to their hearing peers. It was also expected that children with CIs would have a significantly lower ability to store and process verbal information in the short term.

## **METHODOLOGY**

### **Participants**

The study involved 35 children with cochlear implants (16 boys and 19 girls) aged 6 to 15 years ( $M = 10.7$ ;  $SD = 3.16$ ) and 23 children with typical hearing (11 boys and 12 girls) aged 6 to 15 years ( $M = 10.2$ ;  $SD = 3.17$ ). The hearing group was matched with the CI group by gender and chronological age (for every two or more CI users of the

same age, a hearing child of the same age or up to six months younger was selected). All participants had average or above average non-verbal cognitive abilities, which were assessed using Raven's Standard Progressive Matrices (Raven, 1994).

All children in the CI group were prelingually profoundly deaf or deaf, they had hearing parents, were integrated into regular schools, and used oral communication as their primary mode of communication at home. In addition, all participants with hearing loss were implanted before the age of 4 years (earliest implantation at 14 months, latest at 44 months). Hearing data were collected from medical documentation. The average aided hearing threshold in the implanted ear was 35 dB. The participants were fitted with modern cochlear implant systems from Cochlear (CI24RE, CI422 and CI512) and Med-El (Pulsar, Maestro and Sonata). All CI electrodes were active, the speech processors were regularly programmed, and the children used their devices throughout the waking hours. Most participants ( $n = 27$ , 82%) had unilateral CIs, four had bilateral implants, and four used a hearing aid in addition to a CI.

## Measures

The *Peabody Picture Vocabulary Test* (PPVT-III-HR; Kovačević et al., 2009) was used to assess receptive vocabulary. This is a standardised test for the Croatian language that is frequently used for diagnostic and research purposes. The child is presented with four pictures and asked to choose the one that corresponds to a spoken word. The test consists of 204 words that are categorised into 17 groups according to difficulty.

The *Test for Reception of Grammar* (TROG-2:HR; Bishop, Kuvač Kraljević, Hržica, Kovačević, & Kologranić Belić, 2014) was used to assess receptive morphosyntactic skills. It consists of 80 items classified into 20 blocks, each targeting different syntactical grammatical structures. Each item presents a sentence along with four pictures. The task is to select the picture that correctly represents the meaning of the sentence.

*Digit span tasks* were used to assess verbal working memory. The task requires the repetition

of a sequence of digits in the same order (forward span) and in reverse order (backward span), which assesses short-term memory or verbal information processing.

## Data collection procedure

Participants were recruited through institutions and clinics where they received habilitation services, with prior approval from institutional Ethics Committees. Testing was conducted individually with each participant in a quiet, well-lit, and comfortable environment, typically in a single session that lasted between 60 and 90 minutes. The session began with the nonverbal cognitive skills assessment (Raven's Standard Progressive Matrices), followed by the language comprehension and verbal working memory tests.

The data were collected as part of a wider study of predictors of receptive language skills in children with CIs. The study was approved by the Ethics Committee of the Faculty of Education and Rehabilitation Sciences of the University of Zagreb (Class: 602-04/20-42/8, 20 March 2020) and by the SUVAG Polyclinic (Class: 510-08/20-01, 6 October 2020).

## RESULTS

All statistical analyses were conducted using SPSS software (version 26.0). The study compared the language and cognitive abilities of school-aged children with CIs and their hearing peers using four measures: grammar comprehension (TROG-2:HR), receptive vocabulary (PPVT-III-HR), and verbal working memory (both forward and backward digit span). Prior to the group comparisons, the normal distribution of the continuous variables was tested. As the Shapiro–Wilk test indicated significant deviations from normality, non-parametric statistical methods were used in the subsequent analyses.

### Descriptive analysis – Language comprehension and verbal working memory

The descriptive statistics provide an overview of the performance of the two groups with respect

to receptive vocabulary and grammar comprehension (expressed as standard scores), as well as verbal working memory, measured through for-

ward digit span (verbal short-term memory) and backward digit span (verbal processing) (Table 2).

**Table 2.** Descriptive statistics for vocabulary and grammar comprehension, as well as verbal working memory in children with cochlear implants and children with typical hearing ( $n_{CI} = 35$ ;  $n_{TH} = 23$ )

Measure	Group	M	C	Min.	Max.	SD
Grammar comprehension (TROG-2:HR)	CI	77.34	76.00	55	113	15.87
	TH	108.30	108.00	91	123	8.31
Vocabulary comprehension (PPVT-III-HR)	CI	70.00	67.00	50	102	15.00
	TH	104.91	105.00	85	127	12.94
Working memory – storage (forward digit span)	CI	4.69	5.00	3	7	1.02
	TH	5.61	5.00	4	9	1.12
Working memory – processing (backward digit span)	CI	3.57	3.00	2	6	1.04
	TH	4.26	4.00	2	6	1.14

*Note:* C, Median; M, Mean; CI, children with cochlear implants; TH, children with typical hearing; SD, Standard Deviation

In order to gain a better understanding of grammar comprehension in the CI group, an analysis was carried out using percentile ranks, a quantitative measure frequently used in clinical practise. These results are shown in Table 3. Most children with CIs (74%) scored in the low range — below the 25th percentile — with six participants scoring in the extremely low range, below the 1st percentile.

A total of 23% of CI users achieved average scores (between the 25th and 75th percentiles), most of them in the low average range. The same proportion of hearing peers also achieved average results, but in the upper average range. Only one child with a CI achieved a high score (81st percentile), in contrast to 60% of their hearing peers who scored in the high range.

**Table 3.** Distribution of TROG-2:HR grammar comprehension scores by percentile ranks in children with cochlear implants and children with typical hearing

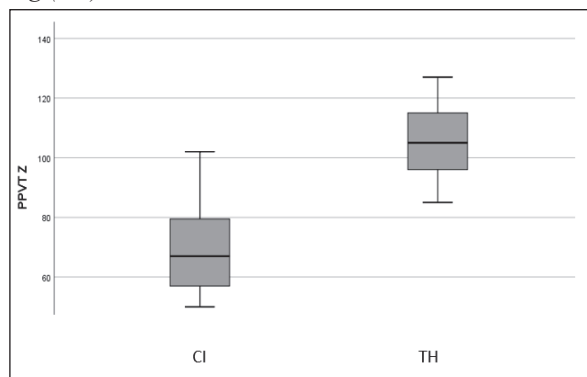
	TROG-2:HR			
	N	Below 25th percentile	between the 25th and 75th percentiles	Above 75th percentile
CI	35	26 (74%)	8 (23%)	1 (3%)
TH	23	2 (9%)	7 (30%)	14 (61%)

*Note:* CI, children with cochlear implants; TH, children with typical hearing

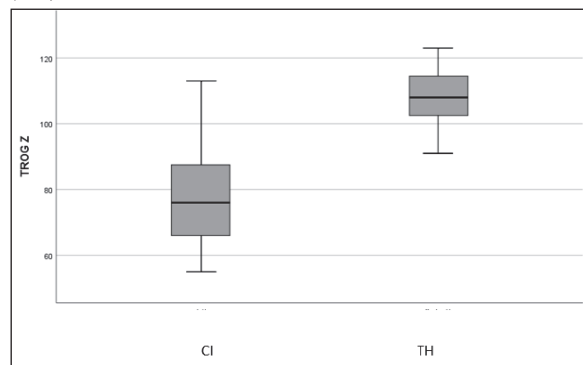
Data visualisation was used to demonstrate the distribution of scores, identify outliers, examine patterns of variability within each group, and interpret group differences between children with CIs and those with typical hearing. The distributions of the standardised scores for vocabulary comprehension (PPVT-III-HR) and grammar comprehension (TROG-2:HR) clearly show advantages in favour of the hearing group, which are reflected in higher median scores, as well as greater variability within the CI group. It is noteworthy that a larger number of children with CIs are in

the lowest quartile, indicating that a significant proportion of this group performs below average (Fig. 1 and 2).

**Figure 1.** Differences in vocabulary comprehension between children with CIs and those with typical hearing (TH)



**Figure 2.** Differences in grammar comprehension between children with CIs and those with typical hearing (TH)



### Differential analysis – Differences in language comprehension and verbal working memory

In order to determine the statistical significance of the observed between-group differences in receptive vocabulary and grammar and verbal working memory, a Mann-Whitney U test was

performed, with the results interpreted at a significance level of  $p < 0.05$ . The analysis showed that vocabulary knowledge, grammar comprehension, as well as the short-term storage and processing of verbal information in working memory were significantly lower in the group of children with CIs compared to their hearing peers (Table 4).

**Table 4.** Results of the Mann-Whitney U test comparing vocabulary and grammar comprehension, as well as verbal information storage and processing between children with cochlear implants and children with typical hearing ( $n_{CI} = 35$ ;  $n_{TH} = 23$ )

	Mann-Whitney U	p	Cohen d (confidence interval 95%)
Grammar comprehension (TROG-2:HR)	38.00	<b>0.000</b>	2.344 (1.634 - 2.98)
Vocabulary comprehension (PPVT-III-HR)	37.50	<b>0.000</b>	2.352 (1.764 - 3.144)
Working memory – storage (forward digit span)	251.00	<b>0.016</b>	0.667 (0.318 - 1.417)
Working memory – processing (backward digit span)	257.00	<b>0.21</b>	0.637 (0.1 - 1.177)

The descriptive data in Table 2 shows that children with CIs have, on average, a significantly weaker receptive vocabulary (large effect), a significantly weaker comprehension of grammar (large effect), and a moderately lower capacity for short-term storage and verbal information processing compared to hearing peers.

Additionally, the Wilcoxon signed-rank test was used to analyse the within-group differences in language comprehension and working memory (Table 5). In the typically hearing group, receptive vocabulary and grammar comprehension were comparably developed. As expected, however, significant

differences were found in the storage and processing of verbal information. Hearing children were able to store a larger number of words (5-6 words) compared to the number that they were able to process (about 4 words). In contrast, a statistically significant and moderately large difference between receptive vocabulary and grammar comprehension was found in children with CIs. These children had a much better developed vocabulary in comparison to their comprehension of grammar. Like their hearing peers, children with CIs showed better short-term storage (4-5 words) compared to their level of verbal information processing (3-4 words).

**Table 5.** Results of the Wilcoxon signed-rank test for within-group differences in vocabulary and grammar comprehension, as well as verbal information storage and processing in children with cochlear implants and children with typical hearing ( $n_{CI} = 35$ ;  $n_{TH} = 23$ )

	Group	Wilcoxon	p	r
Vocabulary comprehension (PPVT-III-HR) – Grammar comprehension (TROG-2:HR)	CI	- 2.77	<b>0.006</b>	0.468
	TH	- 1.00	0.315	/
Working memory – storage (forward digit span) – Working memory – processing (backward digit span)	CI	- 4.37	<b>0.000</b>	0.739
	TH	- 4.25	<b>0.000</b>	0.886

*Note:* CI, children with cochlear implants; TH, children with typical hearing

### Correlation analyses – Relationship between language comprehension and verbal working memory

In order to gain a deeper insight into the relationship between language and cognitive variables, both between and within the two groups of children, a Spearman correlation analysis and Fisher's Z-transformation analyses were conducted.

The correlation analysis showed a moderately positive correlation between grammar comprehension and receptive vocabulary in the group of children with CIs ( $\rho = 0.575$ ), indicating that children with a larger vocabulary probably also have a better understanding of grammar, and vice versa. Moderately positive correlations were also found between grammar comprehension and short-term verbal storage ( $\rho = 0.446$ ), as well as between receptive vocabulary and short-term verbal storage ( $\rho = 0.453$ ). This implies that children with a better developed vocabulary and a better comprehen-

sion of grammar probably also have a larger short-term verbal storage, and vice versa. A moderately high positive correlation was observed between verbal storage and verbal processing, suggesting that children with better short-term storage also tend to have better processing ability. However, the correlations between the language variables and the backward digit span (verbal processing) were not statistically significant in the CI group (Table 6).

In the group of typically hearing children, no statistically significant correlations were found between language and cognitive variables, nor between the language variables themselves, probably due to skewed data variability. The only significant correlation observed was a very strong association between forward and backward digit span ( $\rho = 0.89$ ), indicating a high likelihood that children with stronger verbal storage also show stronger verbal processing (Table 6).

**Table 6.** Spearman correlation analysis for the group of children with cochlear implants and the group of children with typical hearing ( $n_{CI} = 35$ ;  $n_{TH} = 23$ )

	Group	1.	2.	3.	4.
Grammar comprehension (TROG-2:HR)	CI	-			
	TH	-			
2. Vocabulary comprehension (PPVT-III-HR)	CI	<b>0.575**</b>	-		
	TH	- 0.07	-		
3. Working memory – storage (forward digit span)	CI	<b>0.446**</b>	<b>0.453**</b>	-	
	TH	0.389	0.111	-	
4. Working memory – processing (backward digit span)	CI	0.253	0.274	<b>0.487**</b>	-
	TH	0.383	0.151	<b>0.894**</b>	-

*Note:* CI, children with cochlear implants; TH, children with typical hearing; \*\* indicates  $p < 0.01$ , \* indicates  $p < 0.05$ .

To investigate whether the strength of the correlations differed significantly between the groups, Fisher's Z-transformation was applied (Table 7). A statistically significant difference was found between the two groups in the correlation between receptive vocabulary and grammar comprehension ( $Z = 2.544$ ,  $p < 0.05$ ). In the CI group, this correlation was moderate, positive, and statistically significant, while no significant

correlation was found in the hearing group. The results show that all other group differences with respect to correlations were not statistically significant, suggesting that the overall patterns of associations between language abilities (vocabulary and grammar comprehension) and working memory (verbal storage and processing) do not differ significantly between children with CIs and their hearing peers.

**Table 7.** Spearman correlations by group, Z-values, and corresponding p-values ( $n_{CI} = 35$ ;  $n_{TH} = 23$ )

Pair of variables	CI ( $\rho$ )	TH ( $\rho$ )	Z-values	P
Grammar comprehension (TROG-2:HR) - Vocabulary comprehension (PPVT-III-HR)	<b>0.575**</b>	- 0.07	2.544	<b>0.011</b>
Grammar comprehension (TROG-2:HR) - Working memory - storage (forward digit span)	<b>0.446**</b>	0.389	0.242	0.810
Grammar comprehension (TROG-2:HR) - Working memory - processing (backward digit span)	0.253	0.383	- 0.509	0.611
Vocabulary comprehension (PPVT-III-HR) - Working memory - storage (forward digit span)	<b>0.453**</b>	0.111	1.323	0.186
Vocabulary comprehension (PPVT-III-HR) - Working memory - processing (backward digit span)	0.274	0.151	0.453	0.651

*Note:* CI, children with cochlear implants; TH, children with typical hearing

## DISCUSSION

### Between and within group differences

The results of this study show that the vocabulary knowledge of congenitally deaf or severely hard of hearing children with CIs is statistically significantly lower - up to two standard deviations - than that of their hearing peers. These results are consistent with previous studies (AuBuchon et al., 2015; Blomquist et al., 2021; Conway et al., 2011; Dettman et al., 2016; Fitzpatrick et al., 2012; Hrasinski et al., 2019; Kronenberger & Pisoni, 2019; Kronenberger et al., 2021; Percy-Smith et al., 2013; Ruffin et al., 2013). Scores in the CI group ranged from 50 to 102, with only seven children with CIs scoring within the normative range for the hearing population (range = 85-115), in contrast to all hearing participants who scored within the expected norms (range = 85-127).

In addition to lower vocabulary knowledge, grammar comprehension was also found to be significantly lower in children with CIs compared to their hearing peers - by two standard deviations. Similar findings were reported by Hrasinski et

al. (2019), whose participants with CIs (of primary school age) achieved an average standardised score of 66 in the Croatian version of the TROG. Willstedt-Svensson et al. (2004), who used the Swedish version of the TROG, and May-Mederake (2010), who used the German version, also reported lower scores for grammar comprehension in children with CIs.

The present study also shows that 74% of children with CIs scored in the low range (below the 25th percentile), 23% were in the low average range, and only one child was in the high range (above the 75th percentile). Nikolopoulos et al. (2004) reported comparable results, while Colletti et al. (2011) documented more favourable results for children implanted before 12 months of age (58% above the 75th percentile), highlighting the importance of early implantation for favourable outcomes in language comprehension.

Although these low scores in vocabulary and grammar comprehension are consistent with previous research findings, they are even more concerning, given that this study only included children with favourable language developmental

conditions: early implantation (before 4 years of age, i.e., during the sensitive period), oral communication as the primary form of interaction, age-appropriate non-verbal cognitive abilities, no additional developmental difficulties, regular school involvement, as well as modern cochlear implantation systems, along with consistent use and programming of the device. These findings suggest that the extensively studied personal, audiological, technical, and habilitation factors - although important - do not fully explain the variability in language outcomes in children with CIs (Almomani et al, 2021; Davidson et al, 2014; Duchesne & Marschark, 2019; Geers & Nicholas, 2013; Thomas & Zwolan, 2019).

There is growing evidence that cognitive factors play a role, particularly verbal working memory, which enables the temporary storage and processing of phonological information that is essential for language comprehension. In the present study, children with CIs performed significantly lower than their hearing peers at storing verbal information, indicating a lower capacity of short-term verbal working memory. Additionally, the CI group also scored lower on the backward digit span, suggesting a reduced verbal processing capacity. These findings are consistent with previous studies that have reported reduced phonological storage and limited verbal processing in children with CIs (AuBuchon et al., 2015; Davidson et al., 2019; Geers et al., 2014; Harris & Terlektsi, 2011; Kronenberger et al., 2021).

Different authors have proposed different explanations for these results. One explanation emphasises the effects of early auditory deprivation. Although CIs provide access to sounds, children with prelingual deafness may continue to exhibit atypical perceptual patterns and sensory coding because they have not had adequate auditory experiences in early development (Cleary et al., 2001). An alternative explanation proposed by Nittrouer et al. (2017) is that the low-resolution auditory signals provided by the implant may limit the development of phonological awareness and impair the efficient phonological encoding required for verbal working memory.

The results also showed that typically hearing children have a balanced language profile - their vocabulary and comprehension of grammar are equally developed, as would be expected in typically developing children. In contrast, the CI group showed a different pattern. Although their vocabulary was also lower than that of their hearing peers, it was largely and significantly better developed than their grammar comprehension. This discrepancy suggests that the acquisition of grammatical structures is more challenging in this population and that morphosyntactic difficulties tend to persist, which is consistent with previous research (Hrastinski et al., 2019). In the cognitive domain, both groups showed the same developmental pattern: verbal memory capacity outperformed processing ability, albeit at an overall lower level in the CI group, which in turn indicates a strain on phonological processing in the context of limited auditory input.

### **Relationship between language comprehension and verbal working memory**

Investigating the relationship between language and working memory is essential for understanding language development, especially in children with CIs, where both processes occur under conditions of adaptation to artificial auditory input. In the CI group, moderately positive correlations were found between vocabulary comprehension and verbal short-term memory, as well as between grammar comprehension and verbal short-term memory. These findings reveal an important relationship between language and cognitive skills in the CI group that is consistent with the bidirectional model of language and working memory (Gathercole & Baddeley, 2014), which assumes that a well-developed working memory supports language skills.

Interestingly, no significant correlations were found between cognitive variables and vocabulary or grammar comprehension in the group of typically hearing children, probably due to skewed data variability in this group.

Although no statistically significant group differences were found in terms of the correlations

between language and cognitive variables, in general, more significant and stronger correlations in the CI group suggest that language development in these children is likely to be more dependent on working memory capacity, or maybe even more reliant on cognitive resources such as working memory as a compensatory mechanism. These findings are consistent with previous studies showing that altered phonological representations due to limited auditory input increase the cognitive load during language processing in children with CIs (Kronenberger et al., 2014; Nittrouer et al., 2013). Therefore, language comprehension in this population may be better explained by models that integrate cognitive functions and language abilities, which has important implications for both therapeutic and educational interventions.

### **Limitations of the study and implications for practice**

This study has several limitations that should be emphasised. Firstly, the sample size was relatively small due to an effort to homogenise the heterogeneous population of children with hearing impairments, which limits the generalisability of the findings and reduces the statistical power of the tests. Secondly, the instruments used assessed only certain aspects of working memory and language abilities, while other important cognitive domains such as attention, processing speed, and expressive language were not considered.

Despite these limitations, the findings point to the need for an integrated and multidisciplinary approach to assess and promote language development in children with CIs. Such an approach should not only monitor language input and output, but also systematically evaluate underlying cognitive processes, particularly verbal working memory and processing capacity. In clinical practice, this implies that speech therapy programmes should recognise the potential need for individualised strategies, especially for children who continue to show language delays, despite early implantation and favourable developmental conditions. Furthermore, collaboration between audiologists, speech-language pathologists, educators, and psychologists is essential to ensure a comprehensive

understanding of each child's profile, in order to tailor habilitation plans effectively.

Future research should build on these findings by conducting longitudinal studies with larger and more diverse samples, and by including additional aspects of language and cognition. Moreover, further research should include other potential factors influencing language outcomes in children with CIs in order to determine their synergistic effect in association with other cognitive factors. Ultimately, intervention models should extend beyond auditory training and language development to address the broader neurocognitive profile of the child, considering working memory as both a protective and limiting factor in language acquisition.

### **CONCLUSION**

This study found that both vocabulary and grammar comprehension is significantly lower in prelingually deaf children with CIs compared to their hearing peers. These findings are particularly worrying given that the participating children had favourable developmental conditions, such as early implantation, lack of additional developmental difficulties, use of oral communication, and participation in regular school. These factors are generally considered to be predictors of successful language development, and one would expect the results to be comparable to those of hearing children. This raises the legitimate question of why language outcomes continue to lag behind, despite favourable conditions, and what aspects of the current habilitation approach need to be revised in order to improve language skills in this population.

One possible explanation comes from the study of verbal working memory, a cognitive function closely linked to language acquisition and processing. The results of the present study also show that children with CIs performed worse on verbal working memory tasks than their hearing peers. In particular, language variables were more strongly associated with working memory measures in the CI group than in the hearing group. This pattern may reflect the activation of compensatory mech-

anisms based on cognitive resources that children with CIs use to try to compensate for their limited auditory input.

These findings show that a deeper understanding of the specific interactions between language and cognitive factors is essential for the develop-

ment of differentiated and individualised habilitation strategies. Such approaches could achieve optimal language outcomes for each individual child with a CI by addressing both language and cognitive needs in an integrated manner.

## REFERENCES

- Almomani, F., Al-momani, M. O., Garadat, S., Alquadah, S., Kassab, M., Hamadneh, S., Rauterkus, G., & Gans, R. (2021). Cognitive functioning in deaf children using cochlear implants. *BMC Pediatrics*, *21*, 71. <https://doi.org/10.1186/s12887-021-02534-1>
- AuBuchon, A. M., Pisoni, D. B., & Kronenberger, W. G. (2015). Short-term and working memory impairments in early-implanted, long-term cochlear implant users are independent of audibility and speech production. *Ear and Hearing*, *36*(6), 733–737. <https://doi.org/10.1097/AUD.000000000000189>
- Baddeley, A. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience*, *4*(10), 829–839. <https://doi.org/10.1038/nrn1201>
- Bishop, D. V. M. (1989). *Test for reception of grammar*. Medical Research Council.
- Blomquist, C., Newman, R. S., Huang, Y. T., & Edwards, J. (2021). Children with cochlear implants use semantic prediction to facilitate spoken word recognition. *Journal of Speech, Language, and Hearing Research*, *64*(5), 1636–1649. [https://doi.org/10.1044/2021\\_JSLHR-20-00319](https://doi.org/10.1044/2021_JSLHR-20-00319)
- Cleary, M., Pisoni, D. B., & Geers, A. E. (2001). Some measures of verbal and spatial working memory in eight- and nine-year-old hearing-impaired children with cochlear implants. *Ear and Hearing*, *22*(5), 395–411. (URL za broj časopisa) <https://journals.lww.com/ear-hearing/toc/2001/10000>
- Cole, E., & Flexer, C. (2019). *Children with hearing loss: Developing listening and talking*. Plural Publishing.
- Colletti, L., Carner, M., Miorelli, V., Guida, M., Colletti, V., & Fiorino, F. G. (2011). Cochlear implantation at under 12 months: Report on 10 patients. *The Laryngoscope*, *121*(1), 177–181. <https://doi.org/10.1097/01.mlg.0000157838.61497.e7>
- Conway, C. M., Karpicke, J., Anaya, E. M., Henning, S. C., Kronenberger, W. G., & Pisoni, D. B. (2011). Nonverbal cognition in deaf children following cochlear implantation: Motor sequencing disturbances mediate language delays. *Developmental Neuropsychology*, *36*(2), 237–254. <https://doi.org/10.1080/87565641.2010.549869>
- Davidson, L. S., Geers, A. E., & Nicholas, J. G. (2014). The effects of audibility and novel word learning ability on vocabulary level in children with cochlear implants. *Cochlear Implants International*, *15*(4), 211–221. <https://doi.org/10.1179/1754762813Y.0000000051>
- Davidson, L. S., Geers, A. E., Hale, S., Sommers, M. M., Brenner, C., & Spehar, B. (2019). Effects of early auditory deprivation on working memory and reasoning abilities in verbal and visuospatial domains for pediatric cochlear implant recipients. *Ear and Hearing*, *40*(3), 517–528. <https://doi.org/10.1097/AUD.0000000000000629>
- Dettman, S. J., Dowell, R. C., Choo, D., Arnott, W., Abrahams, Y., Davis, A., Dornan, D., Leigh, J., Constantinescu, G., Cowan, R., & Briggs, R. J. (2016). Long-term communication outcomes for children receiving cochlear implants younger than 12 months: A multicenter study. *Otology & Neurotology*, *37*(2), e82–e95. <https://doi.org/10.1097/MAO.0000000000000915>
- Donolato, E., Giofrè, D., & Mammarella, I. C. (2017). Differences in verbal and visuospatial forward and backward order recall: A review of the literature. *Frontiers in Psychology*, *8*, 663. <https://doi.org/10.3389/fpsyg.2017.00663>
- Duchesne, L., & Marschark, M. (2019). Effects of age at cochlear implantation on vocabulary and grammar: A review of the evidence. *American Journal of Speech-Language Pathology*, *28*(4), 1673–1691. [https://doi.org/10.1044/2019\\_AJSLP-18-0161](https://doi.org/10.1044/2019_AJSLP-18-0161)
- Fitzpatrick, E. M., Olds, J., Gaboury, I., McCrae, R., Schramm, D., & Durieux-Smith, A. (2012). Comparison of outcomes in children with hearing aids and cochlear implants. *Cochlear Implants International*, *13*(1), 5–15. <https://doi.org/10.1179/146701011X12950038111611>
- Gathercole, S. E., & Baddeley, A. D. (2014). *Working memory and language*. Psychology Press.

- Geers, A. E., & Nicholas, J. G. (2013). Enduring advantages of early cochlear implantation for spoken language development. *Journal of Speech, Language, and Hearing Research*, *56*(2), 643–655. [https://doi.org/10.1044/1092-4388\(2012/11-0347\)](https://doi.org/10.1044/1092-4388(2012/11-0347))
- Geers, A. E., Nicholas, J. G., & Sedey, A. L. (2014). Language skills of children with early cochlear implantation. *Ear and Hearing*, *35*(5), e44–e62. <https://doi.org/10.1097/01.aud.0000051689.57380.1b>
- Harris, M., & Terlektsi, E. (2011). Reading and spelling abilities of deaf adolescents with cochlear implants and hearing aids. *Journal of Deaf Studies and Deaf Education*, *16*(1), 24–34. <https://doi.org/10.1093/deafed/enq031>
- Hoff, E. (2013). *Language development*. Cengage Learning.
- Hrastinski, I., Pribanić, L., & Mrvica, I. (2019). Razumijevanje rječnika i gramatike učenika s kohlearnim implantatom. *Logopedija*, *9*(1), 1–8. <https://hrcak.srce.hr/224580>
- Kral, A., Kronenberger, W. G., Pisoni, D. B., & O'Donoghue, G. M. (2016). Neurocognitive factors in sensory restoration of early deafness: A connectome model. *The Lancet Neurology*, *15*(6), 610–621. [https://doi.org/10.1016/S1474-4422\(16\)00034-X](https://doi.org/10.1016/S1474-4422(16)00034-X)
- Kronenberger, W. G., Colson, B. G., Henning, S. C., & Pisoni, D. B. (2014). Executive functioning and speech-language skills following long-term use of cochlear implants. *Journal of Deaf Studies and Deaf Education*, *19*(4), 456–470. <https://doi.org/10.1093/deafed/enu011>
- Kronenberger, W. G., & Pisoni, D. B. (2019). Assessing higher order language processing in long-term cochlear implant users. *American Journal of Speech-Language Pathology*, *28*(4), 1537–1553. [https://doi.org/10.1044/2019\\_AJSLP-18-0138](https://doi.org/10.1044/2019_AJSLP-18-0138)
- Kronenberger, W. G., Montgomery, C. J., Henning, S. C., Ditmars, A., Johnson, C. A., Herbert, C. J., & Pisoni, D. B. (2021). Remote assessment of verbal memory in youth with cochlear implants during the COVID-19 pandemic. *American Journal of Speech-Language Pathology*, *30*(2), 740–747. [https://doi.org/10.1044/2021\\_AJSLP-20-00276](https://doi.org/10.1044/2021_AJSLP-20-00276)
- May-Mederake, B., Kuehn, H., Vogel, A., Keilmann, A., Bohnert, A., Mueller, S., ... Coninx, F. (2010). Evaluation of auditory development in infants and toddlers who received cochlear implants under the age of 24 months with the LittlEARS® Auditory Questionnaire. *International Journal of Pediatric Otorhinolaryngology*, *74*(10), 1149–1155. <https://doi.org/10.1016/j.ijporl.2010.07.003>
- Nittrouer, S., Caldwell-Tarr, A., Low, K., & Lowenstein, J. H. (2017). Verbal working memory in children with cochlear implants. *Journal of Speech, Language, and Hearing Research*, *60*, 3342–3364. [https://doi.org/10.1044/2017\\_JSLHR-H-16-0474](https://doi.org/10.1044/2017_JSLHR-H-16-0474)
- Nittrouer, S., Caldwell-Tarr, A., & Lowenstein, J. H. (2013). Working memory in children with cochlear implants: Problems are in storage, not processing. *International Journal of Pediatric Otorhinolaryngology*, *77*(11), 1886–1898. <https://doi.org/10.1016/j.ijporl.2013.09.001>
- Nikolopoulos, T. P., Dyar, D., Archbold, S., & O'Donoghue, G. M. (2004). Development of spoken language grammar following cochlear implantation in prelingually deaf children. *Archives of Otolaryngology–Head & Neck Surgery*, *130*, 629–633. <https://doi.org/10.1001/archotol.130.5.629>
- Percy-Smith, L., Busch, G., Sandahl, M., Nissen, L., Josvassen, J. L., Lange, T., Rusch, E., & Cayé-Thomasen, P. (2013). Language understanding and vocabulary of early cochlear implanted children. *International Journal of Pediatric Otorhinolaryngology*, *77*(2), 184–188. <https://doi.org/10.1016/j.ijporl.2012.10.014>
- Ruffin, C. V., Kronenberger, W. G., Colson, B. G., Henning, S. C., & Pisoni, D. B. (2013). Long-term speech and language outcomes in prelingually deaf children, adolescents and young adults who received cochlear implants in childhood. *Audiology & Neurotology*, *18*(5), 289–296. <https://doi.org/10.1159/000353405>
- Semel, E., Wiig, E. H., & Secord, W. (2013). *Clinical evaluation of language fundamentals—Fifth edition (CELF-5)*. Pearson.

- Thomas, E. S., & Zwolan, T. A. (2019). Communication mode and speech and language outcomes of young cochlear implant recipients: A comparison of auditory-verbal, oral communication, and total communication. *Otology & Neurotology*, *40*(10), e975–e983. <https://doi.org/10.1097/MAO.0000000000002405>
- Velandia, S., Martinez, D., Goncalves, S., Pena, S., Bas, E., Ein, L., Prentiss, S., Telischi, F., Angeli, S., & Dinh, C. T. (2020). Effect of age, electrode array, and time on cochlear implant impedances. *Cochlear Implants International*, *21*(6), 344–352. <https://doi.org/10.1080/14670100.2020.1788859>
- Wieringen, A., & Wouters, J. (2014). What can we expect of normally developing children implanted at a young age with respect to their auditory, linguistic and cognitive skills? *Hearing Research*, *322*, 171–179. <https://doi.org/10.1016/j.heares.2014.09.002>
- Willstedt-Svensson, U., Löfqvist, A., Almqvist, B., & Sahlén, B. (2004). Is age at implant the only factor that counts? The influence of working memory on lexical and grammatical development in children with cochlear implants. *International Journal of Audiology*, *43*(9), 506–515. <https://doi.org/10.1080/14992020400050065>
- Wilson, B. S., Dorman, M. F., Gifford, R. H., & Tucci, D. L. (2024). Language and literacy skills in children with cochlear implants: Past and present findings. In *Pediatric cochlear implantation: Learning and the brain* (2nd ed., pp. 3–74). Springer. [https://doi.org/10.1007/978-3-031-67188-3\\_1](https://doi.org/10.1007/978-3-031-67188-3_1)