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# Passive sentence comprehension difficulties and its related factors in children with cochlear implants

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ABSTRACT

*Objectives:* The purposes of this study were to investigate which syntactic structures, from active and passive sentences, sensitively differentiate children with cochlear implants (CIs) from children with normal hearing (NH), to explore the correlations among working memory (WM) and other factors for each group, and to examine predictors of the active and passive sentence scores for both groups.

*Methods:* Twenty deaf children with CIs and 20 children with NH, aged 8–14 years, were included in this study. Sentence comprehension skills were measured using the picture-pointing comprehension task, which consisted of active and passive sentences. The WM capacity was tested by the digit forward, digit backward, word forward, and word backward span tasks.

*Results:* Passive sentence type was a significant predictor to differentiate between the two groups ($p < .05$). In the CI group, passive sentence scores were significantly correlated with age, duration of an implant use, receptive vocabulary scores, and WM scores (all $p$ values $< .05$). In the stepwise regression analysis, WM capacity was a significant factor in predicting the passive sentence scores of children with CIs ($p < .05$).

*Conclusion:* Passive sentence type was a significant factor in distinguishing the CI group from the NH group. The WM capacity was an important predictor accounting for individual differences in processing complex sentence types for children with CIs. The results indicate that a complex syntactic form may serve as a clinically critical index in detecting higher-level cognitive and linguistic processing difficulties in good performers after implantation.

## 1. Introduction

A cochlear implant (CI) safely and effectively facilitates the development of auditory abilities in deaf children, who have limited benefits from conventional hearing aids [1]. The benefits of a CI have been confirmed for speech perception, speech production, language skills, and academic achievement across the studies [2,3]. However, the developmental patterns of higher-level language processing in children with CIs have been under debate. Some studies suggested that the language skills of children with CIs are comparable to those of age-matched children with normal hearing (NH) [4,5], whereas other studies reported that children with CIs struggle with language delay or deficits [6,7]. To date, several groups of researchers have found that age at implantation is an important factor in language development in children with CIs [1–3,7]. Children implanted at earlier ages demonstrated better performance on phonological processing and vocabulary tasks than children implanted later.

It is critical to note, however, that individual differences still manifest themselves, even for children with early implantation, although deaf children are now being implanted prior to 2–3 years of age. In other words, age at implantation does not seem to be the only factor associated with individual variabilities in language-related outcome measures for children with early implantation [8,9]. Previous studies [7,10] reported that phonological processing skills were more important in children with CIs than age at implantation for word acquisition. However, these studies were limited to the word-level processing and did not focus on higher-level linguistic and cognitive abilities, such as the domain of sentence processing, for school-aged children who have used CIs for a long time. Thus, further studies need to explore more diverse clinical outcome measures to sensitively capture individual differences in linguistic and cognitive changes after implantation. More recently, factors related to language processing and their association with cognitive functions have gained considerable attention in identifying specific features of language development in children who are implanted at younger ages, in order to better understand their language learning process.

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Sentence comprehension abilities are very important skills for children with CIs in being academically successful in school and maintaining good relationships with peers [11,12]. Previous studies involving sentence-level investigations of children with CIs can be separated into two categories: auditory speech perception and reading comprehension. Evidence from speech perception abilities suggested that deaf children obtained significant benefits to open-set speech perception at a sentence level after implantation, and their performance was related to demographic factors, such as preoperative residual hearing and duration of deafness [13,14]. A group of researchers reported that the reading comprehension skills of children with CIs tended to be lagging behind those of children with NH, and their skills were associated with speech perception abilities, vocabulary knowledge, word recognition, and phonological awareness in children with CIs [15–17].

In general, sentence comprehension is a linguistically and cognitively challenging process for children, given that they need to hold linguistic information in a short period of time and compute syntactic structures at the same time to comprehend sentences containing a series of semantic and syntactic information [18–21]. Some studies have investigated the link between sentence comprehension abilities and individual differences in working memory (WM) capacity [19,20]. Montgomery and Evans [19] found that verbal WM significantly predicted complex sentence comprehension abilities in children with specific language impairment (SLI) and language-matched children. The results suggested that WM may serve as an underlying mechanism associated with abilities to interpret complex sentences for children. To date, a small number of researchers have tried to examine the relationship between cognitive functions and linguistic components for children with CIs [7,10,22,23]. They reported that cognitive functions, as mostly indexed by phonological WM, were associated with individual differences in language development for children with CIs. However, to the best of our knowledge, none of the previous studies examined the differential effects of syntactic structures on sentence comprehension and their relation to WM for children with CIs.

WM capacity is defined as cognitive resources that are responsible for maintenance and computation of linguistic information [24]. For children with CIs, there are several verbal WM measures used to evaluate their WM capacity such as digit span, word span, and reading span [8,22,25]. It is important to consider the modality to present WM stimuli for children with CIs in order to evaluate their WM capacity reliably, as their auditory channels are weak. Thus, the current study employed a visual paradigm to present verbal WM tasks for children with CIs to minimize the influence of auditory-perception levels on tasks. The current WM stimuli consisted of digits and words that are clearly associated with linguistic and verbal domains, but those verbal WM stimuli were presented visually. Consistent with the WM measurement paradigm, we also presented sentence comprehension stimuli using a visual paradigm, in which reading abilities were required to encode the sentence stimuli.

The current study employed the complexity notion in a single-sentence level based on the participant's age. In a single-sentence level, the most widely studied syntactic structures from the complexity perspective are comparisons between active and passive sentences [19,26]. Passive sentence structures are more difficult to process than active sentences, given that the thematic roles are reversed in passive structures [21,26,27]. In the passive sentence, the patient is moved from its original place to the subject position, and the agent is placed after the by-phrase. For instance, the passive counterpart of the active sentence, "The cat chases the dog", is "The dog is chased by the cat". Thus, passive sentence structures are required to go through more complex linguistic computations than active sentences. To the best of our knowledge, in sentence processing levels for children with CIs, none of the studies specifically focused on the comparisons between passive and active sentences from the perspective of syntactic complexity.

The current study investigated how syntactic complexity plays a role in differentiating children with CIs who have good performance on the word level from children with NH. This approach is novel to examining language-processing difficulties at the sentence level for school-aged children with CIs. We predicted that a more complex syntactic structure, such as passive sentences, should be a more sensitive predictor than active sentences in differentiating the groups even for children with CIs who show fairly good performances on word-level tasks (i.e., monosyllabic word tasks and receptive vocabulary tasks). We further explored the relationships between sentence comprehension abilities and verbal WM capacity for children with CIs and children with NH. Finally, we identified whether there were significant cognitive factors that could account for sentence comprehension abilities in each group.

## 2. Materials and methods

### 2.1. Participants

Twenty children with CIs (10 females and 10 males) participated in this study. Each child with CIs met the following inclusion criteria: (a) implantation under 3.5 years of age, (b) aged between 8 and 14 years at the time of testing (c) no additional disabilities (e.g., autism, cerebral palsy), and no severe inner-ear malformation (e.g., common cavity, severe hypoplasia), and (d) ability to communicate verbally. Preoperatively, all children showed no response at the auditory brainstem response (ABR), and they were fitted with conventional hearing aids in two ears. They attended the aural habilitation program in a school for the deaf and/or an auditory habilitation centers. All children used the Cochlear Corporation Nucleus multichannel CI. Postoperatively, their aided thresholds were below 30 dB HL. The mean chronological age was 144.1 months (*SD* = 22.5, *range:* 108–172). The average age of hearing impairment identification was 10.8 months (*SD* = 7.6, *range:* 7–31) and the average age at hearing aid fitting was 14.2 months (*SD* = 6.3, *range:* 6–31). The average age at implantation was 31.5 months (*SD* = 7.5, *range:* 21–41), and the mean duration of an implant use was 112.8 months (*SD* = 20.3, *range:* 86–140). The mean score of the Receptive and Expressive Vocabulary Test–Receptive (REVT–R) [28] was 121.5 (*SD* = 28.4, *range:* 76–167), and mean phoneme scores of open-set monosyllabic word test [29] was 86.2% (*SD* = 4.6, *range:* 80.8–93.8). The mean WM scores was 18.8 (*SD* = 4.4, *range:* 13–28).

Twenty children with NH (13 females and 7 males) participated as part of the control group. The children underwent a hearing screening using warble tone at frequencies of 500, 1000, 2000, and 4000 Hz at 20 dB HL to ensure no hearing impairment was present. The parental reports did not indicate any history of a speech-language or cognitive disorder in any of them. The children were matched individually to children with CIs based on the chronological age of 3 months ( ± 3 months). The mean chronological age was 143.1 months (*SD* = 19.6, *range:* 104–171) and the average REVT-R [28] score was 134.2 (*SD* = 21.7, *range:* 96–164). The mean WM scores was 25.8 (*SD* = 5.1, *range:* 19–36).

Both groups showed no significant difference in chronological age ($t = -0.142$, $p = .888$) and vocabulary ($t = 1.585$, $p = .121$) between groups. WM scores between the two groups showed a significant difference ($t = 4.647$, $p = .000$). The demographic data of the children are presented in Table 1.

### 2.2. Materials and procedures

Children with CIs and children with NH were tested on sentence comprehension and WM tasks individually in a quiet room. The stimuli of the sentence comprehension and WM tasks were presented visually only so that children with CIs could process information using only a visual input. The receptive vocabulary was assessed using REVT-R [28], and the speech perception abilities in children with CIs were measured