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Phonological processing skills and its relevance to receptive vocabulary development in children with early cochlear implantation

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ABSTRACT

Objectives: The purposes of this study were to investigate phonological processing skills for children with cochlear implants (CIs) in comparison with children with normal hearing (NH), and to assess whether phonological processing skills can explain variance in receptive vocabulary scores in children with CIs.
Methods: Twenty-five deaf children who received a CI before 2 years of age were included in this study, and they ranged from 4 years to 6 years 11 months. Twenty-five children with NH as a control group were matched to children with CIs on the basis of chronological age with 3 months. Phonological processing skills were measured by the phonological awareness (PA), nonword repetition (NWR), and rapid automatized naming (RAN) tasks. Receptive vocabulary skills were also tested by the Peabody Picture Vocabulary Test – Korean version.
Results: Children with CIs performed significantly lower than children with NH on PA ($p < .05$) and NWR ($p < .001$) tasks. Children with CIs showed slower naming speed than children with NH, which did not reach the significant level ($p > .05$). Among phonological processing skills, PA contributed significant amount to receptive vocabulary skills in children with CIs ($p < .001$).
Conclusions: Children with early implantation receive substantial benefits for developing lexical access skills. However, children with CIs showed delays in PA and NWR in comparison with age-matched children with NH. For children with CIs, PA among phonological processing skills plays an important role of developing receptive vocabulary skills.

1. Introduction

Cochlear implants (CIs) have been established as a safe and effective means of improving auditory performance for deaf children when benefit from a conventional hearing aid is limited [1]. A CI provides deaf children with increased access to spoken language, and greater early spoken language ability is associated with higher levels of speech perception, better speech intelligibility, and better vocabulary skills compared with deaf children who do not use a CI [2]. These findings are consistent with the growing body of research which suggests that children implanted at earlier ages may have more opportunities to develop lexical representations, develop better speech perception, and improve phonological processing skills than children implanted later [2,3].

Based on numerous studies [1–3], age at implantation accounted for much of the variance in outcomes of children with CIs. However, age at implantation alone does not account for a wide variability among children with early implantation in speech perception and language outcomes [4,5]. Although many deaf children are now being implanted at 2 years or younger, individual differences in children with early implantation are still an unsolved issue that needs to be answered [2,3]. Many researchers have investigated a number of demographic variables (e.g., age at implantation, amount of residual hearing, and duration of an implant use, etc.) affecting CI outcomes in deaf children [2,3,6]. However, demographic variables and traditionally measured outcomes are limited in explaining differences. Identifying and understanding other sources of variability and measuring underlying processes for these children will be useful in predicting CI outcomes, developing new habilitation program, and gaining a better understanding of how deaf children encode and process speech information using a CI.

In our study, we focused on phonological processing skills and receptive vocabulary skills in children with CIs. Phonological processing skills such as encoding phonological representations of spoken words, maintaining them in memory, and retrieving them efficiently are important skills that affect word learning and language development [7–9]. Phonological processing refers to the use of phonological information in processing written and oral information, requiring cognitive operations on the sound system of

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a language. The components of phonological processing include phonological awareness (PA), phonological memory (PM), and lexical access [7,8]. PA is defined as the ability to abstract and manipulate segments of spoken language, typically measured by tasks in which children have to match, blend, delete, or count sounds within words. PM is the coding of information in a sound-based representation system, commonly measured by digit span or nonword repetition (NWR) tasks. The NWR task requires a child to identify a string of heard phonemes, to retain them in a short-term memory, and to produce the same sequence as speech. Lastly, lexical access is the retrieval of lexical sound-based representations from long-term memory, which is measured by rapid automatized naming (RAN) tasks such as letters, digits, or color naming. These tasks tap several skills including phonological processing and executive functioning, and the performance of these tasks rely on speech output and language process [7,8].

Numerous studies [4,7,10–14] documented that children with CIs develop phonological systems that are stronger than those of deaf children without CIs, but weaker than those of children with normal hearing (NH). Children with CIs have an advantage over deaf children without CIs in terms of developing phonological processing skills [10]. Spencer and Tomblin [7] explored the phonological processing skills in children with CIs ($n = 29$) who used a CI over 4 years. Scores on PA and NWR tasks of children with CIs were significantly poorer than those of children with NH. Scores in RAN tasks were not significantly different between children with CIs and children with NH. They suggested that lexical access is more highly salient for children with CIs than PA and PM. Tse and So [14] found that Cantonese-speaking preschoolers with CIs and their NH peers had similar levels of syllable awareness, phoneme awareness, and rhyme awareness. However, children with CIs showed significantly poorer performance on tone awareness and phonological knowledge tasks than their NH peers. Children with CIs may not acquire sensitively to phonological structure on a typical timetable, and half the children with CIs continue to perform on language and reading tasks more than 1 SD below the mean of their NH peers [15].

Among children with CIs, earlier and greater access to spoken language provides greater opportunity to rapidly access the phonological structure and develop PA [10,12]. James et al. [10] reported that children implanted early (between 2 and 3.6 years) had significant growth on rhyme awareness, whereas late implanted children (between 5 and 7 years) showed no significant gains in PA over time. Similarly, Johnson and Goswami [12] also reported that early implanted children had better PA skills than those of late implanted children, although all children derived benefit from a CI in the development of the PA skills necessary for developing efficient word recognition skills. Moreover, several studies [16,17] documented that PA was significantly correlated with speech perception and language in children with CIs. These previous studies supported the view that deaf children had gains in PA skills after implantation, although not specifically addressing individual variations in CI outcomes.

Little is currently known about all three phonological processing components (i.e., PA, PM, and lexical access) especially in children with early implantation compared to NH controls. Additionally, investigating the predictors affecting receptive vocabulary skills is an urgent area of research in children who received a CI early. The present study hypothesized that deaf children who received a CI before the age of 2 years would have a fairly good performance in phonological processing tasks. Thus, it was expected that children with CIs and children with NH would show similarities and no difference in three phonological processing components. Furthermore, phonological processing skills would be strongly associated with receptive vocabulary skills in children with CIs and the valuable predictors of receptive vocabulary skills would be phonological processing abilities including PA, PM, and RAN. Therefore, the purposes of the current study were (1) to investigate phonological processing skills for children with CIs in comparison with children with NH, and (2) to assess whether phonological processing skills can explain variance in receptive vocabulary scores in children with CIs.

2. Methods

2.1. Subjects

Twenty-five children with CIs (11 females, 14 males) participated in this study. For every individual child with CIs, the child was selected based on four criteria. First, the children had to receive a CI before the age of 24 months. Second, at the time of testing, the children had to be between the age of 4 years and 6 years 11 months. Third, the children had no severe inner ear malformation and/or no additional disabilities (i.e., autism, visual impairment, and cognitive disabilities, etc). Fourth, scores of the open-set monosyllabic word test in children with CIs were over 85% at the phoneme level. Lastly, the children had to use oral-only communication (i.e., no use of any form of manual communication). Preoperatively, all children used conventional hearing aids and received auditory training in the auditory habilitation centers. All children with CIs showed no response at the preoperative auditory brainstem response (ABR). All of them underwent successful implantation with complete electrode insertion, and they used the Cochlear Corporation Nucleus multichannel cochlear implant. Aided thresholds of all children with cochlear implants were below 30 dB HL after implantation. The mean chronological age was 64.76 months ($SD = 9.48$). The average age at fitting hearing aids was 14 months ($SD = 7.27$), and the average at start of the habilitation program was also 14 months ($SD = 7.27$). The average age at implantation was 20.88 months ($SD = 3.88$). The mean duration of an implant use was 43.88 months ($SD = 10.28$).

Twenty-five children with NH (13 females, 12 males) participated as a control group. The children were matched individually to children with CIs on the basis of chronological age with 3 months (±3 months). The mean chronological age was 64.36 months ($SD = 8.53$). There was no age difference between groups ($t = 0.157$, $p > .05$). These children underwent a hearing screening using warble tone at frequencies 500, 1000, 2000, and

Table 1
Demographic data of the subjects.

	CI group ($n = 25$)	NH group ($n = 25$)
Sex (F:M)	11:14	13:12
Age at testing (MO)	64.76 (9.48)	64.36 (8.55)
Age at fitting HAs (MO)	14 (7.27)	
Age at start of the habilitation program (MO)	14 (7.27)	
Age at implantation (MO)	20.88 (3.88)	
Duration of an implant use (MO)	43.88 (10.28)	
Phoneme scores of monosyllabic word test (%)	92.4 (6.13)	

Note. CI = cochlear implant; NH = normal hearing; F = female; M = male; MO = months; HAs = hearing aids.
Numbers in parentheses indicate standard deviation.
All children with cochlear implants showed no response at preoperative auditory brainstem response.
All children with CI group underwent successful implantation with complete electrode insertion, and they have used the Cochlear Corporation Nucleus multichannel cochlear implant.
Aided thresholds of all children with cochlear implants were below 30 dB HL after implantation.