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Longitudinal performance of spoken word perception in Mandarin pediatric cochlear implant users

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ABSTRACT

Objective: The objective of the present study was to investigate the longitudinal performance on open-set word perception in Mandarin children with cochlear implants (CIs).
Methods: Prospective cohort study. One hundred and five prelingually deaf children implanted with CIs participated in the study. The Standard-Chinese Version of Monosyllabic Lexical Neighborhood Test (LNT) and Multisyllabic Lexical Neighborhood Test (MLNT) were used as open-set word perception evaluation tools. Evaluations were administrated at 6, 12, 24, 36, 48, 60, 72, and 84 months post CI stimulation, respectively.
Results: (1) Spoken word perception performance of congenitally deaf children with CIs improved significantly over time. (2) The fastest improvement occurred in the first 36 months after initial activation, then the improvement slowed down and the final peak score of 81.7% correct was achieved at 72 months after initial activation. (3) Early implanted children exhibited better longitudinal performance. (4) Lexical factors affected consistently in each evaluation session. For lexically harder words, such as monosyllabic hard words, there was substantial room for improvement even after long-term use of CI.
Conclusions: (1) CI continuously provided significant benefits in word perception to children with severe/profound sensorineural hearing loss. (2) Age at implantation and Mandarin lexical factor affected longitudinal performance significantly.

1. Introduction

Spoken-word perception assessment has been widely used among children who use CIs: (1) to determine potential candidacy prior to implantation; (2) to investigate the development of auditory, speech and language skills post-implantation; (3) to reflect the benefits provided by a CI in real-world listening conditions to some extent; (4) and to provide information to facilitate rehabilitation/habilitation programs [1–3]. Because auditory/speech improvement does not progress at a constant rate, longitudinal or long-term follow-up results provide useful information to reflect the communication benefits of pediatric implantation. Moreover, longitudinal observations also provide professionals with information relating to implant use and safety issues. Thus, long-term studies of word perception have been a useful tool to reflect real world effectiveness of CIs in children [4].

Mandarin Chinese is different from many western languages in structural features. In Mandarin Chinese, each character is a morpheme, which is the smallest unit of sound and meaning. Another characteristic of Mandarin Chinese is that it is a tonal language in which the tonal patterns convey lexical meaning. Several studies have indicated that Mandarin CI users exhibited deficits in lexical tone perception as well as tone production [5–7],

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which may be due to the pitch information is not explicitly presented in the electrical stimulations in the contemporary CI technology. To date, only limited information is available concerning long-term CI outcome in Mandarin-speaking children. This paper presents data collected over a 7-year period from children implanted at Beijing Children's Hospital and Beijing Tongren Hospital.

Cochlear implantation technology has been used for 20 years in China, and a large number of children with severe to profound sensorineural hearing loss have benefited from this well-established technology. However, due to a lack of standard spoken word recognition testing material appropriate for Mandarin-speaking, congenitally deaf children, only a very limited number of studies on long-term spoken word recognition ability in a representatively large number of Mandarin-speaking, congenitally deaf children with CIs have been reported. To address this concern, we have developed a spoken word recognition test theoretically motivated by the Neighborhood Activation Model (NAM) [8] and have used it to collect longitudinal performance data.

The English version of Monosyllabic Lexical Neighborhood Test (LNT) and the Multisyllabic Lexical Neighborhood Test (MLNT) are widely used to assess spoken word recognition at pre-implant and/or post-implant follow-up outcome [9–12]. Both the LNT and MLNT are theoretically based on the assumptions of the NAM [8], which emphasizes the process of lexical activation and selection of the target word perception. According to the NAM, the lexical characteristics of word frequency (i.e., the number of occurrence of the target word in the specific language) and lexical density (i.e., the number of phonemically similar words surrounding the target word) both influence spoken word recognition performance. In addition, Kirk et al. [9] demonstrated that word length also affects performance. That is, multisyllabic words are recognized with greater accuracy than monosyllabic words. This is likely due to the fact that multisyllabic words come from sparse lexical neighborhoods. Stimuli in the lists were drawn from the Child Language Data Exchange System (CHILDES) [13] which represented typical verbal productions of normal hearing children aged between 3 and 5 years. Previous reports have showed that lexical characteristics, such as frequency and lexical density, influenced word recognition both independently and in combination, these reports have supported the relevance of the NAM in different languages in both normal hearing children and hearing impaired children [3,9,12,14,15] (e.g., Taiwanese, English, standard Mandarin). That is, both normal hearing children and hearing impaired children organize words into similarity neighborhoods in their long-term auditory memory. When there are stimuli, children make use of the acoustic–phonetic similarity information to implement target word recognition.

Building upon the work of Kirk and Pisoni, the Standard-Chinese version of the LNT and MLNT were developed and validated [16]. As described in Liu et al., the stimulus items were drawn from a database containing verbal productions of typically developing children aged 3–6 years [16]. Thus the stimulus items represent early-acquired vocabulary of Mandarin-speaking children and are appropriate to assess open-set spoken word recognition skills in this population. During the development of the Chinese version of LNT and MLNT, characteristics of the Mandarin language also were taken into account. For example, the selection of homophones and polyphones (e.g., one written word that has two different pronunciations) were avoided during the stimulus selection. As Mandarin was a tonal language, tone substitution was also considered when calculating the neighborhood density. The items were encoded into two lexical groups by implementing median splits on word frequency and lexical density. That is, words with a frequency above the median were coded as high-frequency words, whereas words with a frequency below the median were coded as low-frequency words. Similarly, words with a number of neighbors above the median were coded as high neighborhood density, or dense, and words with a number of neighbors below the median were coded as low neighborhood density, or sparse.

The purposes of the present study was to explore open-set spoken word recognition development over time in Mandarin-speaking, congenitally deaf children who received CIs.

2. Methods and material

2.1. Participants

Longitudinal speech perception skills were examined in pediatric CI users. Participant inclusion criteria included: (1) at least 6 months of CI experience; (2) used Standard Mandarin as the primary means of oral communication; (3) had bilateral severe to profound sensorineural hearing impairment; (4) severe to profound hearing impairment occurred before 1 year of age; (5) used a unilateral CI as the only sensory aid; (6) had no other disabilities besides hearing impairment (e.g., cognitive disabilities, intellectual delays, physical disabilities, visual disabilities, etc.); and (7) had no auditory neuropathy spectrum disorder before cochlear implantation, as determined by a combination of assessment using auditory brainstem response (ABR), distortion product evoked otoacoustic emission (DPOAE), and cochlear microphonics (CM). In all, 105 pediatric CI users met the above criteria and participated in the study. Informed consents were signed by the parents of the participants. The type of CIs consists of Advanced Bionics, Cochlear, and Medel. Informed consents were signed by the parents of the participants.

Table 1 presents the demographic data of the participants. The participants consisted of 65 males and 40 females, and therefore the percentage of male and female participants was 61.9% and 38.1% correct, respectively. Among all the participants, 58 children had hearing aid experience prior to implantation, which accounted for 55.2% of the total population. The remaining 47 children had no hearing aid experience prior to implantation, and the corresponding percentage was 44.8%. Although a hearing aid trial was recommended for all potential CI candidates, not all families could afford to purchase hearing aids prior to cochlear implantation. Among the participants who had hearing aid experience prior to implantation, 11 cases (19.0%) had bilateral hearing aids and the remaining 47 (81.0%) used a unilateral hearing aid. As shown in Table 1, hearing aid use prior to implantation ranged from 1 month to 66 months, with a mean duration of 15.3 months (SD = 17.2). For the duration of hearing aid use prior to implantation, 19.4% of the participants had hearing aid experience of <3 months, and the percentages of hearing aid use experience prior to implantation of 3–6 months, 7–12 months, 13–24 months, 25–36 months, and longer than 36 months were 14.5, 25.8, 14.5, 6.4, and 19.4%, respectively. Age at implantation ranged from 0.9 to 15.5 years old, and with a mean of 3.1 years old (SD = 2.3). The distribution of age at implantation is plotted in Fig. 1. The hearing thresholds were

Table 1
Participant demographics characteristics ($N = 105$).

	Min	Max	Mean	SD
Age at time of implantation (year)	0.9	15.5	3.1	2.3
Duration of HA use prior to implantation (month)	1.0	66.0	15.3	17.2
Aided threshold of implanted ear, 0.25 kHz, dB HL	20.0	40.0	32.5	6.5
Aided threshold of implanted ear, 0.5 kHz, dB HL	20.0	40.0	35.2	7.0
Aided threshold of implanted ear, 1.0 kHz, dB HL	25.0	40.0	33.2	7.7
Aided threshold of implanted ear, 2.0 kHz, dB HL	25.0	45.0	35.5	7.2
Aided threshold of implanted ear, 4.0 kHz, dB HL	25.0	45.0	36.5	7.5