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Mandarin Chinese speech recognition by pediatric cochlear implant users

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ABSTRACT

Objectives: Because of difficulties associated with pediatric speech testing, most pediatric cochlear implant (CI) speech studies necessarily involve basic and simple perceptual tasks. There are relatively few studies regarding Mandarin-speaking pediatric CI users' perception of more difficult speech materials (e.g., words and sentences produced by multiple talkers). Difficult speech materials and tests necessarily require older pediatric CI users, who may have different etiologies of hearing loss, duration of deafness, CI experience. The present study investigated how pediatric CI patient demographics influence speech recognition performance with relatively difficult test materials and methods.
Methods: In this study, open-set recognition of multi-talker (two males and two females) Mandarin Chinese disyllables and sentences were measured in 37 Mandarin-speaking pediatric CI users. Subjects were grouped according to etiology of deafness and previous acoustic hearing experience. Group 1 subjects were all congenitally deafened with little-to-no acoustic hearing experience. Group 2 subjects were not congenitally deafened and had substantial acoustic hearing experience prior to implantation. Multiple linear regression analyses were performed within each group using subject demographics such as age at implantation and age at testing.
Results: Pediatric CI performance was generally quite good. For Group 1, mean performance was 82.3% correct for disyllables and 82.8% correct for sentences. For Group 2, mean performance was 76.6% correct for disyllables and 84.4% correct for sentences. For Group 1, multiple linear regression analyses showed that age at implantation predicted disyllable recognition, and that age at implantation and age at testing predicted sentence recognition. For Group 2, neither age at implantation nor age at testing predicted disyllable or sentence recognition. Performance was significantly better with the female than with the male talkers.
Conclusions: Consistent with previous studies' findings, early implantation provided a significant advantage for profoundly deaf children. Performance for both groups was generally quite good for the relatively difficult materials and tasks, suggesting that open-set word and sentence recognition may be useful in evaluating speech performance with older pediatric CI users. Differences in disyllable recognition between Groups 1 and 2 may reflect differences in adaptation to electric stimulation. The Group 1 subjects developed speech patterns exclusively via electric stimulation, while the Group 2 subjects adapted to electric stimulation relative to previous acoustic patterns.

1. Introduction

Cochlear implants (CIs) can restore hearing sensation to patients with profound sensorineural hearing loss. Many post-lingually deafened adult CI users are capable of high levels of speech understanding. CIs allow deaf children to acquire similarly high levels of speech understanding [1]. Similar to adult CI populations, there is a wide variability in pediatric patient outcomes [2]. While many studies have explored pediatric CI patient performance [2–5], most of these studies have focused on English speech perception by English-speaking pediatric CI users. Previous studies with French [6,7], Belgian [8], and Dutch [9–11] pediatric patients showed that cochlear implantation greatly benefited the speech development of these profoundly deaf children.

The majority of native Mandarin-speaking CI users were implanted as children. Most Chinese pediatric CI users are pre-lingually deafened, i.e., they did not acquire speech before deafness, typically because of congenital hearing loss. There is a sensitive period for development of the human central auditory

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pathways, beyond which there is limited plasticity [12]. Therefore, implantation at an early age is crucial for pre-lingually deafened CI users' speech development. Other pediatric CI users may have acquired speech through acoustic hearing (aided or unaided) before deafness. For these (typically) late-implanted pediatric patients, CI outcomes may depend on the duration and quality of acoustic hearing during auditory development. Extended auditory deprivation due to hearing loss may limit the benefit of cochlear implantation. Alternatively, post-lingually deafened pediatric CI users may greatly benefit from implantation if there was sufficient exposure to acoustic hearing. In general, little is known about differences in speech performance between pre- and post-lingually deafened Mandarin-speaking pediatric CI users.

English, French, German and Dutch are non-tonal, Indo-European languages. In contrast, Chinese (which is spoken by the greatest number of people in the world) is a tonal, Sino-Tibetan language. Mandarin Chinese syllables are produced with one of the four lexical tones: Tone 1 (high-flat), Tone 2 (rising), Tone 3 (falling–rising), and Tone 4 (falling). The same syllable produced with different tones can have vastly different meanings [13,14]. Fundamental frequency (F0) cues contribute strongly to Chinese tone recognition, which in turn contributes strongly to Chinese sentence recognition. Because CI devices typically provide only 12–22 spectral channels (too few to support good frequency resolution), Chinese tone recognition is difficult and CI users must rely more strongly on amplitude and duration cues [15].

Most CI speech perception studies (with adults or children) research have been conducted with English-speaking subjects. There are comparatively few CI studies with Chinese CI users. Several Taiwanese studies have investigated Mandarin Chinese-speaking CI users' speech perception. Huang et al. [13] evaluated speech performance and auditory function in four adult, Mandarin-speaking, post-lingually deafened users of Cochlear's Nucleus-22 device; they found significant and continuous improvement in all subjects' speech perception and auditory capabilities after implantation. Wu and Yang [14] reported a negative correlation between Chinese vowel, word, sentence recognition and age at implantation for Chinese pediatric CI users. Peng et al. [16] found that pre-lingually deafened pediatric CI users exhibited poor Mandarin Chinese tone recognition and tone production. Wang et al. [17] found long-term benefit for cochlear implantation in a longitudinal study with Taiwanese pediatric CI users. Recent studies have focused on the contribution of Chinese tone recognition to CI users' understanding of Mandarin Chinese [18–20].

To date, most Chinese pediatric CI studies have evaluated speech understanding in terms of language awareness [21], lexical tone production and perception [22,23], Cantonese word recognition [24], as well as closed-set Mandarin early speech perception [25]. Because of general difficulties associated with testing children (e.g., limited language development, subject attention, etc.), very few studies have evaluated Chinese CI users' open-set word or sentence recognition with multiple talkers. Understanding words and sentences is essential to daily life, and may better reflect the ultimate benefit of implantation for pediatric patients. Some Mandarin-speaking pediatric CI users may be old enough to understand more difficult or complex speech materials (e.g., words and sentences produced by multiple talkers). Older pediatric CI users may also have different etiologies of hearing loss. Some may be congenitally deafened and implanted at an early age, while others may have experienced significant amounts of acoustic hearing (aided or unaided) before implantation. As such, speech pattern development may be different across pediatric CI users. Pre-lingually deafened CI users develop speech patterns exclusively via electric hearing. Other CI users may adapt novel electric stimulation patterns to previous acoustic patterns; depending on age at onset of hearing loss and/or the severity of hearing loss, these acoustic patterns may (or may not) be sufficient for adaptation. Different types of speech tests may elicit differences between pediatric CI users. Word recognition may be more sensitive to the peripheral representation, while sentence recognition may depend greatly on contextual cues.

In this study, speech recognition was measured in Mandarin-speaking pediatric CI users to see how patient demographics influence performance with relatively difficult test materials and methods. Subjects were grouped according to etiology of deafness and previous acoustic hearing experience. Group 1 subjects were all congenitally deafened with little-to-no acoustic hearing experience. Group 2 subjects were not congenitally deafened and had substantial acoustic hearing experience prior to implantation. Open-set multi-talker (2 male and 2 female talkers) disyllabic word and sentence recognition was measured in each subject. Multiple linear regression analyses were performed to see whether patient demographics (e.g., age at implantation, age at testing) predicted speech performance.

2. Methods

2.1. Subjects

Thirty-seven pediatric CI users participated in this study. All subjects were implanted at the Shanghai Eye, Ear, Nose & Throat (EENT) hospital; this study was conducted in the Vision and Audition Center of the Shanghai EENT hospital. Subject inclusion criteria consisted of bilateral profound sensorineural hearing loss, no evidence of mental retardation, at least 6 years old and Mandarin Chinese as the native language. The profound hearing loss was confirmed using auditory brainstem response (ABR). The morphologies of middle and inner ear were evaluated with high resolution computer tomography (HRCT) and all showed no pathological CT findings.

Table 1 shows demographic details for all subjects. There were 21 male and 16 female subjects. Across all subjects, the mean age at testing was 8.6 years (range: 6.0–17.9 years), the mean age at implantation was 4.2 years (range: 1.2–17.5 years), and the mean amount of CI experience was 4.4 years (range: 0.3–11.1 years). All but two subjects were implanted with Cochlear's Nucleus-24 device (ACE strategy); two subjects were implanted with Advanced Bionics' HiRes 90K device (Fidelity 120 strategy). All subjects were unilateral CI users. Five subjects were implanted in the left ear, and 32 subjects were implanted in the right ear.

Subjects were divided into two groups according to the etiology of deafness and the amount of previous acoustic hearing experience. Group 1 consisted of 27 subjects. All subjects in Group 1 were congenitally deafened and diagnosed with severe or profound sensorineural hearing loss, as confirmed by objective auditory testing (ABR). Ten subjects in Group 1 were given high-power hearing aids (HAs) for several months before implantation to see whether there was potential low-frequency acoustic hearing (there was not). The remaining 17 subjects in Group 1 were implanted soon after diagnosis of severe sensorineural hearing loss and did not use HAs prior to implantation. Given the congenital deafness and the very limited exposure to acoustic hearing, Group 1 subjects would be generally considered to be pre-lingually deafened. For Group 1, the mean age at testing was 8.0 years (range: 6.0–14.5 years), the mean age at implantation was 2.6 years (range: 1.1–7.7 years), and the mean amount of CI experience (age at testing – age at implantation) was 5.4 years (range: 1.5–11.1 years).

Group 2 consisted of 10 subjects. Etiology of deafness varied across Group 2 subjects; none were congenitally deafened. Nine of the 10 subjects used HAs before receiving their CIs; the mean HA