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Tone and sentence perception in young Mandarin-speaking children with cochlear implants

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ABSTRACT

Objectives: The purpose of this study was to examine the outcomes of cochlear implantation in young children in terms of (1) perception of lexical tones in quiet, (2) perception of sentences in quiet and in noise, (3) the effects of five demographic variables (i.e., preoperative hearing level, age at implantation, duration of cochlear implants use, maternal educational level, and whether a child underwent a hearing aid trial before implantation) on lexical tone perception and sentence perception, and (4) the relationship between lexical tone perception and sentence perception.
Methods: 96 participants, aged from 2.41 years to 7.09 years, were recruited in mainland China. The children exhibited normal cognitive abilities and received unilateral implants at an average age of 2.72 years, with ages ranging from 0.69 to 5 years of age.
Results: The mean score for tone identification was 77% (SD = 13%; chance level = 50%). Tone 2/tone 3 was the most difficult tone contrast to identify. Children with a longer duration of CI use and whose mothers had more years of education tended to perform better in sentence perception in quiet and in noise. Having undergone a hearing aid trial before implantation and more residual hearing were additional factors contributing to better sentence perception in noise. The only demographical variable that related to tone perception in quiet was duration of CI. In addition, while there was a modest correlation between tone perception and sentence perception in quiet ($r_s = 0.47$, $p < 0.001$), the correlation between tone perception in quiet and sentence perception in noise was much weaker ($r_s = -0.28$, $p < 0.05$).
Conclusions: The findings suggested that most young children who had been implanted before 5 years of age and had 1–3 years of implant use did not catch up with their aged peers with normal hearing in tone perception and sentence perception. The weak to moderate correlation between tone perception in quiet and sentence perception might imply that the improvement of tone perception in quiet may not necessarily contribute to sentence perception, especially in noise condition.

1. Introduction

Cochlear implants (CIs) help children with hearing impairment (HI) by partially restoring hearing sensation and improving speech perception, speech production and language skills. Since 1995, more than 8500 children with hearing impairment (HI) under the age of 7 years in mainland China have received CIs [1]. However, this number is far from satisfactory considering the fact that there are 115,000 children under the age of 7 years with severe to profound HI and 30,000 children born with HI every year [2]. The number of CIs is expected to increase rapidly over the next few years as a result of economic development and philanthropic efforts. In 2011, the Chinese central government allocated funding to implant a further 17,000 children over the next four years [1]. As the number of cochlear implantees increases, there is an urgent need to document the outcomes and understand how the outcomes could be improved in this population.

In CI systems, temporal cues in speech signals are mostly coded via amplitude fluctuations in the envelope of the incoming signals

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and the temporal fine structure in the signals are usually largely discarded. The spectral cues are mostly encoded via place of electrical stimulation along the cochlea [3]. Due to the limited number of intracochlear electrodes (from 12 to 22 in most current implant systems), electrode interactions, possible tonotopic shifts and warping in the spectral-tonotopic mapping, only coarse spectral cues are transmitted by the current implant devices [4,5]. Even so, high levels of speech perception can be achieved in quiet via current implants [3]. However, due to limited fine spectro-temporal cues transmitted by current implants, the biggest challenge facing children with CIs is in perception of speech in noise and tones [6–9].

1.1. Tone perception in quiet in Mandarin-speaking children with CIs

Mandarin is a tonal language. Based on F0 height and contours, the four Mandarin lexical tones can be characterized as: flat and high for tone 1, rising for tone 2, low and dipping for tone 3, and falling for tone 4 [10,11]. A change in tone leads to a change in lexical meaning among syllables composed of the same sequence of consonants and vowels [12,13]. For example, the meaning of the syllable, /ba/ is 'eight (八)' with tone 1, and 'father (爸)' with tone 4.

Despite the presence of secondary acoustic cues including duration, amplitude contour, spectral envelop of the speech signal and visual cues, the perception of tones largely depends on the fundamental frequency (F0) contours [14,15]. Due to the insufficient transmission of the F0 via CIs [7,16], lexical tone perception in Mandarin-speaking children with CIs is unsatisfactory [17]. The average tone perception scores are about 60–75% correct (chance = 50% correct) [10,18]. Furthermore, reports on children's ability to identify tone contrasts seem to differ across studies. For example, Peng et al. [10] found that children seemed to perform better whenever tone 4 was contrasted with other tones while Zhou et al. [18] reported that there was no significant difference in tone identification scores among the six tone contrasts (the four tones are paired to make six pairs of tone contrast). The difference in findings might be related to variations in test materials and the presentation methods used in the studies; that is, Peng et al. used a live voice presentation whereas Zhou et al. used recorded stimuli in which the duration of the test items were equalized. It is uncertain whether children with CIs are able to use duration cues to perceive tones. In order to predict more precisely the tone perception ability of a child in real life and allow comparison across the present and future studies, the first aim of this study was to use a standardized recorded tone perception measure, without equalizing the duration of the tone tokens, to investigate tone perception in young Mandarin-speaking children.

1.2. Factors that contribute to tone perception in children with CIs

Various factors have been found to contribute to the ability of children with CIs to perceive tones in children with CIs. Of these, age at implantation and duration of CI use are factors that have received the most attention in previous research. Han et al. [11] reported that early implantation was related to better tone perception performance in 20 children with prelingual hearing impairment and who had been implanted at a mean age of 5.21 years (range: 1.3–13.5 years), and whose mean length of CI use was 2.43 years (range: 0.6–4.2 years). However, Peng et al. [10] found that these two factors were not significantly related to the ability to perceive tones in 30 children who had been implanted at a mean age of 5.67 years (range: 2.25–10.25 years) and whose mean length of CI was of 3.58 years (range: 1.58–6.42 years). Besides age at implantation and duration of use, Zhou et al. [18] also examined how well familial variables (e.g., family size and household income), device variables (e.g., implant type and speech processing strategy) and educational variables (e.g., communication mode and duration of speech therapy) predicted tone-perception performance in 107 children who had been implanted between the ages of 1.11 and 12.95 years (mean = 3.96, SD = 2.70 years) and whose mean duration of CI use was 1.29 years (range = 0.09–4.90 years). Only age at implantation and duration of CI use were significant predictor variables, jointly accounting for 28.6% of the variance in tone perception outcomes. Variations in findings might have resulted from the use of different test materials and from the different demographical characteristics of participants. While these variables represent those most commonly found in the cochlear implant literature, some variables that are of clinical and theoretical interest in the context of mainland China have not been included.

These factors may include maternal educational level, whether a child has undergone a hearing aid trial (HAT) before implantation and pre-implant hearing level. Due to late identification of hearing impairment, a lack of hearing healthcare professionals and financial reasons, a large proportion of pediatric implantees in mainland China do not undergo a HAT. By including whether a child had undergone a HAT as a predictor in the present study, we were able to investigate whether this factor would have a positive impact on post-implant tone perception. However, children with more residual hearing before implantation might be more likely to undergo a HAT. A HAT might, therefore, serve as a "proxy" for pre-implant hearing level. To avoid this, the effects of pre-implant hearing level on tone perception were controlled when examining the effect of a HAT on tone perception. In addition, in view of a lack of hearing re-habilitation programs in mainland China, it was expected that mothers with higher educational levels would be able to identify hearing impairment earlier, and be better at seeking appropriate help and contributing to the re-habilitation process than those with lower educational levels. Higher maternal educational level might also contribute to tone perception in Mandarin-speaking children with CIs. Therefore, another aim of this study was to explore the contribution of these three factors (i.e., whether a child had undergone a HAT before implantation, preoperative hearing level and maternal educational level), in addition to age at implantation and duration of CI use, in the prediction of tone and sentence perception in young children with CIs in mainland China

1.3. Speech perception in quiet and in noise

Previous reports have shown that English-speaking children with CIs experience a significant reduction in speech perception performance when noise is introduced. The reduction in scores could be 20–35 percentage points compared to the quiet situation, depending on the signal-to-noise ratios (S/Ns), the type of speech stimuli and noise (e.g., Eisenberg et al. [19]; Schafer and Thibodeau [20]). Even for speech perception in quiet, children with CIs, as a group, do not perform as well as their hearing peers after 5 years of CI use [21].

Mandarin-speaking children with CIs may struggle more to recognize speech than their English-speaking peers. Lexical tones are important cues for recognizing Mandarin sentences [22]. However, due to their unsatisfactory tone perception performance [10,18], children with CIs may have difficulties in using tonality for sentence perception. Furthermore, while the use of bilateral CIs, a HA on the nonimplant and frequency modulation (FM) system may improve speech (e.g., disyllabic word, sentences) recognition in noise (e.g., speech-shaped noise, babble) [20,23–26], most children in mainland China use unilateral implants only; their potentials for speech perception are not optimized.

Very few studies have reported on the ability of preschool implantees in Mainland China to perceive sentence in noise. Using the Mandarin Pediatric Sentence Intelligibility (MPSI) test [27], Zheng et al. [28] described sentence perception both in quiet and in