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Tone perception and production in pediatric cochlear implants users

LI XU^{#1}, XIUWU CHEN^{#2}, HONGYUN LU³, NING ZHOU⁴, SHUO WANG², QIAOYUN LIU³, YONGXIN LI², XIAOYAN ZHAO², and DEMIN HAN²

¹School of Rehabilitation and Communication Sciences, Ohio University, Athens, OH, USA,

²Department of Otolaryngology – Head & Neck Surgery, Beijing Institute of Otorhinolaryngology, Beijing Tongren Hospital, Beijing, China,

³Key Laboratory of Speech and Hearing Sciences, East China Normal University, Ministry of Education, Shanghai, China

⁴Kresge Hearing Research Institute, University of Michigan, Ann Arbor, MI, USA

These authors contributed equally to this work.

Abstract

Conclusions: In prelingually deaf children with cochlear implants, tone perception and production performance are highly correlated. This result is consistent with the hypothesis that tone perception is the prerequisite for good tone production.

Objectives: Previous research has shown remarkable deficits in tone perception and production in native tone languagespeaking, prelingually deafened children with cochlear implants. The purpose of the present study was to investigate the relationship between tone perception and production in those children.

Methods: Twenty-five prelingually deaf children with cochlear implants participated in the study. All subjects were Advanced Bionics CII/90K users with various lengths of implant use. To evaluate tone perception performance, subjects completed a computerized tone contrast test. For tone production performance, an artificial neural network was used to evaluate the accuracy of tones recorded from each of the 25 subjects.

Results: Large individual differences in tone perception and production performance were observed in these subjects. Tone perception accuracy ranged from 50.0 to 96.9% correct (chance performance = 50% correct; mean = 71.0% correct). Tone production performance ranged from 19.4 to 97.2% correct (mean = 52.0% correct). A strong correlation was found between tone perception and production performance in this group of subjects ($r = 0.805$).

Correspondence: Li Xu MD PhD, School of Rehabilitation and Communication Sciences, Ohio University, Athens, OH 45701, USA. Tel: +1 740 593 0310. Fax: +1 740 593 0287. XuL@ohio.edu.

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Keywords

Tone language; children; prelingual deafness; lexical tone

Introduction

Lexical tone, defined as the fundamental frequency (F0) variation of the vocalic part of a syllable, is important for tone languages such as Mandarin Chinese. Mandarin Chinese has four distinct tone patterns (see Xu et al. [1] for details) whereas Cantonese, a Chinese dialect, has six distinct tone patterns (see Ciocca et al. [2] for details). Contemporary multichannel cochlear implants typically stimulate a subset of 16–22 electrodes with a constant-rate electric pulse train that is modulated in amplitude by the temporal envelope of corresponding bandpass filters (see Loizou [3] for a review). Thus, pitch information is not explicitly presented in the electrical stimulations in current cochlear implant technology [4]. Therefore, lexical tone presents a particular challenge to cochlear implant users who speak tone languages.

Many studies have demonstrated that prelingually deafened children with cochlear implants who speak tone languages have difficulties in perceiving lexical tones. While the average accuracy in tone recognition in Cantonese or Mandarin Chinese ranged from 60% to 70% correct [2,5–8], there was a large variation in tone recognition performance (ranging from chance to nearly perfect) across the cochlear implant users (see Xu and Zhou [9] for a review).

Several studies examined tone production performance in prelingually deafened children with cochlear implants who speak tone languages [10–14]. Consistent with the data on tone recognition performance, tone production in prelingually deafened children with cochlear implants showed enormous individual differences in production accuracy as assessed by subjective judgment [10–12] or perceptual recognition by normal-hearing adults [13], and objective acoustic analysis [14]. While most of the prelingually deafened children with cochlear implants had fairly poor tone production, a small portion of them reached a performance that is equivalent to that of normal-hearing children [13,14].

Results from a limited number of studies on the relationship between tone perception and production were inconclusive. In a previous study [11], Peng et al. reported a weak but significant correlation ($r = 0.44$, $p = 0.015$) between tone identification and production accuracy in a group of 30 pediatric Mandarinspeaking implantees aged from 6 to 12.6 years old. However, when the three best performers were removed from the analysis, the correlation was no longer statistically significant ($r = 0.01$, $p = 0.98$). In the present study, we sought to test the hypothesis that good tone perception is a prerequisite for good tone production in prelingually deafened children with cochlear implants. Our results confirmed a strong correlation between tone perception and production.

Material and methods

Twenty-five prelingually deafened children with cochlear implants (18 boys and 7 girls) who are native Mandarin Chinese speakers were recruited from Beijing and Shanghai, the two largest cities in China. The mean age was 9.5 years (range 2.1–21.5 years; SD = 5.4). All children were Advanced Bionics CII/90K HiResolution or HiResolution 120 users, with 0.1–8.1 years of implant experience (3.1 ± 2.5 years). The age at implantation was 1.3–20.8 years (6.4 ± 5.2 years). The use of human subjects was reviewed and approved by the Institutional Review Boards of Ohio University, Beijing Tongren Hospital, and East China Normal University.

Tone perception test

A computerized tone contrast test (see Han et al. [15] for details) was administered to each of the subjects. The tone perception test involved identifying tones from six Mandarin tone contrasts using a two-alternative forced choice paradigm. In each presentation, a tone token was played via a loudspeaker while two pictures of the tone contrast being tested were shown on the computer screen. All the monosyllabic words used in the test are simple Chinese words that the children of this age group were familiar with. The child was instructed to point to the picture that corresponded to the meaning of the word that he/she heard. The testing consisted of 48 presentations [12 words (i.e. 6 tone contrasts) \times 2 speakers \times 2 repetitions] without feedback. Training with feedback was provided before the test.

Tone production test

Speech materials were recorded using a picture-naming procedure. In each trial, 1 of the 36 pictures used in the tone perception test was displayed on the computer screen, and the task of the child was to name the picture (see Han et al. [15] for the list of the 36 words). The elicited speech was recorded at a sampling rate of 44100 Hz with a 16-bit resolution in quiet rooms.

The F0 contours of the vowel part of the recorded words were extracted using an auto-correlation method. The update rate of the F0 extraction was 8 ms with a frame size of 24 ms. The accuracy of the extracted F0 contours was manually examined with reference to the narrowband spectrograms of the tokens [10,14].

An artificial neural network [16,17] was used to objectively assess the tone production accuracy of the children. Our previous studies have demonstrated that results of the neural network analysis show a strong correlation with the perceptual measure using normal-hearing adult listeners [14,16,17]. The neural network was first trained with F0 data of the tone tokens from the 61 normal-hearing children that were reported in a previous study [16]. The trained neural network was then fed with the F0 data of the tone tokens from the 25 children with cochlear implants. By comparing the outputs of the neural network and the target tones, a percent correct score for tone production was derived for each of the children with a cochlear implant.

Results

Tone perception scores of the 25 subjects ranged from 50.0 to 96.9% correct (chance = 50% correct) with an average of 71.0% correct (SD = 15.0%). Tone production accuracy of the subjects ranged from 19.4 to 97.2% correct (chance = 25% correct) with an average of 52.0% correct (SD = 23.8%). Figure 1 shows the scatter plot of tone perception (abscissa) and tone production (ordinate) performance. The correlation between tone perception and production performance was statistically significant ($r = 0.805$; $p < 0.001$).

Although it was not the focus of the present study, we performed correlational analysis between tone perception and production performance and various demographic variables (such as age at implantation, duration of implant use, chronological age, etc.). Age at implantation was found to be the only significant predictor for tone production performance. Figure 2 shows the scatter plot of tone production performance versus age at implantation. The correlation coefficient (r) of the linear fit was 0.495 ($r^2 = 0.245$, $p = 0.011$). With a quadratic fit of the data, the r^2 slightly increased to 0.276.

Discussion

The results of the present study showed a strong correlation between tone perception and tone production performance in prelingually deafened children with cochlear implants. Consistent with the assumption that perception precedes production in typical developing children [18], children with good tone perception tend to perform better in tone production. Although correlation does not imply causality, our result is consistent with the hypothesis that tone perception is the prerequisite for good tone production in children with cochlear implants.

In a previous study [11], a weak but significant correlation was reported between Mandarin tone perception and production in 30 prelingually deaf children with either MedEl or Nucleus cochlear implants ($r = 0.44$, $p = 0.015$). However, when the three top performers were removed from the analysis, the correlation disappeared ($r = 0.01$, $p = 0.98$). In a more recent study [19], 24 prelingually deafened children with Nucleus cochlear implants were tested for the English intonation perception and production accuracy. The correlation coefficient between the intonation utterance accuracy and identification accuracy was moderately high at 0.627 ($p = 0.001$). The present study examined lexical tone perception and production in children with the Advanced Bionics CII or 90K cochlear implants. With this particular population of subjects, we found a strong correlation between tone perception and production ($r = 0.805$, $p < 0.001$). The effects of implant devices on the relationship between tone perception and production are worth exploring in future studies, especially when other variables, such as age at implantation, duration of implant use, device type, etc., are partialled out.

Individual variability has become a persistent characteristic in the findings of the previous studies that measured tone perception or production performance in implanted children [2,5–8,10–15]. The present study again demonstrated that both tone perception and tone production ranged from chance level to nearly perfect level. When we examined the

potential contributing factors for the large variability in performance, only age at implantation was found to be a significant contributor for tone production. A recent study of Cantonese tone production in congenitally deaf children with cochlear implants also indicated that early implantation (before the age of 4 years) is crucial for good tone production [12]. Our results showed that all good performers of tone production (i.e. 80% correct) had received their cochlear implants before approximately 6 years of age (Figure 2). However, age at implantation accounted for only a quarter of the variance in tone production performance. Our ongoing studies are targeting to recruit a much larger sample size than that used in the present study. Such studies will have the statistical power to perform multiple regression analysis and to identify multiple variables that might contribute to the performance in tone perception and tone production in children with cochlear implants.

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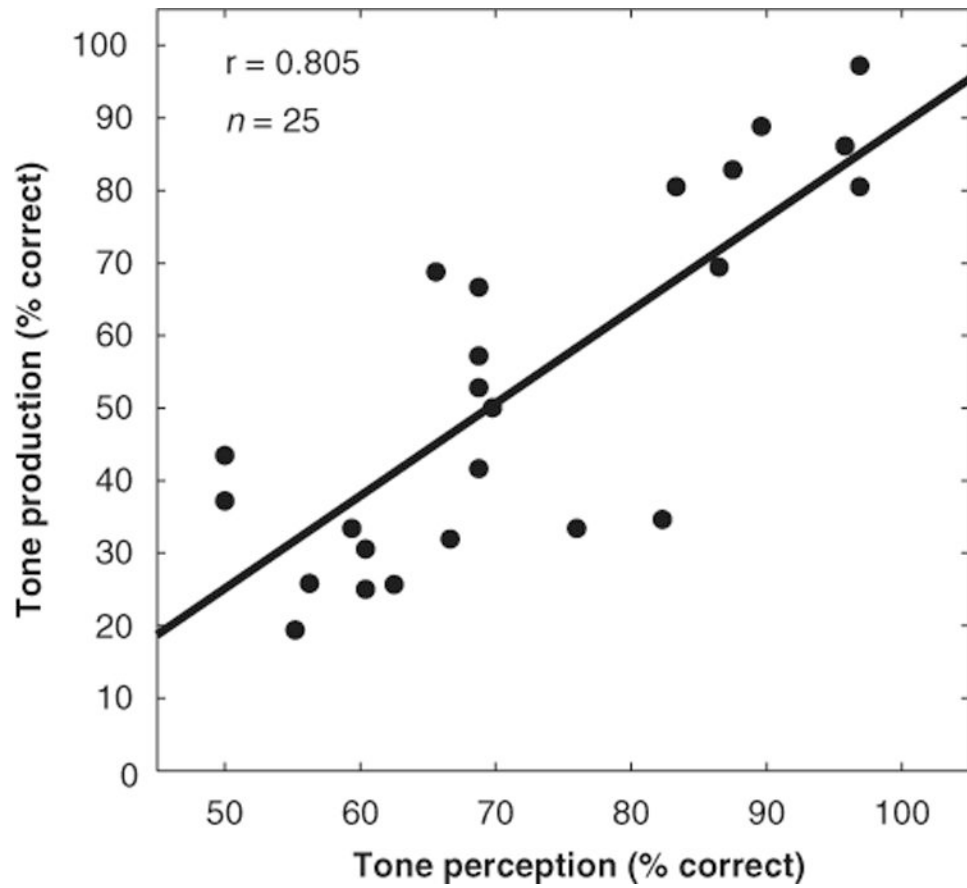


Figure 1. Correlation between tone perception and tone production performance in the 25 prelingually deafened children with cochlear implants. Each symbol represents one of the subjects and the solid line represents the least-squares fit of the data.

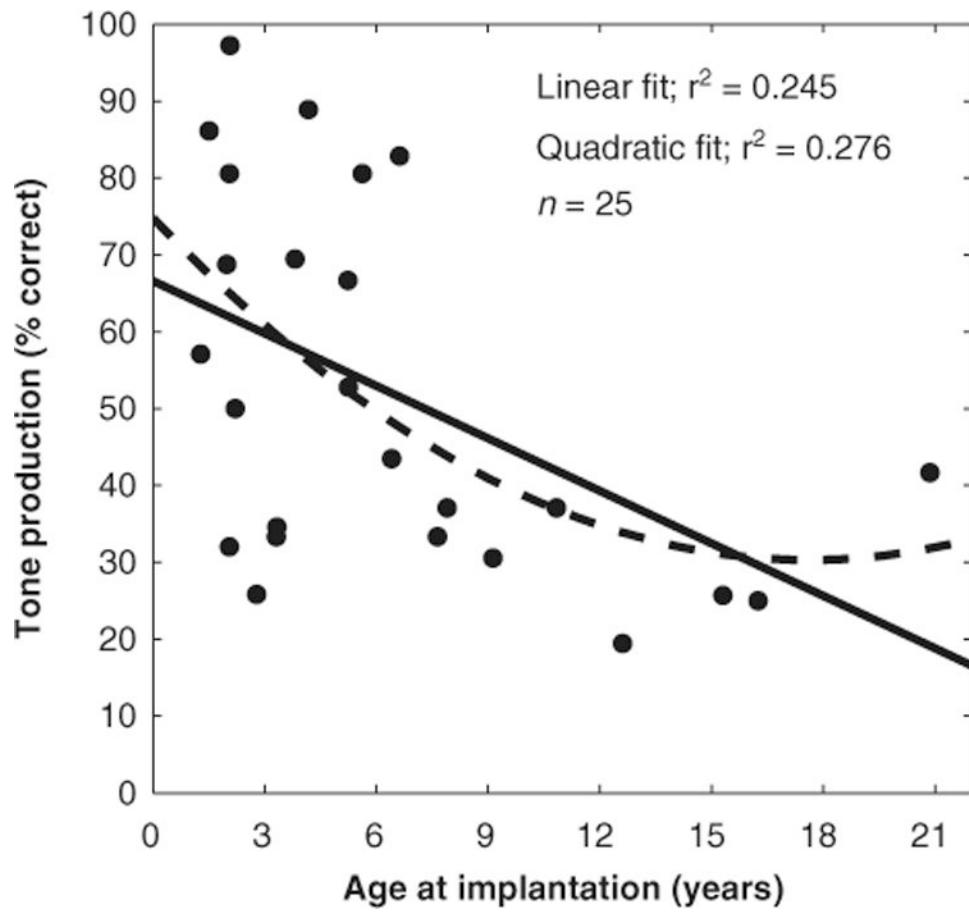


Figure 2. Scatter plot of tone production performance versus age at implantation. Each symbol represents one of the subjects. The solid line and the dashed line represent the linear and quadratic fit of the data, respectively.