Comparison of Fundamental Frequency between Monolingual and Bilingual Children with a Cochlear Implant

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Abstract: *Background and Objective*: Cochlear implantation influences acoustical and perceptual characteristics of voice in CI children. However, there is limited knowledge of the type and amount of influence of multilingualism on these characteristics of voice in CI children. The present study aimed to comparatively investigate fundamental frequency (F0) between two groups of bilinguals and monolinguals in children who recently underwent CI.

Methods: This was a cross-sectional comparative study conducted on Persian-Arabic bilingual children (n=25) and monolingual Persian children (n=25) matched in age and gender. All children had congenitally profound hearing loss and received a unilateral CI before the age of two years. The participants were asked to sustain the vowel /a/ and vowel /e/ on a single breath for 4 seconds, and the F0 value was measured using Praat software. For each participant, the F0 was measured three times and then averaged as mean F0.

Results: Our findings indicated no significant differences in terms of mean F0 for the vowels of /a/ and /e/ in monolingual and bilingual groups ($p>0.05$).

Conclusion: Bilingual Persian-Arab children with CI display vocal characteristics that are largely comparable with those of their monolingual Persian peers with CI.

Keywords: Cochlear Implant, Fundamental frequency, Children, Bilingual, Monolingual.

INTRODUCTION

Normal hearing is essential to facilitate speech and language development in children. It has been demonstrated that auditory deprivation caused by deafness has a significant influence on oral language acquisition and development as well as school performance in affected children [1-3]. These children may also experience difficulties in controlling the loudness and pitch of their voices during continuous phonation, which may result in perceived variation in loudness and pitch [4].

The stimulation of the auditory nerve can restore the effect of sensory deprivation in deaf children through hearing aids or cochlear implant (CI) prosthesis. Nowadays, CIs have become a widely accepted therapeutic method for children with severe to profound hearing loss, in whom the benefit of hearing aids is restricted [5]. Several studies illustrated that cochlear implantation in hearing-impaired children leads to the recovery of hearing capacity and promotes speech understanding and oral linguistic development [6-10]. Early implantation in children will provide auditory feedback on the timing, intensity and frequency of sounds, which in return will support better communication as well as the individual's ability to monitor their own voice [11-13].

Necessary acoustical processing pertains to the auditory system capacity to process incoming auditory information which is not speech-specific, such as "pitch" cues. Pitch is generally described as the psychological correlate of frequency [14]. Pitch is important for speech and music perception, and may also play a crucial role in our ability to segregate sounds that arrive from different sources. For tonal languages, accurate pitch perception is more important, providing phonemic, lexical, and semantic information [15]. As a direct correlate of voice pitch, fundamental frequency (F0) measures the speed of vocal fold vibration during phonation [16]. F0 may be coded either through temporal cues or through place cues in CI recipients. The temporal aspect of pitch may be perceived depending on the periodicity of or the temporal envelope of the incoming signal, while the place coding of pitch results from the tonotopic organization of the cochlea [17-19].

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Voice differentiation among talkers is crucial to understand two competing talkers. Normal hearing (NH) listeners greatly benefit from voice differences based on specific voice cues to differentiate two talkers. However, CI users suffer difficulties in perceiving and effectively utilizing voice cues. The literature on perception of voice cues by CI users indicates that CI listeners could significantly suffer from poor pitch perception [16]. CI listeners could not distinguish F0 differences between two or more competing speakers and have more considerable difficulties than NH listeners with discriminating questions from statements and distinguishing pitch contours in tonal languages [17,20,21]. F0 can be coded through temporal cues or spatial (place) cues and facilitates the voice-pitch perception. The temporal pitch perception is based on the periodicity of the signal or of the temporal envelope of the signal. Different studies have shown that CI users preserve temporal pitch perception seems to be relatively preserved in CI listeners so that the function of this pitch cue is similar between NH and CI listeners. Place-pitch is generated from stimulating different segments of the cochlea and has been shown that CI users could not use them effectively [22,23]. The impairment is highlighted in speech-like stimuli, where dynamic spectral envelope fluctuations may interfere with spectral changes induced by F0 differences.

F0 is affected by several factors such as anthropomorphic differences of phonatory system, ethnicity, gender, age and emotional state of speakers [24-26]. In addition to the physical or other functional factors, socio-cultural factors such as bilingualism may also influence pitch characteristics (F0) of sounds [27]. Altenberg and Ferrand [28] reported that the English/Russian bilinguals consistently had a higher mean F0 than the age and gender-matched peers of a monolingual Russian or English.

Strong neuroimaging and electrophysiological evidence indicate cochlear implantation influences acoustical and perceptual characteristics of voice in CI children. However, there is limited knowledge of the type and amount of impact of multilingualism on these characteristics of the voice. The present study aims to compare vocal features (F0) across two groups of bilinguals and monolinguals in early CI children.

METHODS

I. Participants

This was a cross-sectional analytic study conducted on congenitally profound hearing-impaired children (25 Monolinguals, 25 Bilinguals) who received CI before the age of two years participated. Their mean age at the time of implantation was 20 months (± 2.93) and mean length of CI experience was 5.11 years (± 0.86).

All children were implanted unilaterally, during the years 2014 and 2016, in the Otolaryngology Department of Ahvaz Jundishapur University of Medical Sciences (AJUMS), Iran. These were identified following the implementation of the universal newborn hearing screening program [29]. They were operated under the same pediatric CI protocol, and all CI electrodes were inserted successfully into their cochlea. The inclusion criteria were bilateral hearing impairment, right-handedness, normal IQ according to Wechsler Abbreviated Scale of Intelligence (WASI), no previously reported diagnosis of learning difficulties, no neurological nor motor speech impairments.

Monolinguals were defined as those who reported speaking only Persian and had no previous exposure by caregivers or parents who spoke another language. Bilinguals were exposed to Persian and Arabic languages from birth and reported to have used them daily in private life as well as in professional activities.

Informed consent was obtained from the parents or guardian proxies of all participating children. The local Ethics Committee approved the study of Human studies of AJUMS, Ahvaz, Iran (Code No.: IR.AJUMS.REC.1395.2) that were in complete accordance with the ethical standards and regulations of human studies of the Helsinki declaration (2014) [30]

II. Procedure

Acoustic data were collected in a soundproof booth, using a head-mounted microphone positioned at a distance of three centimetres from the speaker's lips and recorded to an external audio interface at a sampling rate of 44.1 kHz. The participants were asked to sustain the vowel /a/ and vowel /e/ on a single breath for 4 seconds. Three trials of the sustained vowel task were performed and recorded. Each subject practised vowel prolongation before recording. To obtain F0, after removing 500 milliseconds of the ‘‘Onset" and "Offset" of each signal, the middle portion of the signal was chosen and then analyzed with Praat software (version 5.3.13). Then the average F0 was calculated by averaging across the three trials of the vowel for each participant. All settings remained at their default settings for both male and female participants.

III. Statistical Analysis

The descriptive statistics were presented as mean ± standard deviation (SD). The independent sample t-test was utilized to examine the between-group differences. The collected data were analyzed with the statistical package of SPSS (SPSS Inc., Chicago, IL; Version 18). A p-value of <0.05 was determined to be statistically significant for all analyses (2-tailed).

RESULTS

A summary of the demographic data for each group shown in Table **1**.

Table 1: Demographic Information in Monolingual and Bilingual Children

Variable	Group		p-value
	Bilingual	Monolingual	
Age (years)	8.52 ± 0.64	8.03 ± 0.64	0.31
Sex	12 M; 13 F	14 M; 11 F	0.77

Chi-square test showed a similar proportion of males and females across groups (χ^2 test; p = 0.845), and that the age of participants was proportionate across groups (Independent sample t-test; p=0.317).

Table 2: The Mean (±SD) Fundamental Frequency (Hz) of Vowels in Monolingual and Bilingual Children with a Cochlear Implant

Vowel	Group		p-value
	Monolingual	Bilingual	
/a/	287.8 ± 21.90	288.27 ± 6.65	0.81
/e/	301.20 ± 9.74	311.28 ± 15.11	0.14

The mean and standard deviation of the F0 for the vowels of /a/ and /e/ are demonstrated in Table **2**. Our findings revealed that there was no statistically significant difference for mean F0 between the monolingual samples when compared to the bilingual samples (Table **2**).

DISCUSSION

In the present study, acoustic parameters (F0) in monolingual/ bilingual CI children were evaluated through isolated vowels. This approach has the advantage of reducing speech production complexity. Because of the notable role of the F0 in pitch perception, auditory stream segregation and speech perception in a noisy environment, the F0 is an essential cue for all subjects to focus on a specific talker during communication; then, it may provide further support for bilingual children [31-34]. Bilingual individuals modulate the F0 of their voice when the switch from one language to another language [35], suggesting that the F0 operates as a language cue for a target speaker when communicating in a bilingual situation.

Our findings revealed that the Persian-Arabic bilingual children had a higher mean F0 than Persian monolinguals wearing CIs. However, there were no significant differences for F0 values between the monolingual children when compared to the bilingual samples, indicating that bilingual speakers of Persian-Arabic may not produce significantly different vocal characteristics compare with that of monolingual speakers of Persian. An increment of F0 in bilingual children in this study may be attributed to uncertainty or lack of confidence in these group of children, resulting in higher F0 values.

Several studies have compared the performance of CI users and NH listeners on voice perception and differentiation of different talkers. Green *et al*. reported that CI listeners have more considerable difficulties than NH listeners with distinguishing questions from statements [21,36]. He *et al*. reported that CI users have more significant problems in discriminating pitch contours in tonal languages compared to healthy peers [37]. Furthermore, Stickney *et al*. comparatively assessed the speech recognition as a function of F0 separation of the target and competing for a sentence between NH and CI. They processed the combined sentences for NH listeners through either a standard implant simulation or a new algorithm which additionally extracted a slowed-down version of the temporal fine structure [38]. They reported that no benefit of increasing F0 separation for the CI or simulation groups, indicating that CI users do not benefit from F0 differences between competing speakers [38]. These findings highlight the importance of temporal fine structure for speech perception and demonstrate a potential remedy for the difficulty in the perceptual segregation of competing speech sounds.

Bunta and Douglas [31] also compared the language skills of bilingual Spanish- and English - speaking children with those of their monolingual English speaking peers. Their findings showed that children had a hearing impairment and used hearing aids and/or CIs. These authors concluded that the language skills of the bilingual and the monolingual subjects were commensurate.

The findings of the studies on voice perception and F0 could be summarized as (1) the F0 is a useful cue for segregating competing speech sounds and (2) the F0 is better represented by the temporal fine structure than by the temporal envelope. However, current CI speech processing algorithms emphasize temporal envelope information and discard the temporal fine structure.

The age of CI influences vocal maturation of children as it establishes access to the sound, which is necessary for the maturation of voice. Thus, the current investigation was conducted on early implanted children (<2 years). It has been found that children with late CI may experience difficulties in controlling their own voice pitch and loudness during sustained phonation process. However, early CI will result in a more prolonged auditory feedback exposure as well as more magnificent children's ability to monitor their own voice. This leads to better oral communication.

CONCLUSION

Our study demonstrated that bilingual Persian-Arab children with CI display vocal characteristics that are broadly comparable with those of their monolingual Persian peers with CI.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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