ACOUSTIC ASPECTS OF SENTENCE STRESS IN CHILDREN WITH COCHLEAR IMPLANT

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Abstract

The study intended to examine the acoustic features of stress F0, duration, and intensity in children using cochlear implants and compare these features with those in normal hearing children. Seven children with congenital profound hearing impairment fitted with multichannel cochlear implants and equal number of normal hearing children participated in the study. The participants narrated a picture depicting a 'living room' for about 2-3 minutes. The utterances were classified into separate intonation units and primary stressed syllable identified in each intonation unit. The stressed syllables were acoustically analyzed to measure duration, F0, and intensity using Praat software. The statistical analysis was carried out using SPSS version 12.0. The mean duration of primary stressed syllable in children with cochlear implant was 0.32 s (SD = 0.11) and in normal hearing children it was 0.19 s (SD = 0.08). The mean F0 in children with cochlear implant was 339.89 Hz (SD = 56.14) whereas in normal hearing children it was 306.37 Hz (SD = 51.21). The mean intensity was 80.83 dB (SD = 5.49) in children with cochlear implant and 83.51 dB (SD = 5.17) in normal hearing children. The independent samples t- test revealed significant difference between the two groups of participants for all acoustic measures. The results of the current study seem to suggest that children with cochlear implant distinctly produced sentence stress but the acoustic correlates of stress are significantly different from those produced by individuals with normal hearing. Hence, the results emphasize the need to consider inclusion of suprasegmental aspects in the speech-language rehabilitation of children with cochlear implant.

Key Words:- F0, duration, intensity, hearing impairment

The sentence stress refers to the prominence given to any particular syllable in a sentence. The prominence is brought about by increased duration, F0, and intensity compared to other syllables in a sentence (Cruttenden, 1997). Inappropriate stress patterns have been described as "typical" of individuals with hearing impairment (Hargrove, 1997). Ando and Canter (1969) reported that individuals with hearing impairment produced only stressed syllables. They did not distinguish between stressed and unstressed syllables (Osberger & Levitt, 1979). Similarly, Nickerson (1975) reported that individuals with hearing impairment tend to vary pitch less often resulting in excessive stress on all syllables or a flat monotone stress pattern throughout the utterance. Many investigators reported consistent errors in acoustic measures of stress in children with hearing loss. McGarr and Harris (1983) demonstrated variable use of F0, amplitude, or duration to signal stress contrasts with no stereotypic acoustic pattern in a client with hearing loss. These individuals used excessively high pitches (Angelocci, Kopp & Holbrook, 1994; Martony, 1968), abnormal temporal patterns such as smaller proportional shortening of unstressed syllables with respect to stressed syllables (Stevens, Nickerson & Rollins, 1978; Osberger & Levitt, 1979) i.e., deaf children uttered stressed and unstressed syllables with less of a difference in duration than children with normal hearing. Tye-Murray (1987) observed speakers with hearing impairment intentionally lengthened stressed vowels relative to unstressed vowels, but the intended stress

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patterns were not always correctly perceived by listeners.

It is of interest to consider whether deaf speakers problems in producing stress patterns are due to impaired motor control of speech or to linguistic factors. To answer this question, Tye-Murray and Folkins (1990) asked deaf and hearing participants to speak sets of homogenous syllable strings which they could tap out with a finger, and hence could understand. Strain gauges monitoring lower lip and jaw movements revealed that deaf and hearing participants produced different durations and displacements for stressed and unstressed syllables. There was no evidence that motor abilities affected the production of stress patterns in the deaf speakers. Thus, when the deaf participants understood a given stress pattern they could speak it, even when they did not articulate the correctly. This outcome showed that the deaf participants were not aware of phonemic distinctiveness via stress.

Measurements of speech fundamental frequency (F0) in hearing impaired people, however, have presented mixed and conflicting results. Horii (1982) reported higher than normal F0 values for 12 speakers with hearing impairment aged 16-19 years. Leder, Spitzer and Kirchner (1987) found recently that F0 was significantly higher in individuals with profound post lingual hearing impairment than in hearing persons. Children with severe to profound prelingual hearing loss reportedly exhibit particular problem in learning to coordinate control of their breath in producing speech. Without experience to guide them they may attempt to speak on inspiration as well as expiration, using ingressive as well as egressive airstreams. They tend to produce short bursts of speech and then run out of breath because they do not take sufficient breath before beginning to speak. Their spoken sentences are thus broken up by pauses, which interfere with the speech flow (Leder et al. 1987). The pauses make their speech stressful to listen to and understanding of their message difficult (Hudgins & Numbers, 1942; Calvert & Silverman, 1975; Forner & Hixon, 1977). These problems of co-ordinating breathing and phonation compound their errors in the articulation of vowels and consonants and difficulties with suprasegmental features.

Data on speech production of individuals using cochlear implant suggests that suprasegmental and segmental properties of speech are influenced by the auditory feedback provided by the implants. Qualitative and quantitative changes in speech production skills are evident in a large number of deaf children using cochlear implants (Te, Hamilton, Rizer, Schatz, Arkis & Rose, 1996). Although suprasegmental performance tends to be higher following implantation, it appears to plateau after implantation and no further improvement is observed in individuals with post lingual deafness (Tobey et al., 1991).

It has been reported that cochlear implant users show improvement in voice quality, intonation pattern, volume control, and intelligibility. Iler-Kirk and Edgerton (1983) examined voice parameters in 4 cochlear implant users - 2 male and 2 female. They found that in the implant-on condition, the fundamental frequency of 2 male participants decreased and the variability in intensity also decreased. The 2 female participants also showed improvement but, in their case, fundamental frequency and variability in intensity increased in the direction of normal. Leder, Spitzer and Kirchner (1987) also found that fundamental frequency decreased in male cochlear implant users and that this change was noticed almost immediately. The use of contrastive stress patterns has also been examined. It has been observed that cochlear implant users show an improvement in the use of contrastive stress patterns (Waters, 1986). Leder, Spitzer, Milner, Flevaris-Phillips, Richardson and Kirchner (1986) reported decreased variability in acoustic measures of stress post-implantation compared to non-stereotypical acoustic pattern prior to implant in an adventitiously deaf individual. The more recent study by Lenden and Flipsen (2007) examined longitudinally the prosody and voice characteristics of 40 conversational speech samples obtained from 6 young children with prelingual severe to profound deafness who had been fitted with multichannel cochlear implant devices. The samples were obtained at 3-month intervals over 12-21 month periods and analyzed using the Prosody Voice Screening Profile (Shriberg, Kwiatkowski & Rasmussen, 1990). The most problematic aspects of prosody and voice for these children appeared to be the use of stress (lexical, phrasal, and/or emphatic). However, children with cochlear implant demonstrated significant improvements in the use of stress over a period of time.

The previous research relating to prosodic aspect of stress in individuals with cochlear implants primarily focused on the qualitative aspects of stress. The acoustic correlates of stress in children with cochlear implant were little addressed. Thus the current study examined the acoustic parameters of F0, duration, and intensity in the spontaneous monologue speech samples obtained from 7 young children with prelingual profound deafness who were fitted with multichannel cochlear implant devices and compare these features with those in normal hearing children.

Method

Participants

Seven right handed congenital and profoundly hearing impaired children fitted with multichannel cochlear implants participated in the study. The demographic and clinical details of the participants are given in Table 1. The participants included 3 male and 4 female children. The age range of the participants varied from 6.4-8.4 years with the mean age of 7.5 years. All the participants were native Telugu speakers who could speak in simple sentences. All children with cochlear implant were fitted with multichannel Nucleus 24 with ACE signal processing strategy and were attending speech therapy based on the Auditory Verbal Therapy (AVT) framework for about 6 months to 3 years post-implantation at the same speech rehabilitation centre. Although the therapy duration was variable, all children could speak in at least simple sentences. The language skills of the participants at the time of recording the speech sample were measured using Receptive and Expressive Emergent Language Skills (Bzoch & League, 1971) test. Prior to implantation they had attended speech therapy based on multisensory approach for about 1-2 years. They were fitted with analog behind-the ear hearing aid before implantation. None of the participants had any associated problems.

Table 1: Characteristics of participants with cochlear implant

Participant	Gender	Age (years)	Implantation age (years)	Language age (months)		Implant type	Processing strategy
				RLA	ELA		
CI 1	F	8.1	5.0	33-36	30-33	Nucleus 24	ACE
CI 2	F	8.4	6.5	33-36	27-30	Nucleus 24	ACE
CI 3	F	7.2	6.5	27-30	24-27	Nucleus 24	ACE
CI 4	F	7.3	6.0	27-30	27-30	Nucleus 24	ACE
CI 5	M	8.6	7.0	27-30	27-30	Nucleus 24	ACE
CI 6	M	6.5	5.0	27-30	24-27	Nucleus 24	ACE
CI 7	M	6.4	5.5	27-30	24-27	Nucleus 24	ACE

In order to draw comparison with the speech of non-hearing impaired individuals, 7 age and gender matched normal hearing children were recruited for the study. The participants did not present any previous history of speech, language or hearing deficits as ascertained by the information provided by their parents or guardians. All the participants were native speakers of Telugu.

Stimulus

The stimulus constituted a single comprehensive picture card that depicted a 'Living Room' of general Indian household. Some of the events that constituted the picture card were a woman playing with her daughter, a man on a sofa reading a news paper, a baby playing with toys on the floor, a television set in a corner of a room, a painting hung on a wall, a cat under the table, among others. Initially, a pilot study was carried out to confirm:

(a) that expressive speech of minimum 3 minutes could be elicited from the participants.

(b) the possible occurrence of different grammatical classes in Telugu.

Five normal hearing participants aged 6-8 years narrated the events related to the selected picture stimuli. Analysis of the discourse content revealed that the participants described the picture for about 2-3 minutes and there was sufficient scope for use of various grammatical classes such as nouns, verbs, adjectives, pronouns, postpositions, and conjunctions. There was also scope for repeated use of some of the grammatical categories. More importantly, the chosen stimulus facilitated generation of a significant number of sentences thus enabling collection of large corpus of speech sample.

Procedure

Recording procedure

Prior to recording of speech sample, informed consent in writing for participation in the study was obtained from the parents/guardians of all participants. Prior to the actual recording of speech sample of participants, the principal investigator demonstrated narration of picture using another stimulus to each participant. All the participants were given sufficient time to formulate the utterances and get familiarized about the picture to be narrated. The picture was placed in front of participants and they were instructed to observe and verbally describe as many events, things, activities etc. about the picture. The speech sample was recorded in a single trial in a quiet environment. The duration of recording ranged between 2-3 minutes across participants. The participants' utterances were recorded using Transcend digital voice recorder with a uni-directional microphone placed at a distance of about 10 cm from the mouth.

Analysis

Perceptual analysis

The basis for perceptual analysis was to identify the intonation units and to determine the primary stressed syllable in each of these intonation units. The perceptual identification of intonation units and primary stressed syllables was necessitated because they were fundamental to acoustic analysis of features of stress. The recorded utterances were transcribed by the principal investigator using The International Phonetic Alphabet (revised to 1993, updated 1996). This is done identify the speech sounds in each utterance. The utterances were classified into separate intonation units by the principal investigator. An intonation unit (IU) was operationally defined as 'a sequence of words combined under a single, coherent intonation contour' (Chafe, 1987). The perceptual criteria adopted for demarcating intonation units were: presence of at least one stressed syllable, significant pause between intonation units, phrase final lengthening, anacrusis, and pitch reset (Cruttenden, 1997). Another judge who was a qualified speech-language pathologist with experience in analysis of prosody also identified the intonation units independently. The item-by-item inter-judge reliability coefficient 'Alpha' for identification of intonation units was found to be 0.9404. The judgment task was repeated after 2 weeks time by the principal investigator and other judge to establish intra-judge reliability. The item-by-item intra-judge reliability coefficient 'Alpha' for the principal investigator was found to be 0.9804 and for another judge it was 0.9702. Later, 3 speech-language pathologists independently identified the primary stressed syllable in each intonation unit. The item-by-item inter-judge reliability coefficient 'Alpha' was found to be 0.9904. The judgment task was repeated after one week to establish intra-judge reliability. The item-by-item intra-judge reliability coefficient 'Alpha' for the 3 judges were 0.9905, 0.9503, and 0.9802 respectively.

Acoustic analysis

The utterances of participants recorded on a digital voice recorder were transferred to a computer for the purpose of acoustic analysis using Praat software. The speech signal was digitized at a sampling rate of 22000 Hz. The F0 and intensity range was set between 75-500 Hz and 40 to 90 dB respectively while the window frame length of analysis was 25 ms. The pitch analysis was done using autocorrelation method. The F0 and intensity related measures were read directly from the pitch and intensity contours. The duration of the primary stressed syllable was measured as the time difference between onset and offset of stressed syllable in intonation unit. In order to obtain accurate duration measurements and facilitate discernible boundaries of stressed syllables, the utterances were displayed on a wide-band spectrogram. The spectrographic analysis was done using the Fourier method and involved Gaussian window weighting. The pre-emphasis level was set at 6.0 dB/octave. The acoustic measurements of temporal, F0, and intensity cues to stress were carried out by the principal investigator. To check for the reliability of measurement of temporal, F0, and intensity parameters, about 20% of the speech sample was measured independently by another speech pathologist. The inter-judge reliability coefficient 'Alpha' for measurement of acoustic features was found to be 0.9604. The data obtained for duration, F0, and intensity was statistically analyzed using SPSS 12.0 software.

Results

A total of 251 intonation units were observed in children with hearing loss where as children with normal hearing demonstrated significantly lower intonation units of 76 only. In each intonation unit one primary stressed syllable was identified perceptually. The ear marked primary stressed syllable was acoustically analyzed by Praat software to obtain the measures related to duration, F0, and intensity.

Duration of primary stressed syllable

The mean duration of primary stressed syllable in intonation units of speech of children with cochlear implant was 0.320= 0.11). It ranged from 0.06 s to 0.72 s. In children with normal hearing, the mean duration of primary stressed syllable was 0.19 s (SD = 0.08) and ranged from 0.07 s to 0.35 s (see Table 2, Figure 1). To determine the difference in mean duration of primary stressed syllable between the two groups of participants, independent samples t-test was used. The results revealed highly significant difference, $t(324) = 4.5$, $p < .000$.

Figure 1: Mean duration of primary stressed syllable in children with cochlear implant and children with normal hearing.

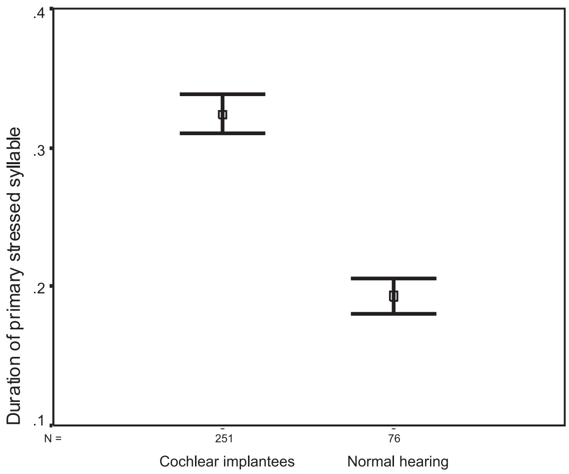

Table 2. *Mean duration of primary stressed syllable in children with cochlear implant and children with normal hearing.*

Groups	n	N	Minimum (Hertz)	Maximum (Hertz)	Mean (Hertz)	SD
Cochlear implantees	7	251	159.43	491.23	339.89	56.14
Normal hearing	7	76	214.40	457.20	306.37	51.21

F0 of primary stressed syllable

The mean F0 of primary stressed syllable in intonation units of speech of children with cochlear implant was 339.89 Hz (SD = 56.14) with a range of 331.80 Hz. In children with normal hearing, the mean duration of primary stressed syllable was 306.37 Hz (SD = 51.21) and ranged 242.80 Hz (see Table 3, Figure 2). The independent samples t-test for the difference in significance of mean duration of primary stressed syllable in children with cochlear implant and children with normal hearing revealed highly significant difference t(324) = 9.4, p < .000.

Figure 2. Mean F0 of primary stressed syllable in children with cochlear implant and children with normal hearing.

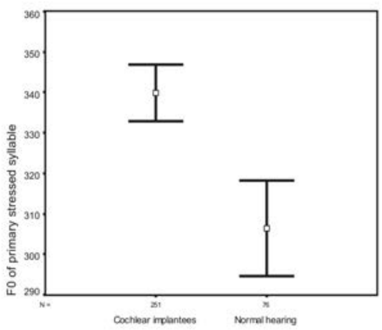

Table 3. Mean F0 of primary stressed syllable in children with cochlear implant and children with normal hearing.

Groups	n	N	Minimum (Hertz)	Maximum (Hertz)	Mean (Hertz)	SD
Cochlear implantees	7	251	159.43	491.23	339.89	56.14
Normal hearing	7	76	214.40	457.20	306.37	51.21

Intensity of primary stressed syllable

The mean intensity of primary stressed syllable in intonation units of speech of children with cochlear implant was 80.83 dB (SD = 5.49). It ranged from 64.60 dB to 89.53 dB. In children with normal hearing, the mean duration of primary stressed syllable was 83.51 dB (SD= 5.17) and ranged from 65.50 dB to 88.82 dB (see Table 4, Figure 3). The independent samples t-test was administered to examine the significance of difference in the mean duration of primary stressed syllable between the two groups of participants. The results revealed highly significant difference, t(324) = -3.8, p < .000

Figure 3: Mean F0 of primary stressed syllable in children with cochlear implant and children with normal hearing.

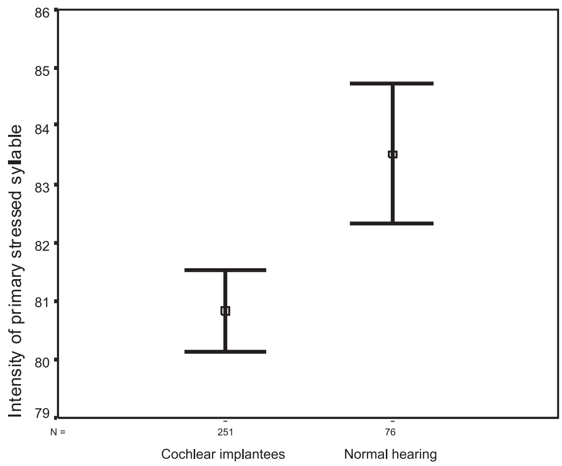

Table 4: *Mean intensity of primary stressed syllable in children with cochlear implant and children with normal hearing*

Groups	N	N	Minimum (dB)	Maximum (dB)	Mean (dB)	SD
Cochlear implantees	7	251	64.60	89.53	80.83	5.49
Normal hearing	7	76	65.50	88.82	83.51	5.17

Discussion

A certain degree of homogeneity in terms of age of onset of hearing loss, type of cochlear implant, and speech therapy technique used was maintained across participants with cochlear implants. The homogeneity is also reinforced by the standard deviation scores of all the three acoustic parameters investigated. The standard deviation values in children with cochlear implants were similar to those found in children with normal hearing for the acoustic parameters of duration, F0, and intensity. The homogeneity facilitated group comparison of data between the two groups of participants.

As evident from the results, the children with cochlear implant presented higher number of intonation units (251 intonation units) relative to children with normal hearing (76 intonation units). In other words, although they described the picture in simple sentences, they did not produce the sentence in one single utterance. They inserted frequent and lengthy pauses between the words in a sentence that resulted in frequent F0 resettings and hence more number of intonation units. Where as, children with normal hearing narrated the picture in lengthier utterances and hence longer and lesser number of intonation units.

Although they produced, greater number of intonation units, the utterances of children with cochlear implant may not be labeled monotonous. They could produce both stressed and unstressed syllables i.e. They could bring distinction between stressed and unstressed syllables. The results are in sync with those of Lenden and Flipsen (2007), and Waters (1986) who found significant improvement in the use of stress over a period of time in children with cochlear implant. However, for the stressed syllables, the acoustic correlates of duration and F0 were found to be significantly higher than normal hearing individuals where as the intensity was significantly lesser in children with cochlear implant. Usually, marked and rapid improvements in acoustic aspects of prosody are demonstrated in post lingually deaf individuals fitted with cochlear implant (Iler-Kirk & Edgerton, 1983; Leder et al., 1987; Tobey et al., 1991). However, the results of prelingually deaf children with cochlear implant seem to suggest that the acoustic features of stress are not yet stabilized in these individuals. They are still significantly different as is usually observed in individuals with profound hearing loss (Martony, 1968; Stevens et al., 1978; Osberger & Levitt, 1979; Horii, 1982; Leder et al., 1987; Angelocci et al., 1994).

Conclusions

The results of the current study seem to suggest that children with cochlear implant distinctly produced sentence stress but the acoustic correlates of stress for all 3 parameters of duration, F0, and intensity are significantly different from those produced by individuals with normal hearing. The mean duration and F0 were higher in children with cochlear implant compared to children with normal hearing. However, the mean intensity was relatively lower in children with cochlear implant than children with normal hearing. The children with cochlear implant produced shorter intonation units compared to individuals with normal hearing. The results of the current study bear implications on the need to include suprasegmental aspects in the speech-language assessment and treatment of children with cochlear implant. Since the prosodic correlates of speech vary across languages, it would be interesting to replicate the study in children with cochlear implant speaking other languages.

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