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Acquisition of voice onset time in Hindi speaking children with cochlear implant

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ABSTRACT

Background: The acquisition of voice onset time (VOT) in plosive consonants among hearing-impaired individuals has long been of interest to many researchers especially following the use of a hearing device such as the cochlear implant. The aim of the study was to study acquisition of voice onset time in Hindi speaking children with cochlear implant.
Methods: A total of 15 CI subjects were chosen who were attending the speech and language therapy in Hindi and age matched 15 normal hearing children were selected for the study. Subjects were divided into 3 age groups according to hearing experience.
Results: The present study investigated the VOT values of voiced and voiceless plosives produced by Hindi-speaking prelingually deafened CI children with duration of CI experience ranged between 4 to 10 years. The results were then compared to a group of NH children with chronological age similar to the hearing experience of the CI children.
Conclusions: A longitudinal study is recommended to continue monitoring the CI children acquisition of the voicing contrast to determine at what hearing age the difference would be insignificant between the CI and NH groups and whether similar developmental trend would continue.

Keywords: Voice onset time, Prelingual deafness, CI children

INTRODUCTION

The acquisition of voice onset time (VOT) in plosive consonants among hearing-impaired individuals has long been of interest to many researchers especially following the use of a hearing device such as the cochlear implant. Cochlear implant is an electronic device which is surgically implanted for the individual with severe to profound hearing loss which provides monaural hearing stimulation. The binaural listening in normal persons always provides better auditory discrimination than monaural. The study on developmental acquisition of the VOTs gives an insight in mechanism of the motor control of the voicing contrast.

Voice onset time (VOT) is the length of time that is measured between the release of a closure of a plosive and the onset of voicing. The early study of VOT made by Lisker and Abramson 1957 says VOT is a measurable acoustic parameter, resulting from the temporal co-ordination between laryngeal and supra-laryngeal gestures.[1] It can be divided into two types which are voicing lag and voicing lead. When voicing occurs after the release of air through the glottal closure, it is referred to as voicing lag and is measured in positive VOT values. If the voicing occurs before the actual release of air, prior to glottal closure, this is then referred as voicing lead and is measured in negative VOT values.

Plosive sounds at word initial position are often chosen by phoneticians due to the acoustical perspectives of word. It is due to the fact that listeners have a higher tendency to pay their attention to the beginning of a sound in a word than the middle or the final position. Moreover, the initial position is often viewed as the cue for an individual with hearing loss especially those who use hearing devices. The ability to detect the initial consonant from a word being uttered, benefits the hearing impaired listeners as it signifies a commencement of conversation. Voicing is a phonological contrast which begins to develop early in the speech of children. The acquisition of voicing in normal population is an ongoing process as children's voicing capabilities tend to continue developing as they grow older.[2]

Cross linguistics studies show, VOT values are different for different languages. For example, English plosives have no negative VOT values but are contrasted based on short and long lags acoustic cues for the voiced and voiceless plosives, respectively. Voiced plosives are characterized by voicing lead that have negative VOT values, while voiceless plosives have positive values of voicing lag.[2,3] These features of negative and positive VOT values for voiced and voiceless plosives, respectively, are also seen in the Hindi language.

In Asian Languages indeed there has been considerable work in VOT particularly on Korean and Hindi plosives.[4] VOT has been shown to be useful indication for a wide range of languages but for the mean time there have been no systematic studies of VOT in Hindi particularly in children with cochlear implants or hearing-impaired children in general.

Hearing is important for self-monitoring of the production of the plosive consonants. In the absence of hearing, VOT anomalies (as compared to normal hearing) have been reported even in postlingually deafened adults. For example, Kishon-Rabin et al investigated the effect of auditory feedback on speech production of five postlingually deafened adults who were implanted with the Nucleus 22 cochlear implant device.[5] They measured the changes in the speech production of the subjects pre and post-implantation at 1, 6 and 24 months using various acoustic measurements including the VOTs. The results supported the hypothesis that restoration of hearing helps to recalibrate the mechanism of speech production as the adult CI users were able to monitor their articulation and their acoustic output.[6,7]

Aims and objectives

The study objectives were as followed: To investigate the (1) VOT values across the hearing age (i.e. the duration between the activation of the implant and the time of testing or duration of CI experience); (2) differences between CI and NH children in terms of their VOT values across the age groups; and (3) Relation of VOT values according to the age of implantation.

METHODS

The present study was conducted in the department of ENT & HNS, during the period July 2016-August 2017, at Late Shri Lakhi Ram Agrawal Memorial Medical College & Hospital Raigarh, Chhattisgarh.

Inclusion criteria

Inclusion criteria were using Hindi as their dominant language; prelingual deafness; had a duration of CI experience for at least 4 years and a maximum of 10 years at the time of the study; used mainly oral communication mode; had no other disabilities besides hearing loss such as neurological impairment, mental retardation, autism and others; and had parents' consent to participate in the study. The same criteria were followed for the NH group children.

Exclusion criteria

Exclusion criteria were age below 10 years; child was operated with cochlear implant; then his hearing experience is considered as 4 years; compared with 4years normal hearing child.

A total of 15 CI subjects were chosen who were attending the speech and language therapy in Hindi and age matched 15 normal hearing children were selected for the study (suppose a 6 years child was operated with cochlear implant, at the age of 2 years, then his hearing experience is considered as 4 years and he is compared with 4 years normal hearing child). Subjects were divided into 3 age groups according to hearing experience:

I) 4 years to 6 years

II) 6 years to 8 years and

III) 8 years to 10 years

There were 5 subjects in each hearing age group.

1) Test procedure

Speech samples were collected by conducting a single data collection session with the CI subjects at Medical College Hospital with the parents' consent. Recording was performed in a fairly quiet room in a sound treated chamber. Each session took about 10 – 20 minutes to complete. Each subject was required to complete a picture-naming task which consists of 41 pictures with voiced /b, d, g/ and voiceless /p, t, k, / plosives at word initial position, presented through a HP pavilion DV series laptop. Subjects were asked to name the picture one by one when it was shown on the computer screen while the responses were audio- recorded using Apple i-phone 6s digital audio recorder for a later analysis. After the subjects had completed a trial, the task was repeated with random presentations of the pictures to avoid memorization and to encourage spontaneous responses from the child.

If the subject had problem naming any of the pictures or gave wrong answers, the researcher provided assistance by performing either by: (1) completing the incomplete sentence or (2) describing the features of the objects; or (3) performing the gesture function of the object. Average VOT values from the two repeated trials for each sound category were calculated for the statistical analysis.

2) Data analysis

The speech samples collected were transcribed into the PRAAT software 4.3.33 in which the samples were displayed in the spectrogram view. By using PRAAT, VOT values were measured in milliseconds (ms) and the average VOT values from the two trials, for each of the sounds were calculated. Further statistical analyses were conducted using the Statistical Package for Social Sciences (SPSS) version 18.

Descriptive analyses were used to get the mean and the standard deviation values of the voiced and voiceless plosives across the age and study groups. A one-way ANOVA was used to determine the hearing age effect within the CI group. To compare with the NH group, a two way multivariate analysis was performed with group and age as the fixed factors. For the correlation analyses, Pearson correlation was used to analyze the correlations between the VOT values of voiceless plosives /p, t, k/ and the age at implantation and duration of CI experience, while the Spearman correlation was utilized for the voiced plosives /b, d, g/ as the data distribution was not normal for these sounds.

RESULTS

VOT values across the hearing age (experience)

Within the CI group alone, there was a significant hearing age effect for all the VOT values of the voiced and voiceless plosives. Table 1 shows the F and p-values of the one-way ANOVA analysis, the mean and the standard deviations (SDs) for each of the plosive across the hearing age and the post hoc analyses. In general, it can be seen from Table 1 that the significant VOT differences were evidenced in the 4 to 6 years and 8 to 10 years age groups, but not between the 6 to 8 years hearing experience groups.

Comparing the VOT values between the CI and NH children

A two-way multivariate analysis was performed to examine the group and age effects on the VOT values of all the plosives. Table 2 reveals the F and p values of both the CI and NH group with respect to age, and the interaction between the two independent variables.

Table 1: The F statistics and p values of the hearing experience for all plosives within CI group, the post hoc analysis showing the difference between the age groups.

Plosives	F- value (hearing exp)	p value	Mean standard deviation			Post hoc analysis
			4 to 6 yrs	6 to 8 yrs	8 to 10 yrs	
/p/	F (2, 12)=12.880	0.001	15.159±2.122	19.155±1.139	22.997±2.006	4 to 6 y-p=0.0112 6 to 8 y-p=0.001 8 to 10 y-p=0.042
/t/	F (2, 12)=9.006	0.004	20.245±1.455	20.779±2.041	26.723±4.221	4 to 6 y-p=1.000 6 to 8 y-p=0.005 8 to 10 y-p=0.014
/k/	F (2,12)=44.221	0.000	22.340±1.391	25.112±2.144	33.561±2.223	4 to 6 y-p=0.331 6 to 8 y-p=0.000 8 to 10 y-p=0.000
/b/	F (2,12)=5.332	0.048	-3.913±16.410	-21.755±6.513	-21.778±4.112	4 to 6 y-p=0.064 6 to 8 y-p=0.060 8 to 10 y-p=1.000
/d/	F (2,120=12.910	0.002	5.236±25.665	19.661±3.665	-24.343±4.033	4 to 6 y-p=0.435 6 to 8 y-p=0.043 8 to 10 y-p=0.001
/g/	F (2,12)=122.433	0.000	28.889±5.788	30.492±6.555	-34.322±12.783	4 to 6 y-p=1.000 6 to 8 y-p=0.000 8 to 10 y-p=0.000

Table 2: The F statistics and p values for the hearing experience age effects of the group and age with the interaction between the group and age for all the voiced and voiceless plosives.

Plosives	F-value group	P value group	F-(age)	P-(age)	F-(group and age)	P-(group and age)
/p/	F (1,24)=99.006	0.000	F (2,24)=6.322	0.003	F (2,24)=0.677	0.032
/t/	F (1,24)=39.661	0.000	F (2,24)=4.551	0.033	F (2,24)=0.641	0.667
/k/	F (1,24)=11.883	0.004	F (2,24)=15.650	0.000	F (2,24)=1.332	0.442
/b/	F (1,24)=17.876	0.000	F (2,24)=2.244	0.307	F (2,24)=0.992	0.674
/d/	F (1,24)=20.278	0.000	F (2,24)=8.435	0.002	F (2,24)=1.231	0.455
/g/	F (1,24)=12.554	0.002	F (2,24)=11.011	0.001	F (2,24)=0.054	0.549

Table 3: The correlation analyses between the age at implantation and hearing age of the CI children and the mean VOT values for all the plosives.

VOT	/p/	/t/	/k/	/b/	/d/	/g/
Age at implantation	r=0.040 p=0.887	r=0.200 p=0.401	r=0.501 p=0.067	r=0.002 p=994	r=-0.40 p=0.13	r=-0.546 p=0.035
Hearing age	r=0.824 p=0	r=0.699 p=0.004	r=0.885 p=0	r=- 0.624 p=0.013	r=-0.54 p=0.03	r=-0.661 p =0.007

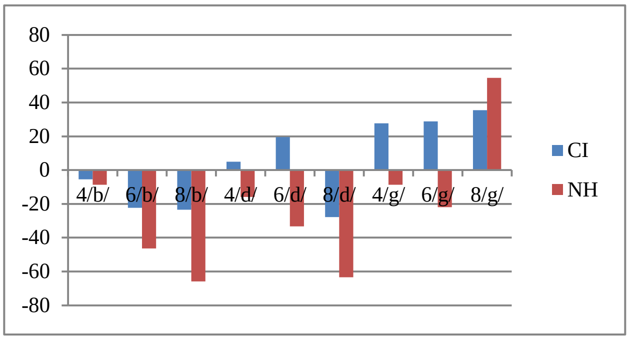

Figure 1 (a): The mean VOT values for voiced plosives /b,d,g/ as a experience of age and place of articulation for the CI and NH groups.

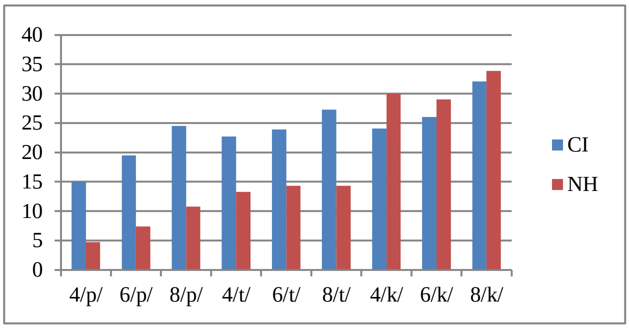

Figure 1(b): The mean VOT values for voiceless plosives /p,t,k/ as a age and place of articulation for the CI and NH groups.

It can be seen from Table 2 that the main effect of group (i.e. comparing between the CI and NH groups) was significant for all VOTs of the voiced and voiceless plosives across all the age groups except for VOT/b/. There was no interaction between the group and age suggesting that the pattern of responses was similar across age for both the study groups. In general, for the voiced plosives /b, d, g/, the mean VOT values decrease (more negative values) as the age increases (Figure 1a) while for the voiceless plosives /p, t, k/, as the age increases, subjects in both groups showed longer mean (more positive) VOT values (Figure 1b).

For the CI children with 4 to 6 years of hearing age, the mean VOT for voiceless /k/ sound was similar to the mean VOT for voiced /g/ sound (~25 ms) suggesting these velar sounds were perceived as similar. That is, there is an effect of substitution of the voiced for the voiceless sounds. The separation of the equivalent VOTs was observed in the 6 to 8 years hearing experience with the CI group.

For the voiceless plosives /p, t/, the CI children consistently showed longer mean VOTs than the NH children across the age group but not for the /k/ sound in which the mean VOTs for CI were shorter than the NH children across the age groups (Figure 1b).

The following figures show the mean VOT values for the voiced (1a) and voiceless (1b) plosives as a function of age and place of articulation for both the CI and NH groups.

Correlation analysis

The VOT values were submitted for simple bivariate analyses with the age at implantation and duration of CI experience (i.e. the hearing age of the CI subjects). Table 3 shows the correlation coefficients and the p-values obtained in this analysis.

The correlation analyses between the age at implantation and hearing age of the CI children and the mean VOT values for all the plosives. Pearson correlation was used for the /p, t, k/ sounds while the non-parametric Spearman correlation was utilized for the voiced /b, d, g/ correlations. Values in bold are significant correlations (Table 3).

DISCUSSION

The present study investigated the VOT values of voiced and voiceless plosives produced by Hindi-speaking prelingually deafened CI children with duration of CI experience ranged between 4 to 10 years. The results were then compared to a group of NH children with chronological age similar to the hearing experience of the CI children.

Our first main finding was that within the CI group, hearing experience effect was significant especially between the 4 to 6 years group and 8 to 10 years groups. The results suggested that in general, 6 years hearing experience through the cochlear implant device seemed to be the ‘cut-off’ point for a leap in the ability of the Hindi CI children to monitor their production of the plosive sounds in terms of its voicing contrast. Again there was improvement of VOTs in 8 to 10 years hearing experience group. This was evidenced from our data as the 6 to 8 years group didn’t show significant difference in terms of their VOTs. There was a significant effect of hearing experience. As the experience of hearing through the CI device increased, the mean VOTs of the voiceless plosives became longer and more negatives for the voiced plosives, which supported the findings of others that show suitable changes of VOT over time with hearing experience. The presence of hearing ability allows the auditory feedback loop to operate and enable the CI children to monitor production of the speech sounds.

Comparing the mean VOTs of all plosives comparison between the CI and NH groups revealed that there was significant difference in mean VOT values and hearing experience of both the CI and NH group, suggesting that the pattern of responses were similar across the age groups.[8] The results indicated that the use of CI helps to give significant access to sounds to enable auditory feedback monitoring. These prelingually deaf CI children with minimum hearing experience have difficulty in sharp perception of the voicing contrast comparable to NH, especially for the children with 4 to 6 years hearing experience with the implant for the more posterior place of articulation sounds (i.e. /k/ and /g/).[9-11]

The more anterior voiceless plosives /p, t/ consistently show longer VOT values for the CI as compared to the NH children according to hearing experience except for the /k/ sound. For the voiceless velar /k/, the CI subjects had shorter mean VOTs than the NH group across all hearing ages. It could be possible because of the coordination and timing between laryngeal and oral articulation takes place in the presence of hearing.[12,13] The fact that this sound is produced at the back of the articulatory organ, makes it more difficult for the CI children to perceive the voicing cue. It is known that place of articulation cue relies on frequency information and this cue is available in the cochlear implant system through different activation of the electrode placed.

It has been shown that CI users who had difficulties to discriminate speech sounds were associated with improper cochlear electrode placement. This hypothesis is further supported by examining our VOT data for the voiced velar /g/ which showed striking differences especially for the younger age groups.[14] The subjects with shorter duration of CI experience had positive VOT values as compared to the NH subjects who consistently had negative VOT values. The results which showed similar mean VOTs for voiced and voiceless velar sounds for the CI children with 4 to 6 years hearing experience, which was around 25 ms, suggested overlapping perception of these sounds. That is, there was an effect of substitution of the voiced for the voiceless sounds or vice versa. The separation of the cognate VOTs was observed in the 6 year hearing experience with the CI as negative mean VOT was obtained for the voiced /g/.[15]

Our present finding supported an earlier study which found that prelingually deaf children who had worn their CIs for a longer time were more likely to produce the place of articulation correctly. Other studies have reported that as the hearing experience increases, hearing-impaired speakers will increase their speaking rate and variability in speaking rate and vocal loudness have also been shown to affect the VOT values.[16,17]

Hearing experience however, significantly correlated with all the mean VOTs as several studies have shown that hearing experience for the hearing-impaired speakers help to recalibrate the mechanism for motor control of the voicing contrast that lead to more accurate speech production. Earlier age at implantation did not necessarily mean better speech production suggesting acquisition of the voicing contrast ability is a developmental process and hearing experience is important to allow the child to learn to produce the necessary upper vocal tract and laryngeal gestures and to coordinate them with very precise timing according to the rule of the language.[18,19]

CONCLUSION

The prelingually deafened Hindi CI children showed similar pattern of acquisition of the voicing contrast as their NH peers. Hearing ability obtained through their CI device helps to activate the auditory feedback loop in these hearing-impaired children with a leap in performance observed upto 6 years of hearing experience. Velar sounds seemed to be more difficult to differentiate because of overlapping perception of the voiced and voiceless sounds of /k/ and /g/ was suspected, as the mean VOTs for these sounds for the 4 to 6 years hearing experience groups were similar at around positive value of 25 ms. A longitudinal study is recommended to continue monitoring the CI children acquisition of the voicing contrast to determine at what hearing age the difference would be insignificant between the CI and NH groups and whether similar developmental trend would continue.

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