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Analysis of Temporal parameters in the Speech of the Children with Hearing Loss

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Abstract

The surge of literature indicates that the to develop more effective speech training procedures for the subjects with hearing loss, it is necessary to study the deviation in their speech from that of the normal-hearing subjects and hence, the analysis of speech of the subjects with hearing loss becomes essential. The current investigation aimed at studying the temporal parameters of vowel and consonants in the speech in children with hearing loss. Sixteen bisyllabic words with stop consonants and vowels, uttered by participants with severe sensorineural hearing loss and age and gender-matched normal hearing participants in the age range of eight to ten years were recorded and the temporal parameters namely vowel duration, closure duration, consonant duration, voice onset time, burst duration, and word duration were analysed acoustically. Results of statistical analyses revealed that there were significant differences in vowel duration, voice onset time, closure duration and consonant duration between the participants of two groups. No differences in burst duration were observed between the participants of both groups.

Keywords: Vowel duration, Consonant duration, Voice Onset Time, Temporal analysis, Hearing loss

Introduction

Hearing loss either at birth or soon after birth and during early childhood have been reported to be having impact on almost all aspects of development of the child, but the most apparent function affected by hearing loss has been the ability to communicate using speech and verbal language[1–4]. Several researchers have reported the effect of hearing loss on the acquisition and production of speech[5–9]. Hearing has also been found to be essential for monitoring one's own speech production. Normal speech production requires auditory reception for monitoring of speech[10].

"The oral communication skills of the subjects with hearing loss have long been of concern to educators of the children with hearing loss, speech pathologists and audiologists because the adequacy of such skills can influence the social, educational and career opportunities available to these individuals"[11]. Many researchers in the past have used acoustic analysis of speech to find out the characteristics and errors in the speech of the subjects with hearing loss. "Use of acoustic analysis of speech for studying the speech production offers several advantages, such as it is non-invasive, needs relatively simple instrumentation, may be used routinely to depict changes in the physical characteristics of frequency, intensity and the duration of speech segments"[12,13]. Acoustic analysis of speech of the subjects with hearing loss permits the finer consideration of some aspects of both correct and incorrect production than would be possible using methods applied in the subjective procedures[11]. It provides an objective description of the speech of the subjects with hearing loss. More information about the characteristics of the speech of the subjects with hearing loss would help in making use of the advances in the technology with maximum effectiveness, facilitating the oral production skills of the individuals with hearing loss.

Both the segmental and suprasegmental characteristics of the speech of the children with hearing loss have been described by researchers. Therefore, to develop more effective speech training procedures for the subjects with hearing loss, it is necessary to study the deviation in their speech from that of the normal-hearing subjects and hence, the analysis of speech of the subjects with hearing loss becomes essential.

Many researchers in the past have used acoustic analysis of speech to find out the characteristics and errors in the speech of the subjects with hearing loss. "Use of acoustic analysis of speech for studying the speech production offers several advantages, such as it is noninvasive, needs relatively simple instrumentation, may be used routinely to depict changes in the physical characteristics of frequency, intensity and the duration of speech segments"[12,13]. Acoustic analysis of speech of the subjects with hearing loss permits the finer consideration of some aspects of both correct and incorrect production than would be possible using methods applied in the subjective procedures[11]. It provides an objective description of the speech of the subjects with hearing loss. More information about the characteristics of the speech of the subjects with hearing loss would help in making use of the advances in the technology with maximum effectiveness, facilitating the oral production skills of the individuals with hearing loss.

Vowel duration has been studied by various investigators, under different conditions. Gopal has defined vowel duration as the duration from the onset of the vowel to the offset of the vowel[14]. Vowel duration is the duration from the onset of the vowel to its offset measured in terms of milliseconds[15]. Whitehead and Jones have revealed that in normal hearing subjects and subjects with hearing loss, vowels were significantly longer in duration in a voiced consonant environment when compared with the voiceless environment[17]. There have been several studies in various Indian languages also reporting significantly longer vowel durations in the speech of the children with hearing loss[18,19]

Studies on consonant duration have revealed that in general, the subjects with hearing loss had longer durations when compared to the subjects with normal hearing[20]. Nataraja et al had also reported that the consonant duration, in the subjects with hearing loss, was longer compared to normal hearing subjects and the range of consonant duration were even higher in subjects with hearing loss compared to the normal hearing subjects[15]. Sony had also analysed the acoustic and spectral parameters in the speech of Malayalam speaking children with hearing loss and had reported that the consonant duration was significantly longer in the speech of the children with hearing loss compared to that of the children with normal hearing. The standard deviation values of the consonant duration in the speech of the children with hearing loss were also higher compared to that of the children with normal hearing[21]. Thus, the studies on the consonant duration have revealed that the duration of consonants was longer in the subjects with hearing loss compared to the subjects with normal hearing.

Closure duration has been defined as "the acoustic interval corresponding to articulatory closure for a stop or affricate consonant. It is identified on a spectrogram as an interval of relatively low energy, conspicuously lacking in formant pattern or noise"[22]. Whitehead and Jones had studied closure duration in normal hearing subjects, subjects with hearing loss who had intelligible speech and subjects with hearing loss who had partially intelligible speech. The results indicated that the subjects with hearing loss had longer closure durations[16]. Closure duration was longer for bilabial stops than lingua alveolar stops and considered that it might have been an essential factor to improve intelligibility. Closure duration might have been more because subjects with hearing loss had been found to use high subglottal air pressure to produce louder speech as they lack auditory self-monitoring. Nataraja et al had reported that the hearing-impaired subjects had higher mean closure duration values compared to the normal hearing subjects[23]. Nataraja et al had studied closure duration in subjects with hearing loss and five normal hearing subjects and had revealed that the closure duration in the speech of the children with hearing loss was longer compared to normal hearing children. This was found to be probably the consequence of the exaggerated articulation resulted in tensed articulator, which requires greater air pressure for the release. Accumulation of greater air pressure behind the articulator might take a long time which was reflected in longer closure duration[15]. Also, the high range of closure duration in the speech of the children with hearing loss was because of the greater variability exhibited by the children with hearing loss. Similar results were also reported by recent studies[21,24].

Burst duration has been defined as a brief interval of aperiodic sound which follows the silent gap. Burst refers to the noise created during the release of a stop consonant[22]. Burst duration is a transient noise produced as a part of the production of stop consonant on the release of the occlusion which has been found to be not more than 40 msec. Nataraja et al have studied burst duration in the speech of the subjects with hearing loss and age and sex-matched controls. The study showed that the burst duration was longer in the speech of children with hearing loss and this indicated that the children with hearing loss had tense articulators resulting in longer burst durations. Most of the times, a singleton plosive was substituted by a geminate cluster, especially for voiced plosives by the children with hearing loss. This was probably the reason as to why the voiced plosives had longer burst duration compared to unvoiced plosives[15]. But, Savithri had found that the unvoiced plosives had longer burst duration compared to the voiced plosives in subjects with hearing loss[25]. Chithra and Sony had also reported that the subjects with hearing loss had a longer burst duration than the normal hearing subjects and the voiced plosives had longer burst duration compared to the voiceless plosives[21,24].

Voice onset time has been defined as the time difference between the release of a complete articulatory constriction and the onset of quasi-periodic vocal fold vibration and has been considered the primary cue for differentiation of prevocalic stops along the voicing dimension[26]. Leeper et al have reported no significant difference between subjects with hearing loss and normal hearing subjects in terms of voice onset time[13]. Shukla has also studied voice onset time in both normal hearing subjects and the subjects with hearing loss and observed positive voice onset time values for voiceless stops in subjects with hearing loss[27]. Monsen, by measuring voice onset time spectrographically for 36 subjects with profound hearing loss on word-initial stops (/p/, /t/, /k/ and /b/, /d/, /g/) observed that some of the children had distinguished the cognates in the standard form. voice onset time values were longer for the voiceless than, the voiced segments and voice onset time contrasts were longer for velars than for the alveolars and bilabials[28]. However, most of the subjects with hearing loss had not shown the voiced-voiceless distinction and deviated from normal speakers.

Thus, the review of literature has shown that most often, the temporal measures have been considered to be reflecting the characteristics of speech (segmental aspects) i.e., the vowels and consonants. Thus, the acoustic and temporal analysis of speech of the subjects with hearing loss becomes essential to know the factors affecting the intelligibility in subjects with hearing loss.

Method

Participants

The present study included two groups of participants. Group 1 consisted of ten male CHL with a mean age of 10.5 $\pm$ 1.1 years (range 9 to 11 years). All the participants of group 1 had congenital bilateral sensorineural hearing loss with a pure tone average greater than 70 dBHL in the better ear as per the audiometric testing. All the participants were attending speech and language therapy and using binaural hearing aids regularly at least for the past three years. Group 2 also included ten male CNH with a mean age of 10.4 $\pm$ 0.9 years (range 9 to 11 years). Participants of group 2 had normal hearing sensitivity in both the ears as per the audiometric testing and age-appropriate speech and language skills. Participants of both groups were native speakers of Kannada (an Indian Language spoken in Karnataka state in Southwestern India) and were able to read Kannada words. None of the participants had a history of neurological, psychological or other problems. Participants of both groups belonged to middle socio-economic status as per socioeconomic status scale[29].

The number of participants was determined based on the statistical power analyses using G-Power (ver. 3)[30] using the mean and standard deviation values of the parameters in the speech of CHL reported by earlier investigators[15,24]. The power of the test was assigned a value of 0.8 and the α error probability of 0.05. Convenience and purposive sampling were employed in selecting the participants. The purpose of the voice recording was explained to all the participants, and informed consent was obtained. The institutional ethical committee approval was obtained prior to the study.

Materials

Eighty simple bisyllabic meaningful Kannada words (CVCV) (without geminate clusters) with voiced and unvoiced bilabial (/p/ and /b/), dental (/t/ and /d/), velar (/k/ and /g/) and retroflex (/ṭ/ and /ḍ/) stop consonants in initial and/or medial position and vowels /a/, /i/, /u/, /e/ and /o/ were selected from Kannada textbooks meant for children studying in the first, second and third standard. In order to select the words that were most familiar to the children aged eight to ten years, three primary school teachers, who were native speakers of Kannada, were instructed in Kannada, to rate each word based on the familiarity to the children of eight to ten years. They were as to rate the word as "not familiar", if the word was used by the children in the class less than 50% of the time, as "familiar", if the word was used approximately 50% to 75% of the time by the children in the class, and "most familiar" if the word was used approximately more than 75% of the time by the children in the class. Sixteen of forty words which were rated as "most familiar" by all the teachers were selected. The words were selected such that there met the following criteria, i.e., two words in each with the voiced bilabial, dental, velar, retroflex stop consonants and the unvoiced bilabial, dental, velar, retroflex stop consonants in the initial and medial position.

Data collection

The recording was carried out in a sound-treated room used for audiometry which met the ANSI specifications prescribed for hearing evaluation[31]. The room was free from distraction and had a comfortable temperature and well lit. Each participant was seated comfortably in a chair in front of the laptop during the recording. Each target word typed on the card (6"x 4" size) was presented to the participants. The CNH were instructed in Kannada to read the word written on the card. Similar instructions were given to CHL in the auditory and visual modality (using gestures). Each CHL wore the hearing aids suitable for his/her hearing loss during the evaluation. All the participant were asked to repeat the word three times, and the speech samples were recorded using a dynamic microphone onto the Praat software (version 6.0.56)[32]. The microphone was placed at a distance of 15 cm from the participant's mouth. All the samples were digitised at a sampling frequency of 44.1 Hz and 16 bits/sample quantisation. Thus, 16 words, uttered three times each, yielding 48 utterances were recorded from each participant and were stored on the hard disk for analyses. Out of the three recordings of each word, the most stable recording was chosen for analysis.

Acoustic analysis

The vowel duration of the vowels /a/, /i/, /e/, /u/, /a:/, /o:/ and /e:/ and the consonant duration, closure duration, voice onset time, burst duration and word duration of the voiced and unvoiced bilabial (/p/ and /b/), dental (/t/ and /d/), velar (/k/ and /g/) and retroflex (/ṭ/ and /ḍ/) stop consonants in medial position were measured (in ms) using Praat software in the utterances of the participants of both the groups. Vowel duration, consonant duration, closure duration, burst duration and VOT were extracted from all the words uttered by the participants of both the groups were tabulated and statistically analysed.

Results and discussion

As a part of the statistical analyses, mean, standard deviation and range were determined. Shiparo Wilks test of normalcy was carried out to check the normal distribution. It was found from results of the Shiparo Wilks test that all the parameters showed normal distribution. As all the parameters showed normal distribution, the independent samples t-test was performed within each temporal parameter to determine differences between the participants of both the groups.

Closure Duration

As it can be noted from **Table 1**, stop consonant /p/ showed the highest value of closure duration in the utterances of participants of Group 1. The lowest mean value of closure duration was observed in the stop consonant /ḍ/. The SD values of closure duration of the stop consonant /g/were highest, and the stop consonant /ṭ/ showed the lowest. In the utterances of the participants of Group 1, the range of closure duration varied from 486.92 ms in the utterance of /g/ to 108.88 ms in the utterance of /ṭ/. The stop consonant /p/ showed the highest closure duration and /ḍ/ had the lowest mean closure duration in words uttered by the participants of Group 2. Lowest SD was found in /t/ and the highest was noted in /p/. The range of the closure duration varied from 120.60 ms (in /p/) to 24.78 ms (in /d/).

The mean closure duration values in case of participants with hearing loss were higher for all stop consonants compared to participants with normal hearing. The closure duration of the stop consonants in Group 1 showed larger variability than in Group 2. The range of the closure duration values was also higher in Group 1 than in Group 2. Inspection of Table 1, also showed that there were significant differences in the closure duration values, of all the stop consonants between the participants of Group 1 and Group 2. Therefore, it was concluded that the participants with hearing loss had significantly longer closure durations in all stop consonants compared to the participants with normal hearing.

The study carried out by Calvert had also shown that the subjects with hearing loss had extended closure duration of plosives, i.e., nearly five times the average duration of normal speakers[20]. Whitehead and Jones had also reported that the subjects with hearing loss had longer closure durations. They had also reported longer closure duration for bilabial stops than lingua-alveolar stops, and they considered that it might be an essential factor affecting the intelligibility. They had attributed the longer closure duration to the use of high subglottal air pressure by subjects with hearing loss to produce greater loudness for auditory self-monitoring of the speech[16].

Nataraja, Savithri, Sreedevi, and Sangeetha had studied five hearing-impaired subjects and five normal hearing subjects and had reported that the hearing-impaired subjects had higher mean closure duration values compared to the normal hearing subjects[23]. Nataraja et al. had studied closure duration in subjects with hearing loss and normal hearing subjects and had revealed that the closure duration in the speech of the children with hearing loss was longer compared to normal hearing children. This was found to be probably the consequence of the exaggerated articulation in the speech of the children with hearing loss. Exaggerated articulation resulted in tensed articulator which requires greater air pressure for the release[15]. Accumulation of greater air pressure behind the articulator might have taken long time which was reflected in longer closure duration. Also, the high range of closure duration in the speech of the children with hearing loss was because of the greater variability exhibited by the children with hearing loss. Second, in normal hearing children, closure duration of unvoiced plosives was longer compared to voiced plosives. However, in the speech of the children with hearing loss, closure duration of voiced plosives was longer than that of the unvoiced. Thus, it was opined that closure duration was one of the parameters used to differentially produce voiced and unvoiced plosives. This indicated that children with hearing loss were not efficient in the using of closure duration to differentiate voiced and unvoiced plosives.

Savithri had also reported increased closure duration in the speech of subjects with hearing loss[25]. Chithra had found significantly higher mean closure duration values in subjects with hearing loss compared to the normal hearing[24]. Sony observed that the closure duration was significantly longer in the speech of the participants with hearing loss than in normal hearing, in all the stop consonants[21]. The results of the present study are in consonance with the earlier studies. Therefore, it was concluded from the results of the present study that the participants with hearing loss had significantly longer closure durations in all stop consonants compared to the participants with normal hearing.

Voice Onset Time

Inspection of **Table 2** show that among the unvoiced consonants, /k/ in initial position had the highest positive voice onset time and /p/ in initial position had the lowest voice onset time in Group 1. SD was highest in /k/ and lowest in /t/ in medial position. Range of positive voice onset time varied from 24.79 ms in /t/ (in medial position) to 61.99 ms in /p/ (in medial position). In voiced consonants, highest negative voice onset time was noted in /ḍ/ (in medial position) and lowest voice onset time was found in /g/ (in initial position) in Group 1. /g/ (in medial position) had the highest SD and /d/ (in medial position) had the lowest SD values. The voice onset time values ranged from 101.02 ms in /b/ (in initial position) to 182.7 ms in /ḍ/ (in medial position). In Group 2, among the unvoiced consonants, /k/ in initial position had the highest positive voice onset time and /ṭ/ in medial position had the lowest voice onset time in Group 2. The SD was highest in /t/ (in medial position) and lowest in /k/ (in medial position). Range of positive voice onset time varied from 14.78 ms in /k/ (in medial position) to 29.91 ms in /p/ (in medial position). In voiced consonants, highest mean negative voice onset time and SD were noted in /g/ (in medial position) and lowest mean voice onset time and SD were found in /b/ (in initial position). The voice onset time values ranged from 44.38 ms in /b/ (in initial position) to 119.93 ms in /g/ (in medial position). The mean voice onset time values in Group 2 were higher than in Group 1 in all the consonants except for /k/ and /ṭ/. SD values and the range were higher in Group 1 than in Group 2.

Table 2 also presents the results of the independent sample t-test carried out comparing the voice onset time values in Group 1 and Group 2 and study of this table showed that the voice onset time values of all the voiced stop consonants of Group 1 were significantly different compared to Group 2, whereas no significant differences in voice onset time values of any of the unvoiced stop consonants were observed, even though the mean values were higher in group 2 for /k/ and /ṭ/ compared to their voiced counterparts. Based on these results and the mean voice onset time values, it was inferred that the participants with hearing loss had significantly shorter voice onset time in the production of voiced stop consonants.

Gilbert and Campbell had observed significantly shorter voice onset time values in subjects with hearing loss than in normal hearing. According to them, the short values was due to the inability of the subjects with hearing loss to coordinate the phonatory and articulatory mechanism[33]. The results of the present study also evidenced that there were significantly lower voice onset time values for the voiced stop consonants uttered by the participants with hearing loss and the present study results support the findings of the study by Gilbert and Campbell[33].

Nataraja et al. had also studied the speech of the children with hearing loss and normal hearing and had concluded that the lead voice onset time in normal hearing children was significantly longer than in children with hearing loss. Lag voice onset time was significantly longer in normal hearing children than in children with hearing loss. Standard deviation and range of both lead and lag voice onset time were higher in the normal hearing group. Lead voice onset time in the normal hearing group was longest for dentals and shortest for velar consonants. In the speech of the children with hearing loss, the longest voice onset time was for dentals and shortest was for bilabials respectively. Lag voice onset time in the speech of the children with normal hearing was longest for velars and shortest for retroflex. In the speech of the children with hearing loss, it was velars and bilabials had shown the longest and shortest voice onset time respectively[15].

Shukla had also reported that the majority of the subjects with hearing loss had not shown negative voice onset time for the voiced consonants(27). Similar findings have also been reported by other studies[21]. However, Leeper et al. had reported no significant difference in voice onset time between subjects with hearing loss and normal hearing[13]. The results of the present study are in agreement with the findings of most of the studies except for the findings reported by Leeper et al. According to Osberger and Mc Garr, "the voicing errors evidenced in the speech of subjects with hearing loss may be due to the failure to coordinate the timing of respiration, phonation, and articulation in attempting to produce voicing contrasts"(11). Thus, the present study revealed that while voiced stops were characterised by lead voice onset time, voiceless stops were characterised by lag lead voice onset time. This is in consonance with the results of earlier studies in children[34], in adults[26] and in Kannada[15,27]. In voiceless stops lag lead voice onset time was observed.

The lead voice onset time was significantly longer in the normal hearing subjects. Similar findings have been reported[15,27,35]. They had opined that the shorter voice onset time in the speech of subjects with hearing loss was due to the reduced intraoral pressure. The reduced lead voice onset time was attributed to the reduced intraoral pressure or inability to maintain voicing in the subjects with hearing loss.

The voice onset time for voiceless stops lengthened as the place of articulation moved backwards in the oral cavity. This was in consonance with the results of the earlier studies[15,26,27,36] and was in contrast to the results of the a study done by Kushalraj and Nataraja[37]. Voice onset time varied inversely with the rate at which oral release gesture was made. The duration of the movement of the articulation that formed the closure was greatest for the tongue body, less for the tongue tip and least for the lips[38,39]. Thus, an increase in the time taken for consonantal release leads to an increase in the time taken for the development of a transglottal pressure drop that was sufficient to initiate voicing and to an increased voice onset time. Hence voice onset time was shortest for retroflex/bilabial and longest for velar stop consonants. Therefore, it was inferred from the results of the present study that the participants with hearing loss had significantly shorter voice onset time in the production of voiced stop consonants and there were no significant differences in the voice onset time of the unvoiced stop consonants.

Burst duration

Stop consonant /k/ in the initial position had the highest mean and SD values of burst duration values in the speech of participants of Group 1, as noticed from **Table 3**. /b/ in the initial position had the lowest mean and SD values of burst duration. The Burst duration values in the speech of the participants of Group 1 ranged from 8.09 ms in /d/ in the initial position to 27.22 ms in /d/ in the medial position. Whereas the highest and lowest mean burst duration values were noted in /k/ and /d/ (in the initial position) respectively, for the participants of Group 2. Highest SD values were found for /g/ and the lowest SD values were found for /d/ (in the initial position). The burst duration values in the utterances of the participants of Group 2 varied from 6.54 ms (in /d/ in the initial position) to 22.56 ms (in /ṭ/ in the initial position). The mean burst duration of all the stop consonants, except for /ṭ/ and /d/ in the initial position and for /p/ and /d/ in medial position were lower in Group 1 than in Group 2. However, Group 1 showed a lower range of burst duration than Group 2.

Table 3 also shows the results of the comparison of the burst durations of Group 1 and Group 2 using the Independent sample t-test. The results of the independent sample t-test showed that there were no significant differences between the burst duration of consonants uttered by the participants of Group 1 and Group 2. Therefore, it was concluded based on these results and the mean burst values, that the participants with hearing loss and normal hearing had similar burst duration values.

Studies have found that the participants with hearing loss had a longer burst duration than age and gender-matched controls. The study also found that the voiced plosives had longer burst duration compared to the voiceless[15,21,24]. The present study has also shown that even though there were no significant differences in the burst duration of consonants between the subjects with hearing loss and normal hearing, the participants with hearing loss had longer burst durations than the participants with normal hearing. Thus, the results of the present study were in accordance with the findings of the earlier studies.

Studies have found that the longer burst duration in the speech of children with hearing loss indicated that the children with hearing loss had tense articulators resulting in longer burst durations. Most of the times, a singleton plosive was substituted by a geminate cluster, especially for voiced plosives by the children with hearing loss[15]. This was probably the reason as to why the voiced plosives had longer burst duration compared to unvoiced plosives. Another interesting finding was that velars had the longest burst duration and retroflex had the shortest burst duration. This was in consonance with the earlier studies. It was thus inferred that velars were produced by a bulkier articulator, that is the back of the tongue and retroflex were produced by the tip of the tongue. When a bulky articulator was involved, the time taken for its movement was longer and also resulted in multiple articulatory releases.

The energy in the transient release varies as a function of several factors, including the cross-sectional area of the constriction just after release, the resonant cavity in front of the point of release, perhaps, the release gesture itself. Thus for /b/, for which, there was essentially no front cavity and for which the release gesture was rapid[40], usually displayed a weak transient. While for /g/, for which the cross-sectional area between tongue and palate was relatively large, and the front cavity was narrowly tuned, and for which tongue release was relatively slow, displayed the longest burst of the three stops, including on occasion as Fischer-Jorgensen noted, a “double” release transient perhaps was due to a suction effect. Burst energy for /d/, with the smaller cross-sectional area between the tongue and alveolar ridge and a more broadly tuned front cavity for /b/, was in the midway. The present study also evidenced similar results and thus supports the findings of these earlier studies[41].

Consonant duration

Inspection of **Table 4** show that /b/ in the medial position had the highest values and /t/ in the initial position had the lowest values of consonant duration in the utterances of the participants of Group 1. /t/ in the initial position showed the lowest SD values, and /g/ in the medial position showed the highest SD values. The consonant duration ranged from 543.56 ms in /g/ (medial position) to 26.56 ms in /p/ (initial position). The stop consonant /p/ in the medial position showed the highest values of consonant duration in words uttered by the participants of Group 2, and the lowest mean consonant duration was observed for /t/ in the initial position. Lowest SD value was found for /t/ in the initial position, and the highest SD value was noted for /p/ in the medial position. The range of consonant duration values varied from 139.59 ms (/p/ in the medial position) to 14.96 ms (/t/ in the initial position). The mean duration values of for all the stop consonants in the utterances of the participants of Group 1 were higher than that of Group 2 except for /p/ and /t̪/ in the initial position. The consonant duration in the utterances of the participants of Group 1 showed larger variability than in Group 2. The range of the consonant duration was also higher in the utterances of the participants Group 1 than that of Group 2.

Inspection of Table 4 also show that /b/ in the medial position had the highest values and /t/ in the initial position had the lowest values of consonant duration in the utterances of the participants of Group 1. /t/ in the initial position showed the lowest SD values, and /g/ in the medial position showed the highest SD values. The consonant duration ranged from 543.56 ms in /g/ (medial position) to 26.56 ms in /p/ (initial position). The stop consonant /p/ in the medial position showed the highest values of consonant duration in words uttered by the participants of Group 2, and the lowest mean consonant duration was observed for /t/ in the initial position. Lowest SD value was found for /t/ in the initial position, and the highest SD value was noted for /p/ in the medial position. The range of consonant duration values varied from 139.59 ms (/p/ in the medial position) to 14.96 ms (/t/ in the initial position). The mean duration values of for all the stop consonants in the utterances of the participants of Group 1 were higher than that of Group 2 except for /p/ and /t̪/ in the initial position. The consonant duration in the utterances of the participants of Group 1 showed larger variability than in Group 2. The range of the consonant duration was also higher in the utterances of the participants Group 1 than that of Group 2.

Table 4 also shows the results of the independent samples t-test comparing the consonant duration presented by the participants of both the groups. Significant differences between Group 1 and Group 2, were observed, in the consonant duration of all the stop consonants except for the stop consonant p/, /t/, /k/, /t̪/, and /b/ in the initial position and /g/ in the medial position. These results and the mean values observed led to the conclusion that the participants with hearing loss had significantly longer consonant duration values compared to the participants with normal hearing.

Studies have found that the consonant duration was longer and the range was higher in the subjects with hearing loss compared to the subjects with normal hearing. Further, these studies had also revealed that the standard deviation values of the consonant duration were higher in the participants with hearing loss compared to the subjects with normal hearing[15,20,21,27]. The results of the present study have also been in agreement with the findings of the earlier studies.

Nataraja et al had studied hearing-impaired subjects and normal hearing subjects within the age range of ten to eleven years and had reported that the normal hearing subjects had higher mean for consonant duration of voiceless phonemes whereas the hearing impaired had it for voiceless phonemes. The study also showed that the increase in consonant duration in subjects with hearing loss was due to exaggerated articulation in the subjects with hearing loss. Exaggerated articulation had resulted in a tensed articulator, which had required greater air pressure for the release. The buildup of greater air pressure behind the articulator must have taken a long time for the release of the articulator, enhancing the closure duration, burst duration and the voice onset time, which in turn prolonged the consonant duration. Also, the high range of consonant duration in the speech of subjects with hearing loss was attributed to the greater variability exhibited by the children with hearing loss[15]. As the results of the present study also showed that the consonant duration in the speech of the subjects with hearing loss was significantly higher than that of normal hearing children, the results of the present study support the findings of the earlier study.

Vowel duration

The average values of vowel durations of repetitions of each word were determined and have been presented in **Table 5**. The vowel /o:/ had shown the highest mean and the vowel /e:/ had shown the lowest mean values in Group 1, as noticed from Table 3.19 and Graph 3.5. The vowels /i/ and /e:/ had the highest and lowest SD values. The vowel duration ranged from

167.04 ms (in the vowel /e:/) to 349.78 ms (in the vowel /o:/). The vowel /e:/ and vowel /e/ had shown the highest and lowest mean and SD values of vowel durations, respectively, in the utterances of participants of Group 2. The range of the vowel duration varied from 71.48 ms in the vowel /a/ to 123.45 ms in the vowel /o:/. The mean vowel durations of Group 1 were higher than Group 2 except for the vowel /e:/. Group 1 showed higher variability in the vowel durations than that of Group 2. The range of the vowel duration was also higher in Group 1 compared to that of Group 2.

Table 5 also shows the results of the Independent samples t-test comparing the vowel duration between the participants of both the groups. It was observed from Table 3.20 that there were significant differences in the vowel duration between Group 1 and Group 2 in all the vowels, except for /i/, /u/, and /o:/. It was concluded, based on these results and the mean values, that the participants with hearing loss showed significantly longer duration for the vowels compared to the participants with normal hearing.

Vowel durations are found to be longer in the voiced consonant environment compared with the voiceless environment in the utterances of the subjects with hearing loss[16]. The results of the present study have been partly in agreement with these results as longer durations of vowels were noted only in voiced dental and bilabial consonant environment compared to their unvoiced counterparts in the speech of the participants with hearing loss. Past studies have found that the subjects with hearing loss had significantly longer vowel duration values compared to that of the normal hearing subjects[15,23,42,43]. Sony had also reported that the vowel duration was substantially longer and the SD values were also higher in the speech of the participants with hearing loss compared to that of the participants with normal hearing[21].

Studies have analysed the characteristics of vowels in participants with normal hearing and hearing loss and found significantly longer vowel duration in the speech of the participants with hearing loss compared to that of the normal-hearing[18,19,44,45]. As the results of the present study also showed that the vowel duration in participants with hearing loss was longer and variability was also higher compared to the normal-hearing participants, it can be stated that the results of the present study have been similar to the findings of the earlier studies. Thus, the participants with hearing loss had significantly longer vowel duration values compared to the participants with normal hearing, as per the results of the present study.

Conclusion

The objective of the study was to analyse the temporal parameters of vowel and consonants in the speech in children with hearing loss. Sixteen bisyllabic words with stop consonants and vowels, uttered by participants with severe sensorineural hearing loss and age and gender-matched normal hearing participants in the age range of eight to ten years were recorded and the temporal parameters namely vowel duration, closure duration, consonant duration, voice onset time, burst duration, and word duration were analysed acoustically. Results of statistical analyses revealed that there were significant differences in vowel duration, voice onset time, closure duration and consonant duration between the participants of two groups. No differences in burst duration were observed between the participants of both groups. The results of the present study can be used to further determine the effect of corrections or transformations of the temporal parameters to approximate the speech parameters in the speech of normal hearing subjects and to determine the effect of correction of each of the temporal parameters in the speech of participants with hearing loss on their speech intelligibility.

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Tables

Table 1: *Mean (in ms), Standard Deviation (SD) and the results of the Independent sample t-test comparing the closure duration in the utterances of the participants of both the groups.*

	Group 1		**Group 2**		**t value**	**df**	***p*-value**
	Mean	**SD**	**Mean**	**SD**			
/p/	214.38	77.74	147.16	33.84	-2.50	12.29	0.02*
/t/	162.12	62.31	112.07	7.80	-2.52	9.28	0.03*
/k/	195.78	86.97	117.98	19.32	-2.761	9.88	0.02*
/ṭ/	167.83	39.96	118.27	20.01	-3.50	18	0.00*
/b/	212.35	105.01	80.18	15.36	-3.93	9.38	0.00*
/d/	195.25	133.53	61.88	8.62	-3.15	9.07	0.01*
/g/	209.70	173.13	67.80	10.96	-2.58	9.07	0.02*
/ḍ/	156.07	72.46	52.94	18.62	-4.35	10.18	0.00*

Mean- measured in ms, SD- standard deviation, * At 0.05 level of significance.

Table 2: *Mean (in ms), Standard Deviation (SD) and range of voice onset time of the consonants in the words uttered by the in the utterances of the participants of both the groups.*

		Group 1			**Group 2**			**t value**	**df**	***p*-value**
	Position	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**			
/p/	I	4.02	20.05	61.97	17.64	5.92	18.91	2.05	18	0.65
/p/	M	8.15	18.6	61.99	16.34	8.23	29.91	1.27	18	0.21
/t/	I	7.25	11.19	35.95	13.26	9.47	28.75	1.29	18	0.21
/t/	M	9.28	9.2	24.79	12.06	10.30	28.43	0.63	18	0.53
/k/	I	31.78	21.24	56.01	24.75	5.30	19.43	-1.01	10.1	0.33
/k/	M	31.28	23.2	61.57	20.76	4.9	14.78	-1.39	9.81	0.19
/ṭ/	I	12.22	15.7	46.23	8.45	9.32	24.54	1.29	18	0.21
/ṭ/	M	10.42	13.8	45.02	7.67	9.6	22.96	-0.51	18	0.61
/b/	I	-24.93	33.68	101.02	-66.64	15.91	44.38	-3.62	13.03	0.00*
/b/	M	-28.94	41.50	141.02	-66.65	17.20	54.38	-2.65	18	0.01*
/d/	I	-20.34	40.32	151.23	-81.62	20.23	75.03	-3.50	18	0.00*
/d/	M	-29.33	32.90	101.87	-75.72	20.80	67.23	-3.76	18	0.00*
/g/	I	-19.92	42.59	134.21	-78.96	32.08	105.50	-2.76	9.88	0.02*
/g/	M	-25.92	55.20	174.21	-89.86	39.50	119.93	-3.76	18	0.00*
/ḍ/	I	-20.56	43.34	144.11	-76.43	34.21	106.23	-2.58	9.07	0.02*
/ḍ/	M	-40.10	52.30	182.70	-86.61	26.30	80.83	-2.51	18	0.02*

Mean- measured in ms, SD- standard deviation, I- Initial position, M- Medial position, *At 0.05 level of significance.

Table 3: *Mean (in ms), Standard Deviation (SD) and range of burst duration of the consonants in the words uttered by the in the utterances of the participants of both the groups.*

		Group 1			**Group 2**			**t value**	**df**	***p*-value**
	Position	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**			
/p/	I	17.51	4.69	10.72	19.33	4.17	14.05	2.058	10.56	0.06
/p/	M	19.50	5.73	16.65	18.62	2.47	7.85	-0.44	12.22	0.66
/t/	I	17.30	5.50	16.90	19.30	4.91	18.15	-0.85	18	0.40
/t/	M	19.30	6.71	16.39	20.30	3.78	12.95	0.40	18	0.68
/k/	I	24.45	8.40	23.12	24.82	6.06	21.22	0.11	18	0.91
/k/	M	22.23	7.65	21.23	22.34	5.34	20.54	0.17	18	0.86
/ṭ/	I	18.55	4.12	13.36	18.07	6.12	22.56	-0.20	18	0.84
/ṭ/	M	18.21	5.34	14.23	18.72	5.23	20.12	1.27	18	0.21
/b/	I	13.70	3.19	8.92	14.56	3.86	11.73	0.54	18	0.59
/b/	M	13.90	5.75	18.92	15.35	3.32	9.83	0.69	18	0.49
/d/	I	13.88	3.29	8.09	13.34	2.27	6.54	-0.43	18	0.67
/d/	M	24.44	8.07	27.22	20.01	5.48	18.93	1.77	18	0.09
/g/	I	19.36	7.76	19.02	23.51	6.35	22.50	1.41	18	0.17
/g/	M	14.34	5.65	17.34	20.21	4.72	19.34	0.63	18	0.53
/ḍ/	I	16.46	4.62	13.71	13.88	4.27	14.60	-1.29	18	0.21
/ḍ/	M	15.21	5.45	14.20	14.21	5.23	13.62	2.05	18	0.65

Mean- measured in ms, SD- standard deviation, I- Initial position, M- Medial position, *At 0.05 level of significance.

Table 4: *Mean (in ms), Standard Deviation (SD) and range of consonant duration of the consonants in the words uttered by the in participants of both the groups.*

		Group 1			**Group 2**			**t value**	**df**	***p*-value**
	Position	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**			
/p/	1	26.70	10.13	26.56	28.24	8.59	25.05	0.36	18	0.71
/p/	M	248.83	95.33	240.03	170.63	41.83	139.59	-2.37	12.34	0.03*
/t/	1	19.95	9.66	28.29	19.20	5.61	14.96	-0.21	14.44	0.83
/t/	M	188.50	56.85	145.35	133.60	8.86	29.43	-3.01	9.43	0.01*
/k/	1	26.28	12.16	33.83	30.88	7.88	22.90	1.00	18	0.32
/k/	M	250.92	94.12	233.25	156.86	20.07	62.35	-3.09	9.81	0.01*
/ṭ/	1	58.31	13.19	43.94	65.41	20.06	52.36	0.63	18	0.53
/ṭ/	M	220.68	59.58	165.87	145.49	18.35	54.81	-3.81	10.69	0.00*
/b/	1	241.80	83.96	268.28	111.36	15.37	62.52	-6.31	9.60	0.36
/b/	M	252.76	122.74	349.80	96.54	12.56	44.54	-4.00	9.18	0.00*
/d/	I	189.34	124.89	378.34	74.23	13.43	35.28	-3.01	9.43	0.01*
/d/	M	211.53	138.90	364.32	77.22	10.89	32.68	-3.04	9.11	0.01*
/g/	1	179.02	87.24	279.81	139.25	13.71	53.38	-1.42	9.45	0.00*
/g/	M	222.85	203.77	543.56	88.39	11.41	37.35	-2.08	9.05	0.06
/d/	I	188.45	125.34	278.44	75.54	12.45	36.23	-3.62	13.03	0.00*
/ḍ/	M	159.34	87.64	232.15	69.53	18.84	60.07	-3.16	9.83	0.01*

Mean- measured in ms, SD- standard deviation, I- Initial position, M- Medial position, *At 0.05 level of significance.

Table 5: *Mean (in ms), Standard Deviation (SD) and range of vowel duration of the vowels in the words uttered by the in the utterances of the participants of both the groups.*

	Group 1			**Group 2**			**t value**	**df**	***p*-value**
Target vowel	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**			
a	246.69	86.45	253.60	192.12	31.65	71.48	-2.70	18	0.01*
i	276.23	126.59	326.86	221.12	37.32	89.53	-1.91	10.77	0.08
e	246.13	92.24	265.54	174.55	30.92	80.42	-2.55	13.13	0.02*
u	261.42	108.90	272.33	236.33	35.36	85.05	-0.35	18	0.72
a:	217.22	66.14	180.98	196.34	32.31	89.81	-2.98	12.07	0.01*
o:	276.91	121.37	349.78	235.64	43.56	123.45	-1.12	18	0.27
e:	206.42	58.87	167.04	298.58	46.75	110.19	-2.80	9.85	0.01*

Mean- measured in ms, SD- standard deviation, *At 0.05 level of significance.