Durational Characterstics of Hindi Consonant Clusters

Nisheeth Shrotriya, Rajesh Verma, S.K. Gupta[1] and S.S. Agrawal

Speech Technology Group
Central Electronics Engineering Research Institute, Delhi Centre
NPL Campus, CSIR Complex, Hill Side Road, New Delhi-110 012, INDIA

ABSTRACT

In the present study various durations of closure, preceding vowel etc. have been studied in meaningful Hindi two consonant cluster words with stop consonants (such as /sʌptah/ (week) and /ʃʌ bd (word)). The data included 80 most frequently occurring clusters of Hindi language. All these words were recorded by five male speakers and analysed using the Sensimetrics speech station software package. The analysis showed some very interesting features of the clusters such as closure duration of the clusters is found to play a very important role for the different categories of stop consonants. Further the duration of the voice bar and the vowel preceding the cluster ($-C_1C_2$) is shortened in a cluster words as compared to that for a non-cluster word.

1. INTRODUCTION

The present paper describes an experiment conducted to study the duration of consonant clusters for Hindi language. However such efforts have been made by the researchers of other languages e.g. Swedish (5), English (3,6), Arabic (2) and French (1,7). These studies were conducted to study the compression effect undergone by the vowels and consonants during the occurrence of the cluster. And to define rules which could be used for the synthesis of these words.

Lindblom (5) noted a 15 ms decrease in the duration of the adjacent vowel for the three consonant cluster /str/. This decrease in the duration of the vowel was independent of whether the cluster was pre or post vocalic. He also found that the length of the consonant segments decreases as the cluster size increases. The position of a cluster in a word was also found to have an effect on its duration. Consonant clusters were found longer in word final than in word initial position.

The shortening of the vowel/consonant was also studied by Haggard (3) and Klatt (4). Haggard found that /t/ in "cot" was 21% greater than that in "cost". Klatt showed that a prevocalic, isolated /s/ has a duration of 152 ms, whereas the /s/ in /st/ and /str/ has a duration of 110 ms and 102 ms respectively.

This systematic shortening of the cluster consonants has been interpreted in different ways. Klatt (4) and Haggard (3) explains this shortening due to physiological factors; the anticipation of the consonants is thought to lead to an acceleration in the speech rate. In one of our earlier studies (11) we have shown that gemination (when the two consonants are same) affects the duration of the vowel preceding the geminated stop as well as the closure duration.

Keeping all these facts in mind the following experiment was conducted to anlayse the Hindi consonant cluster words and form rules for their synthesis, which will be incorporated in the Text to Speech system being developed for Hindi language (16).

2. MATERIAL

Most frequently occuring cluster words were selected out of a data base of 250,000 Hindi words. The data base showed that in Hindi language clusters are found in three positons of a word i.e. initial, medial and final. We wanted to take the

Stop-stop cluster combinations	No. of words for each category
/tt/, /kk/	7 x 2 = 14
/pp/, /tt^h/	6 x 2 = 12
/tp/, /tk/, /kt/, /ṭṭ/	5 x 4 = 20
/dd^h/	4 x 1 = 4
/pt/, /bb/, /dd/, /db^h/, /tt^h/ /ḍḍ/	3 x 6 = 18
/bd/, /bd^h/, /dg/, /gg/, /kk^h/	2 x 5 = 10
/gg^h/, /gd^h/	1 x 2 = 2
Total 22 combinations	80 words

Table 1: Stop-stop cluster combinations and number of words in each category.

samples of all possible stop-stop consonant cluster combinations, but in Hindi language so many stop consonants do not form cluster combinations. Further we decided to take only sensible words, reason being that the acoustical properties of the speech sounds highly depend on the dialectal background of speaker. This way we had a total of 80 cluster

[1] Dept. of Physics, A.M.U., Aligarh, INDIA

words which included 54 words with cluster in the medial position and 26 words with cluster in the final position. There were no words in our data with cluster occuring in the initial position. Table 1 shows the stop-stop cluster combinations and the number of words in each category which were chosen for the present study.

3. ANALYSIS PROCEDURE

Five adult male speakers, with normal speech articulation recorded the speech samples. All the speakers were bilingual in the sense that they had Hindi educational background atleast upto senior schooling. All the cluster words were randomized to avoid contextual effects which would be associated with an unvarying order and then recorded on a TEAC cassette deck (model C-2X) using Sennheiser microphone (Model MD-421). The recording was done in the free field of the partially acoustic treated room. All the recorded words were filtered at 70Hz - 7KHz and then digitized at 16 bit, 16k samples per second using Ariel's DSP-16 card on a PC-AT 486. The speech samples were analysed using a Sensimetrics speech analysis package to obtain the audio wave form and spectrograms etc.

4. RESULTS AND DISCUSSIONS

4.1. Closure Duration:

The results of closure duration are presented in the form of rules in Table 2. Closure duration plays an important role for the differentiation between the various categories of stop consonant cluster words. It has different values for different places of articulation. It was found to have greater values for all the categories of Unvoiced stop cluster words as compared to that for the Voiced stop cluster words.

Cluster Combination	No. of Samples	Closure Duration (msec)
Same Unvoiced Stops	25	199
Same Voiced Stops	11	166
Different Unvoiced Stops	17	197
Different Voiced Stops	04	152
UVUA-UVA	11	166
VUA-VA	12	148

UVUA: Unvoiced Unaspirated; UVA : Unvoiced Aspirated
VUA : Voiced Unaspirated ; VA : Voiced Aspirated

Table 2: Closure durations for the different categories of stop-stop consonant cluster words.

For the same unvoiced stop clusters the closure duration was greater by 17% as compared to that for the same voiced stops. Similarly it had greater value of closure for the different unvoiced stop clusters by 15% than that for the different voiced stops. Further the closure duration for UVUA-UVA combination was greater than that for the VUA-VA combination by 9%. There is an overall difference of about 17% betwen the values of closure for the Unvoiced and Voiced stops, former being the greater.

These results about the closure duration are in agreement with the earlier findings (8, 9, 10) in the sense that the closure duration for unvoiced stops are longer than that of voiced.

4.2 Preceding Vowel Duration

The duration of the vowel preceding the cluster ($-C_1C_2-$) was found to be affected. Vowels preceding the cluster were shortened by about 10 to 15 msec as compared to the situation when there is no cluster (e.g. /sʌlkar/ and /sʌkar/). This could be due to the fastening of the speech. While speaking a cluster word articulators move very fast and stress is put on the following portion of the cluster.

Further the vowels before the voiced stop were found to have larger values. This tendancy is found in several other languages (11, 12). The magnitude of the difference of the present study is congruent with that in most of the languages except English. In English the vowels before the voiced consonants can be as much as 50% longer than before voiceless. It is widely believed that this aspect of vowel duration is phonologized in English i.e. is not strictly a phonetically based effect (except that it may be a phonolodized exaggeration of an original phonetic effext (13, 14).

4.3 Voice Onset Time

The voice onset time (VoT) was measured for the second stop consonant of the cluster (C_1C_2) i.e. for C_2 and compared with its VOT in the non-cluster word. The VOT of the consonants in cluster words was found to have greater values than that for the non-cluster words.

Cluster Combination	VOT in Cluster (msec)	VOT in non-cluster (msec)
/-pt-/	15	10
/-tp-/	16	Burst not found for /p/
/-tk-/	29	15
/-kt-/	20	16
/-bd-/	12	07
/-dg-/	30	09

Table 3: Comparison of Voice Onset Time in clusters and non-cluster words.

Further the VOT was very large for the velars, however it may be, because for velars most of the time two bursts were observed and the VOT was measured form the onset of the first burst. The difference between the VOT values of /k/, /g/ and /d/ for cluster was double and some time more than double as compared to that for non-clusters. These results are shown in Table3.

4.4 Other Observations

An interesting phenomenon was noted for those stop-stop consonant clusters, which differed in their place of articulation. An additional burst/spike of duration less than 5 ms, occurred in the middle region of the closure, otherwise there was no such additional burst in the closure. This is shown in Fig. 1, here we have two words /slkka/ and /tʌtpʌr/ . In case of the words like /slkka/ where the two consonants are same the additional burst was not observed in the closure. However for /tʌt pʌr/ where the two consonants (C_1C_2) differ in their place of articulation the additional burst can be seen in the closure.

This burst may be due to the shortening of the cluster consonant. And this shortening phenomenon may be attributed due to the physiological factors; the anticipation of the consonant(s) is thought to lead to an acceleration in the speech rate, resulting shortening of the consonant.

For such cases where the additonal burst was observed the closure duration was noted on both sides of the burst i.e. for C_1 as well as C_2. The results show that these stop consonants when occur in a cluster word have different closure durations as compared to that when occur in a non-cluster word. This duration also seems to depend upon the position of the cluster in a word.

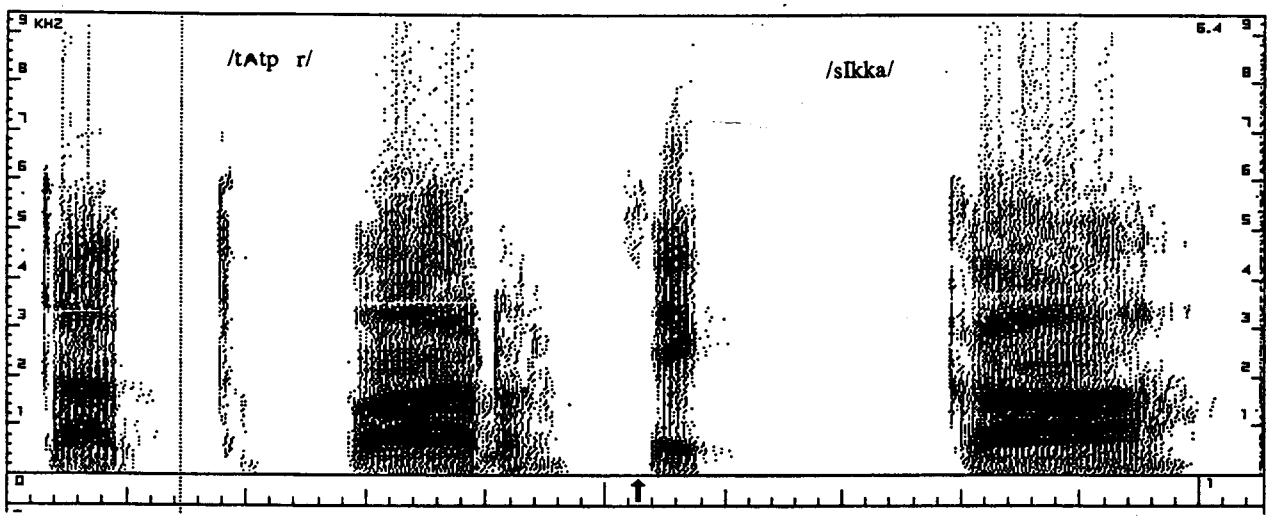

Figure 1: Spectrograms of words / tʌtpʌr/ and /slkka/ showing the fact that an additional burst is observd when the two consonants of the cluster differ in their place of articulation.

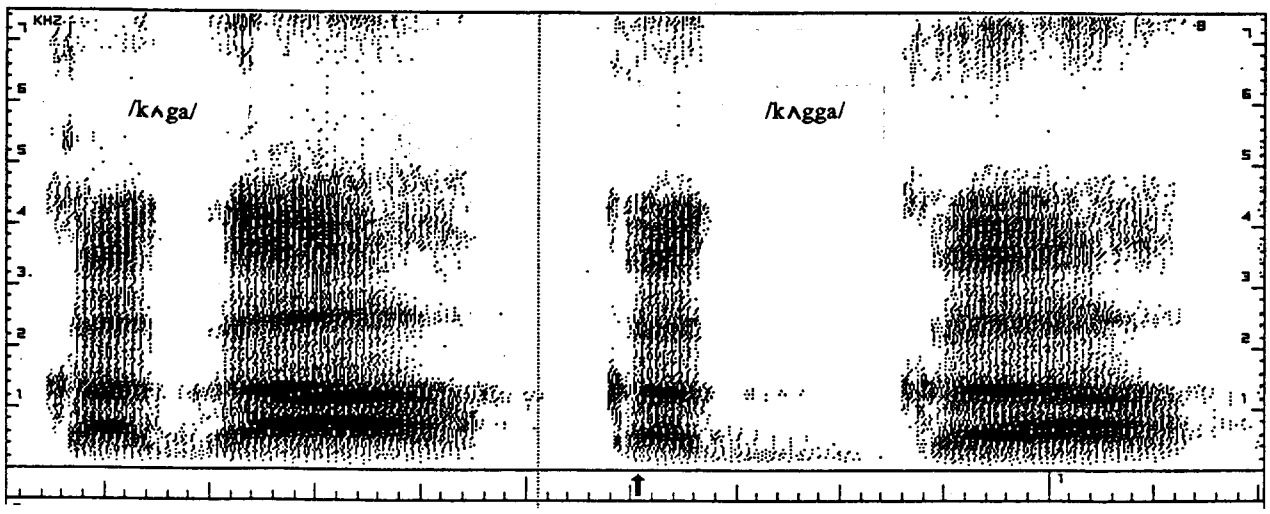

Figure 2: Spectrograms of /kʌga/ and /kʌgga/ indicating that the voice bar is shortened by 15-20 msec in case of the cluster/geminate words whereas it remains through out the closure of a non-cluster/non-geminate word.

These results are shown in Table 4. For example the closure duration of /p/ while occuring with /t/ at C_1 or C_2 position is decreased as compared to that in a non-cluster word. Similarly /k/ has a reduced closure duration at both positions i.e. C1 as well as C_2 while occuring with /t/. However in case of /t/ the closure duration is decreased at C_1 position and increased at C_2 position while occuring with /k/.

Non-Cluster	C D (msec)	Cluster	C D (msec)	
			C_1	C_2
/p/	125	/-tp-/	95	107
/t/	100	/-pt-/	110	130
/k/	110	/-tk-/	98	070
		/-kt-/	55	193

Table 4: Closure durations for those stops for which an additional burst was observed in the closure.

Another interesting feature which seems to be of particular importance is that in case of the voiced stop clusters the voicing was found to have ceased by 5 to 20 msec prior to the stop release. However in case of the noncluster words the voicing is found throughout the closure. This effect can be seen in Figure 2 where the spectrograph of the words /kʌga/ and /kʌgga/ are shown.

5. CONCLUSIONS

The following conclusions can be made on the basis of the above study:
(1) The durations of the vowel preceding the cluster is reduced.
(2) The closure duration is differently effected due to clustering depending upon the different places of articulation.
(3) When the two consonants of the cluster differ in place of articulation, an additional burst is observed in the closure.
(4) VOT of a stop consonant is more in a cluster word as compared to non-cluster word.

6. ACKNOWLEDGMENTS

Award of a Senior Research Fellowship by the Council of Scientific and Industrial Research to one of the authors (Nisheeth Shrotriya) is highly acknowledged. Authors are also thankful to Prof. R.N. Biswas, Director, CEERI for his encouragement and support.

7. REFERENCES

1. Bartkova, K., Sorin , C. "A model of segmental duration for speech synthesis in french", *Speech Communication*, Vol. 6, No. 3, pp. 245-260, 1980.

2. Benkirane, T. "Etude Phonetique et fonctionnelle de la syllable en arabe marocain", Doctoral dissertation, Universite de Provence, Aix-en-provence, 1982.

3. Haggard, M. "Abbreviation of consonants in English pre- and post-vocalic clusters", *J. Phonetics*, Vol. 1, pp. 9-24, 1973a.

4. Klatt, D.H. "Durational characterstics of prestressed word-initial consonant clusters in English", Quart. Progress Report, MIT Research Lab of Electronics, Vol. 108, pp. 253-260, 1973.

5. Lindblom, B. "Some temporal regularities of spoken Sedish", in Auditory Analysis and Perception of Speech, ed. by G. Fant and M. Tatham (Academic press, New York), pp. 387-396, 1973.

6. MacNeilage, P.F. "Electromyographic and acoustic study of the production of certain final clusters", *J. Acous. Soc. Amer.*, Vol. 35, No. 4. pp. 461-463, 1963.

7. Nishinuma, Y., Duez, D., Paboudjian, C. " Autaomatic classification of consonant clusters in French", *Speech Comminication*, 10, 395-403, 1991.

8. Lisker, L., "Closure Duration and the Intervocalic Voiced Voiceless Distinction in English", *Language*, 4331, 42-49., 1957.

9. Reddy, N. *Jour. Instn. Elec. and Telecom. Engrs.*, Vol. 34, No.1, 4571, 1985.

10. Savithri, S.R., *Journal of the Acoustical Society of India*, Vol. 17, No. 1&2, pp 308, 1989.

11. Shrotriya N., Sharma, A.S.S., Verma, R. and Agrawal, S.S. "Acoustical and Perceptual Characterstics of geminated Hindi stop consonants", *Proceedings of ICPhS-95*, Vol. 4, pp. 132-135 , 1995.

12. Chen, M. "Vowel length varoiation as a function of the voicing of the consonant environment, *Phonetica*, 22, 129-159, 1970.

13. Lehiste. I. "Suprasegmentals" Cambridge, MIT Press, 1970.

14. Javkin, H.R. "Phonetic universals and Phonological change: *Report of the phonology Laboratory*, Berkely, No.4., 1979.

15. Kluender, K.R., Diehl, R.L., Wright, B.A. "Vowel length difference between voiced and voiceless consonants: An Auditory explanation, *J. Phonetics*, 16, 153-169, 1988.

16. Verma, R., Sharma, ASS., Shrotriya, N., Sharma, AK., Agrawal, SS. "On the development of text to speech system for Hindi", *Proceedings of ICPhS-95*, Vol. 2, 354-357, 1995.