

Places and Manner of Articulation of Bangla Consonants: A EPG based study

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Abstract

Bangla phoneme inventory consists of 32 consonants out of those 16 are stop or plosive and 4 are affricate. This paper presents the detailed investigation of place and manner of articulation of Bengali phonemes. The place of articulation study of consonants is based on Electropalatography (EPG) system and the manner of articulation study is based on acoustic study of large number of well-spoken Bengali VCV sequences in which V represents the seven Bangla vowels /u/, /o/, /ɔ/, /a/, /æ/, /e/ and /i/ while C represents all the consonants of Bangla. The study shows that in case of Bangla language plosives have three distinct places of articulation namely dental, alveolar and post alveolar and four manner of articulation.

Index Terms: Place of articulation, Manner of articulation, Electropalatography

1. Introduction

Bangla is a part of the Indic group of the Indo-Aryan (IA) branch of the Indo-European family of languages. It is the official state language of the Eastern Indian State of West Bengal and the national language of Bangladesh. It is also spoken in the States neighboring West Bengal, that is, Assam, Bihar, and Orissa as well in the Bengali Diaspora around the world.

Dialect-wise, Bangla is divided into two main branches: Western and Eastern. The Western branch consists of Rarha (South), Varendra (North Central) and Kamrupa (North Bengal) dialect clusters. Rarha is further divided into South Western Bangla (SWB) and Western Bangla, the standard colloquial form of Bangla (SCB) is spoken around Calcutta [1, 2]. The dialects prevalent in the Eastern branch can be clustered into four main regional variants of Barisal, Chittagong, Dhaka and Sylhet. All these varieties show variations in the phonology, morphology, and vocabulary.

Bangla phoneme inventory consists of 32 consonants and 14 vowels (including 7 nasal vowels). Like many other languages of the Indo-Aryan family, Bangla plosives show a four-way contrast in terms of voice and aspiration for four places of articulation. Affricates also show a similar contrast and are often classified with the stops in many traditional grammars. The study of Bangla phonetics has a long history since the early part of the twentieth century. Since the pioneering work of Suniti Kumar Chatterji, a large number of eminent linguists of West Bengal and Bangladesh have contributed to the development of Bangla phonetics. All the previous description of Bangla phonemes is based on human perception. The main objective of this study is to experimentally verify the place and manner of articulation of Bangla Phoneme [3]. This paper describes the first experimental effort for of study of this nature. This study only considers the standard colloquial form of Bangla (SCB).

2. Experimental Setup

The place of articulation is verified using the Electropalatography (EPG) system called Win EPG from Articulate Instruments Ltd. Electropalatography (EPG) namely WinEPG system records the timing and location of tongue contact with the hard palate during continuous speech along with the acoustical signal. The manner of articulation is checked based on the acoustic study of the recorded signal

The technique requires the speaker to wear an artificial palate, which is fitted to the roof of the mouth. Tongue-palate contact is recorded by 62 silver contacts located on the lingual surface of the hard palate. The dynamic tongue-palate contact patterns are displayed live or recorded along with acoustic recording, using software supplied with the instrument. This instrument is now widely used for verification of articulatory position of phonemes for various languages. For these study two custom-made palates, one for male and one for female were made. The place of articulation of the stop consonant and other phonemes of Bangla is verified using the above Electropalatography (EPG) system except the bilabial sounds. The place of articulation of bilabial sound is objectively verified using the movie camera. The Electropalatography (EPG) system can provide the contact information up to velar region. The custom made palate consists of 62 contact points (electrodes) [4]. The contact points are represented as black. The 62 electrodes are distributed in eight rows, which correspond to particular articulatory regions as shown in Figure-1. The manner of articulation is verified using the acoustic evidence of the phoneme.

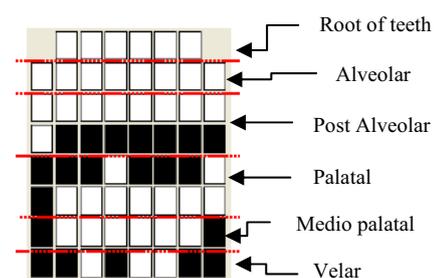


Figure 1: Articulatory regions of the custom made palate

3. Speech material

Simultaneous EPG and acoustic data were recorded. The informant read out a set of nonsense VCV sequences in which V represents the seven Bangla vowels /u/, /o/, /ɔ/, /a/, /æ/, /e/ and /i/ while C represents all the consonants of Bangla. Ten repetitions of the VCV form were recorded for each speaker for the analysis of plosive consonant. For the analysis of stop, same ten repetitions of VC sequence were recorded of the same informant.

Based on acoustic analysis the manner of articulation of consonants was determined. For this purpose

data in VCV context was taken from the 850 Bengali sentences [5]. Altogether speech data of 5 speakers (2 male & 3 female) had been considered for this study. All of them are native speakers of Standard Colloquial Bangla. For the analysis of voiced consonants only those VCV segments were considered in which the occlusion period shows distinct voice bar. Similarly for unvoiced one, only those VCV segments having no voicing in the occlusion region were considered. The number of different VCV segments for different consonants is given in table 1.

Table 1. List of different VCV segments

Type of VCV segments	No. of segments
Unvoiced un-aspirated velar plosive	256
Unvoiced un-aspirated retroflex plosive	276
Unvoiced un-aspirated dental plosive	263
Unvoiced un-aspirated bilabial plosive	242
Unvoiced aspirated velar plosive	260
Unvoiced aspirated retroflex plosive	151
Unvoiced aspirated dental plosive	228
Unvoiced aspirated bilabial plosive	69
Voiced un-aspirated velar plosive	206
Voiced un-aspirated retroflex plosive	49
Voiced un-aspirated dental plosive	186
Voiced un-aspirated bilabial plosive	200
Voiced aspirated velar plosive	117
Voiced aspirated retroflex plosive	28
Voiced aspirated dental plosive	110
Voiced aspirated bilabial plosive	65

It was seen that for un-aspirated voiced and aspirated voiced retroflex plosives the number of data were remarkably low; as in Bangla the occurrence of these consonants in VCV context is very rare. The same phenomena had been also observed in the case of aspirated unvoiced and aspirated voiced bilabial plosives.

4. Methodology

The prepared recording material (as in section 3) was read out by one male and female informants, wearing the artificial sensor palate. The EPG dynamic contact information was recorded in a personal computer with a sampling frequency of 100 Hz along with the acoustic signal using a microphone supplied with the instrument at 22050 sampling frequency 16 bits Mono PCM format. To reduce inconvenience to informants, the recording sessions were limited to 20 minutes duration.

In case of plosive/stop three variables were analyzed: place of release, place of closure and amount of contact area for both the cases. The beginning of the occlusion is identified at the time when contact point spread from left to right end uninterruptedly showing a complete separation of the front and back halves of the palate. However for velars, complete closure is not always revealed. In these cases the frame, which presents the maximum closure, is taken as the frame of closure. Similarly release frames are identified as the ones just before the opening of the closure. For fricatives and affricates the frame, which reveals the maximum constriction, is used. In case of lateral, nasal murmur and trill/flap the middle frame of the complete closure is considered.

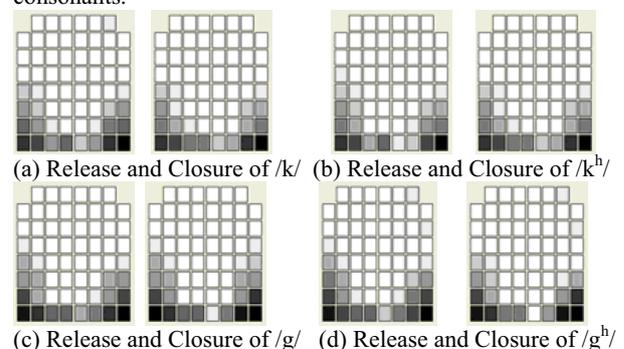
The average of the 10 repetitions for each of the consonant in single vowel context represents the place of articulation of that consonant in the context of that vowel. Finally the place of articulation and the area of contact are determined by the average of all the vowels of both the informants.

5. Result and Discussion

5.1. Plosive and Stop

In Bangla there are four types of plosive consonants according to their manner of production 1) Un-aspirated unvoiced plosives like /k/, /p/ 2) Aspirated unvoiced plosives like /k^h/, /p^h/ 3) Un-aspirated voiced plosives like /g/, /b/ and 4) Aspirated voiced plosives like /g^h/, /b^h/. In aspirated plosive sounds there is an aspiration after the burst. Aspiration is basically the turbulence produced at glottis when it is slightly open. In unvoiced plosives the glottis closes with a small delay after plosion. This delay is known as Voice Onset Time (VOT). The air stream passing through the slightly open glottis often generates some turbulence. When the length of VOT is large enough to make it acoustically perceptible, one hears them as the aspirated counterpart of the phonemes. However even for un-aspirated plosives the VOT still exhibits signature of aspirations but the duration being so small that it is not perceived as aspirated phonemes. In the case of plosives for the measurement of place of release and contact area the EPG frame just before the opening of contact is used. In case of stops the EPG frame corresponding to the beginning of the complete closure is used. For the place of release or place of closure the particular row/rows of EPG frame, which contains the maximum number of contact, is considered. Contact area is measured by the number of contacts made to the total number of electrodes in the whole EPG frame and is expressed as percentage.

All the frames of each of the seven vowels for an individual speaker are collected from the recording. Then each EPG frame is converted into binary matrix by putting 1 in case contact is made (represented by Black) and 0 in case of non-contact (represented by White). The value of each cell is computed by adding the number of 1's for all the frames of the speaker. Then these values are divided by the number of frames obtained by the speaker for that context. This is the average representative frame for that particular context. The overall place of release for each speaker is determined by averaging all the EPG Frame of all the seven vowels. The final place of release is determined after averaging all the data of both speakers. Place of closure is also determined by the same manner. In case of closure only the recording of VC form of the entire stop consonant is considered. Figure 2 represents the overall place of release and closure of the consonant /k/, /k^h/, /g/, /g^h/, /t/, /t^h/, /d/, /d^h/, /n/, /n^h/, /l/, and /l^h/ respectively. It is observed from the figures that place of release and the place of closure of the above Bengali plosive and stop are same. Figure 3 represents the average contact area for all the above consonants.



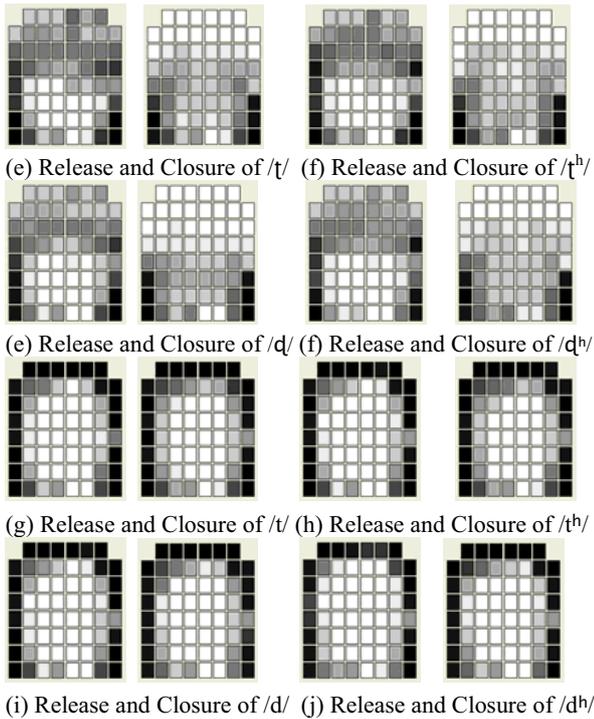


Figure 2: EPG plots of overall place of release and closure

After analyzing the EPG frame data it is observed that there is no closure in the entire artificial palate region for the bilabial consonant /p/, /p^h/, /b/, /b^h/. The video of lip movement of the informant is recorded during the production of this sound and from the video evidence the release is found in the lip region.

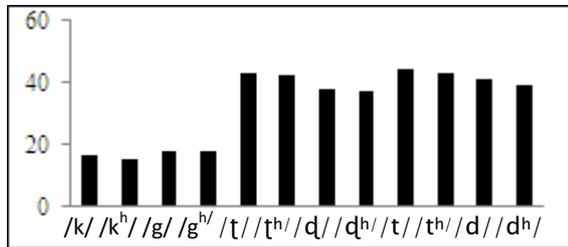


Figure 3: Average area of contact for different plosive

Figure 4 represents the lip closure for the bilabial consonant with neutral vowel /ɔ/. After analyzing the acoustic segment as mentioned in section 3, Table 2 represents the average duration of occlusion period and VOT along with the standard deviation.

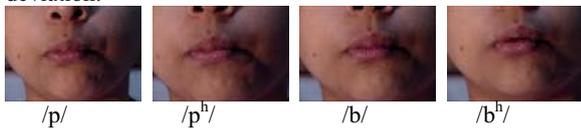


Figure 4: The release frames of lips for bilabial consonant

It is observed from figure 2 and figure 4 that in case of consonants /k/, /k^h/, /g/, /g^h/ the place of release and closure are both Velar so place of articulation of those consonant is velar. Similarly for the consonant /t/, /t^h/, /d/, /d^h/ the place of articulation is Post alveolar and retroflex. For /t/, /t^h/, /d/, /d^h/ the place of articulation is dental. The place of articulation for /p/, /p^h/, /b/, /b^h/ is bilabial. It is also observed from the table 2 that manner of articulation for consonant /k/, /t/, /t/, /p/ is unvoiced and un-aspirated since there is no voice bar during the occlusion period and the VOT is very small. Similarly

there is no voice bar during the occlusion period and VOT is large in case of /k^h/, /t^h/, /t^h/, /p^h/. So those are unvoiced aspirated consonant. In case of /g/, /d/, /d/, /b/ voice bar is observed during the occlusion period and VOT is small so those are voiced un-aspirated consonants and /g^h/, /d^h/, /d^h/, /b^h/ is voiced aspirated consonants.

Table 2. Area of contact with respect to different vowels

Consonants	Occlusion duration [in ms]		VOT duration [in ms]	
	Avg.	Stdv	Avg.	Stdv.
/k/	55.76	15.6	7.18	4.11
/k ^h /	50.23	13.72	46.63	17.69
/g/	44.42	11.22	4.47	2.63
/g ^h /	44.99	13.32	45.89	21.93
/t/	59.77	18.9	3.06	1.31
/t ^h /	58.26	19.07	44.05	16.94
/d/	59.57	17.33	3.31	1.55
/d ^h /	54.33	16.16	48.7	13.26
/t/	64.93	17.6	3.94	1.88
/t ^h /	49.32	17.73	28.02	14.51
/d/	48.86	14.31	3.03	1.82
/d ^h /	42.05	14.68	48.35	17.13
/p/	70.49	21.58	3.59	2.05
/p ^h /	47.41	16.44	32.11	15.11
/b/	51.72	14.42	2.76	1.13
/b ^h /	49.59	14.6	52.51	23.0

5.2. Fricative

Fricative or sibilant sounds are generated by constricting the vocal tract at some point along the vocal tract and forcing the air stream to flow through at a high enough velocity to produce turbulence. The place of articulation of the friction is determined by the EPG frame where the opening is narrowest. Figure 5 represents the overall place of constriction that produces the friction for the fricative consonant /s/, /s/, /h/.

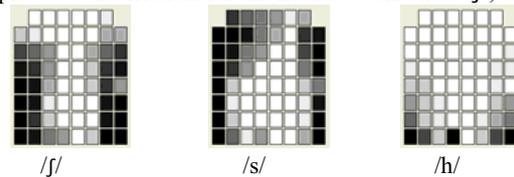


Figure 5: EPG plots of overall place of constriction

5.3. Affricate

An affricate is a combination of plosive and fricative. In Bangla there are again four types of affricates according to their manner of production, 1) un-aspirated unvoiced affricates /tʃ/, 2) aspirated unvoiced affricates /tʃ^h/, 3) un-aspirated voiced affricates /dʒ/ and 4) aspirated voiced affricates /dʒ^h/. In voiced affricate the occlusion is voiced whereas in unvoiced affricates this part is silence. In aspirated affricate sound after friction there is an aspiration in the Voice Onset Time (VOT). In the case of affricates the place of release of the plosion is determined from the EPG frame just before the opening of the closure. The place of articulation of the friction is determined by the EPG frame where the opening is narrowest. Contact area is measured by the number of contacts made to the total number of electrodes in the whole EPG frame and is expressed as percentage. Manner of articulation of the affricates is determined from the acoustic study of the above-mentioned segments. The average occlusion duration and VOT duration

along with the average energy at occlusion period is calculated. Figure 6 represents the overall place of articulation of the plosion and friction for the affricate consonant /tʃ/, /tʃʰ/, /dʒ/, /dʒʰ/.

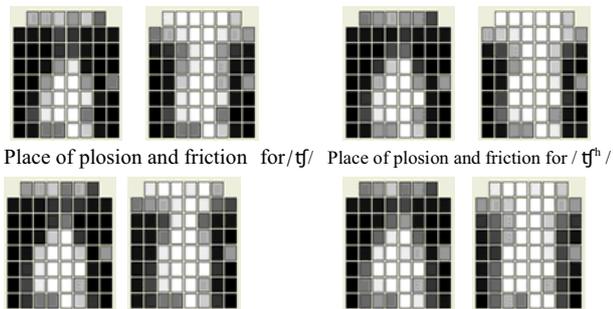


Figure 6: EPG plots of overall place of plosion and friction

The above consonants plosion occurs at alveolar position and friction occurs at post alveolar position. Table 3 shows the average duration of occlusion period and friction period along with the VOT for the above four affricates.

Table 3. Area of contact with respect to different vowels

Consonants	Occlusion duration [in ms]		Friction duration [in ms]		VOT duration [in ms]	
	Avg.	Stdv.	Avg.	Stdv.	Avg.	Stdv.
/tʃ/	41.9	14.8	46.6	12.0	3.6	1.6
tʃʰ/	35.8	12.5	60.8	18.2	27.2	10.9
/dʒ/	41.6	14.0	32.9	10.9	5.0	1.8
/dʒʰ/	34.0	12.9	38.8	12.9	26.0	13.8

5.4. Lateral, Trill and Flap or Tap

The lateral sounds are produced when air escapes around one or both sides of the closure. Bangla has only one lateral sound /l/. The place of articulation of the lateral is determined by the EPG frame collected from the middle of the production of the consonant. In case of trills the articulator (usually the tip of the tongue) is held in a place, and the airstreams causes it to vibrate. Bangla language has only one trill consonant. The place of articulation of the trill is determined by the EPG frame collected from the middle of the production of the consonant. Flap often called a tap, is a momentary closure of the oral cavity. Bangla language has two flaps. One is unaspirated and other one is aspirated. The place of articulation of the flaps is determined by the EPG frame collected from the middle of the production of the flap. Figure 7 represents overall articulatory closure positions for the lateral, trill and flap or tap

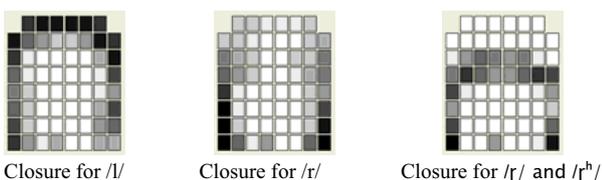


Figure 7: EPG plots of overall place of closure

From the above figures it is observed that during the production of consonant /l/ the articulator is completely closed at front position and air passes through the both side of the tongue. So the Bangla consonant /l/ is bi-lateral and place of articulation is dental. It is observed that there is no complete closure region in the EPG frame in case of /r/. This may be due to the tongue tip vibration rate faster than the frame rate of

the EPG system (100 Hz). Overall place of closure can be considered at alveolar region. In case of Flap or tap the place closure is in the region of post alveolar.

5.5. Nasal murmur

The nasal murmur is produced when vocal cords vibrate but the oral path is closed at some point and the velum is open. Bangla has four nasal murmurs. The place of articulation of the murmur is determined by the EPG frame collected from the middle of the production of the consonant. In this experimental setup nasal air passing evidence is not consider. The nasalization is determined from the acoustic evidence and listening test. Figure 8 represents overall articulatory closure positions for the lateral and nasal murmurs. Complete closure is not observed in the whole palate region in case of nasal murmur /m/. The video of lip movement of the informant is recorded during the production of this sound and from the video evidence the closure is found in the lip region as shown in figure 8.

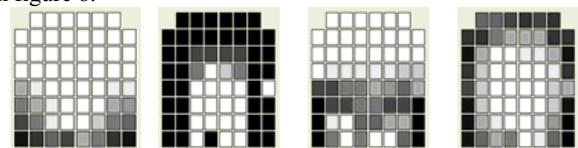


Figure 8: Lips closure for /m/



Figure 8: Lips closure for /m/

The place of closure is in the velar region for /ŋ/, alveolar region for /ɲ/ and dental region for /n/. In case of /ɳ/ the closer is happened in palatal region with retroflexion.

6. Conclusions

The main objective of this study was to experimentally verify the place and manner of articulation of Bangla Phoneme. In case of Bangla plosives four distinct places of articulation namely labial, dental, alveolar and post alveolar exists. In Bangla, lateralization takes place in the dental region. While contacts for labials could be assessed from the frontal video recording, retroflexion has to be assessed only from the spectrographic evidence alone. The collection of hard electropalatographic evidences for place of articulation is necessary for speech sounds of Indian languages because of two reasons. One is that it puts the stamp of objectivity on findings, which are, so far subjective and therefore prone to bias. The other one is that there seems to exist sounds, particularly in eastern India plosives, which are palatal/post-alveolar and at the same time non-retroflex.

7. References

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