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Nature of errors in percentage syllable articulation as an effect of reverberation time on Bangla

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Abstract

This paper identifies the nature of errors in the Percentage Syllable Articulation (PSA) test for Bangla, as a continuation and extension of a study conducted and published by the authors to determine the effects of Reverberation Time (RT) on Bangla. Errors due to RT 2.0 s are enumerated to derive Percent Error (PE) at initial, medial and final positions of phonemes in syllables, for both vowels and consonants. It is found that consonants are more vulnerable to errors than vowels, as their mean PEs are 37.8% and 27.6% respectively. Relative positions of phonemes in syllables have significant effect on PE. For vowels, mean PE increases from 12.1% to 56.7% for their medial and medial plus final positions respectively. For consonants, mean PE rises from 17.1% to 67.8% for their initial and final positions. Variations in PE within same groups of vowels and consonants, exemplify unique inherent characteristics of each phoneme.

Key words: Percent Error; Percentage Syllable Articulation; Reverberation Time; Bangla; Phoneme

Introduction

Percentage Syllable Articulation (PSA) is defined as the percentage of syllables that are heard correctly in a number of syllables presented to a listener (Morfe, 2001). In an acoustically controlled environment, a number of meaningless syllables are played back from pre-recorded sound clips in presence of listeners and they write down 'exactly the sound they hear'. Those written syllables are compared with the original syllables to find the percentage of syllables written correctly. The use of meaningless syllables eliminates any chance of guesswork, in view of the fact that a meaningful word is sometimes understood from the context; even if it is heard partially or erroneously (Ingerslev, 1952).

Reverberation Time (RT) is defined as the time taken for the energy in an initially-steady reverberant sound field to decay by 60 dB, which is quantitatively expressed as, $RT = 0.16V/A$ (s); where, V = room volume (m^3), A = total room absorption (m^2 sabin) (Morfe, 2001).

A long RT causes the different syllables in a speech to get mixed and results a lower PSA (Ingerslev, 1952). The consonants are produced during the transient state of speech, so that the lapse time is very short and frequency components tend to be at the higher frequency range (Maekawa and Lord 1994). Thus, despite their higher frequency spectra, the

energy contents of consonants are quite small and those are easily masked by reverberated preceding sounds in longer RT. In a particular PSA test for a RT 5.0 s, Knudsen (1932) found that the correct recognition of vowel was 93.3% and that of consonant was 76.4%. The preponderance of errors in consonants, which are critical for speech intelligibility, was the result of masking produced by the reverberation of the preceding vowels (Knudsen, 1932). It is also found by Knudsen (1932) and others that some phonetic sounds are more vulnerable for erroneous hearing than others. For an unbiased PSA test, the sets of meaningless syllables should contain phonemes in the same proportion of Relative Frequency of Occurrence (RFO) in a language. Such RFO and sets of meaningless syllables basing on RFO are prepared for English (Dewey, 1923; Beranek, 1949; Fletcher, 1953). In a similar manner, the RFO and sets of meaningless syllables basing on RFO are prepared by Imam *et al.* (2009b) for Bangla, as shown in Table I and Table II.

Facts discussed so far indicate that a language may show a unique PSA and thus nature of errors in phonemes in syllables, if characteristics of phonemes and their RFO differ considerably to those of any reference language. At this point, it is necessary to get an overview of Bangla as a language and its phonetic characteristics.

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Table I. Bangla Alphabets (BA) representing Bangla phonetic sounds, corresponding International Phonetic Alphabets (IPA) and their Relative Frequency of Occurrence (RFO) after Imam *et al.*, (2009b)

Vowels	Cardinal vowel	BA	ই	এ	আ	আ	অ	ও	উ									
	IPA		i	e	e	a	ɔ	o	u									
Semi-vowel	BA	ই্	এ্	ও্	উ্													
	IPA	i̯	e̯	o̯	u̯													
Diphthong	BA	ইই্	ইউ্	উই্	এই্	এউ্	ওই্	ওউ্	ওএ্	ওও্								
	IPA	ij̯	iɥ̯	uj̯	eɨ̯	eɯ̯	oɨ̯	ou̯	oɛ̯	oo̯								
Consonant	BA	প্	ফ্	ব্	ভ্	ত্	থ্	দ্	ধ্	ট্	ঠ্	ড্	ঢ্					
	IPA	p	pʰ	b	bʰ	t	tʰ	d	dʰ	ʈ	ʈʰ	ɖ	ɖʰ					
Modifier / Diacritics (example with (ঋ) /b/))	BA	চ্	ছ্	জ্/য্	ঝ্	ঞ্	খ্	গ্	ঘ্									
	IPA	c	cʰ	ʃ / ð	ʒʰ	k	kʰ	g	gʰ									
Vowel nasalized	BA	ঙ্	ন্/ন্	ম্	ড়্	ঢ়্	র্	ল্	শ্/স্	স্*	হ্							
	IPA	ŋ	n/ɳ	m	ɽ	ɽʰ	r	l	ʃ	s	h							
	RFO	1	1	3	1	3	1	2	1	1	1	1	1					
	RFO	1	1	1	1	1	1	1	1	1	1	1	1					
	RFO	1	1	1	1	4	1	1	1									
	RFO	1	5	3	1	1	6	3	2	1	2							
	BA																	
	IPA																	
	BA																	
	IPA																	
	BA																	
	IPA																	

The IPA representing Bangla Alphabets are based on different sources, like Ali (2001), Sounds of the IPA, CD Version (2003), Khan (2010), Dash (2015) and IPA Chart (2015).

*The sound (স্) /s/ is found in some foreign words adopted in Bangla and in particular contexts e.g. before the dental plosives and (র) /r/, (ল) /l/ and (ন) /n/. For some words borrowed from English and Perso-Arabic origin, Bangla has a voiced twin of /s/, which is sometimes represented by (স্) /z/ (Hai 1961, Hai 1967, Ali 2001, Dash 2015).

As an evidence of rich vocabulary, Bangla has about 50,000 entries and subentries of words as found in Bangla lexicons (Ali *et al.*, 2015). Like any other major languages, it is in a process of adopting many words from other languages. After adoption, those foreign words mostly follow the phonetic characteristics of Bangla (Haq, 2004).

Bangla has a vast array of phonetic sounds comprising twenty eight vowels (seven cardinal vowels, four semi-vowels and seventeen diphthongs) and thirty consonants (Hai, 1961; Hai, 1967; Islam, 1992; Ali, 2001).

All seven cardinal vowels in Bangla have clear nasal form and denote different meaning to a word (Hai, 1961; Hai, 1967; Murshed, 1985), which may increase the total number of vowels as thirty five. On the other hand, English have only twenty vowels (twelve cardinal vowels and eight diphthongs) and twenty four consonants (Hai, 1961). Bangla alphabet is a syllabic alphabet in which all consonants have an inherent vowel (অ) /ɔ/. Absence of this inherent vowel is denoted in Bangla alphabet with a mark / ̣ / (known as (হ্রস্বত) /hrɔʃɔnto/ in Bangla) and a *non-syllabic diacritic* mark / ̣ / is added in IPA (Hai 1967, IPA Chart 2015, Ager 2016).

Table II. Sets of meaningless syllables prepared in proportion to RFO, written in Bangla Alphabet (BA) and International Phonetic Alphabet (IPA) as derived by Imam *et al.* (2009b)

No.	Set 1		Set 2		Set 3		Set 4		Set 5		Set 6		Set 7		Set 8	
	BA	IPA	BA	IPA	BA	IPA	BA	IPA	BA	IPA	BA	IPA	BA	IPA	BA	IPA
01	রট্	rɔt̪	ধট্	t̪ʰɔt̪	নছ্	nɔc	ফন্	p̪ʰɔn	গন্	gɔn	হড়্	hɔɽ	পল্	pɔl	যক্	ʃɔk
02	খাচ্	kʰac	চাড়্	caɽ	যাপ্	jap	চাম্	cam	ঝাট্	ʃʰat̪	লান্	lan	ধাড়্	ɽʰat̪	ডার্	ɽar
03	ব্যাড়্	beɽ	ঘ্যাল্	gʰel	ব্যার্	ber	প্যাল্	pel	য্যাপ্	jep	ত্যাঙ্	t̪ek	ম্যাক্	mek	হ্যাক্	hek
04	জিং	ʃiŋ	মিং	miŋ	হিং	hiŋ	জিক্	ʃik	মির্	mir	লিম্	lim	নিশ্	niʃ	বিং	biŋ
05	যুন্	jun	যুপ্	jup	তুড়্	t̪uɽ	তুং	t̪uŋ	গুং	luŋ	সুং	suŋ	চুক্	cuk	জুপ্	ʃup
06	থেন্	t̪ʰen	ধের্	ɽʰer	খেট্	gʰet̪	ঠের্	t̪ʰer	খেড়্	t̪ʰeɽ	রেয্	rej	ভেং	t̪eŋ	হেন্	hen
07	হোম্	hom	তোশ্	toʃ	ভোশ্	bʰoʃ	মোক্	mok	নোম্	nom	পোর্	por	ভোল্	bʰol	খোট্	kʰoɽ
08	লিই	li:	নিই	ni:	রিই	ri:	বিই	bi:	ভিই	bʰi:	ফিই	pʰi:	সিই	si:	রিই	ri:
09	ঝিউ	ʃʰiu	চিউ	ɽʰiu	ঝিউ	kʰiu	ভিউ	bʰiu	বিউ	biu	টিউ	t̪iu	রিউ	riu	গিউ	giu
10	তুই	t̪ʰui	নুই	nui	লুই	lui	ডুই	ɽui	তুই	ɽʰui	ঘুই	gʰui	তুই	t̪ui	বুই	bui
11	পেই	pei	বেই	bei	গেই	gei	ছেই	cʰei	রেই	rei	লেই	lei	খেই	t̪ʰei	কেই	ʃʰei
12	ধেউ	ɽʰeu	ঠেউ	t̪ʰeu	জেউ	jeu	নেউ	neu	তেই	t̪ei	হেউ	heu	খেউ	kʰeu	লেউ	leu
13	ঘোই	gʰoi	জোই	joi	ফোই	pʰoi	ঝোই	ʃʰoi	ভোই	ɽoi	চোই	coi	রোই	roi	তোই	t̪oi
14	দোউ	ɽou	খোউ	kʰou	কোউ	kou	রোউ	rou	ফোউ	pʰou	জোউ	ʃou	গোউ	gou	লোউ	lou
15	ফোয়	pʰoe	বোয়	boe	নোয়	noe	দোয়	ɽoe	চোয়	coe	কোয়	koe	ঠোয়	t̪ʰoe	মোয়	moe
16	ঠোও	t̪ʰoo	রোও	roo	ঠোও	t̪ʰoo	ঘোও	gʰoo	সোও	soo	ভোও	bʰoo	জোও	ʃoo	দোও	ɽoo
17	ডাই	ɽai	শাই	ʃai	টাই	t̪ʰai	থাই	t̪ʰai	ধাই	ɽʰai	কাই	ʃʰai	হাই	hai	ফাই	pʰai
18	ভাউ	bʰau	গাউ	gau	শাউ	ʃau	রাউ	rau	ঘাউ	gʰau	ঠাউ	t̪ʰau	চাউ	ɽʰau	বাউ	bau
19	ভ্যাও	t̪eo	ছ্যাও	cʰe	র্যাও	reo	য্যাও	jeo	হ্যাও	heo	খ্যাও	kʰeo	ড্যাও	ɽeo	ঘ্যাও	gʰeo
20	ছ্যায়	cʰee	ভ্যায়	t̪ee	ড্যায়	ɽee	ল্যায়	lee	খ্যায়	kʰee	ম্যায়	mee	ঝ্যায়	ʃʰee	র্যায়	reo
21	সায়	sae	ঝায়	ʃʰae	থায়	t̪ʰae	তায়	t̪ae	লায়	lac	ডায়	ɽae	ফায়	pʰae	শায়	ʃae
22	শাও	ʃao	হাও	hao	কাও	kao	রাও	rao	ঠাও	t̪ʰao	বাও	bao	ঘাও	gʰao	থাও	t̪ʰao
23	গয়	gɔe	দয়	ɽe	ঝয়	ʃʰe	সয়	sɔe	ময়	mɔe	থয়	t̪ʰe	বয়	bɔe	তয়	t̪e
24	বও	bɔo	ডও	ɽɔo	ছও	cʰɔo	মও	mɔo	জও	ʃɔo	রও	rɔo	তও	t̪ɔo	ভও	bʰɔo
25	রাক্	rak	ভাক্	bʰak	তস্	t̪os	রখ্	rɔkʰ	লক্	lɔk	মশ্	mɔʃ	রক্	rɔk	সক্	sɔk
27	তন্	t̪ɔn	মক্	mɔk	ধাক্	ɽʰak	ঢাড়্	ɽʰat̪	দাক্	ɽak	গার্	gar	বেক্	bek	ভাষ্	bʰaʃ
27	নাশ্	naʃ	রেন্	ren	মিন্	min	শিন্	ʃin	বুশ্	ruʃ	নাশ্	naʃ	লাছ্	lacʰ	মিত্	miɽ
28	কেল্	kel	ফিন্	pʰin	দের্	ɽer	হেত্	het̪	হির্	hir	কিব্	kib	বিড়্	biɽ	নাড়্	naɽ
29	রেক্	rek	লার্	lar	বুর্	bur	রাট্	raɽ	শাব্	ʃab	তুর্	ɽʰur	হুদ্	ruɽ	রোন্	ron
30	হান্	han	বোক্	bok	হান্	han	ধাক্	ɽʰak	রেম্	rem	নোর্	nor	মেক্	mek	টার্	ɽʰar
31	রাব্	rab	হন্	hɔn	দাল্	ɽal	বিক্	bik	নির্	nir	ভেব্	t̪eb	নুঘ্	nugʰ	নেল্	nel
32	দির্	dir	লাত্	lat̪	নেম্	nem	লোশ্	loʃ	দুন্	ɽun	দাছ্	ɽacʰ	রিত্	riɽ	রিদ্	riɽ
33	তাম্	t̪am	কিন্	kin	নার্	nar	গব্	gab	তের্	ter	রেক্	rek	শন্	ʃɔn	ঠাম্	t̪ʰam
34	কাই	kai	রিদ্	riɽ	ভিক্	t̪ik	লান্	lan	নাত্	naɽ	নিত্	niɽ	হান্	han	ছিক্	cʰik
35	লক্	lɔk	মুর্	muɽ	বেম্	bem	নুদ্	nuɽ	রাছ্	racʰ	কেদ্	keɽ	রাক্	rak	চাক্	caɽ
36	মির্	mir	কাস্	kas	পল্	pɔl	কপ্	kɔp	পিক্	pik	নাধ্	naɽʰ	মিন্	min	নিত্	niɽ

In Bangla, there are as many as twenty plosive consonants,

e.g., (প.) /p/, (ফ.) /p^h/, (ব.) /b/, (ভ.) /b^h/, (ত.) /t/, (থ.) /t^h/, (দ.) /d/, (ধ.) /d^h/, (ট.) /t̪/, (ঠ.) /t̪^h/, (ড.) /d̪/, (ঢ.) /d̪^h/, (চ.) /c/, (ছ.) /c^h/, (জ.) /j/, (ঝ.) /j^h/, (ক.) /k/, (খ.) /k^h/, (গ.) /g/ and (ঘ.) /g^h/. Bangla (প.) /p/, (ব.) /b/, (ত.) /t/, (দ.) /d/, (ট.) /t̪/, (ড.) /d̪/, (ক.) /k/ and (গ.) /g/ are not at all aspirated. Bangla has aspirated counterparts, e.g., (ফ.) /p^h/, (ভ.) /b^h/, (থ.) /t^h/, (ধ.) /d^h/, (ঠ.) /t̪^h/, (ঢ.) /d̪^h/, (খ.) /k^h/ and (ঘ.) /g^h/; which are phonemic and have difference in meaning to its unaspirated counter-part. Moreover, the alveolar and palatal group of sounds in Bangla represented by (চ.) /c/, (ছ.) /c^h/, (জ.) /j/ and (ঝ.) /j^h/ are, unlike English, more plosive than affricates and English does not have corresponding aspirated sounds of Bangla (ছ.) /c^h/, (ঝ.) /j^h/, (ড়.) /ɽ/ and (ঢ়.) /ɽ^h/ (Hai 1961).

There are subtle phonetic differences among many of Bangla phonetic sounds, particularly the consonants, which are very transient in duration, weaker in sound energy and thus more vulnerable for erroneous hearing. For example, in a highly reverberant space, the unaspirated plosive phoneme (ব) /b/ can be easily mistaken with its aspirated counterpart (ভ) /b^h/ and vice versa. These similar phonemes may be termed as 'phonetic twins'. They create obvious scopes of erroneous listening in a highly reverberant space. It is just like making mistakes in recognising a person from identical twins at a glance in a busy crowd. Basing on phenomena discussed so far, a hypothesis can be deduced that there may be some unique nature of errors for phonemes in

syllable sets derived in PSA test for Bangla as an effect of RT. The finding of PSA test by Imam *et al.* (2009b) is shown in Fig 1.

Materials and methods

In the study of Imam *et al.* (2009b), the errors in meaningless syllables were simply counted for finding PSA. A syllable was counted as 'an error', if error occurred in one or more phonemes forming that syllable. In this study, each phoneme of syllables is counted for errors independently. Phonemes are identified in each syllable by analysing its format. Number of phonemes is 3 in Consonant-Vowel-Consonant (CVC) format of syllables, while that is 2 in Consonant-Vowel-Vowel (CVV) format, as VV is a diphthong and considered as a single phoneme.

The PSA for Bangla varies from 93% to 10% for corresponding RTs ranging from 0.0 s to 8.0 s (Imam *et al.*, 2009b). Syllables noted by listeners in PSA test for RT 2.0 s is selected for finding nature of errors, which corresponds to the PSA of 41%; almost the mean value of the highest and lowest data in the PSA test. This selection gives a balanced scope of error and correctness within the test range. Besides, for RT 2.0 s, the average score for comparative preference between intelligibility and liveliness of Bangla remains within the range of ±1 (Imam *et al.*, 2009).

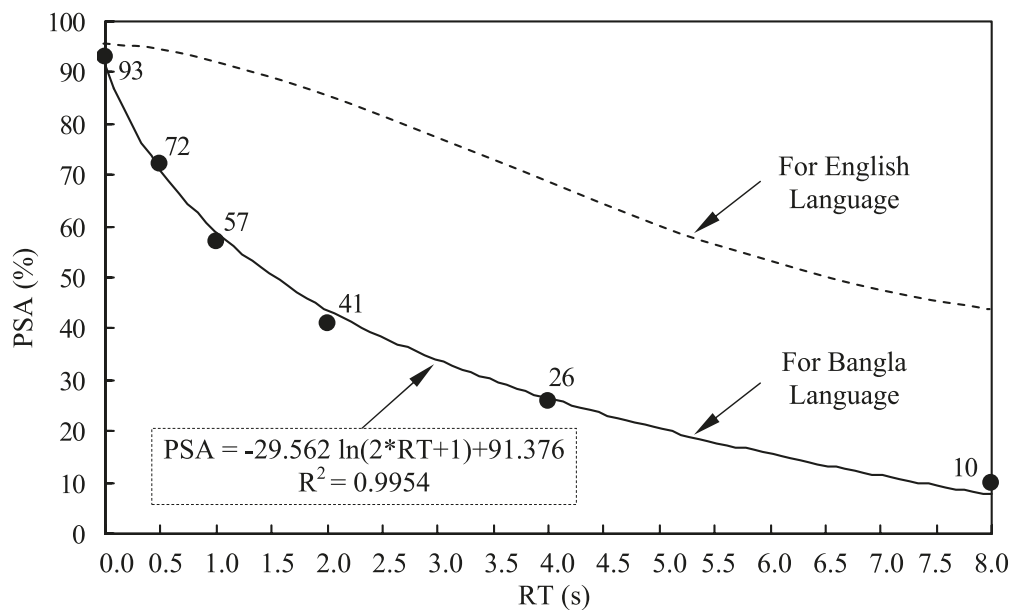


Fig. 1. PSA for a range of RTs for Bangla as derived by Imam *et al.* (2009b), compared to those for English as derived by Knudsen (1932)

Table IV. Classification of errors in consonants as an effect of RT on Bangla (Continued)

Sounds Called	Position in Syllable	No. of Times Called	Classification of Errors																										Total No. of Errors	% of Errors Individual	% of Errors Both						
			প	ফ	ব	ভ	ত	থ	দ	ধ	ন	ত	ঢ	ড	ঢ	ড	ভ	ম	ন	ম	ভ	র	ল	শ	স	হ	ঝ	ঞ									
ফ	Initial	14																											0	0.0							
ফ	Final	14																												12	85.7	42.9					
ক	Initial	56																												4	7.1						
ক	Final	33																												32	97.0	40.4					
খ	Initial	14																												4	28.6						
খ	Final	14																												2	14.3	21.4					
গ	Initial	14																												3	21.4	25.0					
গ	Final	14																												4	28.6						
ঘ	Initial	14																												2	14.3	27.3					
ঘ	Final	8																												4	50.0						
ঙ	Initial	14																												2	14.3	64.3					
ঙ	Final	14																												9	64.3						
ন	Initial	74																												10	13.5	35.7					
ন	Final	38																												30	78.9						
ম	Initial	52																												5	9.6	27.1					
ম	Final	18																												14	77.8						
ভ	Initial	14																												8	57.1	78.6					
ভ	Final	14																												14	100.0						
র	Initial	75																												6	8.0	44.4					
র	Final	51																												50	98.0						
ল	Initial	19																												7	36.8	59.5					
ল	Final	23																												18	78.3						
শ	Initial	14																												3	21.4	32.1					
শ	Final	14																												6	42.9						
স	Initial	28																												0	0.0	23.8					
স	Final	14																												10	71.4						
হ	Initial	28																												8	28.6	28.6					
হ	Final	14																												4	28.6						
		1184	4	11	14	4	10	14	17	9	6	9	6	1	27	4	14	4	6	7	6	4	4	4	27	25	6	19	9	9	1	9	157	5	448	37.8	37.8

Table V. Summary of results

Phoneme Types	Position in Syllables	Percent Errors (%)			
		Min	Max	Mean	SD
Vowel	Medial	2.4	40.0	12.1	13.3
	Medial + Final	28.6	85.7	56.7	16.1
	All	2.4	85.7	27.6	24.5
Consonant	Initial	0.0	85.7	17.1	22.8
	Final	14.3	100.0	67.8	30.2
	Both (In. and Fin.)	14.3	78.6	37.8	16.8
	All	0.0	100.0	37.8	33.5
	All	All Positions	0.0	100.0	34.1

The materials and methods adopted in this study may be summarised as:

Choosing sets of syllables for enumeration of errors > Identifying phonemes in each syllables > Counting errors of vowels at their respective medial and medial plus final positions > Counting errors of consonants at their respective initial and final positions > Tabulation of data > Analysis of data for results

Results and discussions

Error counting results are tabulated in Table III and Table IV for vowels and consonants respectively. Table III and Table IV show that a total number of 686 vowels and 1184 consonants are counted for errors. Table V gives summary of counting of all phonemes.

In Table III, there are 24 vowels, comprising of 7 cardinal vowels and 17 diphthongs. Cardinal vowels are placed at medial positions in test syllables in CVC format, while diphthongs are placed at medial plus final positions in CVV format. In Table IV, consonants are tabulated in pairs of rows for their initial and final positions in CVC and CVV formats. However, the consonant (ঙ) /ŋ/ is tabulated in a single row as it is never used at initial position in Bangla (Dasgupta, 2003). Percent Errors (PEs) are calculated for phonemes for their respective positions in the test syllables. For consonants, PEs are also added for both positions. Some phonemes have lost their distinctive pronunciation in modern Bangla ("Bengali alphabet", 2016). Due to their subtle difference in pronunciation, those are placed together to simplify the study. For example, (ন) /n/, (ণ) /ɳ/ and (ঞ) /ɲ/ are tabulated together as, (ন) / (ণ) /n/ɳ/. Similarly, tabulation is done together as (জ) (য) /j/ð/, (ড়) (ঢ়) /t/ʈ/ and (শ) (স) /ʃ/.

In Table III and Table V, it is visible that vowels are more

vulnerable to errors at medial plus final positions (PE min 28.6%, max 85.7% and mean 56.7%) compared to medial positions (PE min 2.4%, max 40% and mean 12.1%). In Table IV and Table V, it is noticeable that consonants suffer more from errors at final positions (PE min 14.3%, max 100% and 67.8%) than initial positions (PE min 0%, max 85.7% and mean 17.1%). It is interesting to note that 6 consonants, namely (ভ) /b^h/, (ট) /t/, (ঢ) /c/, (জ) /j/, (ঝ) /ʒ^h/, and (স*) /s/, enjoy perfect hearing at initial positions (mean PE 0%), while they suffer measurably at final positions (mean PE 89.9%). The most extreme case occurs to (ঢ) /c/, as PE changes drastically from 0% to 100% for its initial and final positions respectively. As shown in Table IV, following consonants suffers measurably from errors at final positions (from 85.7% to 100%): (প) /p/, (ব) /b/, (ত) /t/, (ঠ) /t/, (ঢ) /c/, (জ) (য) /j/ð/, (ঝ) /ʒ^h/, (ক) /k/, (ড়) (ঢ়) /t/ʈ/ and (র) /r/. In a reverberant room, speakers should take extreme caution to pronounce syllables ending with these phonemes.

So far relative positions are concerned, it is evident that PEs of phonemes follow ascending order from initial to medial and then to final positions in syllables. This is due to the fact that the reverberations of initial sounds of phonemes have masking effect on succeeding sounds of phonemes, making it difficult for understanding. This phenomenon resembles with that found in the study conducted for English by Knudsen (1932).

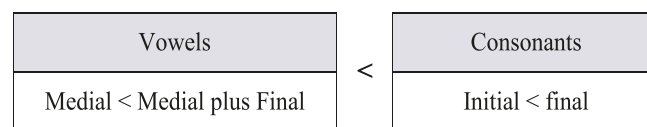


Fig. 2. Ascending order of Percent Error (PE) for various positions of phonemes in syllables.

A comparison of PE of vowels and consonants at different positions shows that in all cases consonants are scoring higher. As the syllables are set in CVC and CVV formats, vowels do not have opportunity to be at initial position and enjoy low PE. Comparing PE mean for medial positions of vowels (12.1%) with that of initial positions of consonants (17.1%), and PE mean for medial plus final positions of vowels (56.7%) with that of final position of consonants (67.8%), it is noticeable that consonants are more prone to errors. An overall comparison of PE mean for all positions also confirms that all consonants are more susceptible to errors (PE mean 37.8%) than that of all vowels (PE mean 27.6%). This phenomenon is explained by Fletcher (1953) for studies on English. For example, in English, the most powerful sound is the vowel /ɔ:/ (as in *awl*), and the faintest sound is the consonant /θ/ (as in *thin*). The ratio of powers between these two is 680:1 (Fletcher, 1953). Thus, vowels

have more masking effect on succeeding consonants, but on the contrary, consonants have less masking effect on succeeding vowels. In both cases, vowels are in advantageous position for scoring lower PE. As discussed so far, the ascending order of PE for different positions of phonemes in syllables is summarised and is shown in Fig. 2.

It is interesting to observe in Table III and Table IV that number of times a phoneme heard erroneously instead of correct ones varies from 0 to 28 times; (এ) /e/ scores 28 as the highest for vowels, while both (ক) /c/ and (ন) /n/ /ŋ/ score 27 as the highest for consonants. For errors due to 'Omissions', as listeners could not write anything, consonants at final positions face a remarkable total number of 157 times errors (PE 13.3% of total errors). The phoneme (র) /r/ makes the highest of 36 omissions in its final position.

Standard deviations (SD) in Table V shows that there is a significant variations of PE within same group (vowels at medial, vowels at medial plus final, consonant at initial and consonant at final), which ranges from SD 13.3% to 30.2%. This phenomenon indicates that there are inherent characteristics of each phoneme influencing variations in PE within same group. Based on understanding from this study, these varying inherent characteristics of phonemes may be assumed as the sound power, frequency content, articulation rate and degree of similarity with other phonemes. Each phoneme may have one or more characteristics at varying levels to influence the effect of RT on it. This phenomenon opens potentials for significant research.

Conclusion

The preponderance of errors is more in consonants than vowels. There is a hierarchy of errors within both consonants and vowels in an ascending order of their initial, medial and final positions in the syllable. A good degree of variations prevails among phonemes in same groups due to other inherent acoustic and phonetic characteristics. The study may help training public speakers and instructors for satisfactory performance in spaces for speech. The findings in this study may facilitate research and development in Digital Signal Processing (DSP) for Bangla, particularly in the field of speech recognition, speech-to-text conversion, dereverberation and so on. The phenomenon of having variations in errors within same groups of phonemes sets scopes for further research to understand the nature of errors more precisely.

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