Voice Onset Time of Voiced Stop Consonants in Hindi Speakers

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INTRODUCTION

Hindi is an Indic language of northern India, derived from Sanskrit and written in the Devanagari script. It is the fourth most widely spoken language in the world, with more than 250 million people speaking it as their first language. There are 20 stop consonants in Hindi as shown in table 1 (Singh & Tiwari, 2016).

Table 1: Arrangement of stop consonants of Hindi alphabet (Singh & Tiwari, 2016)

	Voiceless unaspirated	Voiceless aspirated	Voiced unaspirated	Voiced aspirated
VELAR	/k/	/k^h/	/g/	/g^h/
PALATAL	/c/	/c^h/	/ɟ/	/ɟ^h/
RETROFLEX	/ʈ/	/ʈ^h/	/ɖ/	/ɖ^h/
DENTAL	/t̪/	/t̪^{h}/	/d̪/	/d̪^{h}/
BILABIAL	/p/	/p^h/	/b/	/b^h/

Stop consonants, also known as plosives, are produced when the air flow in oral cavity is momentarily blocked either by the tongue or through closure of lips, followed by its sudden release. Lisker and Abramson (1964) characterized stop consonants in terms of voice onset time (VOT).

VOICE ONSET TIME (VOT)

VOT is the time difference between the initiation of the stop burst and the onset of voicing, i.e., the vibration of vocal folds. On wideband spectrograms VOT is measured in milliseconds as the duration between the vertical spike marking the transient burst of stop release and the first vocal pulse that can be observed at the baseline. It is useful to distinguish at least three types of VOT namely positive VOT, zero VOT and negative VOT.

TYPES OF VOT

Negative VOT: where the onset of vocal fold vibration precedes the plosive release. If the voicing starts before the release (i.e., during the closure phase) of the stop, then the result is described as „voice lead" (or „prevoiced) and is given a negative VOT value. This is the case of voiced plosives.

Zero VOT: where the onset of vocal fold vibration coincides (approximately) with the plosive release. Voiceless un aspirated plosives have zero voice-onset time.

Positive VOT: where there is a delay in the onset of vocal fold vibration after the plosive release. If the voicing starts after the release of the stop, then the result is „voice lag" and is described with a positive VOT value. All voiceless aspirated plosives have positive value of voice- onset time. The amount of lag is important to separate voiceless un aspirated („short lag") from voiceless aspirated („long lag").

VOT values are not absolute; they are rather influenced by several different factors. Considering that VOT is such a valuable object of study, it is essential that researchers have a clear understanding of how it is characterized and what variations are expected when dealing with this phonetic-phonological aspect.

Stop consonants are phonemes produced in the presence of a complete obstruction in the vocal tract (Pickett et al., 1999). During production of a stop consonant, air pressure builds in the vocal tract behind the articulatory obstruction until there is a separation of the articulators (the burst) and the following release

of air and the accompanying frication noise (Speaks et al., 1981). It can or cannot be followed by an aspiration noise. In the English language, the stop consonants phonemes are [/p/, /b/, /t/, /d/, /k/, /g/.

There are various factors affecting the VOT such as place of articulation, following vowel, voiced Or voiceless sound, language of the speaker, gender, rate of speech, and age of the speaker. So there is a need to study these factors and to know how it affects the VOT.

Awan and Stine (2011) studied the possible differences in voice onset time (VOT) between speakers of standard American English (AE) and Indian English (IE) in a continuous speech context. The participants taken were 20 AE speakers, who were native to the Northeastern Pennsylvania region, and 20 IE speakers from the Indian subcontinent who had been residing in Northeastern Pennsylvania. Each subject read a phonetically balanced passage in a comfortable and natural speaking voice, and the recordings were analysed using a combination of waveform and spectrographic analyses. Results indicate that a reduced +VOT appears to characterise IE accent in comparison to AE. In addition, a difference in VOT between genders was observed in AE speakers but not in IE speakers.

Stoltem et al. (2014) investigated effects of age and speaking rate on voice onset time. The production of voiceless stops by near native 12 speakers and this study reports on voice onset time (VOT) analyses of the production of Swedish word-initial voiceless stops /p t k/. Voice onset time is analyzed in milliseconds as well as in percentages of word duration, thereby accounting for speaking rate effects. The results revealed an overall age effect on VOT production; however, this age effect became salient and statistically significant for all three stops only when speaking rate was taken into consideration. Similarly, when speaking rate was accounted for only a small minority of the late learners exhibited actual native like L2 behavior, and most (but far from all) early learners performed within native-speakers range. The results are taken as an indication for relative VOT, as opposed to absolute VOT, constituting liable measure of native like L2 stop production, which has important implications for future research on age effects and maturational constraints in L2 acquisition.

Jinson et al. (2019) Studied the voice onset time on voiced stop consonants in typical malyalam speakers. The three voiced stop consonants /b/,/d/,/g/ were stimulus for this study. The result indicates that age and gender is a factor associated with VOT in typical Malayalam speakers. Females had longer VOT as compared to males.

Need of the study

There are no consistent conclusions drawn with regard to the difference in place of articulation, difference in VOT due to following vowel and difference in VOT due to gender. Indian investigators have reported that perception and production of voice onset time changes as a function of place of articulation and vowel in adults. But little information is available concerning voice onset time changes with respect to following vowel in CV syllable, gender and also place of articulation in Hindi contexts. Also as we already know VOT is dependent on language. Therefore, this investigation will examine changes in mean voice onset time and voice onset time variability with respect to place of articulation, following vowel and gender differences in Hindi speakers.

Aim of the study:

The aim of the study is to measure voice onset time (VOT) of Hindi voiced consonant.

Hypothesis:

The following hypothesis were constructed:

Hypothesis 1 stated that there will be no significant difference between the means of the VOT for the vowels /a/ /i/ and /u/ for the voiced stop consonants /b/, /d/, /g/.

Hypothesis 2 stated that there will be no significant difference among different voiced stop sounds with respect to same vowel for the three places of articulation.

Hypothesis 3 stated that there will be no significant difference between the means of the VOT of voiced stop sounds for male and female.

METHODOLOGY

Aim

The aim of the study was to measure the voice onset time (VOT) of voiced Hindi consonants. Hypothesis: The following hypotheses were constructed:

Hypothesis 1 stated that there will be no significant difference between the means of the VOT for the

vowels /a/ /i/ and /u/ for the voiced stop consonants /b/, /d/, /g/.

Hypothesis 2 stated that there will be no significant difference among different voiced stop sounds with respect to same vowel for the three places of articulation.
Hypothesis 3 stated that there will be no significant difference between the means of the VOT of voiced stop sounds for male and female.

Participants
30 subjects, consisting of 15 males and 15 females, within the age range of 18 to 26 years, mean age = 21.7 years (Males = 21.6 years; Females = 21.9years) participated in the study.

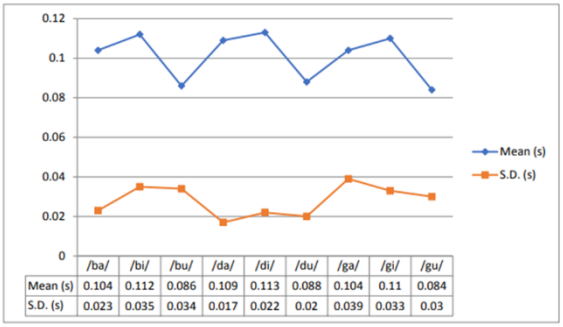
Inclusion criteria
No history of neurological, vascular and motor abnormalities Should be a native Hindi speaker

Exclusion criteria
Subjects outside the age range of 18-26 years Non-native Hindi speakers Materials Microphone (Boat Bass 225)
DELL Vostro 3568 laptop for recording and analysing the stimuli.
PRAAT version (5.2.25 by Boersma and Weenink, 2011)

Procedure
The subjects were made to sit comfortably in a quiet room or soundproof room. Initially, the subjects were familiarized with the test stimuli (CV syllables) and were instructed to utter the test stimuli (CV syllables) at a comfortable loudness level and pitch which were recorded using a high-quality Microphone placed at a distance of 5 cm from the mouth of the speaker and DELL Vostro 3568 laptop. During the formal recording, they were required to read the words in a normal speed. All productions were recorded at a sampling rate of 44.1 kHz. A set of nine CV syllables (/ba/, /bi/, /bu/, /da/, /di/,/du/,/ga/,/gi/, and /gu/) constituting of voiced consonants /b/, /d/, /g/ combined with vowels /a/, /i/, /u/ were used as test stimuli. A total of 270 tokens were recorded from 30 subjects.

Analysis
The recorded samples were fed to a DELL Vostro 3568 laptop loaded with PRAAT version (5.2.25 by Boersma and Weenink in 2011) software program for acoustic analysis of the stimuli recorded. VOT measurements were made directly from the spectrograms by measuring the distance between the release of the plosives to the onset of voicing of the following vowel in each syllable. The data was tabulated.
Statistical Analysis
The obtained data was further statistically analyzed using ANOVA test, post hoc analysis and t-test.

RESULTS AND DISCUSSION



	/ba/	/bi/	/bu/	/da/	/di/	/du/	/ga/	/gi/	/gu/
Mean (s)	0.104	0.112	0.086	0.109	0.113	0.088	0.104	0.11	0.084
S.D. (s)	0.023	0.035	0.034	0.017	0.022	0.02	0.039	0.033	0.03

Figure 4.1 Mean and Standard Deviation (S.D.) for VOT of CV syllables

From figure 4.1 it is observed that the figure traces three curves as it plots the VOT of /a/, /i/ and /u/ for the three places of articulation /b/, /d/ and /g/, indicating that VOT increases for the vowel /i/ and falls for the vowel /u/ for all three places of articulation.

Table 4.1. Comparison of VOT Values of CV syllables as a function of the identity of following vowel

CV syllable	N	Mean (s)	S.D.(s)	95% Confidence Interval for Mean		Repeated measures ANOVA	
				Lower Bound	Upper Bound	F value	P value
/ba/	30	0.104	0.023	0.095	0.112		
/bi/	30	0.112	0.035	0.099	0.124	5.54	0.005
/bu/	30	0.086	0.034	0.073	0.098		
/da/	30	0.109	0.017	0.102	0.115		
/di/	30	0.113	0.022	0.105	0.120	12.651	0.000
/du/	30	0.088	0.020	0.080	0.095		
/ga/	30	0.104	0.039	0.090	0.117		
/gi/	30	0.110	0.033	0.098	0.121	4.6	0.012
/gu/	30	0.084	0.03	0.072	0.095		

From Figure 4.1 and Table 4.1 it can be seen that the mean VOT for /ba/, /bi/, /bu/,/da/, /di/, /du/, /ga/, /gi/,and /gu/is 0.104 s, 0.112s , 0.086s ,0.109s, 0.113s, 0.088s, 0.104s, 0.110s, and 0.084s respectively. The mean VOT of /ba/, /bi/, and /bu/ were statistically compared and yielded highly significant difference with F value 5.54 and and p value 0.005. The mean VOT of /da/, /di/, and /du/ were statistically compared and yielded highly significant difference with F value 12.651 and and p value 0.000 The mean VOT of /ga/, /gi/, and /gu/ were statistically compared and yielded highly significant difference with F value 4.6 and and p value 0.012

Table 4.2 Post hoc analysis of VOT Values of CV syllables as a function of the identity of following vowel

	Bonferroni p value
/ba/–/bi/	0.149
/ba/–/bu/	0.009
/bi/–/bu/	0.002
/da/– /di/	0.21
/da/–/du/	0.000
/di/– /du/	0.000
/ga/– /gi/	0.26
/ga/–/gu/	0.016
/gi/–/gu/	0.001

Post hoc analysis of VOT values among vowels (a, i, u) using Bonferroni tests has been depicted in table no 3. Pair wise analysis shows that there is significant difference between pairs /ba/-/bu/ (p=0.009), /bi/-/bu/ (p=0.002), /da/-/du/ (p=0.000), /di/-/du/ (p=0.000), /ga/–/gu/ (p=0.016), and /gi/-/gu/ (p=0.001). Also no significant difference was found between /ba/-/bi/ (p=0.149), /da/-/di/ (p=0.21), /ga/-/gi/ (p=0.26) pairs respectively

TABLE 4.3 Comparison of VOT values of CV syllables as a function of different place of articulation of voiced stop sound

CV syllable	N	Mean(s)	S.D.(s)	95% Confidence Interval for Mean		Repeated measures ANOVA	
				Lower Bound	Upper Bound	F value	P value
/ba/	30	0.104	0.023	0.095	0.112	0.228	0.75
/da/	30	0.109	0.017	0.102	0.115		
/ga/	30	0.104	0.039	0.090	0.117		
/bi/	30	0.112	0.035	0.099	0.124	0.115	0.89
/di/	30	0.113	0.022	0.105	0.120		
/gi/	30	0.110	0.033	0.098	0.121		
/bu/	30	0.086	0.034	0.073	0.098	0.331	0.732
/du/	30	0.088	0.020	0.080	0.095		
/gu/	30	0.084	0.03	0.072	0.072		

From table 4.3 it can be seen that the mean VOT for /ba/, /da/, /ga/,/bi/, /di/, /gi/, /bu/, /du/,and /gu/is 0.104s, 0.109s , 0.104s ,0.112s, 0.113s, 0.110s, 0.086s, 0.088s, and 0.084s respectively. The mean VOT of /ba/, /da/, and /ga/ were statistically compared and yielded no significant difference with F value 0.228 and p value 0.75. The mean VOT of /bi/, /di/, and /gi/ were statistically compared and yielded no significant difference with F value 0.115 and p value 0.89 The mean VOT of /bu/, /du/, and /gu/ were statistically compared and yielded no significant difference with F value 0.331 and and p value 0.732. Therefore the result shown no significant change or variation with place of articulation.

TABLE 4.4 Comparison of VOT of CV syllables among males and female

CV syllable	Sex	N	Mean (s)	S.D (s)	95% Confidence Interval for Mean		t test p value
					Lower Bound	Upper Bound	
/ba/	M	15	0.099	0.014	0.091	0.106	0.196
	F	15	0.110	0.029	0.095	0.124	
/bi/	M	15	0.114	0.041	0.093	0.134	0.827
	F	15	0.111	0.031	0.095	0.126	
/bu/	M	15	0.081	0.037	0.062	0.099	0.464
	F	15	0.090	0.031	0.074	0.105	
/da/	M	15	0.112	0.019	0.102	0.121	0.342
	F	15	0.105	0.106	0.096	0.113	
/di/	M	15	0.110	0.021	0.099	0.120	0.551
	F	15	0.115	0.023	0.103	0.126	

From figure 4.2 and Table 4.4 it can be seen that the mean VOT of /ba/ in male and female is 0.099s and 0.110s respectively. When statistical comparison of VOT for /ba/syllable was done among males and female, it shows that there is no significant gender

difference (p=0.196). Similarly, the mean VOT of /bi/,/bu/,/da/,/di/,/du/,/ga/,/gi/,/gu/ in male and female is 0.114s and 0.111s, 0.081s and 0.090s, 0.112s and 0.105s, 0.110s and 0.115s, 0.090s and 0.086s, 0.102s and 0.106s, 0.110s and 0.110s, 0.091s and 0.077s respectively. When statistical comparison of VOT for /bi/,/bu/,/da/,/di/,/du/,/ga/,/gi/,/gu/ syllable was done among males and female, it shows that there is no significant gender difference (p>0.05).

DISCUSSION

The aim of the study is to measure voice onset time (VOT) of Hindi voiced consonant. The result shows that the differences between the means of the VOT for /a/ /i/ and /u/ were significant for all three places of articulation. The differences between the means of the VOT for the three places of articulation for the vowels /a/ /i/ and /u/ were not statistically significant. The difference in the means of the VOT between male and female participants for voiced stop sounds was not statistically significant.

Hypothesis 1 stated that there will be no significant difference between the means of the VOT for the vowels /a/ /i/ and /u/ for the voiced stop consonants /b/, /d/, /g/. However, the hypothesis was proved false. The results show that the differences between the means of the VOT for /a/ /i/and /u/ were significant for all three places of articulation. It was observed that the mean value for VOT of CV syllables was highest for /i/ vowel and lowest for /u/ vowel, with /a/ having the intermediate value. The present study is in accordance with the study done by Kaur (2015) to study the effect of vowel height on VOT which revealed that high vowel /i/ have larger voice-onset time than the low vowel /a/. The findings are consistent with the study done by Klatt (1975) where they indicated that the VOT changed as a function of the place of articulation of the plosive and as a function of the identity of the following vowel.

Hypothesis 2 stated that there will be no significant difference among different voiced stop sounds with respect to same vowel for the three places of articulation. The results of the study show that the hypothesis is true. No significant difference was observed between the means of the VOT while comparing /ba/ /da/ and /ga/ statistically. Also no statistical significant difference was found while comparing /bi/ /di/ and /gi/ and /bu/ /du/, and /gu/.

Hypothesis 3 stated that there will be no significant difference between the means of the VOT of voiced stop sounds for male and female. The results of the present study reveals that the difference between the means of the VOT of voiced stop sounds for male and female were not statistically significant. Hence the null hypothesis was rejected. The findings of the present study are in consonance with the study Christopher, Crea, Herring (2007). In their study no significant differences were observed between the VOTs of the male and female speakers. The findings of the study indicate that a speaker's gender was not a factor associated with VOT variability. In conclusion, the findings of the study indicate that the VOT changed as a function of the place of articulation of the plosive and as a function of the identity of the following vowel; the place of articulation and a speaker's gender were not a factors associated with VOT variability.

SUMMARY AND CONCLUSION

VOT is the time difference between the initiation of the stop burst and the onset of voicing, i.e., the vibration of vocal folds. On wideband spectrograms VOT is measured in milliseconds as the duration between the vertical spike marking the transient burst of stop release and the first vocal pulse that can be observed at the baseline. VOT value are not absolute; they are rather influenced by several factors such as rate of speech, gender, age, vowel duration, height of the vowel, place of the articulation, language and so on.

The aim of this study was to measure voice onset time (VOT) of Hindi voiced stop consonant. For this study 30 subjects were grouped into two groups (male and female). A total of 9 CV syllables (/ba/, /bi/,/bu/, /da/, /di/, /du/, /ga/, /gi/,/gu/) consisting of three voiced stop consonants /b/, /d/, /g/ and vowel (/a/, /i/, /u/) were taken as stimulus for the present study. The participants were seated comfortably in front of a computer connected to a microphone kept at a constant distance of approximately 5cm from the mouth of the speaker. The utterances were recorded and acoustically analyzed via PRAAT software. During the formal recording, they were required to utter the each CV syllable in a normal speed. Production of all the CV syllables was recorded with a sampling rate of 44.1 kHz. The VOT values of the target stops were

obtained from the wave form and verified with the spectrogram. As for the spectrographic readings VOT intervals from the beginning of the release burst to the onset of voicing were analyzed. The obtained data statistically analyzed.

The results confirm that in CV syllable the following vowel has a significant effect (p0.05) due to place of articulation of consonants (/ba/, /da/, /ga/). The present study is also in contrast with that done by Kaur (2015), where it has been found that velar place of articulation is associated with the largest VOT following in descending order by alveolar and labial place of articulation. The present study reveals there is no difference in VOT with respect to gender. These results are in consonance with the study done by Christopher et al. (2007), which reported that the speaker's gender was not a factor associated with VOT variability.

In summary, there is significant difference in VOT only with respect to the following vowel and there is no significant difference in VOT with respect to place of articulation and gender.

Limitation of the study

Limited number of participants

Future directions

More number of parameters can be included.

More number of participants can be included.

Study can be done on Hindi voiceless consonants.

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