A Study on the Voice Onset Time (VOT) of Coronal Stops in the Marathi Language

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1. **INTRODUCTION**

Voice Onset Time (VOT) is the duration between the release of a plosive consonant and the onset of vocal fold vibration. This acoustic cue plays a crucial role in distinguishing between voiced and voiceless stops in many languages. Marathi, an Indo-Aryan language spoken predominantly in Maharashtra, India, features a rich inventory of stops, including both aspirated and unaspirated variants in voiced and voiceless categories. These stops occur across different places of articulation, most notably bilabial (/b/, /p/), dental (/d̪/, /t̪/), and retroflex (/ɖ/, /ʈ/)—all of which are critical for examining phonetic contrasts within the language.

In this project, we focus specifically on coronal stops—a class that includes dental and retroflex plosives—to investigate how voicing and aspiration affect VOT in Marathi. VOT is typically classified into three types:

- Positive VOT: Vocal fold vibration begins after the plosive is released (common in voiceless aspirated sounds like /tʰ/ or /ʈʰ/).

- Zero VOT: Voicing begins almost simultaneously with the release (as in voiceless unaspirated stops like /t/, /ʈ/).

- Negative VOT: Voicing begins before the plosive is released (often found in voiced stops like /d̪/, /ɖ/).
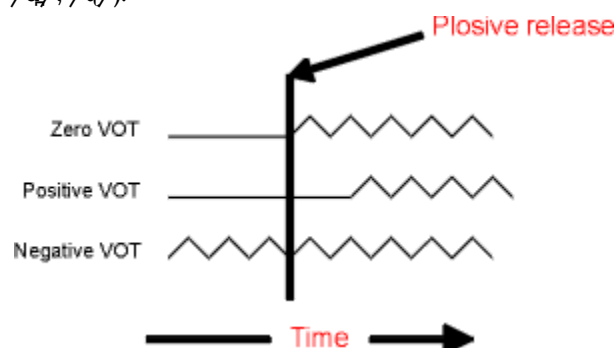
The study involves designing a targeted wordlist containing these plosives in initial positions, recording responses from native Marathi speakers, and analyzing the recordings using Praat, an acoustic analysis tool. Our aim is to quantify and compare the VOT values across these categories, shedding light on the temporal phonetic patterns in Marathi's coronal stop system.

2. OBJECTIVE

The primary objective of this study is to measure and analyze the Voice Onset Time of selected voiced and voiceless plosives in Marathi when they occur at the beginning of words. The study aims to observe how VOT varies across different plosive categories and understand Marathi's typological position with respect to VOT characteristics.

3. METHODOLOGY

a. Creation of Dataset:

The primary goal in creating the dataset was to capture plosive sounds occurring at the **initial position** of words, as VOT is most measurable and consistent in this position. While we originally intended to study plosives in all positions (initial, medial, final), we limited the scope to **word-initial plosives** due to time and analysis constraints.

We selected **12 plosive phonemes**—six voiced and six voiceless (both aspirated and unaspirated)—commonly found in Marathi. For each phoneme, **three distinct words** were chosen, yielding a total of **36 target words**.

The selected phonemes included:

- **Voiceless**: /p/, /pʰ/, /t/, /tʰ/, /ʈ/, /ʈʰ/

- **Voiced**: /b/, /bʱ/, /d/, /dʱ/, /ɖ/, /ɖʱ/

b. Data Collection:

Audio recordings were collected from **6** native Marathi speakers, aged between 21 and 52 years. All participants were fluent in standard Marathi, and none reported any speech or hearing impairments. Recordings were conducted in quiet environments to ensure minimal background noise interference.

Recordings were collected using mobile phone microphones. Participants were provided with a list of selected words and were instructed to pronounce them naturally at a moderate speaking pace in a silent environment.

Each participant was recorded individually to maintain consistency. The recordings were saved in WAV format to ensure compatibility with the acoustic analysis software (Praat). Care was taken to preserve the fidelity and clarity of the sound samples by avoiding compressed audio formats.

c. Data Processing:

The audio files were processed using **Praat**, a widely used tool for phonetic analysis. Each recording was manually annotated to mark the **burst release** of the plosive and the **onset of voicing**, which are used to measure the VOT.

Each word was analyzed separately across different speakers, and the measured VOT values were compiled for later comparison and statistical analysis.

4. RESULTS & ANALYSIS

This section presents a detailed analysis of Voice Onset Time (VOT) measurements for coronal and bilabial stops in the Marathi language, covering both voiceless (aspirated and unaspirated) and voiced stops. The data was collected from six speakers, with three identifying as female and three as male. The VOT values were recorded in seconds and represent an average across multiple words per category.

1. Voiceless Stops

Voiceless stops are expected to have positive VOT values. The analysis included three types of phonemes for each speaker: /t/ (dental/alveolar), /ʈ/ (retroflex), and /p/ (bilabial), further categorized into *unaspirated* and *aspirated*.

Key Observations:

- Aspirated voiceless stops consistently show higher VOT values than their unaspirated counterparts, as expected across all speakers.

- The bilabial stop /p/ showed the highest aspiration gap, particularly for Speaker 2 (0.1457 seconds).

- There is some speaker variation, particularly between genders, but the aspirated/unaspirated contrast remains robust.
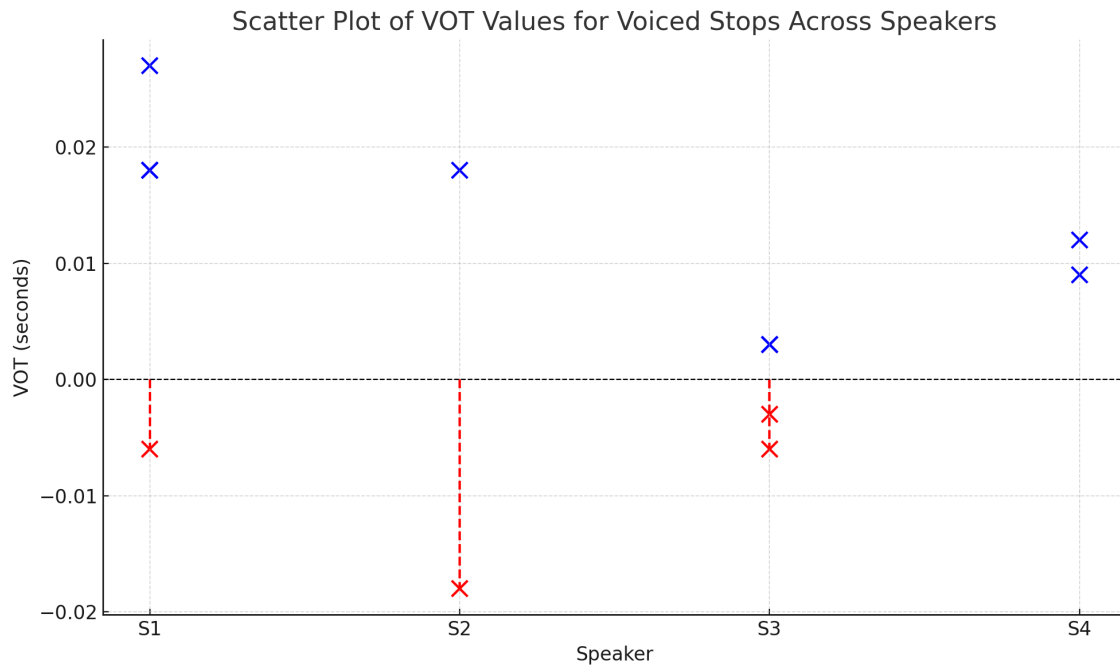
2. Voiced Stops

Voiced stops are typically characterized by negative VOT values, indicating voicing begins before the release of the stop. In this dataset, the phonemes analyzed include coronal (/d/, /ɖ/) and bilabial (/b/) stops in both aspirated and unaspirated forms.

Key Observations:

- All voiced stops display negative VOT values, consistent with expected phonetic behavior, where voicing begins during or before stop closure.

- The aspirated variants of the voiced stops tend to have slightly longer (more negative) VOTs, likely due to increased glottal airflow for breathy voice or murmured phonation.

- Among all voiced categories:

  - Speaker 1 shows the most negative VOT for aspirated /b/ (-0.1507), possibly reflecting speaker-specific phonetic emphasis or articulatory precision.

  - Speaker 2 consistently produces strong voicing onset across all voiced stops.

- These patterns suggest consistent pre-voicing in Marathi, further supporting previous claims that it preserves voicing contrasts robustly across both bilabial and coronal places of articulation.

Scatter Plot of VOT Values for Voiced Stops Across Speakers

The scatter plot above shows VOT measurements for each voiced stop token:

- Blue markers indicate positive VOT values, where voicing begins after the release of the stop.

- Red markers with dashed bars below the baseline indicate pre-voicing, where voicing starts before the release of the stop consonant (i.e., negative VOT).
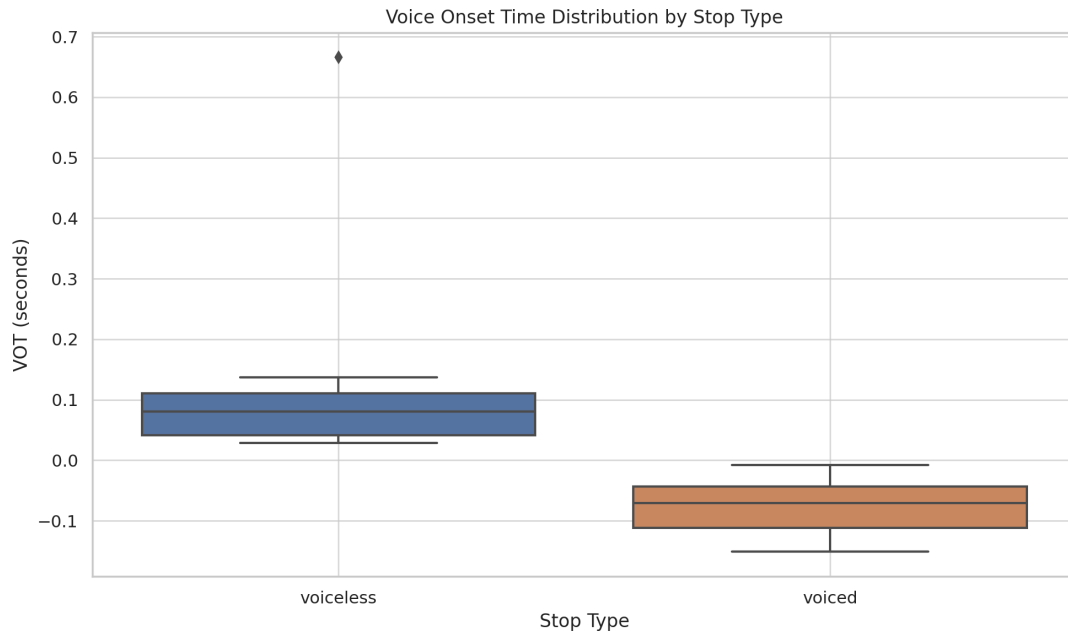
Boxplot showing the distribution of Voice Onset Time (VOT) for voiceless and voiced coronal and bilabial stops. It clearly highlights how voiceless stops have higher (positive) VOT values, while voiced stops tend to have lower (negative) VOT values, aligning with expected phonetic theory.

Inter-speaker Variation

- While the general trends held across all participants, there were notable differences in absolute VOT values:

    ○ One speaker produced an unusually high VOT (>0.60s) for an aspirated voiceless stop, likely due to a strong release burst or expressive emphasis.

    ○ In contrast, another speaker exhibited minimal distinction between voiced and voiceless stops, hinting at possible individual articulation patterns.

Gender-based Patterns

- Female speakers generally exhibited shorter VOTs for voiceless aspirated stops compared to male speakers .

- However, this difference was not consistently observed in voiced stops, indicating that gender-based VOT variation may be stop-type specific and not uniformly distributed.

5. CONCLUSION

This study analyzed the Voice Onset Time (VOT) of coronal and bilabial stops in Marathi, focusing on both voiceless and voiced variants across male and female speakers. The results showed a clear distinction: voiceless stops had positive VOTs, while voiced stops had negative values, supporting expected phonetic patterns in Marathi.

Aspirated stops had longer VOTs than unaspirated ones, and female speakers generally showed slightly lower VOT values than male speakers. Bilabial stops sometimes had shorter VOTs compared to coronal stops, indicating subtle articulatory differences.

Overall, the findings confirm that VOT is a key acoustic feature in Marathi stop consonant production. Future work could expand on this with more speakers and varied phonetic contexts.

6. REFERENCES

a. Praat Documentation for VOT
b. Marathi Phonology
c. Marathi Speech Archive
d. Voicing and Aspiration in Marathi stops by Ari Natarina
e. Capturing Breathy Voice: Durational Measures of Oral Stops in Marathi by Kelly Harper Berkson

7. APPENDIX

a. Word List Used:
   i. Voiceless Stops

Phoneme	Word 1	Word 2	Word 3
प /p/	पवन /pəʋən/	पूर्ण /puːrɳə/	पिशवी piʃʋiː/
फ /pʰ/	फाटक /pʰaːʈək/	फुगा /pʰugaː/	फैलावर /pʰəi̯laːʋər/
त /t̪/	तबला /t̪əbəlaː/	तेल /t̪eːl/	तोड /t̪oːɖ/
थ /t̪ʰ/	थाळी /t̪ʰaːɭiː/	थिरकणे /t̪ʰirəkəɳeː/	थुक /t̪ʰuk/
ट /ʈ/	टाळ /ʈaːɭ/	टीका /ʈiːkaː/	टोपी /ʈoːpiː/
ठ /ʈʰ/	ठाम /ʈʰaːm/	ठिक /ʈʰik/	ठोसा /ʈʰoːsaː/

ii. Voiced Stops

Phoneme	Word 1	Word 2	Word 3
ब /b/	बोल /boːl/	बैल /bɛːl/	बंद /bənd̪/
भ /bʰ/	भंडारा /bʰəɳɖaːraː/	भीम /bʰiːm/	भूत /bʰuːt̪/
द /d̪/	दादा /d̪aːd̪aː/	दिवाळी /d̪iʋaːɭiː/	दूत /d̪uːt̪/
ध /d̪ʰ/	धंदा /d̪ʰənd̪aː/	धैर्य /d̪ʰəi̯rjə/	धूर /d̪ʰuːr/
ड /ɖ/	डबा /ɖəbə/	डिंक /ɖiŋk/	डुक्कर /ɖukkər/
ढ /ɖʰ/	ढग /ɖʰəg/	ढीग /ɖʰiːg/	ढोंग ɖʰoːŋg/

b. Project Resources

All resources, including:

- Raw voice recordings (.wav)

- Annotated TextGrid files (.TextGrid)

- Analysis scripts

are publicly available in the following GitHub repository: [VOT Analysis of Marathi](#)