# AN EXPERIMENTAL INVESTIGATION OF TONOGENESIS IN PUNJABI

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## ABSTRACT

In this study, we provide a detailed phonetic description of the F0 patterns of Punjabi, an Indo-European language that is believed to be be undergoing tonogenesis. The purported emergent tone in Punjabi is associated with only one class of consonants – those which are thought to be historically voiced aspirated, but now may have lost both aspiration and voicing, instead being differentiated from other consonants by F0. Using data from 6 native Punjabi speakers (3F, 3M) and careful phonetic analysis, we confirm that these consonants are now realised as unaspirated, and, word-initially, also as voiceless. We also find that these consonants induce a falling F0 in the following vowel, but only in word-initial position. Noting that Punjabi nouns are usually stressed word-initially, this pattern of restricted F0 modulation closely resembles languages with emerging tone or "pitch accent".

**Keywords:** Tonogenesis; Pitch Accent; Punjabi

## 1. INTRODUCTION

Punjabi is one of the few Indo-European languages reported to have lexical tone. It has approximately 130 million native speakers, concentrated in Northern India and Pakistan, but spread worldwide by a large diaspora population. The tone patterns described in Punjabi are particularly interesting because they are linked to only one class of consonants – those that are believed to have once been voiced aspirated but that are now reportedly realised without aspiration (and sometimes without voicing) and with an added tone.

The set of Punjabi consonants which are relevant for our discussion are the 20 oral stops and affricates, shown in Table 1. In the table, 'T' symbolises voiceless unaspirated manner, 'TH' voiceless aspirated, 'D' voiced unaspirated, and 'DH' are the consonants which were historically voiced aspirated, but whose current phonetic properties we investigate here. The evidence for the historic realisation of these consonants as voiced aspirated can be seen in the Gurmukhi script, used by speakers in the Indian state of Punjab as the primary means of writing Punjabi, as well as in cognates found in closely related languages such as Hindi.

**Table 1:** Punjabi oral stops and affricates. Each cell is represented orthographically by a single unique symbol in the Gurmukhi script. Our goal is to determine the phonetic realization of 'DH'.

| | 'T' | 'TH' | 'D' | 'DH' |
|---|---|---|---|---|
| bilabial | p | p$^h$ | b | ? |
| dental | t | t$^h$ | d | ? |
| retroflex | ʈ | ʈ$^h$ | ɖ | ? |
| "palatal" | ʧ | ʧ$^h$ | dʒ | ? |
| velar | k | k$^h$ | g | ? |

**Table 2:** A near-minimal set containing word-initial consonants with the same PoA but varying in manner. The 'DH' example's phonetic realization is expected based on previous research.

| | 'T' | 'TH' | 'D' | 'DH' |
|---|---|---|---|---|
| Punjabi (IPA) | koɽa | k$^h$oɾa | goɾa | kòɽa |
| English gloss | *bitter* | *rough* | *white* | *horse* |

Existing descriptive sources conflict with one another on the phonetic realisation of the DH consonants. First, there are claims that aspiration no longer occurs [13, 14, 16]. However, [8] claims that some remaining traces of breathiness can be observed in vowels preceding DH consonants. Second, it is thought that voicing is also lost, but only word-initially [13, 14, 16]. Finally, a three-tone system is commonly proposed, in which DH consonants induce low, low-rising, or falling tone in the following vowel; high, rising-falling, or rising tone in the preceding vowel; and mid tone elsewhere [3, 5, 8, 13, 14, 16]. Table 2 shows a frequently documented minimal set motivating these claims.

These previous claims are either impressionistic or based on limited data. In our study, we aim to provide a definitive phonetic characterisation of these consonants, using a comprehensive data set and modern phonetic analysis tools. For reasons of space, we focus here on assessing the following two claims: that DH consonants are now realised as voiceless unaspirated word-initially, but voiced unaspirated word-medially; and that DH consonants induce either a low, low-rising, or falling tone in the following vowel. We leave discussion of tone induced in preceding vowels, as well as of remaining breathiness, for future work.

## 2. METHODS

### 2.1. Speakers and Recordings

Six native Punjabi speakers (three females, three males) were recorded. Participants were recruited through the university and the local Sikh temple, and recordings were done at both locations. Recordings in the UCSD Phonetics Lab's soundproof booth were done using Audacity (16-bit quantization and 44.1 kHz sampling rate) and a head-mounted Shure SM10 microphone. Recordings at the Sikh Foundation Gurdwara San Diego were done in a quiet classroom on the temple premises using Praat [4] (16-bit quantization and 44.1 kHz sampling rate) and a Yeti USB microphone connected to a laptop computer.

### 2.2. Materials and Procedures

A wordlist was constructed that compared the DH consonants with their voiceless aspirated, voiceless unaspirated, and voiced unaspirated counterparts across all possible places of articulation (bilabial, dental, retroflex, "palatal", velar) and across word-initial, word-medial, and word-final positions. Thus, the wordlist consisted of 15 minimal or near-minimal sets of four, or 60 words, though the subsequent analysis excludes word-final position. The number of syllables per word varied (26 monosyllabic, 34 disyllabic) but remained constant across minimal sets. For near-minimal sets, syllable structure and weight was held constant when possible to avoid potential stress shifts.

The wordlist given to participants listed only the Gurmukhi script and the English gloss for each word. All participants were proficient in reading the Gurmukhi script. Each speaker was given the same wordlist in a different randomized order. Each word was read in the carrier phrase [mæ hʊn ___ bol rahi hãː] (*"I am saying ___ now"*) to prevent any confounding phrase-boundary intonational effects. Importantly, carrier phrases were not used in any previous phonetic studies, perhaps partially contributing to the conflicting claims regarding tone. The entire list was read twice by each speaker.

### 2.3. Acoustic measurements

Voice Onset Time (VOT) measurements were taken in Praat. Negative VOT measurements were taken from the beginning of voicing of the stop until its burst. Positive VOT was measured from the beginning of the stop's burst until voicing began in the following vowel. A burst was defined as the first transient (if more than one occurred) before the vowel in the waveform, and voicing was defined as regular glottal pulsing in the waveform. For DH tokens with negative VOT, the presence or absence of aspiration was also noted. Across all tokens, however, aspiration did not occur following DH. VoiceSauce [15] was used to extract duration measurements.

Vowels were also measured in Praat. The vowel onset and offset were set at the first and last glottal pulse of the vowel, respectively. VoiceSauce was used to extract the fundamental frequency (F0) and first and second formants (F1 and F2) from the labeled sound files. F1 and F2 were measured to ensure that vowel quality did not confound the results. For example, a high vowel like /i/ has inherently high F0 [17], so these vowel quality differences must be accounted for in order to isolate whether the consonant is inducing a change in F0. VoiceSauce provided a mean value across the entire value of the above measurements, as well as mean measurements by ninths of the vowels' duration.

### 2.4. Statistical analyses

To test for significant effects, several linear mixed effects models were run. Two models examined whether VOT measurements were different across consonants: one for word-initial position and one for word-medial position. Two separate models were created since our predictions for DH consonants' VOT measurements differ across word position. For F0 measurements, two models examined the mean F0 and ΔF0 (defined as the difference of the last third of the vowel and the first third of the vowel) in the vowel directly following each consonant. As with the VOT models, these models were run separately for each position, for a total of six models.

For the VOT measurements, the fixed effect was Consonant Type (DH, D, T or TH). For the F0 measurements, the fixed effects were: (1) F1 mean, (2) F2 mean, (3) sex, (4) Consonant Type, and (5) NumberSyllables (monosyllabic vs. disyllabic words). The formant measurements were included to control for intrinsic F0 of the vowel. Number of syllables was included since intonational effects over prosodic words are possible, and if present, they will manifest themselves differently if a word is mono- vs. multi-syllabic. In the medial-position models this fixed effect was not included since words were always disyllabic.

For all models, Speaker and Word were included as random intercepts. This was the maximal, uncor-

**Figure 1:** Voice Onset Time for consonants in word-initial vs. word-medial position.

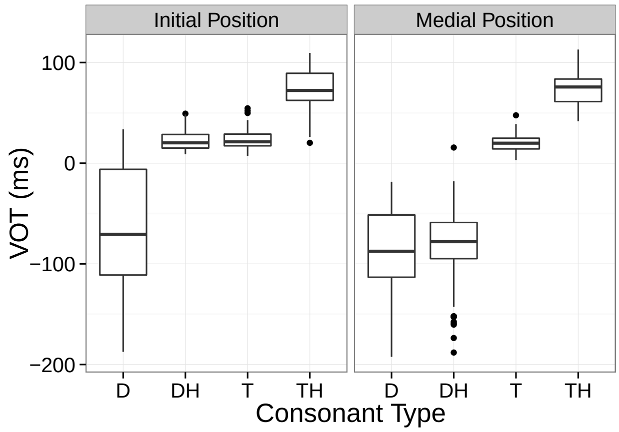
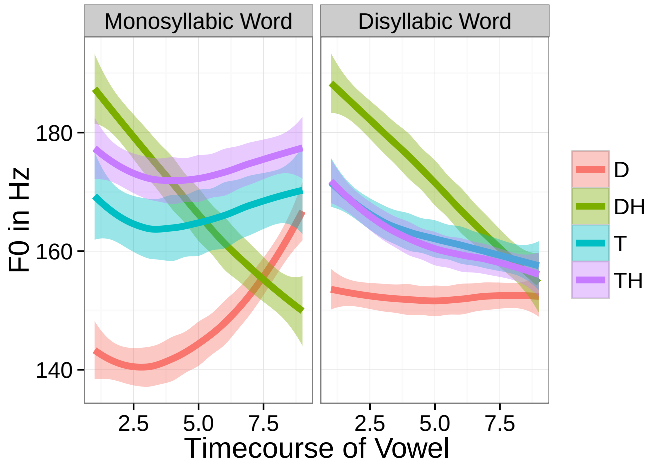



**Figure 2:** Average F0 of vowels (with 50% CIs due to large between-sex differences) following word-initial consonants, contrasting monosyllabic and disyllabic words.




related random-effects structure that converged. For all models, significance of fixed effects was assessed using model comparison. Alpha was set at $p < 0.05$.

## 3. RESULTS

Because we have different predictions regarding DH consonants based on their position in the word, results are separated by consonant position.

### 3.1. Word-initial position

In initial position, VOT (D) < VOT (DH, T) < VOT (TH) (all significant differences at $p < 0.05$). As illustrated in Figure 1, DH and T appear to have collapsed into one voicing category word-initially: voiceless unaspirated.

As shown in Figure 2, vowels following DH consonants appear to have a notable falling pitch contour in both monosyllabic and disyllabic words. This appeared to be true for all but one speaker.[1] For monosyllabic words, there appears to be a rise at the end of the word (except for words with DH consonants), though this is not present for the disyllabic words (since in these cases the target syllable is not word-final). The rising at the end of monosyllabic words may be evidence of rising intonation over prosodic words, which is a common pattern found in related languages (e.g., Bengali [11]).

For our average F0 model, we only find a significant difference in sex ($p < 0.05$, females having higher F0 on average). However, in our $\Delta$F0 model, we find a significant difference in sex ($p < 0.05$, females having greater change in F0) and also a significant interaction between Syllable and Consonant Type ($p < 0.05$). Follow-up regression analyses reveal that vowels following D, T, and TH consonants have a greater $\Delta$F0 in monosyllabic words than in disyllabic words (all significant differences at $p < 0.05$). This is probably due to an intonational rise that is realized over monosyllables, whereas this rise is realized over the second vowel in disyllables. However, this difference is not found for vowels following DH consonants. Instead, results are consistent with a falling F0 target on vowels after DH in both monosyllabic and disyllabic words.

### 3.2. Word-medial position

In medial position, VOT (D, DH) < VOT (T) < VOT (TH) (all significant differences at $p < 0.05$). As shown in Figure 1, DH and D appear to have collapsed into one voicing category word-medially, where they are both voiced unaspirated.

For our model examining average F0, we only find a significant difference in sex ($p < 0.05$, females having higher F0 on average). This model did not find any significant differences in average F0 between DH consonants and other consonants. In our $\Delta$F0 model, no fixed effects were found to be significant. Thus, we have no evidence that F0 of vowels following DH consonants in word-medial position are different from the other consonants.

## 4. DISCUSSION

Our analysis of VOT in word-medial and word-initial consonants provides clear confirmation that Punjabi DH consonants, once voiced and aspirated, are now realised as voiceless and unaspirated word-initially, and voiced unaspirated word-medially.

Turning to tone, the results of our analysis of F0 following consonants are more complex and unexpected. Following word-initial DH consonants, a *falling* F0 was observed, as opposed to low or low-rising as described by most prior accounts. This falling contour was clearly present in all but one speaker. Following word-medial DH, vowels did not differ in F0 compared to other consonants.

Below, we discuss (1) why an originally voiced aspirated consonant might have led to the emergence of falling F0 on the following vowel, and (2) why this phenomenon is only found word-initially.

Tonogenesis is thought to be initiated in some cases by F0 perturbations caused by articulatory constraints during production of a sound [9]. These perturbations can be reproduced and exaggerated by hearer after hearer, eventually leading to the reanalysis of the original sound as containing an F0 change as part of its phonological profile.

The lowered larynx during voiced stops is one potential cause of lower F0 in following vowels. This lowering of the larynx, probably to maintain voicing by decreasing supraglottal pressure, may correspond to slackened vocal folds, and hence slowed vibrations, lowering F0 [9]. Aspiration is another possible cause of lowered F0 in following vowels, due to the vocal fold slackness required to produce aspiration [9]. Evidence for this is seen in the observed tonogenesis in Phnom Penh Khmer; breathiness accompanying a (colloquially devoiced or deleted) trill is the likely cause of an emerging low tone in positions where the trills are deleted [12].

Consonants that combine voicing and aspiration, like the DH consonants, are even more likely to produce F0 lowering in the following vowel; the configuration of the vocal folds necessary to produce voiced aspiration–glottis open at rear for voicing, but sufficient approximation of the anterior folds for aspiration–results in a "murmur", or mixed voicing consonant, with slowed pulses, and thus lowered F0 [1]. The unusual pattern of vocal cord vibration of these murmured consonants is what may cause them to also be misperceived as voiceless [8].

This explains why the combination of voicing and aspiration on DH consonants might have been reanalysed as a gradually lowered, or falling, tone after a voiceless unaspirated consonant. But why is this pattern restricted to word-initial consonants? One answer is that there is simply no tone across the board, and that the apparent tone seen following word-initial consonants is due to phonetic coarticulation effects. However, if the observed F0 change were due to coarticulation, we should expect it to die out towards the end of the vowel. This is true for any changes occurring after T, TH, and D, but not generally after DH. Furthermore, coarticulatory considerations lead us to expect a low onset F0 after DH, with the F0 rising to meet the endpoint of the other consonants. Instead we see a high onset F0 after DH that lowers throughout the duration of the vowel, suggesting that there is a tonal specification on the vowel independent of coarticulatory effects.

A more likely explanation is that the privileged status of initial syllables in Punjabi (initial syllables usually carry stress in disyllabic nouns and adjectives [3]) means they are more likely to bear the effects of tonogenesis. This may be aided by the fact that we observed a general rising F0 in word-final syllables, suggestive of Punjabi being an AP-rise language, similar to other Indian languages such as Bengali [11], Malayalam [2], and Tamil [10]. If F0 starts rising towards the end of a word for the AP post-lexical tone, then this could cancel out any effects of tonogenesis for word-medial stops.

This apparent restriction of tone to word-initial (usually stress-bearing) syllables closely resembles "pitch accent" languages or languages with emerging tone; it is characteristic of such languages to only allow tone in one or two word positions. Swedish and Serbo-Croatian, for example, only have tones on stressed syllables [6, 7]. Our results therefore suggest that Punjabi fits the profile of a language with emerging tone or "pitch accent".

## 5. CONCLUSION

In this paper, we have focused on the phonetic properties of Punjabi 'DH' consonants in word-initial and word-medial position, as well as the tonal properties of the following vowel. Our results confirm previous claims that these historically voiced aspirated consonants are now realised without aspiration, and, word-initially, also without voicing. More surprising is our result that vowels following word-initial DH consonants show a clear falling F0, while no significant F0 differences are found following word-medial stops. In future work, we will describe the properties of DH consonants in word-final position, as well as investigate the patterns of tone and breathiness, if any, on preceding vowels.

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[1] This may be due to the fact that, in contrast to the other speakers, this speaker was younger and had lived a greater proportion of his life in the US. Thus, he might be classed as closer to a heritage speaker, and this could explain his lack of tonal contrasts.