Effects of Stop Laryngeal Features on Duration of Preceding Vowels: Implications for Winter's Law

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Vowel duration as influenced by voicing of following consonants

- Vowels are longer before voiced than voiceless obstruents in many languages, including Hindi (e.g. Durvasula & Luo 2014, Ohala & Ohala 1992)
  - though not all languages, e.g. Polish and Czech (Keating 1979) and some dialects of Arabic (Mitleb 1984), and possibly Telugu (Reddy 1988)
- Explanations have been proposed based on articulation (e.g. Chen 1970, Halle & Stevens 1967) and perception (e.g. Kluender et al. 1988, Javkin 1976)

Vowel duration as influenced by aspiration of following consonants

- Studies on how vowel duration interacts with aspiration, all in Hindi, have varied results
- Some found greater length before aspirated/breathy stops than unaspirated stops (e.g. Durvasula & Luo 2014), but others found no difference (e.g. Ohala & Ohala 1992)
- Hindi is not necessarily representative

Winter's Law

- Winter's law proposes that short vowels in Proto-Balto-Slavic were lengthened before plain voiced stops but not before voiced aspirated stops (Winter 1978)
- It has been questioned whether the law is phonetically natural (e.g. Shintani 1985, Rasmussen 1992)

Participants: Speakers

- 3 native speakers of Hindi (ages 18-45)
- 1 native speaker of Telugu (age 23)

Recordings

- Speakers were recorded in a sound-attenuated booth
- VC nonce words given in the orthography of the target language in randomized order
  - long and short vowels /a/, /i/, /u/ (in Hindi, they also have quality differences)
  - each laryngeal configuration for bilabial, dental, retroflex, and velar stops; two sonorants for comparison
  - Telugu forms were often realized with an excrescent final vowel, as word-final stops are not permitted
- Disfluencies and unclear utterances were omitted

Hypotheses about Aspiration and Breathy Voiced Stops

- Hypothesis: Only voicing has an effect on duration of preceding vowels; aspirated or breathy voiced stops will have the same effects as their plain counterparts
- Counter-Hypothesis 1: Aspiration/breathy release will result in vowels which are longer than vowels before plain stops
- Counter-Hypothesis 2: Aspiration/breathy release will result in vowels which are shorter than vowels before plain stops

Potential explanations: Compensatory timing

- Vowel lengthening before voiced obstruents due to shorter constrictions (Kluender, Diehl & Wright 1988)
  - However, Fowler (1991) found evidence against this perceptual cause of the voicing effect
  - Could the effect depend on the listener's native language?
- If extended to total duration of the stop closure + release, would predict shorter vowels before aspirated stops (voiced or voiceless)

Potential explanations: Phonation type

- The duration of vowels can differ by voicing type
  - Usually contrastively non-modal vowels are longer than their modal counterparts, if there is a difference (Gordon & Ladefoged 2001)
- Would predict longer vowels before breathy voiced stops than plain voiced stops and no effect of voiceless aspirated stops

Potential explanations: F0 (via voicing and breathiness)

- Pitch contours can make vowels seem longer (e.g. Yu 2010), so the F0 drops created by voicing (e.g. Kirby & Ladd 2016) could produce perceived lengthening
  - There is a greater F0 drop caused by breathy voice than modal voice (Hombert, Ohala, & Ewan 1979)
- If breathiness is restricted to the transition to the consonant, this would predict longer vowels before breathy voiced stops than plain voiced stops
- But if breathiness extends through the vowel, decreasing the overall F0, it could produce less of a contour, predicting shorter vowels before breathy voiced stops

Effects of the following consonant: Hindi

Table: Hindi vowel durations (ms) by following consonant

	voiced	voiced aspirated	voiceless	voiceless aspirated
long vowels (iː, uː, aː)	254	256	206	215
short vowels (ɪ, ʊ, ə)	148	148	127	124

Using a mixed effects model, Hindi vowels were significantly longer before voiced than voiceless stops ($p < 0.0001$); consistent with previous work in Hindi

No significant effect of aspiration ($p = 0.86$), nor interaction between aspiration and voicing ($p = 0.66$)

Effects of the following consonant: Telugu

Table: Telugu vowel durations (ms) by following consonant

	voiced	voiced aspirated	voiceless	voiceless aspirated
long vowels	326	336	322	298
short vowels	159	132	147	138

Telugu vowels were not significantly longer before voiced than voiceless stops ($p = 0.57$); consistent with Reddy 1988

Vowels were slightly shorter before aspirated than unaspirated stops ($p = 0.039$)

Weighing explanations

- No effect of aspiration in Hindi; in Telugu, aspirated stops (voiced and voiceless) result in shorter vowels
- Compensatory timing seems appealing – but would need evidence for why Fowler's (1991) results suggest otherwise
- Breathiness + voicing effects on F0 contours could explain the pattern if Telugu vowels assimilate in breathiness – but doesn't seem to account for voiceless aspirated stops

Closure durations in Hindi stops

Table: Hindi stop closure durations (ms)

	voiced	voiced aspirated	voiceless	voiceless aspirated
after long vowels	81	85.4	144.2	140.8
after short vowels	103.2	99.3	158.9	143.9

Using a linear mixed effects model, closures were significantly longer for voiceless stops than voiced stops ($p < 0.001$)

Closures were shorter after long vowels than after short vowels ($p < 0.001$), mostly driven by differences among voiced stops

No significant differences between the closure durations of aspirated and unaspirated stops

Hindi closure duration relative to long vowel duration

A negative correlation between long vowel duration and duration of the stop closure, though not always significant:

- Voiced $r(68) = -0.057$, $p = 0.64$
- Voiced aspirated $r(63) = -0.28$, $p = 0.019$
- Voiceless $r(61) = -0.32$, $p = 0.0071$
- Voiceless aspirated $r(51) = -0.069$, $p = 0.62$

No consistent pattern in correlations between vowel duration and total consonant duration (closure + release)

Hindi closure duration relative to short vowel duration

Smaller negative correlation between short vowel duration and duration of the stop closure, and only among voiced stops:

- Voiced $r(57) = -0.17$, $p = 0.19$
- Voiced aspirated $r(51) = -0.25$, $p = 0.063$
- Voiceless $r(65) = 0.049$, $p = 0.69$
- Voiceless aspirated $r(54) = 0.038$, $p = 0.78$

No consistent pattern in correlations between vowel duration and total consonant duration (closure + release)

Closure duration in Telugu stops

Table: Telugu stop closure durations (ms)

	voiced	voiced aspirated	voiceless	voiceless aspirated
after long vowels	78.6	73.3	138.6	105.5
after short vowels	84.3	85.7	144.7	118.7

Using a linear mixed effects model, closures were significantly longer for voiceless stops than voiced stops ($p < 0.001$)

Stop closures were somewhat longer after short vowels ($p = 0.069$)

No significant main effect of aspiration on closure duration ($p = 0.91$), but an interaction with voicing ($p = 0.0044$)

Closure duration relative to vowel duration in Telugu

Within categories, there was no correlation between the duration of the vowel and the duration of the following stop closure:

- Voiced $r(49) = 0.047$, $p = 0.74$
- Voiced aspirated $r(57) = 0.026$, $p = 0.84$
- Voiceless $r(40) = 0.039$, $p = 0.81$
- Voiceless aspirated $r(50) = -0.14$, $p = 0.32$

Total stop duration relative to vowel duration in Telugu

Data was limited because release duration was only measured when there was no following vowel; perhaps a trend towards negative correlation

- Voiced $r(8) = -0.48$, $p = 0.12$
- Voiced aspirated $r(16) = -0.18$, $p = 0.47$
- Voiceless $r(12) = 0.24$, $p = 0.39$
- Voiceless aspirated $r(9) = -0.18$, $p = 0.59$

Breathiness in Hindi vowels

Table: Hindi spectral tilt (H1-H2)

	voiced	voiced aspirated	voiceless	voiceless aspirated
any vowel	5.6	6.1	6.2	5.3

No significant differences; between voiced aspirated and other stops, $p = 0.68$

Vowels are not breathier before the voiced aspirated/breathy stops than elsewhere

Breathiness in Telugu vowels

Table: Telugu spectral tilt (H1-H2)

	voiced	voiced aspirated	voiceless	voiceless aspirated
any vowel	-3.1	-5.1	-3.0	-3.2

There is a suggestive difference in vowels being breathier before voiced aspirated/breathy stops than elsewhere, though it does not reach significance ($p = 0.077$)

F0 in Hindi (male speakers only)

Table: Hindi maximum F0 (Hz) by following consonant

	voiced	voiced aspirated	voiceless	voiceless aspirated	sonorants
any vowel	159.8	168.2	173.4	176.3	170.6

Table: Hindi minimum F0 (Hz) by following consonant

	voiced	voiced aspirated	voiceless	voiceless aspirated	sonorants
any vowel	140.9	148.7	152.3	156.4	150.0

Trend towards lower F0 before voiced obstruents, but not significant in maximum F0 ($p = 0.095$) or minimum F0 ($p = 0.11$)

No significant effects of aspiration, though vowels before aspirated voiced stops have a trend towards higher F0s than those before plain voiced stops

F0 in Telugu

Table: Telugu maximum F0 (Hz) by following consonant

	voiced	voiced aspirated	voiceless	voiceless aspirated	sonorants
any vowel	213.5	208.9	224.6	228.2	226.5

Table: Telugu minimum F0 (Hz) by following consonant

	voiced	voiced aspirated	voiceless	voiceless aspirated	sonorants
any vowel	188.0	187.1	199.9	203.8	200.4

Before voiced stops, there is a lower F0 minimum ($p = 0.014$) and maximum ($p = 0.0093$)

No significant effect of aspiration, though a trend towards a smaller F0 range before breathy voiced stops

Conclusions: Winter's Law

- The Telugu results suggest that it would be possible to have lengthening before plain voiced stops and not before aspirated voiced stops
- Could inform phonetic characteristics of the PIE voiced aspirates, depending on what explanation is believed

Conclusions: Vowel Lengthening Effects

- What underlies the voicing effect still remains uncertain
- But the interaction with aspiration provides additional information limiting what explanations of the voicing effect are plausible

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