Voicing, aspiration and vowel duration in Hindi

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Abstract

There is extensive evidence that consonantal laryngeal features modulate preceding vowel duration (Chen, 1970). However, it is not clear if both consonant voicing and aspiration affect preceding vowel duration. Previous studies produced inconsistent results with respect to the effect of consonant aspiration on vowel duration, while finding a clear positive correlation with consonant voicing (Maddieson & Gandour, 1976; Ohala & Ohala, 1992; Lampp & Reklis, 2004). Furthermore, the locus of the explanation of these effects is unresolved (Kluender et al, 1988; Fowler, 1992). We conducted an experiment on 7 native standard Hindi speakers, who produced 10 repetitions of 12 nonsense words ending in [d̪, d̪ʰ, t̪, t̪ʰ] that had 3 different CVCVC contexts. In this article we focus on standard Hindi to show the following: (a) As with other languages, there is a vowel duration difference before voiced and voiceless consonants coda (syllable-final) consonants, (b) Vowel durations preceding aspirated coda consonants are longer than those before unaspirated coda consonants, (c) Closure durations of coda consonants are longer for unaspirated consonants and voiceless consonants, (d) Finally, when crucial confounds are controlled for, there is a slight positive, *not negative*, correlation between coda consonant duration and preceding vowel length.

1 Introduction

In this article we focus on the Indo-Aryan language Hindi to show the following: (a) As with other languages, there is a vowel duration difference before voiced and voiceless consonants coda (syllable-final) consonants, (b) Vowel durations preceding aspirated coda consonants are longer than those before unaspirated coda consonants, (c) Closure durations of coda consonants are longer for unaspirated consonants and voiceless consonants, (d) Finally, when crucial confounds are controlled for, there is a slight positive, *not negative*, correlation between coda consonant duration and preceding vowel length. In contrast to the presented paper, in this paper, we delve deeper into the effects of voicing and aspiration on vowel and consonant duration, while ignoring the effect of the same on F1. We decided not to present the effect on F1 because the statistical results were null results, and are therefore difficult to interpret. Furthermore, presenting the results would have also distracted the reader from a more important and specific point (d – above) that the data bear on.

There is an enormous amount of research that has documented the correlation between voicing of coda consonants and the duration of the preceding vowel in numerous languages, e.g. English (House & Fairbanks, 1953; House, 1961), French (Belasco, 1953; Chen, 1970), Russian, Korean (Chen, 1970), Bengali (Kostic & Das, 1972) and so on. The basic finding is that the vowel duration before voiced consonants is longer than that before voiceless consonants. We will call this the *voicing effect*.

Contrastingly, research on the relationship between the aspiration of coda consonants and the duration of the preceding vowel has led to inconsistent results (Maddieson & Gandour, 1976; Ohala & Ohala, 1992; Lampp & Reklis, 2004). Since all of the prior research that we are aware of on this particular topic has focused on Hindi (the target language in this article), we discuss the relevant work in more detail in Section 2. We will call this the *aspiration effect*.

A variety of accounts have been proposed to capture the *voicing effect*, but this is not the case in the case of the *aspiration effect* as the results have been inconsistent. Some of the proposed accounts for the *voicing effect* are production-based accounts such as those that suggest the shortened vowel duration before voiceless consonants is due to the greater articulatory force needed to produce such consonants (Belasco, 1953), and those that attribute the effect to laryngeal adjustments needed to produce voiced consonants (Halle & Stevens, 1967; Chomsky & Halle, 1968). However most of these production-based accounts have been criticized based both on the absence of evidence for their empirical consequences (Chen, 1970) and lack of proper justification for many crucial notions that are invoked (Kluender et al 1988).

Somewhat more recently, some have suggested the possibility of the *voicing effect* being driven by perceptual factors (Javkin, 1976; Kluender et al 1988). Kluender et al (1988) offer a clear and testable perceptual account of the effect. Most importantly, they attempt to link the *voicing effect* to the fact that closure durations of voiced consonants are shorter than those of voiceless consonants (e.g. Lisker, 1957; Stathopoulos & Weismer, 1983; Davis & Summers, 1989). They propose a general auditory contrast account according to which a long vowel duration enhances the perceptual cue of a short closure duration on the following consonant, i.e., the presence of a longer vowel duration makes the short closure duration for voiced consonants sound even shorter, whereas the presence of a shorter vowel duration before voiceless consonants makes the long closure duration sound even longer. They adduce evidence for this claim though a perception experiment that showed, using both speech and non-speech stimuli, that participants appeared to associate longer preceding auditory contexts with shorter following auditory contexts. They provide further evidence from Arabic, where no similar vowel duration differences have been found before voiced and voiceless consonants (Mitleb, 1984; de Jong & Zawaydeh, 2002). Crucially, for them, the little evidence that exists on such durational differences in Arabic suggests an absence of differences in closure durations of voiced and voiceless codas (Flege & Port, 1981).

Although Kluender et al's (1988) account at first sight appears to neatly capture the phonetic facts and the observable linguistic variation, there seems to be some evidence against the viability of the account. Fowler (1992) was not able to replicate their perceptual findings. In fact, she found that participants tend to associate longer vowels in VCV synthetic-speech disyllables with judgments of longer closure duration.

It is important to highlight that while the perceptual claims associated with the *voicing effect*, the production facts associated with the reverse correlation between coda closure duration and preceding vowel duration seem to have remained uncontested, i.e., it has remained relatively uncontested that there is a negative correlation between preceding phonetic vowel duration and following coda consonant duration in production. However, the evidence that has typically been adduced in favor of the said negative correlation, as will become clear in what follows, is statistically inappropriate. The crucial evidence one needs to show for the negative correlation is a case where, when other factors such as voicing and aspiration (amongst others) are controlled for, then there is a negative correlation between closure duration and preceding vowel duration. This to our knowledge has never been shown. Simply put, it is entirely possible for there to be an increased vowel duration before voiced consonants, and for voiced consonants to have shorter closure durations than voiceless consonants in the same language, without there being a negative correlation between closure duration and preceding vowel duration.

In this article, we focus on the Indo-Aryan language Hindi because along with allowing us to answer questions related to closure duration and voicing, it will allow us to probe the question of how vowel duration is related to aspirated, since it is special in having a four-way laryngeal contrast that employs all possible combinations of aspiration and voicing. In Section 2, we present a brief background on the relevant segmental facts of Hindi and previous research related to the vowel length effect in Hindi. In Section 3, we present the methodology of the production experiment. Section 4 presents our findings of the voicing and aspiration effects on vowel duration and closure duration in Hindi. Finally, Section 5 provides concluding remarks.

2 Hindi: relevant language background & research

Hindi is an Indo-Aryan language that is spoken natively by about 258 million speakers largely in the northern states of India (Census of India, 2001). Most relevant to the current article is the fact that Hindi has a 4-way contrast for laryngeal features that employs a full cross-classification of voicing and aspiration, i.e. voiceless unaspirated, voiceless aspirated, plain voiced, and voiced aspirated (Ohala & Ohala, 1972; Esposito et al, 2005). For example, in Table **1**, we present the 4-way contrast for bilabial stops.

Furthermore, at least in the standard dialect, all four types may appear in coda (syllable-final) position.

Coda type	Examples
Voiceless unaspirated	[pa:l] 'take care of'
Voiceless aspirated	[p^ha:l] 'knife blade'
Voiced unaspirated	[ba:l] 'hair'
Voiced aspirated	[b^ha:l] 'forehead'

Table 1: Examples of 4-way stop contrast in Hindi (Esposito et al, 2005)

Previous work on Hindi focusing on the relationship between vowel duration and coda consonants characteristics has replicated the finding of shortened vowel durations before voiceless consonants, but has found inconsistent evidence supporting the effect of coda aspiration on vowel duration and closure duration.

For example, Maddieson and Gandour's (1976) studied the effect of the voicing and aspiration on vowel duration in Hindi. They used a nonsense monosyllable /sa:C/ in a carrier phrase, where C stands for relevant coda consonant, to investigate the aspiration effect of the final dental stops on the preceding vowel /a:/. Their results showed that the preceding /a:/ is longer before aspirated than unaspirated coda consonants. However, subsequent replication efforts have not found the same aspiration effect: In a production study that recorded word-list readings by three Hindi speakers, Ohala and Ohala (1992) report that the *aspiration effect* in Hindi is not consistent: for example, for alveolar stops, the vowel /a:/ is longer before unaspirated /t, p/ than aspirated /t^h, p^h/, but shorter before unaspirated /d/ than aspirated /d^h/, and almost equally long before /b, b^h/[1]. In another study more directly comparable to that of Maddieson and Gandour (1976), Lampp and Reklis (2004) found no vowel lengthening effect of coda aspiration in Hindi. They investigated /dɔC/ nonsense word forms, where 'C' represents four contrastive velar stops / k, g, k^h, g^h /. Table 2 compares their results with Maddieson and Gandour's (1976).

	Maddieson and Gandour (1976)	Lampp and Reklis (2004)
Word form	/sa:C/ where 'C' represents four contrastive alveolar stops.	/dɔC/ where 'C' represents four contrastive velar stops.
Vowel dur. (ms)	t: 160; t^h:185 d: 185; d^h:196	k: 188; k^h:187 g: 217; g^h:221
Conclusion	Vowels in Hindi are usually longer before aspirated consonants than aspirated.	Vowel duration in Hindi is not affected by coda aspiration.

Table 2. Results of previous studies on the coda aspiration effect on vowel duration.

[1] Note that Ohala and Ohala (1992) have not reported any statistic test for this aspiration effect. Also, though they claim the finding rejects Maddieson and Gandour's (1976) proposal of the lengthening effect of aspiration, these two studies are conducted in different contexts. The former examines the intervocalic consonant in /sVCa/ on vowel length, whereas the latter is interested in the coda effect.

The inconsistent findings with respect to the *aspiration effect* could result from differing phonetic contexts of the relevant segments. It is also important to point out, that the *aspiration effect* in the case of only voiced stops in all the studies is in the same direction, i.e., vowels are longer before aspirated voiced stops than unaspirated voiced stops in both studies.

3 Methods

3.1 Participants

Seven native speakers of Hindi (5 men and 2 women) participated in this study. They were all graduate students or post-doctoral researchers at Michigan State University. All of them were originally from the city of New Delhi or nearby. None of them spoke any other dialects of Hindi, and all of them were proficient speakers of Indian English. All participants could read the Devanagiri (Hindi) script.

3.2 Stimuli

One possible reason for the inconsistent results related to coda aspiration in previous studies may be due to different phonetic contexts. To reduce this potential confound, the test items consisted of three different vowels and three different onsets, so as to lower any influence from specific a vowel or onset. The test stimuli consisted of nonsense words following the templates /pasV_1C/, /rakV_2C/ and /mapV_3C/, where V_1 = /i:/, V_2 = /a:/, V_3 = /u:/, and the final consonant was /d̪, d̪ʰ, t̪, t̪ʰ/. Thus, the test items all contained long vowels followed by a dental-alveolar consonant in coda position.

3.3 Procedure

Subjects produced ten repetitions of each test stimulus embedded in the sentence frame *मुझे* ____ *मिला* ‘I found ___’. There were a total of 120 target utterances (12 test items × 10 times), with the same number of fillers. A randomized list of all the stimuli was presented using Praat (Boersma & Weenink, 2012; Wood, 2005) on a laptop screen in the Devanagiri script. The utterances produced by the participants were recorded in a quiet room using the software Audacity with a microphone (Logitech USB Desktop Microphone; Frequency Response – 100Hz-16KHz) at a 44KHz sampling rate (16-bit resolution; 1-channel).

3.4 Measurement

The total vowel duration of each utterance was measured in Praat (Boersma & Weenink, 2012). This was defined as the period from voicing onset following the offset of onset consonant ([s], [k] or [p]) of the crucial syllable to the end of the vowel formants ([i:], [u:], and [a:]). The closure duration of the final consonant started from the vowel offset until the release/aspiration of the consonants.

4 Results

4.1 Effect of voicing and aspiration on vowel duration

Figure **1** shows the mean vowel durations. There is a clear *voicing effect* - vowel duration is longer after voiced stops than after voiceless stops. There is also an observable *aspiration effect* - vowel duration is longer after aspirated stops than after unaspirated stops.

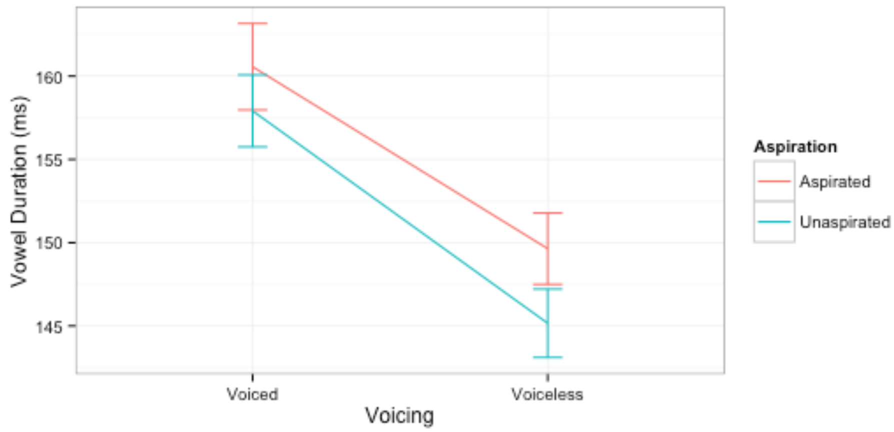

Figure 1: Effect of coda voicing and aspiration on vowel duration
(error bars represent standard error)

A repeated-measures ANOVA was conducted on the dependent variable of vowel duration with the factors of coda aspiration (i.e. aspirated vs. unaspirated), coda voicing (i.e. voiced vs. voiceless). The main effects for both coda aspiration ($F[1,6] = 6.37$, $p< 0.05$) and voicing ($F[1,6] = 26.367$, $p<0.01$) have a statistically significant effect on vowel duration, but the interaction between aspiration and voicing was not significant ($F[1,6] = 0.157$, $p=0.706$).

Hindi, like other languages, has a clear *voicing effect*. Furthermore, our results also support the findings of Maddieson and Gandour (1976) in that the Hindi also shows a clear *aspiration effect*.

4.2 Effect of voicing and aspiration on consonant duration

Figure **2** shows consonant closure durations. In the case of aspiration, closure duration is clearly shorter for aspirated stops than for unaspirated stops. And in the case of voicing, the closure duration tends be shorter for voiced stops than for voiceless stops.

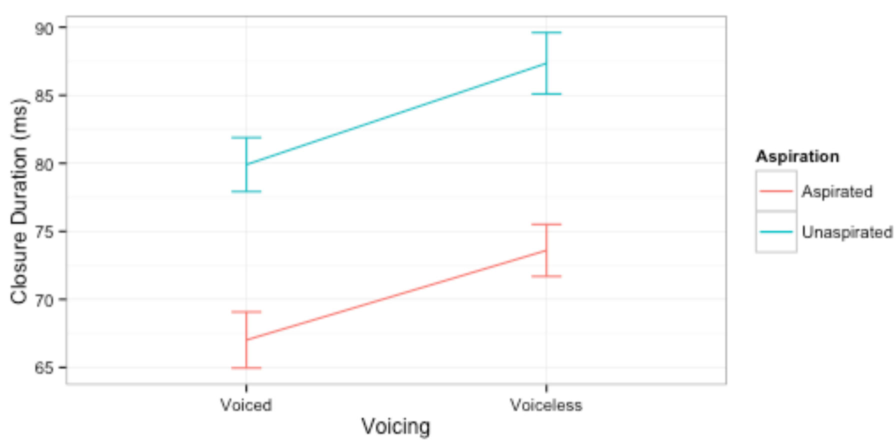

Figure 2: Effect of coda voicing and aspiration on closure duration
(error bars represent standard error)

A repeated-measures ANOVA was conducted on the dependent variable of closure duration with the factors of coda aspiration (i.e. aspirated vs. unaspirated), coda voicing (i.e. voiced vs. voiceless). There was a statistically significant main effect of aspiration (F[1,6] = 11.102, p< 0.05). There was marginally significant effect of voicing (F[1,6] = 4.04, p=0.091). Finally, there was no observable interaction between aspiration and voicing (F[1,6] = 0.048, p=0.833).

The statistical analysis results suggest that, in Hindi, closure duration of an unaspirated stop is more than that of an aspirated stop, and that of a voiceless stop more than that of voiced stop.

4.3 Effect of voicing, aspiration and closure duration on vowel duration

From the preceding subsection (4.1-4.2), it is clear that Hindi has (a) *voicing effect*, (b) *an aspiration effect*, (c) a longer closure duration for voiceless coda consonants compared to voiced coda consonants, and for unaspirated coda consonants compared to aspirated coda consonants. In this section, we show that though there appears to be an inverse correlation between absence of voicing in a coda consonant and preceding vowel duration, the correlation cannot be attributed to closer durations, i.e., it is clear that voiced consonants are shorter than voiceless consonants, and it is clear that vowels are shorter before voiceless consonants, but it is *not* true that vowels are shorter before longer consonants and vice-versa.

As can be seen in Figure **3**, there simply is no negative correlation between closure duration vowel duration for any combination of voicing and aspiration. In fact, at best, there is (weak) positive correlation between the two measures.

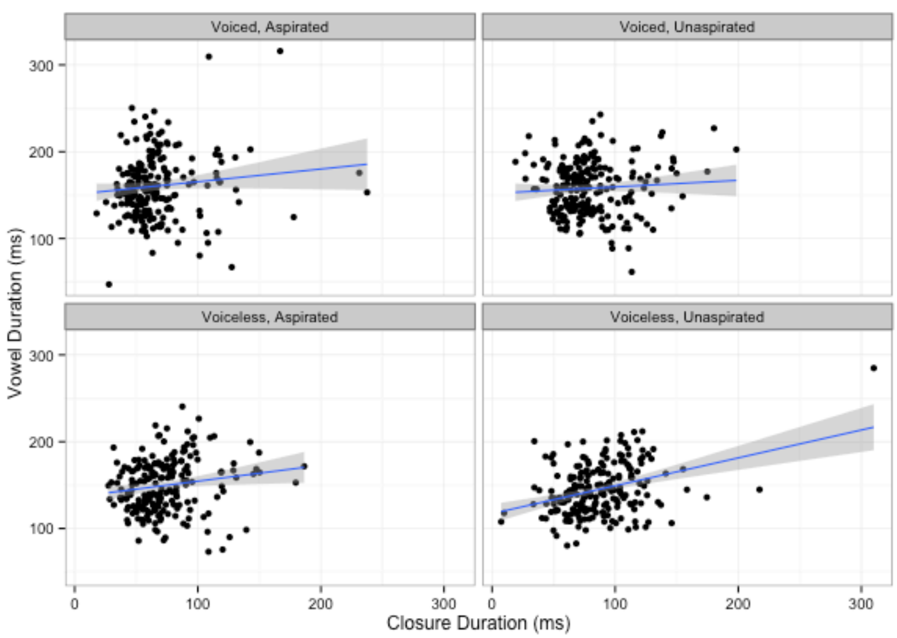

Figure 3: Effect of closure duration, voicing and aspiration on vowel duration (error bars represent standard error)

To further probe the effect of all the factors on vowel duration, a mixed-effects model was fitted with *Vowel Duration* as the dependent variable, and *Closure Duration*, *Voicing* and *Aspiration* as the fixed effects, using the lme4 package (Bates & Sarkar 2005a) in the R statistical programming environment (R Development Core Team 2005). The p-values were calculated using the *lmerTest* package (Kuznetsova, Christensen, & Brockhoff 2013). The factors *Voicing* and *Aspiration* were binary factors while *Closure Duration* was a continuous factor. The random effects structure included random intercepts for subject and tokens. The best model was chosen based on likelihood ratio tests.

	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	151.48	12.52	5.4	12.1	<0.001 ***
Closure Duration	0.14	0.03	825.8	4.35	<0.001 ***
Voicing: Voiced	12.39	1.53	819.3	8.10	<0.001 ***
Aspiration: Aspirated	5.70	1.57	820.1	3.62	<0.001 ***

Table 3: Linear Mixed Effects Model with *Vowel Duration* as the dependent variable

The fitted model in Table 3 suggests that there is a positive effect of all three factors on vowel duration. From the coefficient for *Voicing*, it is clear that voiced codas are associated with longer vowel durations than voiceless codas ($\hat{\beta}$ = 12.39, p<0.001). Similarly, the coefficient for *Aspiration* suggests that aspirated codas are associated with longer vowel durations than unaspirated codas ($\hat{\boldsymbol{\beta}}$ = 5.7, p<0.001). Finally, the coefficient for *Consonant Duration* suggests that an increase in closure duration of the coda consonant is associated with an increase in the vowel duration of the preceding vowel ($\hat{\boldsymbol{\beta}}$=0.14, p<0.001).

The results suggest crucially that there is in fact a small positive correlation between closure duration of the coda consonant and the preceding vowel duration when factors such as voicing and aspiration are controlled for.

5 Conclusion

Our findings show that, in Hindi, vowel duration is significantly affected by aspiration and voicing, thereby we are able to contribute to a previously debated issue. Both an *aspiration effect* (vowels are longer before aspirated stops than before unaspirated stops), and a *voicing effect* (vowels are longer before voiced stops than voiceless stops) are present in the language.

Furthermore, closure duration is clearly affected by coda aspiration: closure duration is longer for unaspirated stops than for aspirated stops. However, our results only show a marginally significant trend in the direction of increased closure duration for voiced consonants.

Finally, and most crucially, our study shows that contrary to previous claims on the issue (Kluender et al 1988), and contrary to what has been subtly assumed by many, the vowel durational differences before voiced and voiceless consonants *cannot* be attributed to an inverse correlation with their closure durations. This is because when appropriate controls are assumed, there is in fact a slight positive correlation between vowel durations and closure durations. Therefore, the production facts related to coda closure duration and preceding vowel duration are clearly in line with the perception facts that Fowler (1992) reported, according to which participants tend to associate longer vowels with judgments of longer closure duration of the following consonant. Furthermore, the results highlight the fact that the *voicing effect* and the *aspiration effect* are far from explained by any current accounts. We hope that this article motivates other researcher towards finding a more satisfying explanation of what has till now been incorrectly thought of as a reasonably well-understood phenomenon.

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