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Nasal Epenthesis in Hindi

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Abstract. Modern Hindi words such as [dãt] 'tooth' and [tʃãnd] 'moon' had similar phonetic structure in Middle Indo-Aryan, with conventional transliterations of *danta* and *čanda*, respectively. The development of the long nasal vowel is usually correlated with loss of the nasal consonant. If so, why does one form still contain a nasal consonant? We argue that a sequence of nasalized vowel + voiced stop (but not voiceless stop) can, for phonetic reasons, engender an epenthetic nasal, and we demonstrate that the same process can be found (nondistinctively) in present-day Hindi and French in the junction between a word-final nasal vowel and a following word-initital voiced stop. A nondistinctive epenthetic nasal can become a 'full' or 'lexical' nasal when listeners reinterpret this transitional event as purposeful or intended.

Introduction

One of the most prominent rules in the development of many of the New Indo-Aryan languages from Middle Indo-Aryan was that of cluster simplification with compensatory lengthening of the preceding vowel. If the cluster consisted of a nasal followed by a consonant, the nasal was lost with the preceding vowel lengthened and nasalized [Beames, 1872; Kellog, 1965; Misra, 1967]. This then is the source of a number of nasalized vowels in Old Hindi [see columns 1–3 of (1)]. In Modern Hindi, however, a number of these words now appear with a homorganic nasal preceding the stop [Ohala, 1983]. Moreover [as noted in Ohala, 1983], there is an interesting asymmetry regarding the appearance of the homorganic nasal as a function of the voicing of the stop. As shown in column 4 of (1), Modern Standard Hindi has $\tilde{\bar{V}}$C[–voice] but $\tilde{\bar{V}}$NC[+voice]. That is, the homorganic nasal appears only if a voiced stop followed.

A question that can be asked is: given Modern Hindi [tʃãnd], etc., was the nasal never lost before voiced stops (contrary to the usual historical scenario given) or has Modern Hindi reintroduced it? The traditional account assumes there *was* a loss of a consonant involved (i.e. clusters involving

(1)

Sanskrit	MIA	Old Hindi	Modern Hindi	Gloss
čandra	čanda	čā̃da	[tʃā̃nd]	'moon'
danta	danta	dā̃ta	[dā̃t]	'tooth'
aŋgana	aŋgana	ā̃gana	[ā̃ŋgə̃n]	'court-yard'

Historical forms are given in their conventional transliteration; modern forms given in IPA. Although not overtly marked, the vowel [a] in Hindi is inherently long.

nasals were simply a subcase of clusters in general), and the evidence for this is that there was compensatory lengthening of the preceding vowel, e.g., Skt *hasti* 'elephant' > Prakrit *hatthi* > MH [hatʰi]. Whether a short nasal consonant nevertheless could have remained before voiced stops is a question that cannot be answered based on the written records. The Old Hindi forms of the above words (column 3) simply reflect the conventionalized orthography, which occasionally showed some variation.

This question regarding the state of nasalization was raised by Entenmann [1977], although he incorrectly attributed to the first author [M. Ohala, 1972] the claim that the nasal was not lost before the voiced stops. [M. Ohala, 1972, offered a synchronic analysis of Hindi, and did not make any historical claims regarding nasal loss or nasal reintroduction.] Nevertheless, the question Entenmann raised is of interest especially since the 'asymmetric' influence of stop voicing with regards to preceding homorganic nasals has been noted for other languages as well [e.g. English; Malécot, 1960]. Based on instrumental data from Hindi, we now believe that the nasal has been reintroduced in Modern Hindi in words such as [tʃā̃nd]. We will present the evidence for this here.

The immediate stimulus for this study was a serendipitous discovery by the first author during a demonstration of nasal air flow recording. One of the utterances happened to have a word-final nasalized vowel followed immediately by a voiced stop which was part of the frame sentence which the test word had been placed in. The printout gave evidence of nasal air flow extending past the nasal vowel and into a following voiced stop in the next word – in essence, creating a nasal + stop sequence. This was important since here was a phonetic nasal – a transitional event – that could not be traced to any underlying or lexical nasal consonant since it appeared in the transition between two words neither of which contained a nasal when spoken in isolation. Unfortunately during this demonstration of nasal air flow there were no control utterances consisting of nasal vowel followed in the next word by a voiceless stop.

Study 1

We first rectified the above-mentioned problem by making audio recordings of 2 native speakers of Hindi pronouncing both types of utterances, i.e., word-final nasal vowels followed both by voiced stop and voiceless stop in the next word.

Figure 1 presents spectrograms from two utterances spoken by a female native speaker (not the first author). The first is from the uttemace [ap jəɦā̃ pɪjo] 'you drink here', the second [ap jəɦā̃ bolo] 'you speak here'. (These spectrograms show only the word [jəɦā̃] plus a portion of the stop +

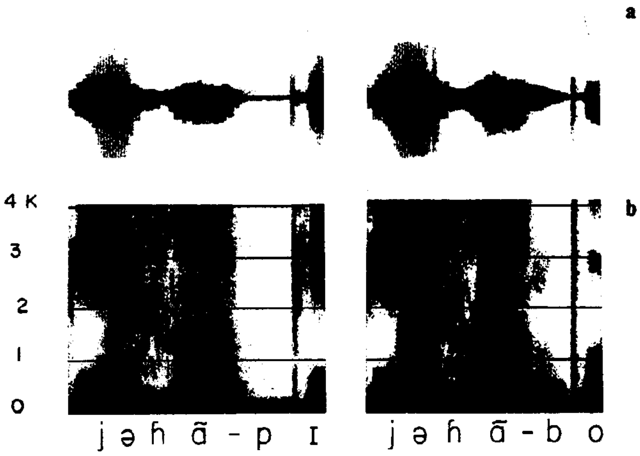


Fig. 1. Waveforms (top) and spectrograms (bottom) of portions of the Hindi utterances [ap jəɦã pɪjo] (**a**) and [ap jəɦã bolo] (**b**). In **b** nasal formants at 1 and 2.5 kHz indicate the creation of a brief nasal at the interface of the nasal vowel and the following voiced stop.

vowel of the following word which started with a [p] on the left and a [b] on the right. In this figure and others word boundaries are marked by hyphens). There is an abrupt spectral change at the end of the nasal vowel and extending into the stop closure of the voiced [b]; some nasal formants are evident at about 1 and 2.5 kHz during this closure. This looks like a nasal and when listened to out of context sounds like a nasal; this does not happen or happens to a lesser extent in the juncture between the nasal vowel and the following voiceless stop. The same pattern was observed for other places of articulation as well.

Study 2

In earlier presentations of these acoustic recordings we encountered justified skepticism as to whether we have interpreted the spectrograms correctly, i.e., whether there is clear evidence of an epenthetic nasal in the initial portions of the voiced stops. To answer this we obtained physiological recordings which gave a more direct indication of nasalization. We sought a noninvasive method which would indicate velic opening and selected a very old technique, the so-called 'nasal olive' [Scripture, 1902, p. 219] to do this. This involves blocking off air flow through one nostril and recording the buildup of pressure behind that resistance. This technique has the advantage of leaving speech largely unaffected since the other nostril is free as is the speaker's mouth. Speech acoustics are manifested as completely normal under this condition, both to the speaker and to the microphone. Our nasal olive consisted of a small dampened cellulose sponge with a plastic catheter penetrating it. The subject simply had to insert this into one of his or her nostrils such that it lodged there with the catheter open to the upstream air pressure.

We obtained nasal air pressure and simultaneous audio recordings from 2 adult native speakers of Hindi, 1 male, 1 female (the latter was the first author), and 2 adult native speakers of French, 1 male and 1 female. We included French speakers in or-

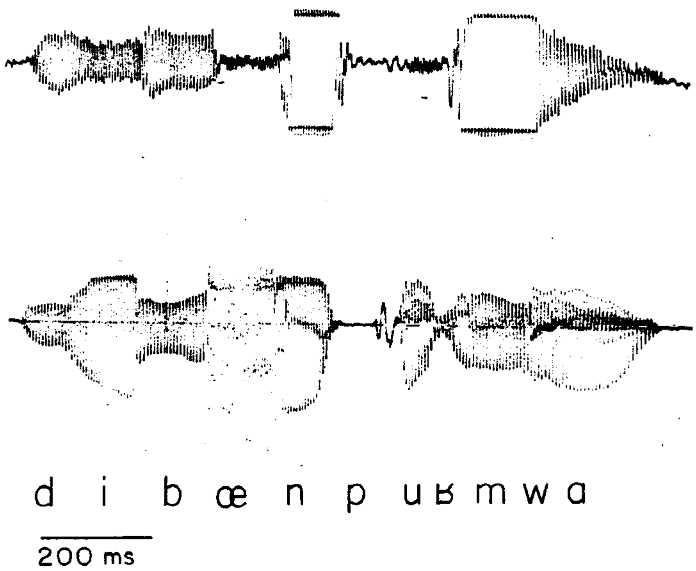


Fig. 2. Nasal pressure (top) and normal microphone signal (bottom) for the French utterance 'dit "bonne" pour moi' [di bœn puʁ mwa], spoken by a female native speaker.

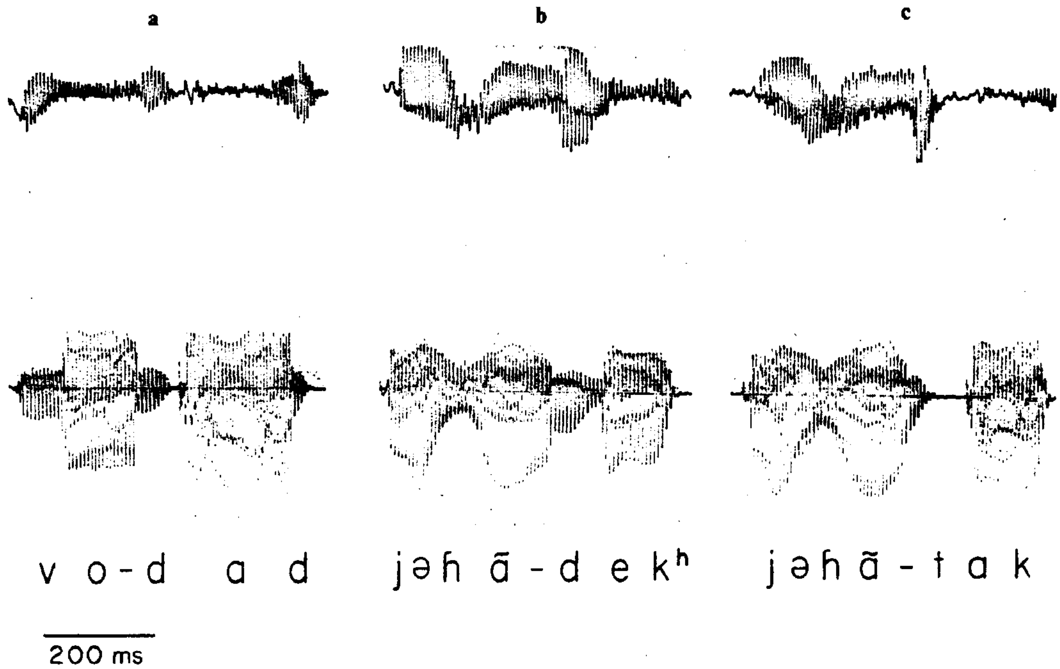


Fig. 3. Nasal pressure (top) and normal microphone signal (bottom) for portions of the Hindi utterances /vo dad kɛhte hɛ̃/ (**a**), /ap jəhã dekʰo/ (**b**), /ap jəhã tako/ (**c**), spoken by a male native speaker.

der to see if these epenthetic nasals would be found in another language with distinctive nasal vowels in word-final position.

The signal obtained with a nasal olive requires some interpretation. Figure 2 presents a record of the French utterance (by the female speaker) 'dit "bonne" pour moi'. The first thing we notice is that the device picks up some vibrations even when the velum is closed; these are microphonic effects and are most noticeable for sounds with low F_1. This includes the high vowel [i] and the voiced consonants [d] and [b]. [This was noticed many years before in probe microphone studies of the nasal cavity by Hirano et al., 1966; see also Clarke, 1978]. For oral sounds with high F_1 (e.g., the low vowel [œ] in 'bonne'), there are practically no microphonics up to the last 20 ms before the nasal. For nasal consonants and nasal or nasalized vowels, however, the signal is very large and in fact goes off scale during the nasal consonants.

We turn now to some representative data for the crucial cases. Figure 3 presents speech samples from the male Hindi speaker. Figure 3 a presents a portion of the utterance /vo dad kɛhte hɛ̃/. The nasal pressure trace shows the expected slight microphonics at the start of the closure of the two voiced [d]s. Figures 3 b and c give portions of the utterances [ap jəɦã dek'o] 'you see here' and [ap jəɦã tako] 'you glance here', respectively. In the juncture between the nasal vowel and the [t] there is a nasal air pressure impulse of some 30 ms duration suggesting that there is a very brief prenasalized segment even in this case. However, at the juncture of the nasal vowel and the voiced stop [d] such a nasal segment is twice as long or about 60 ms. Evidence that these are nasal segments and not just the continuation of voicing comes from the much greater nasal pressure amplitude of these segments in comparison with that in the voiced stops in figure 3 a.

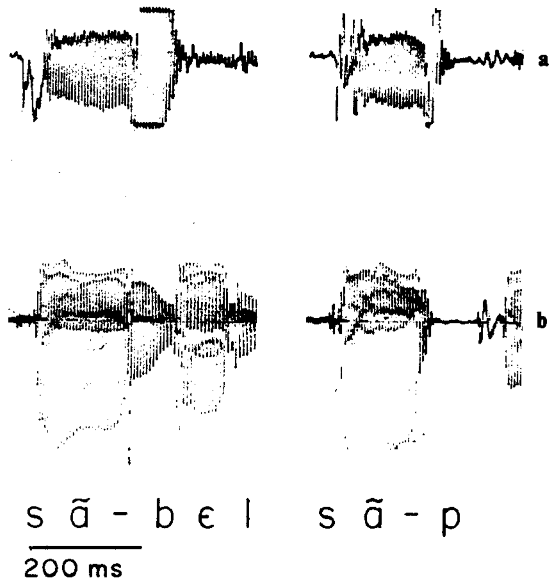


Fig. 4. Nasal pressure (top) and normal microphone signal (bottom) for portions of the French utterances 'dit "saint" bel enfant' [di sã bɛl ãfã] (a) and 'dit "saint" pour moi' [di sã puʁ mwa] (b), spoken by a female native speaker.

Figures 4 a, b show similar traces for portions of the French utterances 'dit "saint" bel enfant' and 'dit "saint" pour moi', respectively, spoken by the female native speaker. At the juncture of the word-final nasal vowel and following voiceless [p] in figure 4 b there is a transitional nasal about 20 ms in duration. However at the juncture of the nasal vowel and the following [b] in figure 4 a such an epenthetic nasal is at least 70 ms long.

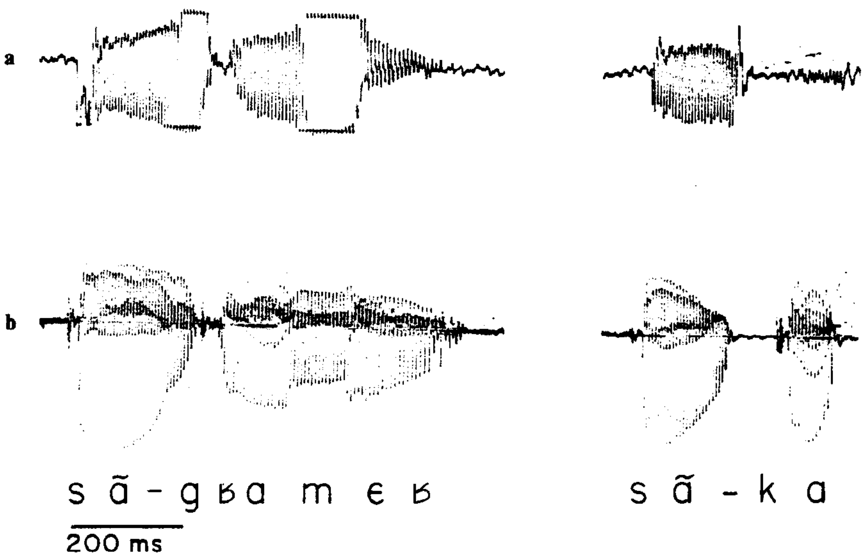


Fig. 5. Nasal pressure (top) and normal microphone signal (bottom) for portions of the French utterances 'dit "saint" grand-mère' [di sɑ̃ gʁɑ̃ mɛʁ] (**a**) and 'dit "saint" quatre fois' [di sɑ̃ katχ fwa] (**b**), spoken by a female native speaker.

Figures 5a, b give portions of the same female French speaker's versions of the utterances 'dit "saint" grand-mère' and 'dit "saint" quatre fois', respectively. Here there is virtually no epenthetic nasal between the nasal vowel and the following voiceless [k] in figure 4b, but in the case of the following voiced [g] in figure 4a this nasal is slightly more than 50 ms long.

Discussion of the Phonetic Data

It is crucial to our argument that the words which provided the cross-word boundary sequences of *nasal vowel + voiced stop* would not actually show a nasal when these words are spoken in isolation. This is true of all the Hindi examples. But in the case of French there are liaison forms of words which in isolation have final nasal vowels that show a final, supposedly 'underlying' nasal consonant, e.g., *bon* 'good' [bɔ̃] but *bon ami* 'good friend' [bɔn ami]. Could the nasal element found in the French examples be this underlying nasal? We suggest not: such liaison consonants appear before a word-initial vowel, not a consonant. Also, the fact that the intrusive nasal is sensitive to the voicing of the stop suggests that it is a purely transitional phonetic phenomenon created by the nasalization of the vowel migrating into the initial parts of the following stops.

We offer the following explanation for the finding that voiced stops following a nasalized vowel may have their initial portion nasalized, i.e., constitute a prenasalized stop. The question we need to answer is: why should voiced stops tolerate velic leakage during the first part of their closure and still be perceived as voiced stops? The reason may be that among the auditory cues for a voiced stop there must be a spectral and amplitude discontinuity with respect to neighboring sonorants (if any), low amplitude voicing during its closure, and termination in a burst; these requirements are still met even with velic leakage during the first part of the stop as long as the velic valve is closed just before the release and pressure is allowed to build up behind the closure. However, voiceless stops have less tolerance for such leakage because any nasal sound – voiced or voiceless – would undercut either their stop or their voiceless character.

Similar behavior of voiced stops following nasal segments seems to be evident in the speech data presented in Yanagihara and Hyde [1966], Suen and Beddoes [1974], as well as that of Roberts and Babcock [1975]. In the first case this is manifested by utterance-initial voiced stops showing nasal airflow (and thus open velum) much closer in time to stop release than was the case with utterance-initial voiceless stops. Yanagihara and Hyde [1966] comment

> ... air emission through the nose continues almost for the whole period of the oral pressure rise or even beyond the peak of the oral pressure in the case of voiced stops. By contrast, in the production of voiceless stops, the nasal air leakage is usually blocked before the attainment of the maximum oral pressure.

Suen and Beddoes [1974] found that whereas the ratio of the duration of a medial voiced labial stop to that of its voiceless cognate in minimal pairs of the sort, *rabid/rapid* was about 0.88, this ratio changed to about 0.43 in pairs of the sort *amble/ample*, indicating that the actual voiced stop closure was disproportionately *shorter* when a nasal consonant preceded.

There is phonological evidence that parallels to a certain extent these sound patterns, at least as regards the propensity of voiced stops, but not voiceless, to become prenasalized. Paradis [1988/89] reports that in Fula in specific morphological environments, a process she called 'nasal spreading' creates prenasalized stops out of voiced (but not voiceless) stops that follow nasal consonants:

(2) /rimd-u-dɛ/ [rim^{n}dudɛ] 'to load a beast'
/jamb-ɛrɛ/ [jam^{m}bɛrɛ] 'ax'

In Japanese strong verbs [Kawasaki, 1981] the conjunctive form of verbs apparently involves the addition of a suffix -te with the stem-final consonant of the verb assimilating to the suffix initial /t/ and thus forming a geminate stop. But if the stem-final consonant is voiced, then instead of the geminate one gets a *nasal + voiced stop* sequence. The Hachijojima dialect of Japanese, however, shows the expected voiced geminate. It seems then that voiced geminates (but not the voiceless ones) tolerated a nasal onset. (There is good reason why voicing would be difficult to maintain on geminate stops unless something 'gives' – in this case the stoppedness of the initial part of the geminate; see data in (3) [from Kawasaki, 1981; see also Shevelov and Chew, 1971]).

The tolerance that voiced stops have for their initial portion to be nasalized or consist of a nasal consonant but for their final portion to be (generally) a fully oral stop supports to some extent the notion that stop offsets contain more useful speech cues than stop onsets [Ohala, 1990; see also Ohala, in press a].

(3) Morphophonemic variation in Japanese strong verbs

Nonpast indicative verb stem	Conjunctive		Translatior
	Standard dialect	Hachijojima dialect	
tatu	tatte		'stand up'
uru	utte		'sell'
but:			
asobu	asonde	asudde	'play'
jomu	jonde	jodde	'read'

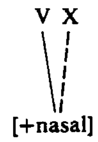
It must be emphasized that at a certain level the intrusive nasals we found in the speech of our speakers were not 'intended' by them. That is, it is not necessary to claim that they are present at the phonological (lexical) level. They could appear due to purely mechanical effects of the vocal tract. Such phonetic nasals, however, may be reinterpreted by listeners such that what was previously unintended or phonetic now becomes in the speech of the listener-turned speaker intended or phonological. This is what is usually meant by the term 'phonologization' [Jakobson, 1972]. Along with the process of phonologization the duration of the now lexical nasal would not implausibly become longer like the duration of other lexical nasals. Thus in the current pronunciation of [tʃãnd] 'moon', the nasal is a full nasal and has a duration near 100 ms [Ohala, 1983, p. 95].

An Autosegmental Account of Intrusive Nasals in Hindi

It may be useful to compare the account we give for the intrusive nasal in these Hindi words with another account using a different approach. Using an autosegment approach, Srivastava [1989] derives the n sal in words such as [tʃãnd] 'moon' (or th similar word [tʃãndi] 'silver') by a ru which spreads the nasal feature from th vowel into the following voiced stop in ac dition to a global constraint ruling out th application of this rule when voiceless stop are involved (because Hindi does not hav voiceless nasals).

Srivastava [1989] proposes that the ab sence of ṼC[+voice], i.e., words such a *[tʃãdi], is explained by a nasal spread ru given in (4) coupled with a global constrair (5) ruling out voiceless nasals ([–voice, +na sal).

(4) Nasal spread:



(5) Global constraint: *[–voice, +nasal]

Thus the homorganic nasal is carved ou of the following stop and shares all feature with the stop except 'sonorant'. We wi refer to such nasals as carved nasals. Thu as shown in (6), [tʃãndi] would have an un derlying form /tʃãdi/ and the nasalit would spread to the stop creating a homorganic nasal.

(6) /tʃ ã d i/

Nasal spread

[+nasal]

[tʃãndi] 'silver'

As shown in (7), this would not apply to [dãt] because nasal spread would create a voiceless nasal (since the features are taken from the following stop which is voiceless) and the global constraint (5) rules that out.

(7) /dãt/

[+nasal] Global constraint would block nasal spread from applying.

[dãt] 'tooth'

(8) shows that words with ṼNC[–voice] such as [ʃãnti] are handled by claiming that the nasal in such words is not created by nasal spread, but is an underlying nasal forming a cluster with the following stop:

(8) /ʃanti/ (underlying oral vowel + nasal + stop cluster)
(via a phonetic rule nasalizing vowels before nasal consonant)
[ʃãnti] 'peace'

The duration of the nasal in words where it was obtained by nasal spread will be shorter (since it must share with the stop a single slot in the timing tier) than the nasal in a word where the nasal was obtained from underlying nasal plus stop cluster, /NC/. Srivastava [1989] mentions spectrographic displays of [pũɲdʒi] 'capital' vs. [pũn + dʒi] 'proper name + honorific suffix' which show the latter to have a longer nasal, but does not include the spectrogram in her paper.

There are some problems with this evidence. First, even though the relevant spectrograms were not published, let us grant that /pũn + dʒi/ 'proper name' (i.e., [pũndʒi]) has a longer nasal than [pũɲdʒi] 'wealth'. We recorded the speech of an adult female speaker of Hindi (not the first author) and made a spectrogram of these words. Figures 6a and b show representative spectrograms and reveal the claimed difference in the duration of the nasals: approximately 99 ms for /pũn + dʒi/ but approximately 55 ms for [pũɲdʒi]. Nevertheless, one would also expect by the same logic that the duration of the stop portion of the following affricate be shorter in /pũɲdʒi/ than in /pũn + dʒi/ since in the former but not the latter some of this duration has to be shared with the carved nasal. But the durations of the stop portions of these affricates in figure 6 are about the same.

But it is difficult to use duration as an indication of whether the nasal is underlying or derived unless one can find word pairs that have no other difference that might influence the duration. In the example just discussed there is the presence or absence of a morpheme boundary which might influence segmental durations, perhaps by affecting syllable structure [see, e.g., Lehiste 1960]. A comparison of words such as [tʃãndi] and [ʃãnti] might seem to present an ideal pair for such a duration test since the nasal in the former is claimed to be carved [see (6)] but the latter to be underlying [see (8)]. Figures 6c and d show samples of these words. In this case the nasal in [tʃãndi] is longer than that in [ʃãnti], a result which does not support Srivastava's [1989] claims.

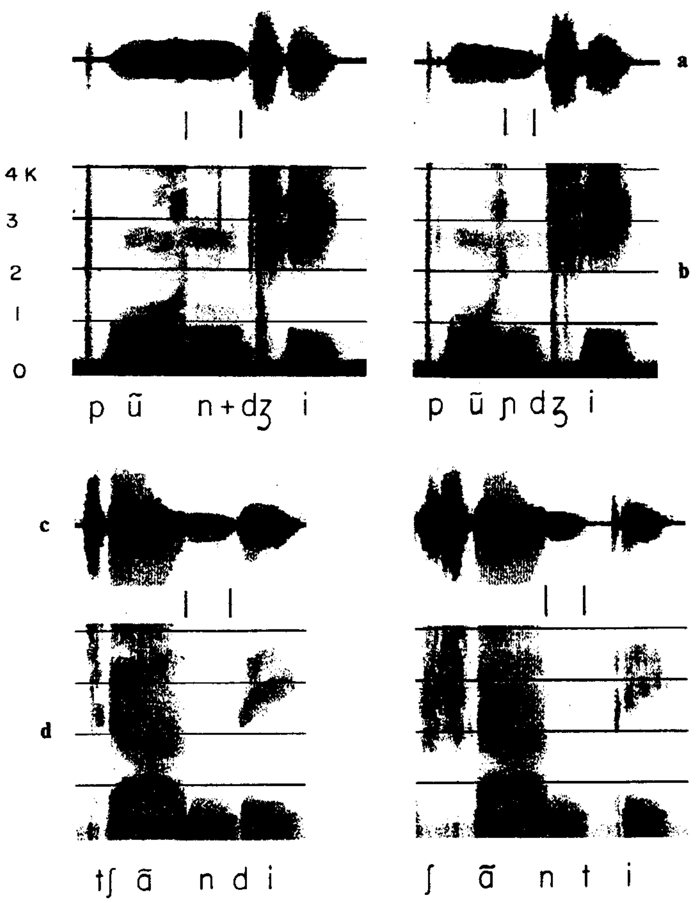


Fig. 6. Waveforms (top) and spectrograms (bottom) of four Hindi words: [pũn+dʒi] 'proper name' (**a**), [pũɲdʒi] 'wealth' (**b**), [tʃãndi] 'silver' (c), and [ʃãnti] 'peace' (**d**). Vertical lines delimit the approximate onset and offset of the nasal consonants in these words.

But in this case the voicing of the stops following the nasals is different and, as we have shown, this by itself might influence the duration of the constituents of a *nasal+ stop* sequence. So here, too, the test is inconclusive.

But before seeking ways to evaluate claims regarding the underlying vs. carved character of nasals, we should also closely examine the basis of the claims. For example, in addition to the words for 'wealth' and 'proper name', Srivastava [1989] also gives the pair /bʰãdʒa/ [bʰãɲdʒa] 'brandished' and /bʰandʒa/ [bʰãndʒa] 'nephew' as another pair showing carved vs. underlying nasals, respectively. The word for 'brandished' was unknown to us and several other native speakers of Standard Hindi we consulted. This makes it impossible – for us, at least – to obtain any unbiased record of its pronunciation: whether we presented the word to subjects via orthography or just pronouncing it to them, we would be implicitly instructing them on its pronunciation. The word for 'nephew' is a common word, but there are no immediately recognizable morphological alternants of the word; it is open to question whether native speakers would be prompted to see a morpheme break between the [n] and the [dʒ] in order to reach an unambiguous analysis of the nasal as underlying (this word is derived historically from /bəhən + dʒa/ 'sister + born'). If so, then the potential problem of the influence of morpheme boundaries on segment durations comes up again. Thus, except via a knowledge of the history of such words, including their orthographic representation, how can a native speaker – or a linguist – reach any definite conclusion about the character of such nasal consonants? (This, by itself, makes it difficult to find crucial minimal pairs on which to make phonetic measurements that could resolve this issue). And yet, claims of nasals being underlying or carved are supposed to be about psychological, not historical, states [see also Ohala, in press b]. It may be a wasted effort to refine ways to evaluate claims of nasals being carved or underlying unless the logical basis of those claims are themselves refined.

Furthermore some of the theoretical underpinnings of the carved vs. underlying nature of nasals may be questioned. The so-called 'timing slot' in nonlinear phonology is basically just a placeholder for the phonological segments whose role in phonological descriptions autosegmental or nonlinear phonology wishes to eliminate or minimize. As far as we are aware no phonetic evidence has been presented showing that there is any durational basis, certainly not a uniform duration, for these slots. Furthermore, given that different places and manners of articulation, position within the syllable and word, etc., lead to different segmental durations [Lehiste, 1970], it is not surprising that such phonetic evidence is lacking: for any phonetic differences or similarities obtained it would have to be shown that they were not caused by differences in segmental types or syllable structure rather than the underlying form [however see Herbert, 1975; Ohala, 1981; Browman and Goldstein, 1986].

There is also a logical problem with the explanatory value of the constraint given in (5). It simply states that voiceless nasals do not occur in Hindi but this is just another way of saying that preceding nasalized vowels do not influence a voiceless stop in the same way as they do voiced stops. It does not give any reason why this should be the case. (In contrast, we have offered a phonetically based account of the reason for this asymmetrical interaction between nasal and stop as a function of the voicing of the stop).

Srivastava [1989] claims that native speakers accept the breakup of the cluster in [ʃãnti] as [ʃãnəti], but not the cluster in [tʃãndi], *[tʃãnədi]. (She does not specify the basis of this claim.) This is given in support of the analysis that the cluster in the former word, but not the latter, is underlying. However, even if we accept this evidence it does not unambiguously support the cluster analysis for [ʃãnti]: impressionistically, it seems native speakers would also not accept the breakup of the cluster in [dãnt] 'suppressed' to *[dãnət] even though this word has a history similar to [ʃãnti]. Psychological evidence on this issue would certainly be welcome, but methods for obtaining it clearly need more refinement.

Thus, lacking supporting evidence (phonetic or psychological), the only thing differentiating the nasal in words like [ʃãnti], where it is supposed to be underlying, and the nasal in [tʃãndi], where it is supposed to be derived by phonological rule, is the posited linkage via association lines between the autosegments [nasal] and [stop]. But this is no evidence at all; the different character of the nasals is reduced simply to a notational difference. This begs the question. There is, in the end, a difference between description and explanation.

Short Nasal Vowels before Stops

Before finishing this paper we would like to try to shed a little light on yet another seemingly odd asymmetry in Hindi phonology regarding the patterning of vowels followed by nasals. Recall that when the long nasal vowels in Hindi are followed by a voiceless tautosyllabic stop there is no intervening nasal consonant, but when followed by a voiced tautosyllabic stop there must be an intervening nasal homorganic to the stop. As it happens, this pattern does not apply to *short* nasalized vowels. There the general pattern in Hindi is to have a homorganic nasal before *both* the voiced and the voiceless obstruent (not just stops). (Some exceptions to this pattern involving $\tilde{V}$C[voice] are discussed in Ohala [1983], but are not directly relevant here.) Thus the following Modern Hindi examples [Ohala, 1983]:

(9)

[ɖə̃ŋk]	'sting of scorpion or wasp'
[ɖə̃ɳʈʰəl]	'stalk, stem'
[mə̃ɲtʃ]	'platform'
[sə̃ntra]	'orange'
[gə̃nda]	'dirty'
[lə̃mba]	'tall'
[tʃə̃ɳʈ]	'cunning'

Why is there is no differential treatment depending on the voicing of the stop here as there was with the long nasal vowels? More specifically, why is there a nasal before a voiceless stop when long nasal vowels do not permit such?

The answer, it seems, is that this is a very heterogeneous set of words in terms of history. First, not all VNC sequences of MIA underwent the cluster simplification process (i.e., there were some exceptions) [Beames, 1872; Kellog, 1965; Misra 1967]. Second, when one traces the history of these words there are multiple causes for the nasal. We give a few examples in (10). The etymology is based on Turner [1966].

(10)

[tʃə̃ɳʈ] 'cunning', Skt *čaṇḍa*, Pali *čaṇḍa-*, Hindi (i.e. Old Hindi) *čā̃ṛ:* Thus it seems to be the case that Modern Hindi devoiced the final stop and not that the nasal was introduced.

[ɖə̃ɳʈʰəl] 'stalk, stem', Skt *daṇḍa:* Turner [1966] gives the Hindi reflexes as *dā̃ḍ, ḍā̃ḍ, daṇḍā, ḍā̃ḍa*, etc. Thus, again, Modern Hindi seems to have devoiced the stop at some point.

[sə̃ntra] 'orange': Varma [1958] gives this as coming from Portuguese [sə̃ŋtəra].

[mə̃ɲtʃ] 'platform' is a direct borrowing from Sanskrit. The Old Hindi word is *mā̃čā* or *mā̃ja* 'bed'.

[ɖə̃ŋk] 'sting', **ḍaṅk-*, Pkt *ḍaṁka-*, Hindi *ḍā̃k:* Turner [1966] lists many of the other languages as having a voiced stop, e.g. Punjabi *ḍaṅg*. Thus it is possible that Modern Hindi devoiced the final stop.

[lə̃mba] 'tall', Pkt *laṁba-*, Hindi has both *lā̃b* and *lambā*.

[gə̃nda] 'dirty': Varma [1958] lists it as coming from Persian.

There is unfortunately no good etymological dictionary for Hindi. Thus tracing the history for many words is difficult. Since we do not claim that all hormoganic nasals before stops (even voiced ones) come from the above-mentioned process, the words in (9) are not a problem in our analysis. Our claims are only for the words which lost the nasal in their development and subsequently seem to have regained it.

Conclusion

In all languages some sound patterns simply enshrine the history of the language. When we seek an explanation of them it is an explanation of how they originated. The pattern still needs to be stated in a synchronic grammar. But this will be a description of the facts, not an explanation. We would claim that the tendency of $\tilde{\bar{V}}$NC[+voice] but $\tilde{\tilde{\bar{V}}}$C[–voice] [i.e. the pattern exhibited by [tʃãnd] 'moon' and [dãt] 'tooth' given in (1)] is best explained by finding a universal (cross-language) phonetic tendency that could trigger a sound change, thus making the difference phonological. We would thus claim that although the constraint of $\tilde{\tilde{\bar{V}}}$NC[+voice] but not *$\tilde{\tilde{\bar{V}}}$C[+voice] is part of the speakers' tacit knowledge, the *explanation* for it is not part of his tacit knowledge but rather part of the physical constraints of the vocal tract. Similarly people are no doubt tacitly aware of the structural similarities between hands and feet (each has 5 articulated digits and pivots in similar ways at the end of the limb), but they do not necessarily know the evolutionary history which underlies this similarity: the fact that both sets of limbs were once used for locomotion and gripping branches.

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Reply to Commentators

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We thank Rischel (R), Pierrehumbert (P), and Keating (K) for their constructive commentaries. R in his thought-provoking remarks has given eloquent expression to the desire that many feel who would like to see a closer, even intimate union between phonetics and phonology. A propos of our paper he raises an interesting question regarding the nature of 'explanation' of sound changes. Is a sound change like nasal epenthesis explained if there is no account given as to why it happened in one language (in our case, Hindi) and not another that would seem to be eligible for it (e.g., French). We answer thus: it is probably not possible to explain why a given sound change happens in one language but not another and it is generally not a fruitful question to pursue. Phonetics can at best explain a sound change by showing, first, that precursors to it are found widely in languages spoken today (e.g., Modern Hindi and French), and, second, that there is a phonetic basis for these precursors. The phonetic precursors – in our case the prenasalized portion of the word-initial voiced stops preceded by nasal vowels – are not themselves sound changes. At least we do not regard them as such. They could lead to sound change when a listener misinterprets them as intended nasals and perhaps exaggerates their duration in producing them. We cannot predict or post-dict when a listener will make such a misinterpretation, but this does not diminish the value of the prediction that a given change involving specific sound types is liable to occur in a specific environment, in a specific direction, etc.

Equally, in speech perception experiments we find out how listeners interpret the speech signal and find out that for a given stimulus some listeners interpret it one way and others in a different way thus yielding the typical ogival response curves, not step functions. Who bothers to delve into why listener A.M. hears one thing but listener D.C. hears something different? It is enough to be able to explain the statistical shape of the response function without worrying about the causes of each individual listener's response [see, e.g., Nearey and Hogan, 1986]. We offer this not as an analogy but as a case directly relevant to sound change, since we believe that this type of sound change originates with listeners' misinterpretations of the intentions of the speaker. In fact the parallels between certain sound changes and the results of speech perception experiments are numerous [Ohala, 1989, in press a].

This view is entirely consistent with the nature of explanation in other scientific disciplines, i.e., *deductive probabilistic*. R cites Lass [1980], who concluded that true sciences are deductive nomological, i.e., can predict things with perfect law-like accuracy. Since linguistics cannot do this, Lass asserted that linguistics was not a science and not capable of explaining anything. But as one of us has argued elsewhere [Ohala, 1987], *none* of the natural sciences are truly nomological in their predictions; to be such would imply perfect knowledge of the universe, which we know is unachievable whether we reach this conclusion from a philosophical basis or from a reading of the history of science. The best we can hope for is probabilistic predictions. The errors in our estimates of the probabilities of sound changes are admittedly much higher than the probabilities one finds in physics, but that does not make our enterprise qualitatively different from physics or any other natural science.

P questions our conclusion that the word-medial nasal in Hindi words with ṽnc [+voice] is phonological or that the nasal that appears across word boundaries in ṽ # c [+voice] environments is not phonological. But we had several reasons for our conclusion: First, in this latter context the nasal that crops up does not appear *before* the word boundary, as P assumes, but after the word boundary; the nasal here takes up some of the duration that would otherwise go to the stop – and the stop is therefore shorter than expected. Second, in numerous other instrumental studies of Hindi stops, a word-initial voiced stop has not been found to be prenasalized in any other context; the only exception is the one we discovered, i.e., after a preceding word-final nasal vowel. Third, we provided a phonetically based reason *why* a voiced stop could tolerate some prenasalization. We may not have anticipated all conceivable objections to our analysis but we find it a bit odd to be told that we should have considered some that, by P's admission, most researchers would judge 'unlikely', e.g., that segments might be longer word-medially than adjacent to a word boundary. Given limited time and resources we felt it would be more fruitful to start by trying to control for obvious sources of error before tackling the unlikely ones. Nevertheless, we can only endorse P's advice that 'we need to think carefully about what evidence we view as sufficient to show that an observed pattern is phonological rather than phonetic'. We look forward to phonology being done in an entirely different, more responsible way from now on as *all* researchers interested in understanding speech sound behavior heed this sensible advice.

Both P and K express disappointment that none of the papers in this volume give any attention to such 'major topics' as feature geometry. In fact, we considered using feature geometry in our account of nasal epenthesis and decided it had no value for us. We lump it with the kind of schemes that P characterizes as 'naive and reckless speculation which any researcher with laboratory experience would be unlikely to give credence to'. First of all, certain aspects of feature geometry strike us as trivial. The proposal to have a 'place node' dominate features like [labial] and [coronal], etc. is a quite transparent translation into graphical terms of the use of cover terms, e.g., in such commonly encountered phrases as 'nasals assimilate to the place of articulation of following stops'. *Ungulate* is a cover term for antelope, cow, goat, etc. Once you have the cover term you can make general statements about the behavior of the individuals covered without having to mention all members of the set each time. E.g., *ungulates* are herbivores. Is this new? Does it explain anything or does it just amount to providing a name to a defined set? Forgive us if we do not find this an impressive achievement. Second, as currently conceived, feature geometry is phonetically and phonologically naive. It can notate, i.e., describe, assimilations but it cannot really explain them. For example, it cannot explain why most medial – c_1c_2-assimilations result in c_1 assimilating in place to c_2 rather than vice versa [but see Ohala, 1990a]. It cannot explain why when a nasal assimilates to labial velars like [w kp gb] they tend to behave like velars, but when a fricative assimilates to labial velars (or the labial velars themselves become fricativized), they tend to behave like labials [but see Ohala and Lorentz, 1977]. Feature geometry cannot explain why the combination of features [+voice] [–continuant] is harder to maintain with velars than with labials [but see Ohala, 1983], nor why back-articulated nasals are less stable, less 'consonantal' than front-articulated ones [but see Ohala, 1975; Ohala and Ohala, in press]. There are numerous other examples [Ohala, 1990b, in press b]. For the object of our paper, although some modification of feature geometry might be able to notate the migration of nasalization into a voiced stop, it would not be able to give a principled reason why this should not occur as well with voiceless stops. The principal cause of the failure of feature geometry is that it attempts to represent the relationships between features and cover terms for features using a system of simple, asymmetric, transitive, dependency relations when, in fact, the behavior of speech sounds is determined by relatively complex causal relations between features: supraglottal closure impacts on the possible states of the glottis for well-known aerodynamic reasons; the state of the glottis impacts on the acoustic and auditory properties of resulting supraglottal articulations for well-known acoustic reasons. For the most part, current implementations of feature geometry ignore aerodynamic and acoustic interactions between features, focussing almost exclusively on an oversimplified conception of speech articulation. In bypassing feature geometry we do not abandon the search for the causes of speech sound behavior; rather we find far more satisfying accounts in current models of speech production and perception – many of them quite formal and all of them based on first principles, not on ad hoc theoretical constructs created only for the problem at hand.

P laments the lack of attention in this collection of papers to 'the single most significant recent development in phonology, which is the technical theory of structure'. She notes that in order to achieve the 'aim of integrated research in phonology and phonetics ... it will be necessary for experimentalists to tackle paradigmatic contrasts and structure in an integrated fashion'. It is hard to know exactly what one should expect from a collection of just 8 papers in a theme issue, but coverage of all important issues might not be feasible for simple logistic and economic reasons. But lest the reader unfamiliar with the literature leave with the impression that P has uncovered a glaring lacuna in this area, we would point out that experimentalists *are* engaged in research on paradigmatic contrasts and structure of speech [e.g., Stevens, 1989; Lindblom, 1984, 1986, 1989].

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