Phonetic Variation of Voiceless Nasals in Drenjongke (Bhutia)*

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Voiceless nasals in Drenjongke (Bhutia), a Tibeto-Burman language, are innovative segments that display variable realizations, not found in neighboring languages. In this paper, we present novel acoustic data that allows to identify four distinct phonetic realization patterns for voiceless nasals. Building upon the gestural model (Browman and Goldstein 1986, 1992), we analyze these variations by considering differences in relative gesture timing. Furthermore, we propose that temporal restrictions on the timing of nasal and laryngeal gestures such that nasals do not immediately follow laryngeals. This gestural restriction is supported by cross-linguistic data which show that the sequence of nasality and laryngeal gesture should be in that order, but not vice versa. The innovative circumstances of voiceless nasals in Drenjongke provided a testing ground to understand how phonetic variations reveal the nature of phonological processes underlying a phonological target (i.e. voiceless nasals).

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Keywords: voiceless nasals, Drenjongke (Bhutia), phonetic variation, gestural model, gesture timing

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1. Introduction

Voiceless nasals have an 'unusual' nature, in which nasal sounds with inherent voicing are produced as voiceless sounds. Acoustic studies such as Bhaskararao and Ladefoged 1991 present a phonetic typology of voiceless nasals demonstrating two different phonetic realizations for voiceless nasals, the first one consists in a voiceless portion followed by a voiced one, and the second is realized without voicing, which they call respectively Type 1 and Type 2. Subsequent studies have advanced our understanding of the phonetic nature of voiceless nasals; they are nasal sounds with a voiceless part. Based on novel acoustic data on Drenjongke, an understudied Tibeto-Burman language, this paper proposes to deepen our understanding of Drenjongke voiceless nasals: Our data suggests that variable realizations of Drenjongke voiceless nasals are constrained by the coordination of nasal gesture and glottal gesture, in which the glottal gesture cannot precede the nasal gesture. This is further supported by cross-linguistic patterns on the relationship between a nasal and a glottal fricative.

Voiceless nasals (also called 'breathy' or 'aspirated' nasals) are relatively rare segments in the world's languages. Only about 4% of the 451 languages listed in the UPSID Database (UCLA Phonological Segment Inventory Database, Maddieson 1984) comprise such segments in their phonological inventory (Chirkova 2019). Languages in which voiceless nasals are contrastive are much less common (Ohala and Ohala, 1993), yet contrastive voiceless nasals are found in a number of language families such as Tibeto-Burman, Hmong-Mien, Tai-Kadai or Mon-Khmer (Matisoff 2003, Chirkova *et al.* 2013, 2019): Burmese (Ladefoged 1971, Dantsuji 1984, 1986), Mizo (Bhaskararao and Ladefoged 1991), Angami (Bhaskararao and Ladefoged 1991, Blankenship *et al.* 1993), Xumi (Chirkova *et al.* 2019), Sre (Manley 1972), Achang (Dai 1985), Sui (Wei & Edmondson 2008: 586), Chadong (Li 2008: 598), Prinmi (Ding 2014), Hakha Lai (Peterson 2003), Anong (Sun and Liu 2009) and Niuwozi (Ding 2003). Bantu languages show voiceless nasals when a nasal prefix precedes a root-initial voiceless stop (Maddieson & Sands 2019): Sukuma (Maddieson 1991), Pokomo (E.71) and Bondei (G.24) (Huffman and Hinnebusch 1998), Ikalanga (Mathangwane 1998), as well as Nyarwanda (Demolin and Delvaux 2001). Voiceless nasals are also reported in the Ikema dialect spoken in Miyako, Okinawa in Japan (Hayashi 2013).

The acoustic investigation of Burmese voiceless nasals by Dantsuji 1984 led to the conclusion that in Burmese, voiceless nasals are composed of a voiceless nasal friction of weak intensity at the beginning, and a voiced nasal portion with higher intensity at the end. The voiced portion of the voiceless nasal is much shorter than that of regular voiced nasals, such that the durations of the voiceless and the voiced portions are negatively correlated. Based on this finding, Dantsuji argues for only one nasal phoneme, which comprises both a voiced and a voiceless part.

Ohala and Ohala 1993 show that voiceless nasals are only 'half-voiceless'; they have a voiced nasal portion in the end. According to them, this suggests that voiceless nasals lose their place feature during consonant constriction. As such, they claim that the place

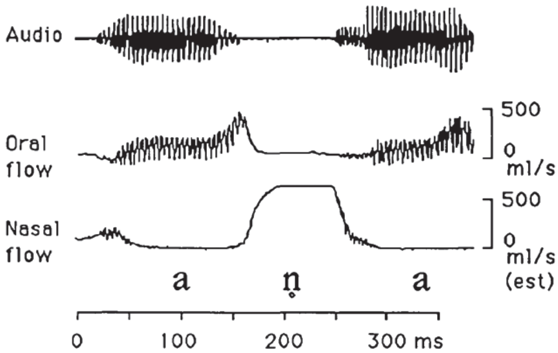

Figure 1 An illustration of Type 1 voiceless nasal, from Bhaskararao and Ladefoged 1991

of articulation of voiceless nasals such as [n̥, m̥, ŋ̊] can be differentiated only based on the transitions in the surrounding vowels. A study by Ladefoged and Maddieson 1996 suggests that in Burmese, since the glottis is mostly spread during the voiceless nasal but not in the voiced nasal, the primary cue for the nasal voicing contrast is whether the glottis is spread or not.

What these studies point out is that the aerodynamics of voiceless nasals is typically binary: one part is produced with nasal airflow only and the other part exhibits both nasal and oral airflow. Bhaskararao and Ladefoged 1991 and Blankenship *et al.* 1993 identify two distinct types of voiceless nasals. In Figure 1, reproduced from Bhaskararao and Ladefoged 1991, the voiceless nasal begins with nasal airflow with no oral airflow. Just before the production of the vowel, the nasal airflow abruptly decreases, and the oral airflow increases.

This Type 1 voiceless nasal in Figure 1 is the kind of voiceless nasal that is typically observed in Burmese (spoken in Myanmar) or Mizo (spoken in Mizoram, India). It involves a two-step process. First, oral airflow is blocked by the tongue tip against the alveolar region, the velum is lowered to allow a peak in nasal airflow and the glottis is spread. Second, the vocal folds gradually become closer to generate glottal vibration while the velum becomes raised and the tongue tip lowered, thus decreasing nasal airflow while increasing oral airflow. This second part in the articulation of voiceless nasals, whether it be lowering the tongue tip for alveolars, or opening the mouth for labials, or lowering the velum for velars, enables formant transition information to cue the place distinctions in voiceless nasals (cf. Ohala and Ohala 1993).

Unlike Type 1 voiceless nasals that are produced with a two-step process, the second type of voiceless nasals in Figure 2 is produced in a single step. Voiceless nasals in Angami (spoken in Nagaland, India) show no voicing throughout their production. The acoustic signal shows glottal vibration due to the spread glottis, but place distinctions between voiceless nasals can still be made based on the varying degree of nasal airflow (Bhaskararao & Ladefoged 1991). The first portion of the articulation sees nasal air flow increase to reach a peak, which then progressively decreases during the second part, while a sudden increase in oral air flow indicates the release of the closure.

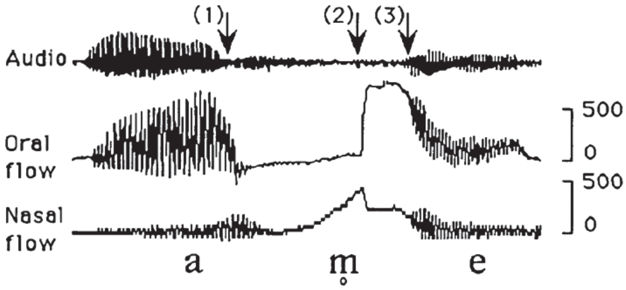

Figure 2 An illustration of Type 2 voiceless nasal, from Bhaskararao and Ladefoged 1991

Table 1 Comparison between Proto Tibeto-Burman form and Burmese written form. Superscripts mark tonal categories. The entry numbers of PTB Forms are based on STEDT[1].

gloss	Proto Tibeto Burman (PTB)	written Burmese	
'to give'	*g/s-naŋ (#5820)	*hnang*^{2}	(high tone)
'to borrow'	*r/s-ŋ(y)a (#2541)	*hnga*^{2}	(high tone)
'nose'	*s-na ~ *s-naːr (#803)	*hna*	(low tone)

The emergence of voiceless nasals is often attributed to a diachronic sound change where a consonant + nasal (Cn) cluster turns into a voiceless nasal (Ohala and Ohala 1993). In Burmese, voiceless nasals probably originate from the historic /s/+nasal cluster: [n̥a] 'nose' in Burmese corresponds to *sna* in orthographic Tibetan. Sturtevant 1940 reconstructs *sn and *sm for the voiceless nasals [n̥] and [m̥] in Primitive Greek, as does Thurneysen 1946 when reconstructing proto forms for voiceless nasals. Ohala and Ohala 1993 find in these diachronic explanations that a sonorant that loses its voicing becomes similar to an obstruent, e.g., a fricative. In two-step articulation cases, they argue that when a [-sonorant][+sonorant] sequence, where the [-sonorant] part is a fricative, is substituted for a similar [-sonorant][+sonorant] sequence, then the [-sonorant] part is a voiceless nasal.

Voiceless nasals may emerge from consonant clusters even if the first segment is not the sibilant /s/. Nishida 1970, 1975 hypothesizes that Burmese voiceless nasals derive from *Cn clusters based on comparisons with early Tibetan forms. Data in Table 1 demonstrates that some voiceless nasals in Burmese stem from consonant clusters such as **sn-*, **gn-* or **rn-*.

Examples from Icelandic in Jessen and Péturrsson 1998 also suggest that voiceless nasals can arise from non-sibilant sounds. The Icelandic voiceless nasals in (1) show that a historic **kn* cluster corresponds to a voiceless nasal.

(1) Voiceless nasals in Icelandic and cognates in German

a. Icelandic	[n̥iːvʏr]	'knife'	[n̥jeː]	'knee'
b. German	[knif]	'knife (low German)'	[kni]	'knee'

1) The Sino-Tibetan Etymological Dictionary and Thesaurus (https://stedt.berkeley.edu/)

Although a variety of studies investigate the acoustic properties of these sounds, the issue of the phonological interpretation of voiceless nasal is still, as far as we are aware, left unsolved. Indeed, the two-step articulation of these consonants raises the issue of whether they should be treated as a single segment with a single feature or a cluster of two distinct entities with two separate phonological features (cf. Ohala and Ohala 1993: 233). The widespread view treats voiceless nasals as a single phoneme (Cornym 1944, Sprigg 1965, Okell 1969, Nishida 1972, Dantsuji 1984 among others); voiceless nasals are voiceless segments with a low-level phonetic rule inserting voicing at the end (Bhaskararao and Ladefoged 1991). An opposing view is found in McDavid 1945 who proposes that voiceless nasals should be regarded as consonant clusters, since diachronic changes indicate that voiceless nasals have emerged from consonant clusters, but McDavid's proposal results in confounding diachronic evidence with synchronic phonological patterns.

The present study has several goals. The first is a report on fieldwork data of production of voiceless nasals in Drenjongke, an understudied Tibeto-Burman language (Namgyal *et al.* 2020). The acoustic characteristics of voiceless nasal consonants show inter- and intra-speaker variation regarding the realization of glottal frication and nasality. Building upon the Gestural Model (Browman and Goldstein 1986), we claim that this phonetic variation can be accounted for by a difference in the relative timing of the different gestures involved in the articulation of voiceless nasals (i.e., velic and glottal aperture). The second goal is proposing a restriction concerning the gestural timing between the velic aperture and the glottal aperture. We argue that at least in Drenjongke, the glottal aperture cannot precede the velic aperture in the production of voiceless nasals. We support our claim about this restriction by examining phonotactics of cross-linguistic data from English, French, and Korean among others.

The remainder of this paper is organized as follows. After reviewing the phonological inventory of Drenjongke with a focus on previous studies on voiceless nasals, section 2 shows an analysis of novel Drenjongke acoustic data. Section 3 is an attempt to account for the phonetic variation observed in the realization of Drenjongke voiceless nasals by proposing an articulatory phonology analysis within the gestural model framework (Browman and Goldstein, 1986). The discussion in section 4 addresses the issue of directionality biases in fricative-sonorant clusters and also examines cross-linguistic phonotactic patterns.

2. Voiceless Nasals in Drenjongke

2.1 Drenjongke Phonology

Drenjongke (also known as "Bhutia", "Hloke" or "Sikkimese"), is a Tibeto-Burman language spoken by about 80,000 speakers in the state of Sikkim, in the north of India. Impressionistic descriptions of the phonological inventory of the language have been provided in van Driem 2016 and Yliniemi 2005, 2019. Acoustic and articulatory properties have been investigated in detail in a series of papers which main findings are summarized in Namgyal *et al.* 2020.

	bilabial		alveolar		retroflex		alveolo-palatal		palatal		velar		glottal	
voiceless/voiced plosive	p	b	t	d	ʈ	ɖ					k	g	ʔ	
aspirated/devoiced plosive	pʰ	b̥	tʰ	d̥	ʈʰ	ɖ̥					kʰ	g̊		
voiceless/voiced affricate			ʦ	ʣ			ʨ	ʥ						
aspirated/devoiced affricate			ʦʰ				ʨʰ	dʑ̥						
voiceless/voiced nasal	m̥	m	n̥	n					ɲ̊	ɲ	ŋ̊	ŋ		
voiceless/voiced tap or trill			ɾ̥	ɾ										
voiceless/voiced fricative			s	z			ɕ	ʑ						
devoiced sibilant fricative				z̥				ʑ̥						
voiced approximant		w								j				
voiceless/voiced lateral			ɬ	l										

Figure 3 Consonant inventory of Drenjongke, reproduced from Namgyal *et al.* 2020

As presented in Figure 3, a chart of Drenjongke consonants reproduced from Namgyal *et al.* 2020, plosives have four places of articulation (bilabial, alveolar, retroflex and velar). Together with affricates they exhibit a four-way laryngeal contrast, which was investigated in Lee *et al.* 2019a, 2019b. Namely, they can be voiceless, aspirated, voiced and voiced aspirates (also called devoiced[2)]). For fricatives on the other hand, only three laryngeal categories can be observed (voiceless, voiced, voiced aspirates), as presented in Guillemot *et al.* 2019a. The articulatory properties of retroflex consonants have been investigated with ultrasound data in Lee *et al.* 2019c and Guillemot *et al.* 2020.

Drenjongke has 5 short and 8 long vowels, which are contrastive, and differ both in terms of duration and quality (van Driem 2016). A remarkable property in Drenjongke long vowels is that their phonetic realization is subject to variations (e.g., alternation between long vowel and vowel with a coda consonant inserted), a phenomenon that has been specifically investigated in Lee *et al.* 2019d and Guillemot *et al.* 2019b.

Lastly, tone is contrastive in syllables with a vowel only or with a nasal onset; Drenjongke has a two-tone system, high and low. Syllables can also be high or low register. In the transcriptions in this paper, high tone is indicated by an acute accent, and low by a grave accent on the vowel. Tone patterns with laryngeal categories are post-lexical; a syllable with an onset that is a voiceless or an aspirated consonant is followed by a high tone, while when

2) Although the literature usually tends to use the term "devoiced" in order to reflect the historical origins of the laryngeal category in the South Bodish language, based on the results of acoustic analyses we choose to use the term "voiced aspirates", following the descriptions in languages with a four-way laryngeal contrast.

the onset is a voiced and voiced aspirate consonant it bears a low tone. Issues pertaining to prosody and tone in Drenjongke are discussed in Lee *et al.* 2018, 2019e and 2020.

Although a preliminary description of the phonological inventory of Drenjongke was proposed in Yliniemi 2019, to the best of our knowledge, there is no study accounting for the phonetic characteristics of Drenjongke voiceless nasals. The present study aims to fill this gap by providing and analyzing acoustic data for Drenjongke voiceless nasals.

2.2 Voiceless Nasals in Drenjongke

Previous impressionistic descriptions of the phonological inventory of Drenjongke report that the language has eight nasal phonemes, which contrast in terms of voicing (Yliniemi 2019, van Driem p.c.), such as [+voice] /m, n, ɲ, ŋ/ and [-voice] /m̥, n̥, ŋ̊, ɲ̊/. While voiced nasals can be found in word-initial, word-medial and in coda position[3], voiceless nasals appear only in word initial position. Yliniemi 2019 points out that aspiration is reduced in word-medial position, causing all the “breathy” phoneme series (i.e., voiceless liquids and voiceless nasals) to not occur at all. The distribution of /ŋ̊/ and /ɲ̊/ seems to be complementary as the former occurs only preceding non-front vowels and the latter precedes front ones only[4].

The voicing contrast in nasals is illustrated in the minimal pairs in (2) from Yliniemi 2019. Voiced nasals can bear either a high or low tone (as exemplified in 2a). However, voiceless nasals, like other voiceless phonemes in Drenjongke, exclusively belong to the high register.

(2) Voiced and voiceless nasals in Drenjongke

a. **labials**	/m/ vs. /m̊/	/mà/ ‘mother’	/má/ ‘wound	/m̥a/ ‘down, lower’
b. **alveolars**	/n/ vs. /n̊/	/nà:/ ‘here’	/ná/ ‘ear’	
c. **palatals**	/ɲ/ vs. /ɲ̊/	/ɲìm/ ‘sun, day’	/ɲ̥im/ ‘sister-in-law’	
d. **velars**	/ŋ/ vs. /ŋ̊/	/ŋàk/ [ŋàʔ]‘speech’	/ŋ̥aʔ/ ‘invocation’	/ŋ̥a/ ‘nose’

Yliniemi 2019 describes Drenjongke voiceless nasals as complex segments, in which the voiced part is preceded by the voiceless part, resulting in phonetic realization of [m̊m], [n̊n], [ɲ̊ɲ], and [ŋ̊ŋ]. This impressionistic description corresponds to what Bhaskararao and Ladefoged 1991 identify as a Type 1 voiceless nasals found in Burmese or Mizo.

Other sonorants such as the rhotic and the lateral in Drenjongke also exhibit a similar contrast in word-initial position: [là] ‘pass’ vs. [ɬá] ‘deity’ or [ràm] ‘be broken’ vs. [ɾ̥ám] ‘break (trans.)’ (Yliniemi 2019, Namgyal *et al.* 2020). These sonorants are described as having realizations akin to the nasals where the voiced component is preceded by a voiceless part. Both voiceless rhotic and lateral have cognate sounds in other Tibeto-

3) Note that the palatal nasal /ɲ/ is the only one that does not occur in the coda position (Yliniemi 2019). A reviewer pointed out that this distributional restriction of /ɲ/ is common across languages in Southeast Asia, except for the Austroasiatic languages.

4) The distribution of these two voiceless nasals may suggest that they are variants of the same phoneme, but further exploration is required to establish the relationship between the two sounds.

Table 2 Experiment stimuli with voiceless nasals[5)]

Drenjongke	Gloss	POA
m̥e	‘lower’	labial
n̥abe	‘pillow’	alveolar
n̥o	‘snot’ [Lachen dialect]	alveolar
ɲ̊ap[6)]	‘to claim, seize’	palatal
ɲ̊a	‘borrowed’	palatal
ɲ̊eː	‘trap’	palatal
ɲ̊ik	‘to squeeze’	palatal
ɲ̊ima	‘impure’	palatal
ŋ̊aːle	‘early’	velar

Burman languages in the areas such as Tibetan and Dzongkha. When comparing Drenjongke with these other languages, voiceless nasals may be a novel group of sounds unique to Drenjongke. Acoustic results reported in this paper address the characteristics of these newly emerged sounds.

2.3 Acoustic Analysis of Drenjongke Voiceless Nasals

In this subsection, results based on analyses of acoustic data on voiceless nasals recorded from twelve Drenjongke native speakers are reported. Drenjongke speakers show that they aim for a phonological target for voiceless nasals, but that phonetic realizations of voiceless nasals are variable. We were able to identify and categorize at least four different realizations: (I) voiceless nasal, (II) nasal, (III) aspiration and (IV) inversion. After describing the data collection process, each pattern is introduced in detail.

2.3.1 Data Collection

Data collection sessions for the analysis of Drenjongke voiceless nasals are based on recordings collected in Sikkim, India in 2018 and 2019. Twelve speakers were recruited by the local coordinators; all of them were teaching Drenjongke at primary or secondary schools. Recordings were made using a TASCAM Linear PCM Recorder (DR-100MK III) and Shure WH30-XLR head-worn microphone with a 44.1 kHz sampling frequency. Participants were asked to take part in a reading task. Stimuli were presented on powerpoint slides in English to the participants, who had to translate them to the corresponding Drenjongke word in a frame sentence (/ŋa X lap to ĩ/, ‘*I say X.*’)[7)]. A set of randomized wordlists was recorded five times. All stimuli are listed in Table 2 below.

5) A reviewer pointed out that the dataset has a bias toward palatal sounds. The frequency of voiceless nasals is not high, and our consultants came up with examples that were biased toward palatals. The recordings of this data are available online by accessing the project archive website (PhoPhoNO Digital Archive 2020).

6) /ɲ̊ap/ and /ɲ̊a/do not pattern with the description in Yliniemi 2019, as he reports that /ɲ̊/ should be preceding front vowels only. However, this data was provided to one of the project collaborators by native speakers.

7) Recordings took place after a training session during which participants checked the meaning of the English words with the experimenter.

Table 3 Intra-speaker and inter-speaker variations for voiceless nasals

Speaker	Gender	Pattern I	Pattern II	Pattern III	Pattern IV	Total
SIP048	F	0	9	1	21	31
SIP050	F	0	16	1	21	34
SIP051	F	25	3	2	12	42
SIP052	M	6	24	0	5	35
SIP053	M	14	13	0	0	27
SIP054	M	2	5	9	27	43
SIP055	M	9	13	17	4	43
SIP057	M	22	17	1	2	42
SIP058	M	12	13	0	9	34
SIP071	F	0	15	4	3	22
SIP072	F	20	13	1	0	34
Total		110	141	36	100	395

The data obtained from the recordings was processed using a series of Praat scripts (Boersma and Weenink 2020). Boundaries for preceding and following vowels of target sounds were annotated manually. The preceding vowel in the frame sentence was fixed as [a].

Errors found in the data (e.g., the speaker did not produce the intended word, recording noise) were excluded manually. Note that the experimental methodology (i.e., words presented in English only) is inherently responsible for the accuracy errors, as not all speakers were familiar with the stimuli words. One speaker was excluded of the dataset due to his low accuracy. On the other hand, variability being often observed in the phonetic realization of Drenjongke codas (e.g., alternation between glottal stop and long vowel; Yliniemi 2019, Lee *et al.* 2019d, words which diverging realization could be attributed to phonetic variation were included in the dataset for analysis.

2.3.2 Results

The analysis of the data obtained from our recordings suggests that there is no unique phonetic realization of the voiceless nasal in Drenjongke but at least four different patterns: (i) a voiceless nasal corresponding to Bhaskararao and Ladefoged 1991's Type 1 that articulates the nasality at the end of glottal frication, (ii) a nasal without voicelessness, (iii) glottal frication but no nasality on the consonant portion, and (iv) an inversion in the consonantal portion: a voiced nasal consonant followed by glottal frication. In addition, we observed intra-speaker and inter-speaker variations (see Table 3). That is, a single speaker can produce several different phonetic realizations for the same phoneme, sometimes across repetitions of the same word. None of the items examined were realized with a single pattern type only. While the phonetic realization expected was pattern I, among the four patterns observed, it was pattern II (i.e., the voiced nasal) which had the highest frequency. Inversely, pattern III (i.e., aspiration only) was rare. Moreover, there seems to be a tendency among speakers to prefer some pattern over the others, with inter-speaker differences (e.g., pattern I and II for SIP053 and 57, and pattern III and IV for SIP054).

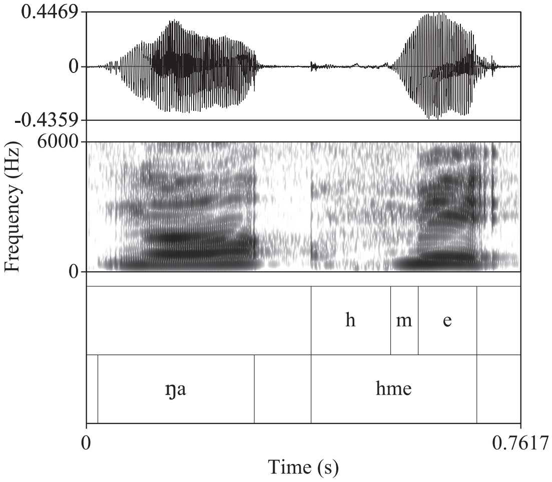

Figure 4 Spectrogram of a voiceless nasal pattern (pattern I) that is produced from a voiceless nasal stimulus /m̥e/ in a frame sentence by a female speaker (SIP072)

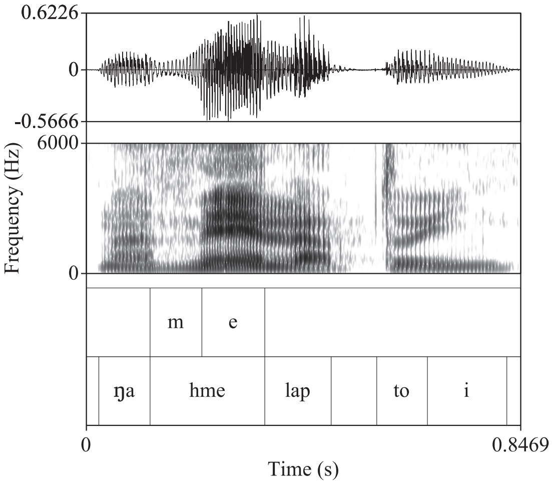

Figure 5 Spectrogram of a voicing pattern (pattern II) that is produced from a voiceless nasal stimulus /m̥e/ in a frame sentence by a male speaker (SIP058)

The first pattern corresponds to what Bhaskararao and Ladefoged 1991 describe as a Type 1 voiceless nasal. This pattern is represented in Figure 4 produced by a female participant. After the vowel in the frame sentence, no voicing is observed on the first part of the articulation ([h]), and the spectrogram shows glottal frication, corresponding to the opening of the glottis described by Bhaskararao and Ladefoged. Although the present data does not include nasal airflow measurements, the spectrogram shows aspiration coming from the nasal cavity during articulation. In the second step of the articulation (represented as [m]), we observe a voicing bar at the foot of the spectrogram with a weaker formant structure that contrasts with the following vowel [e].

Figure 5 illustrates the second pattern. The target sound is a voiceless nasal, but the

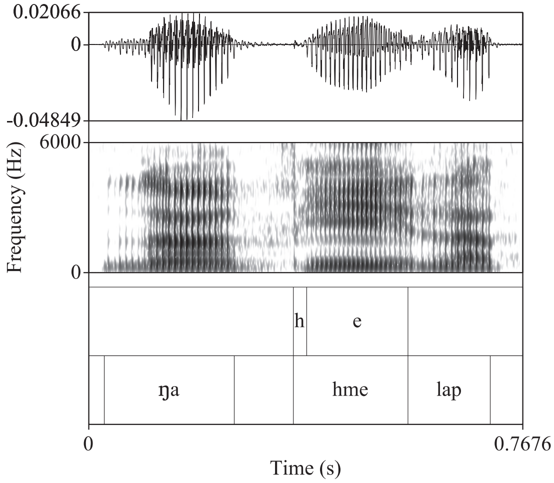

Figure 6 Spectrogram of a voiceless pattern (pattern III) that is produced from a voiceless nasal stimulus /m̥e/ in a frame sentence by a male speaker (SIP055)

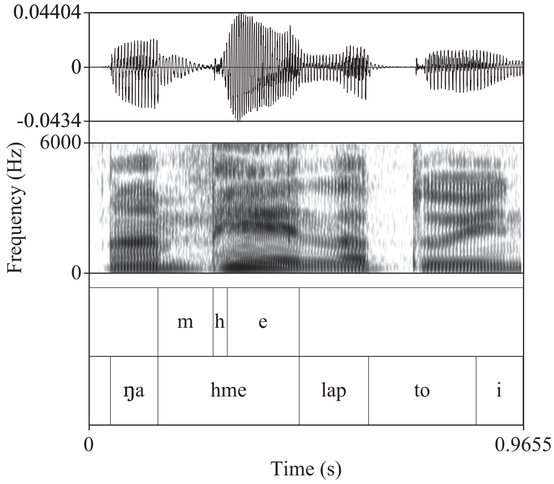

Figure 7 Spectrogram of an inversion pattern (pattern IV) that is produced from a voiceless nasal stimulus /m̥e/ in a frame sentence by a male speaker (SIP054)

spectrogram in Figure 5 produced by a male speaker suggests that no glottal gesture precedes the onset of voicing of the nasal consonant ([m]); that is, there is no aspiration and only the nasal portion remains in the acoustic signal making it similar to voiced nasals.

In the third pattern, nasality is absent in the consonant target and only the aspiration is realized at the target syllable onset. In Figure 6, a voiceless nasal is produced by a male speaker; we can observe a stronger frication in the consonant portion ([h]) with an absence of voicing component, differing from the first two patterns.

The last pattern is illustrated in the spectrogram in Figure 7 pronounced by a male speaker. The spectrogram shows a voicing bar as well as weaker formant structure right after the preceding vowel, suggesting the nasal sound is produced ([m]) before glottal aperture. The onset of the target word, annotated as [h], only shows strong glottal frication and no voicing: a realization found also in the third pattern.

This pattern is in contrast with the first pattern, as the glottal gesture and the nasal gesture are reversed. While the first pattern has voicelessness followed by voicing, in the fourth pattern, the voiced part of the nasal is realized first, followed by the glottal gesture. It is also in contrast with previous descriptions of the voiceless nasals in Drenjongke ([m̥m], in Yliniemi 2019, for example), and the phonetic definitions (for Type 1 and Type 2) proposed by Bhaskararao and Ladefoged 1991, which suggest that voicelessness should appear first in voiceless nasals.

2.4 Summary

What the acoustic data presented in section 2.3 suggests is that although there is a single phonological target (i.e. the voiceless nasal consonant), its phonetic realization is not uniform. These results raise a question about phonological targets concerning voiceless nasals. Are voiceless nasals a single phoneme or a consonant cluster (i.e., /h/+/N/)? Our findings can be interpreted that Drenjongke speakers possess a coalesced double target for the phonological representation of voiceless nasals. If Drenjongke speakers have a single target for voiceless nasals, we would expect uniform phonetic realization with no inversion-type pattern, since inversion implies the presence of a double target. We also expect that intra-speaker variation would be minimal, although inter-speaker variation may occur. The variability observed in our data can be accounted for only if we consider the hypothesis that there is a double target, that is, a voiceless glottal frication (i.e. /h/) and a voiced nasal, and that speakers variably realize one, the other, or both of the targets.

Here we take a short excursion to voiced and voiceless rhotics and laterals in Drenjongke. The voicing contrast in rhotics and laterals is more stable; as far as we know, no variations are observed in their phonetic realizations. Voiceless rhotics and laterals are also found in related languages such as Tibetan and Dzongkha (van Driem 1992), suggesting that these sonorants have corresponding reflexes in other Tibeto-Burman languages. A survey of forty Tibeto-Burman languages shows that languages can have voiceless rhotics and laterals even though they do not have voiceless nasals. Voiceless nasals appear to be innovative segments in Drenjongke, as they cannot be found in adjacent languages such as Dzongkha or Tibetan. For example, the Drenjongke word for 'pillow' is [ŋ̊abø] with a voiceless nasal, but 'pillow' in Dzongkha is [haŋbo]. We claim that the non-uniformity of the phonetic implementation of voiceless nasals reflects their relative novelty. It may be the case that we are witnessing a sound change in progress, that is, the process of shifting from a double target (patterns II, III and IV) to a coalesced single target (I) voiceless nasal, with analogous properties to similar segments in other languages.

3. Phonetic Variation in the Realization of Voiceless Nasals

The phonetic implementation of Drenjongke voiceless nasals shows non-uniformity in our acoustic data. This raises the questions of why we observe such variability in the realization of these segments, and how we can account for this phenomenon. The inter-item and inter-speaker variation in our results suggest that voiceless nasals are in the process of being lexicalized; otherwise we would expect uniformed phonetic realizations of them. In this section, we attempt to account for these variable phonetic patterns in a gestural model framework (Browman and Goldstein 1986, 1992) analysis. What we suggest is that the variability in the phonetic realization of voiceless nasals can be attributed to a difference in the timing of the gestures involved in their articulation.

3.1 Voiceless Nasals in the Gestural Model

Further insights about voiceless nasals that display four variable realizations can be gained from analysis based on articulatory phonology. Building on the featural analysis in section 3.1 as a representation of voiceless nasals, the articulatory phonology analysis we propose demonstrates how two types of gestures, velic aperture and glottal aperture, coordinate in generating voiceless nasals.

The gestural model in articulatory phonology proposed by Browman and Goldstein 1986, 1992 suggests that phonological processes originate from the change in the timing between articulations and their magnitude. They introduce a way to deal with various phonological phenomena that remained unexplained until now by emphasizing the link between the phonological and physical structures of speech in order to account for the organization of speech in 'both space and time'. In (relative) opposition to more traditional approaches to phonological representation and autosegmental phonology (Goldsmith 1976, Clements 1980), in which phonological representations are made based on one (or several) linear sequences of non-overlapping segments in terms of tiers, the gestural framework does not make use of phonological features. Instead, it proposes gestures, which the authors define as 'events that unfold during speech production and whose consequences can be observed in the movements of the speech articulators', in order to represent utterances phonologically. If phonological patterns are different realizations of gestures that depend on a change in the relative timing of each gesture, voiceless nasals are good candidates for examining the theory, because two idiosyncratic gestures are at work in the production of voiceless nasals.

In autosegmental theory, a spreading or narrowing of the glottis corresponds to the presence or absence of the privative [spread glottis] feature; in the gestural model, the glottal movement is a function of the (gradient) timing and magnitude of the glottal gesture. In Browman and Goldstein 1986, 1992's analysis, allophonic variation results from the overlap of invariant gestural units. In the case of the allophonic variation between aspirated and unaspirated stops in English, the gestural theory analyzes that the variation is not due to the opening or the closure of the glottis itself, but to the timing and magnitude of the glottal opening. Likewise, clusters with /s/ and a following stop cannot be aspirated because English has a constraint that restricts the glottal opening gesture in the word-initial position to once only.

```
(i) [hn]

VEL                             [- - - - - - - - - - [n] - - - - - - - - - -]
TT
TB        [- - - - - - V1 - - - - - -]                                          [- - - - - - V2 - - - - - -]
LIPS
GLO                             [- - - - - - [h] - - - - - -]
```

```
(ii) [n]

VEL                             [- - - - - - - - - - [n] - - - - - - - - - -]
TT
TB        [- - - - - - V1 - - - - - -]                                          [- - - - - - V2 - - - - - -]
LIPS
GLO
```

```
(iii)  [h]

VEL
TT
TB      [- - - - - -    V1   - - - - - -]                                       [- - - - - -    V2   - - - - - -]
LIPS
GLO                                                [- - - - - - [h] - - - - - -]
```

```
(iv) [n.h]

VEL                          [- - - - [n] - - - -]
TT
TB        [- - - - - V1 - - - - -]                                                   [- - - - - V2 - - - - -]
LIPS
GLO                                                       [- - - - [h] - - - -]
```

Figure 8 The four voiceless nasal patterns in the gestural model framework. Adapted from representations in Browman and Goldstein 1992 and Steriade 1990
(VEL: velic aperture, TT: tongue tip, TB: tongue body, LIPS: lips, GLO: glottal aperture)

The four patterns of variation in voiceless nasals are represented in Figure 8 based on a standard gestural model framework. The velic aperture (VEL) produces a nasal sound as it allows airflow into the nasal cavity. The tongue tip (TT) gesture and the tongue body (TB) gesture are responsible for vowel production and place of articulation of consonants. The lips gesture (LIPS) is active when labial sounds are produced, and the glottalic aperture (GLO) gesture controls the opening of the glottis.

Pattern I represents voiceless nasals of Type 1 in Bhaskararao and Ladefoged 1991, which correspond to a simultaneous timing of the velic aperture and glottal aperture gesture at the beginning. Towards the end of the consonant, the glottalic aperture gesture is narrowed for the production of the following vowel, while the velic aperture gesture remains open until the vowel production begins. In pattern II, the glottal aperture gesture is not present while the glottis is narrowly open to produce the vibration typically associated with nasal sounds. In pattern III, the velic aperture gesture is deleted, and the glottal aperture gesture only is articulated as the word onset. Pattern IV shows an inversion pattern, as the velic aperture gesture precedes the glottal aperture after completion of the tongue body gesture for the preceding vowel.

The variation in the realization of voiceless nasals shows an asymmetry between the timing of the velic aperture gesture and the glottal aperture gesture. While the velic aperture gesture may co-occur with the glottal gesture, it never is initiated after the onset of the glottal aperture gesture. We propose that the variation observed in Drenjongke voiceless nasals follows a constraint, in which the velic aperture gesture should not follow the glottal aperture gesture: the tautosyllabic [hn] sequence is banned. If Drenjongke allowed a violation of this constraint, we would expect to see variation patterns where a preceding vowel becomes aspirated or where a following vowel becomes nasalized. The absence of these two patterns validates our proposed constraint in Drenjongke. In non-simultaneous variations, such as pattern IV, the glottal aperture gesture is articulated after a prosodic boundary, further corroborating that Drenjongke speakers do not favor a contiguous production of the velic aperture and the glottal aperture gestures.

In Dzongkha, a Tibeto-burman language spoken in Bhutan and closely related to Drenjongke, the word for 'pillow' is [haŋbo]. The cognate in Drenjongke is /hŋabø/ [ŋ̊abø] 'pillow'. The first syllable with the /h/+/V/+/ŋ/ sequence in Dzongkha is realized with a voiceless nasal in Drenjongke. If Dzongkha also follows the constraint where the velic aperture gesture should not follow the glottal aperture gesture, the syllable [haŋ] avoids the environment by the presence of a vowel between the two gestures.

4. Articulatory Constraints in Drenjongke and Other Languages

The variation patterns found in the phonetic realization of Drenjongke voiceless nasals are proposed to be restricted by articulatory constraints of the velic aperture gesture and the glottal aperture gesture. Namely, these constraints can be interpreted as a directionality in the order of the two gestures involved in the phonetic realization of voiceless nasals. This idea of directional restrictions of articulatory gestures was raised in Browman and Goldstein 1986, 1992. They argue that restricted sequences in English are the results of constraints that apply on the gestures themselves. Their account of allophonic variation of English aspiration is an example of a constraint on glottal aperture gesture: only one glottal gesture is allowed in the word-initial position.

For voiceless nasals, if the two gestures were allowed to be combined in any order, we would expect to find phonetic realizations that reflect such a free order in languages: both velic → glottal gesture (i.e. /nh/ sequence) and glottal → velic (i.e. /hn/sequence) would occur. On the other hand, if an asymmetry in the realization of these two features is a norm, we would expect a bias against the glottal → velic sequence, as we found in Drenjongke voiceless nasals. This gestural bias would result in variations that rearrange the timing of the gesture so that the velic aperture gesture precedes the glottalic aperture gesture, as we observe in the present case.

Cross-linguistic patterns suggest that this potential asymmetry between the velic and glottal aperture gestures is not limited to Drenjongke; when a nasal and a glottal fricative appear sequentially languages prefer the nasal-fricative sequence to the fricative-nasal sequence.

Korean offers an interesting example of the bias against /hn/ sequences. An /h/ occurring between sonorants undergoes optional deletion, while an /h/ before or after a plosive becomes instead an aspirated segment. Underlying /h/ before or after a stop consonant merges into an aspirated consonant: (a) after a stop, /pap + hana/ [$\text{pap}^{\text{h}}\text{ana}$] ‘a bowl of rice’, /kuk + hana/ [$\text{kuk}^{\text{h}}\text{ana}$] ‘a bowl of soup’, and (b) before a stop /noh + ta/ [$\text{not}^{\text{h}}\text{a}$] ‘to put down’, /noh + ko/ [$\text{nok}^{\text{h}}\text{o}$] ‘to put down and’. When an /h/ appears before a sonorant, the /h/ is deleted: /noh + ɨnik’a/ [noɨnik’a] ‘because of putting down’. When /h/ appears after a nasal, either /h/ is deleted or a boundary is inserted before the glottal fricative: /pam + hako/ [pamago] ~ [pam#hago] ‘with a chestnut’ (Kim-Renaud 1975, Kang 2003, Kim 2005, Cha *et al.* 2005, Park 2015). The /h/ deletion environment can be comparable to environments that trigger voiceless nasals. Korean phonotactics does not allow voiceless nasals on the surface. As such, /h/ after a nasal can only be realized after a short pause, otherwise the /h/ is deleted.

In English, tautosyllabic sequences with /h/ preceding a nasal sound are absent from the phonotactics.[8)] Sequences with a nasal preceding an /h/ are found in words such as *un-healthy* or *un-happy*, but the sequence is separated by a morpheme boundary. Fricatives such as /s/ can precede nasals word-internally in words such as *small* and *snail*.

As for French, the /h/ sound is not part of the French phoneme inventory, and it does not have surface realization. Even so, restrictions concerning nasal and fricative sequences are observed. Fricatives in French may appear after a nasal under two conditions: (a) nasal-fricative sequences such as /ns/, /ms/, /nf/, /mf/ are only allowed when a word boundary is present: e.g. *bonne soirée* [bɔnswaʁe] ‘good evening’, or (b) fricatives may follow a nasalized vowel: e.g. *bonsoir* [bõswaːʁ] ‘good evening’. The fricative-nasal sequences are more restricted because /sn/, /sm/ clusters are banned in the native French lexicon, and found only in loanwords such as *snowboard* [snobɔʁd], *smiley* [smajle] or *schnaps* [ʃnaps] (Dell 1995).

Going back to Drenjongke, even though there is variability in the phonetic realizations, we do not see any merger pattern (which would correspond to a Type II in Bhaskararao and Ladefoged 1991’s description) but inversion (i.e., pattern IV) or deletion of one of the gestures (i.e., pattern II and III) only, which shows that Drenjongke speakers have a clear

8) Greenlee 1973, Hooper 1977, Smith 1973 and Ohala and Ohala 1993 report that children acquiring English have a tendency to make mistakes in the production of /sn/ and /sm/ clusters and pronounce them as voiceless nasals (e.g. ‘Smith’ as [m̥it] or ‘sneeze’ as [n̥id]).

control of the laryngeal gesture. They are treating it like a sequence of gestures as if they were moving from a two-steps progress (i.e., /h/+/n/), and therefore voiceless nasals are realized as a Type I where glottis control is still there. The analysis of variability as different realizations of glottal timing is consistent with that of Kingston 1990 who proposes perceptual reasons for articulatory alignment.

A possible answer to the question of why the phonetic realizations observed in our data match Bhaskararao and Ladefoged 1991's Type I (and not Type II) can be found based on the proposal made by Silverman 1996. In his analysis of voiceless nasals, he claims that Type I (that he calls "pre-voicelessness") is optimal articulatorily, because it is more economic based on recoverability. He proposes three constraints to account for the variations in voiceless nasals: economize, recover and overlap. Based on these constraints, a Type II involving a merger, that is, a breathy nasal, is articulatorily costlier, which explains why Type I is preferred. This provides further support for a view where voiceless nasals in Drenjongke are an on-going process: Voiceless nasals can arise as a Type I but not a Type II due to articulatory costliness. This is also why the variable patterns in the current data do not include a breathy nasal "merger" type. If we consider a typology of diachronic change based on Silverman 1996 we postulate that a Type I voiceless nasal would always arise first (or as a first stage). Type II on the other hand might arise later, or emerge from a different process.

Lastly, while we propose that differences in glottal gesture timing are responsible for the variations observed), an alternative account to this kind of variability is offered in Howe and Pulleybank 2001. In their view, it is not glottal timing but syllable structure that plays a crucial role. However, although our data does not dispute the argument presented in Howe and Pulleybank 2001; it does also not provide further evidence for it.

5. Conclusion

This paper has presented new data on voiceless nasals from Drenjongke. Based on the analysis of the acoustic data, we identified four different patterns of phonetic realization which are subject to inter- and intra-speaker variation. While the first pattern corresponds to the expected realization of a voiceless nasal segment based on the literature, the three others suggest a more complex status of these consonants in the phonological inventory. Pattern II and III are characterized by the realization of nasality only for the former and aspiration only for the latter. In the fourth pattern, although the phonetic implementation of the voiceless nasal segment includes both aspiration and nasalization, these appear in reverse order compared to what is expected, that is, nasality precedes aspiration. These four patterns were used variably by speakers in their production of voiceless nasals, and although some preferences for specific patterns could be observed among speakers, no speaker used a single pattern exclusively. In addition, no specific pattern could be associated with a specific item, as all four patterns could be observed for each stimulus. In the second part of this paper, we attempted to account for phonetic variation by an analysis of the patterns of realization following the framework of gestural phonology.

Drenjongke has innovative voiceless nasals that are not found in related languages in the region. Our data also suggests that voiceless nasals are not lexicalized yet in Drenjongke as they have various intra- and inter-speaker realizations in terms of phonetic implementation of the phonological target. Examination of the four distinct variations within the gestural phonology framework (Browman and Goldstein 1986, 1992) reveals that the glottal gesture can occur before (or simultaneously with) the velic gesture in Drenjongke, but once the velic gesture ends, it is not possible to have a glottal gesture; this restriction limits the variation that we observe in our data, and, which is also supported by cross-linguistic examination of various nasal and glottal fricative sequences in a variety of languages.

As a final comment, we acknowledge that Drenjongke voiceless nasals might possibly be characterized as 'aspirated' nasals, rather than 'voiceless' nasals. Detailed phonetic underpinning of voiceless nasals must be accompanied with articulatory data measures nasal airflow or vocal cords vibration. Such data would reveal acoustic parameters that can be used for predicting the presence of voiceless nasals. As this phonetic work is beyond the scope of the current paper, we defer these issues until future work.

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