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Nasal release, nasal finals and tonal contrasts in Hanoi Vietnamese: an aerodynamic experiment

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Abstract

The present research addresses three issues in the phonetics of Hanoi Vietnamese: (i) What are the airflow characteristics of the obstruent-final rhymes? (ii) Rhymes with final nasal consonants /m/, /n/, /ŋ/ show no acoustic trace of the final nasal segment when they carry tone B2 (orthographic tone *nặng*); does the nasal airflow on these rhymes differ significantly from what is observed on obstruent-final rhymes (which, from a phonological point of view, do not have any nasal segment)? (iii) How often are nasal-final, glottally constricted rhymes followed by a nasal release, and is this release similar to the nasal release which has been reported for rhymes with final obstruents /p/, /t/, /k/?

Nasal airflow measurements of 391 syllables read by one speaker (and supporting data from two other speakers) go to show that nasal airflow

does not distinguish successfully between nasal-final rhymes carrying tone B2 and obstruent-final rhymes, and that unvoiced nasal release is more frequent after obstruents /p/, /t/, /k/ than after B2-tone rhymes ending in nasals. By contrast, simultaneously recorded oral airflow brings out a clear difference between these two sets of rhymes, confirming that voice quality plays a key role in maintaining the distinction between these rhymes, which are similar from the point of view of oral articulation.

1. Introduction

Vietnamese is a textbook example of the development of tones from consonantal contrasts, the main stages of the process having been clarified by comparative linguistics (most prominently by Maspero 1912, Haudricourt 1954, and Ferlus 1998). In synchrony, Vietnamese tones epitomise the **contour-plus-voice quality** type. Sonorant-final syllables (ending in a vowel or a nasal consonant /m/, /n/, /ŋ/) can carry tone A1, A2, B1, B2, C1, or C2; obstruent-final syllables can carry tone D1 or D2, as shown in Table 1. The orthography somewhat misleadingly identifies tones B1 and D1 (both written as *sắc*) and tones B2 and D2 (as *nặng*).

A1 (<i>ngang</i>)	high	B1 (<i>sắc</i>)	rising	C1 (<i>hỏi</i>)	falling-rising, OR falling-laryngealised, OR falling-breathy
A2 (<i>huyền</i>)	low	B2 (<i>nặng</i>)	glottal constriction cuts off the syllable	C2 (<i>ngã</i>)	medial glottal constriction

D1 (<i>sắc</i>)	high-rising
D2 (<i>nặng</i>)	low

Table 1. The tone system of present-day Hanoi Vietnamese: number, traditional name in Vietnamese writing, and short indication on phonetic realisation. Tones A1 to C2: appear only on sonorant-final syllables; tones D1 and D2: appear only on obstruent-final syllables.

The phonetic realisation of the tones was described on the basis of kinaesthetic introspection by Thompson 1965, and documented experimentally by several studies (see Nguyễn Văn Lợi and Edmondson 1998, Phạm 2003, Brunelle 2003, Vũ-Ngọc et al. 2005 and references therein).

As a general rule, tones and syllables combine freely within each of the two tone subsystems. In one case, however, the voice quality has a bearing on the realisation of certain phonemes: syllables under tone B2 are “cut off abruptly” by glottal constriction (Thompson 1965:16); under this tone, final nasals do not appear on spectrograms as distinct segments. This is illustrated by figure 1, which shows spectrograms of syllable / $\gamma\epsilon\eta$ / (phonetically: [$\gamma\epsilon\eta$]) carrying nonglottalised, level tone A1 and glottally constricted tone B2 (spelling: *ganh* and *ganh*, respectively) as spoken in isolation by a 19-year-old male native speaker (recorded at the LIMSI-CNRS laboratory). No exception to this pattern was found in recordings of four other speakers. Inspection of spectrograms suggests

that the vowel is nasalised, but paradoxically, the same hint of nasalisation (weakening of the amplitude of the first formant relatively to the second) is also found on obstruent-final syllables, which, from a phonological point of view, do not comprise any nasal segments. Nasal airflow measurements appear useful to gain further insights into this issue.

Nasal airflow recordings also yield information on velum lowering **after** the end of the syllable. In the cases where there is a **voiced** nasal release, the nasal character of the release can be established auditorily and by means of spectrograms (Michaud 2004 reports such a release in 37% of the cases); in the cases where this release is unvoiced, nasal airflow recordings appear necessary.

If these rhymes are indeed followed by a nasal release, this in turn raises the issue whether the release is similar to that reported by Ladefoged and Maddieson (1996:129) for rhymes with final obstruents, traditionally described as **unreleased** (a characteristic transcribed by the diacritic [̚] in the IPA): they note that, in Vietnamese, final /p/, /t/, /k/ “are usually released, but the release is by lowering the velum while the oral closure is maintained, so that a short voiceless nasal is produced.” (This is not contradictory with Ohala’s observation [Ohala 1975] that the velopharyngeal port is closed during obstruents to attain sufficient intra-oral pressure: in Vietnamese, the lowering of the velum takes place **after** the oral closure is attained.)

Lastly, the investigation also comprises oral airflow measurements, which shed additional light on the voice quality of the three tones at issue. Airflow measurements for tones A1 to C2 on syllable /ta/ are reported by Nguyễn Văn Lợi and Edmondson 1998; the present investigation extends the measurements to obstruent-final syllables, and to the entire paradigm of vowels found in Vietnamese.

2. Method

2.1. Language materials

The corpus includes all the combinations of the 16 vocalic nuclei and final consonants, with tones D1 and D2 (final consonants /p/, /t/, /k/) and tone B2 (final consonants /m/, /n/, /ŋ/), i.e. a total of 144 syllables. These syllables consist in **rhymes**, without any initial consonant. Two carrier sentences were used; the subjects were instructed to imagine the following contexts:

(1) An elderly person has trouble reading a word in a newspaper; you say in a clear and polite way: “This is the word ____”. The Vietnamese phrasing is as follows: *Người cao tuổi không thấy rõ ; anh đọc cho người ấy một cách vừa rõ, vừa lịch sự: “Đây là chữ ____ ạ.”* In IPA transcription (tones not included): /dɛj.la.tʃu ____ a/.

(2) You have taught a child time and again how to read a certain word, but the child won’t remember; you are getting angry, you read out again with strong emphasis: “This is the word ____, can’t you see?!” In Vietnamese: *Anh đã dạy cho con nhiều lần rồi, con vẫn chưa nhớ ; anh*

hơi bức tức, anh đọc một cách rất mạnh : “Đây là chữ _____ cơ mà !”

/dɛj.la.tɕw ____ kɿ.ma/.

For brevity, condition 1 will be referred to as R, for Respectful, and condition 2 as E, for Emphatic.

The same items were also elicited as a list, with the following instruction:

Read syllable by syllable, clearly and distinctly (Anh đọc từng âm tiết một, một cách rất rõ).

2.2. Recording session

The main informant was one of the investigators: Vũ-Ngọc Tuấn, a native speaker aged 58. He speaks fluent French and is a long-time resident in France; two speakers who had recently arrived from Hanoi were also recorded (following the same procedure), in order to confirm the validity of the observations made on data from the main speaker. The workstation EVA2 (documented in Teston and Ghio 2002) was operated by a speech therapist, Bernard Roubeau. The EVA2 station allows for the simultaneous recording of oral and nasal air pressure and airflow (i.e. a total of four channels) plus audio and electroglottographic signals; the setup used in the experiment included nasal airflow, oral airflow, electroglottographic signal, and audio signal. The mouth mask is relatively supple, leaving a reasonable amount of freedom of jaw movement, which is of special importance because the corpus comprises phonemes that require different degrees of jaw opening.

This experimental setup is fully innocuous but somewhat invasive; moreover, the subject receives a strongly distorted auditory feedback due to the mouth mask. This caused many more reading mistakes than in previous recordings, which involved only a microphone and an electroglottographic neckband. A total of 391 syllables for the main speaker were finally retained.

2.3. Interpretation of the nasal airflow signal

Nasal airflow does not correspond to acoustic nasalisation in a straightforward way. Aerodynamic and fiberscopic studies show that the duration of positive nasal airflow is always shorter than the actual lapse of time when the velum is lowered (to the best of our knowledge, this phenomenon was first reported by Amelot et al. 2004); at the point where the velum is lowered, nasal airflow may be nil or even negative, as velum lowering creates a brief depression in the nasal cavity (Benguereel 1974:109). The opening of the velo-pharyngeal port is a necessary condition for the nasal cavity to resonate, but not a sufficient condition. Combining several exploratory techniques appears useful in order to assess when the nasal cavity does actually resonate; in particular, an audio signal can be recorded at the nostril (Tronnier 1994; this method, also used by Montagu 2004, recalls pioneering work by Rousselot 1897-1908); this measurement was deferred for technical reasons.

Interpretation of the oral airflow signal

Unlike the Rothenberg mask used by Nguyễn Văn Lợi and Edmondson 1998, the EVA2 captors do not record the fine detail of the puff of air of each glottal cycle: the resulting airflow curve is, as it were, smoothed over a few milliseconds. The oral airflow signal is used to obtain information on the evolution of airflow within the syllable, allowing comparison across syllable sets.

2.4. Treatment of the data

Oral airflow alone did not appear as an appropriate reference for determining the beginning and endpoint of the syllables: comparison of the audio and oral airflow signals shows that oral airflow crosses zero some time **after** the stop articulation. As noted by Barry and Kuentzel (1975:263), every movement of the speech organs can cause a change in volume of the supra-glottal cavity, which in turn affects the primary airflow readings: a reduction of volume will augment egressive airflow, while an expansion will reduce it. For instance, in the case of a final /k/, continuing tongue and jaw movement after occlusion result in a decrease in volume of the cavity in front of the stop closure and hence in positive airflow. Visual inspection and measurements of the first forty tokens show that the time lag between occlusion and nil airflow varies strongly across items. It is therefore no surprise that researchers who use changes in oral airflow as a criterion for segmentation still rely mainly on spectrographic data (e.g. Cohn 1990:37). Our segmentation relies on inspection of the

audio signal and on spectrograms to approximate the beginning of voicing and, at the end of the rhyme, the time of closure (oral closure for obstruent-final syllables, glottal closure for nasal-final syllables under tone B2).

A script written under the technical computing environment Matlab automatically detects the amplitude and position of the local maxima of oral and nasal airflow within each rhyme, and samples the airflow values at equally spaced time points to create average curves as plotted in figures 4-9.

To investigate nasal release after these rhymes, a second script detects the local maximum of the derivative of nasal airflow (i.e. the point in the airflow curve where the slope is steepest). This script was applied only to the items within a carrier sentence. A threshold is empirically set at the lowest value observed for the initial consonant /m/ of the final particle /ma/: this threshold is used to distinguish cases of abrupt nasal release (as in figure 3) from cases where there is either no release of air at the nostrils or a gradual release (as in figure 2).

3. Results

Only the results for the main speaker are set out below. Data from the two other speakers were examined qualitatively; they appear to confirm the quantified observations made on the data of the main speaker; for practical reasons, however, their quantitative analysis must be deferred until another publication.

3.1. Nasal airflow

Qualitative description by inspection of the signal. Figures 2 and 3 show representative examples of nasal-final syllables (carrying tone B2) and obstruent-final syllables (carrying tone D1 or D2), respectively. In figure 2, the target syllable is /um/; the corresponding portion of the nasal airflow signal shows neither a sustained positive airflow as at the end of the last syllable of the sentence on the vowel /a/, which is nasalised after /m/, nor a crossing of the zero line which would be caused by lowering of the velum (a phenomenon which appears before the initial nasal consonant /m/ within the cluster of final particles /kx.ma/, and is pointed out on the figure by a dashed-line arrow). Egressive nasal airflow is found between the end of the syllable and the final particles; in comparison to the rapid increase in nasal airflow for the consonant /m/, this nasal release often has a gentle slope: the derivative does not show any clear positive peak. By contrast, in figure 3 (target syllable: /uk/, tone D2), nasal release starts abruptly, shortly after the end of the target syllable: the brief crossing of zero, characteristic of velum lowering, is as clear for the nasal release following the stop consonant as for the nasal consonant /m/ within the particle cluster; the steepness of the airflow curve at onset of positive airflow is comparable to that of the nasal consonant (in this instance, it is even twice as high). Nasal airflow during the target syllable is, if anything, higher for the syllable with a final stop than for the syllable

with a final nasal; these values are so low that they may in fact be best described as *nil* in both cases.

Quantitative results. Figures 4 and 5 present averaged nasal airflow values for reading conditions R and E: individual curves are resampled at 20 equally spaced time points, averaged, and plotted against their averaged duration. The figures for the syllables read in isolation (not included here for reasons of space) predictably show greater variation; the overall conclusion is nonetheless the same: no significant amount of nasal airflow is found on any of the three sets of syllables. The curves for B2 and D2 are almost identical; the nasal airflow of D1 is the most consistent, and the closest to zero.

Nasal airflow is a function of intra-oral pressure and resistance at the velar-pharyngeal port; intra-oral pressure is known to vary with the degree of constriction associated to different vowels. In order to ascertain to which extent the standard deviation in figures 4 and 5 can be accounted for by differences in vowel articulation, figures 6 to 8 show the results sorted into three vowel sets: front vowels /i/, /e/, /ɛ/; back vowels /u/, /ʊ/, /o/, /ɔ/, /ɔ/; and the open vowel /a/. (The results under condition R are similar.) The averaged curves for each subset are normalised for duration to facilitate comparison. Small differences in the shape of the curve do emerge (nasal airflow for vowel /a/ tends to decrease in the course of the syllable, whereas it increases slightly for front vowels), but

the overall nasal airflow is rather similar for the three sets of vowels.

Tables 2 and 3 provide airflow values on target syllables.

reading condition	tone	mean position of nasal airflow peak (on a 1-100 scale)	average of peak airflow values, in cm ³ /s; in brackets: standard deviation
E (58 syllables)	B2	44	16.0 (16.4)
	D1	61	10.2 (16)
	D2	68	16.2 (5.5)
R (50 syllables)	B2	43	28.0 (22.6)
	D1	44	14.9 (6.55)
	D2	38	25.6 (11.7)

Table 2. Nasal airflow values on syllables in carrier sentences. The average difference of about 9 cm³/s across the two conditions is not significant: it is within the margin of experimental uncertainty.

condition	tone	mean position of the nasal airflow peak (on a 1-100 scale)	average of airflow peak values, in cm ³ /s; in brackets: standard deviation
without initial consonant (141 syllables)	B2	27	21.1 (14.5)
	D1	27	13.3 (13.6)
	D2	29	21.5 (21.5)
with initial /t/ (142 syllables)	B2	37	-3.07 (4.64)

	D1	83	2.44 (2.53)
	D2	56	2.67 (2.53)

Table 3. Nasal airflow values on isolated syllables.

As cautioned in the **Method** section, no conclusions can be drawn from these values as to the actual degree of acoustic nasalisation; the similarity of the patterns observed nevertheless suggests (however paradoxical it may seem) that the degree of nasalisation is fairly similar in nasal-final rhymes carrying tone B2 and in obstruent-final rhymes carrying tone D2—an impression which receives support from qualitative analysis of spectrograms.

Table 4 provides data on the nasal release following the target syllable.

		syllable category			
reading condition	measurement	B2-	D1-	D2-	final
		tone syllable	tone syllable	tone syllable	particle /ma/
E	number of cases of abrupt nasal release	6/24 (25%)	11/20 (55%)	8/14 (57%)	(all)
	maximum of the derivative at release (averaged)	6x10 ⁻⁴	0.001	0.0013	0.0014
	total intersyllabic airflow	0.023	0.028	0.034	0.023

	% of intersyllabic duration at which nasal release occurs, and standard deviation	40 (37)	50 (12)	47 (20)	n.a.
R	number of cases of abrupt nasal release	5/17 (29%)	19/19 (100%)	12/13 (92%)	(none)
	maximum of the derivative at release (averaged)	7×10^{-4}	0.0014	0.0020	n.a.
	total intersyllabic airflow	0.038	0.033	0.044	0.023
	% of intersyllabic duration at which nasal release occurs, and standard deviation	25 (38)	33 (14)	44 (17)	n.a.

Table 4. Quantified data on nasal release in-between the end of the target syllable and the beginning of final particles (for short: **intersyllabic nasal release**).

From this table, it appears that **abrupt** (and plausibly **audible**) nasal release is twice as frequent after obstruents as after nasals; on average, the slope of nasal airflow is twice higher when the velum is lowered after an oral stop than at the release of the glottal constriction of tone B2.

3.2. Oral airflow

The oral airflow, recorded simultaneously with the nasal airflow, offers information on the voice quality associated with the three tones at issue (B2, D1, D2). One of these tones (B2) was included in the study by

Nguyễn Văn Lợi and Edmondson 1998, which relied on airflow recordings of six speakers of Northern Vietnamese (using a Rothenberg mask, which records oral and nasal flow together). These authors report for tone B2 an increasing closed-phase duration and a reduction of airflow in the course of the syllable, the increasing tension finally bringing the glottal folds to stasis (*ibid.*, p. 16). Study of tones B2, D1 and D2 by electroglottography (a measurement of vocal fold contact area) recently confirmed this description (Michaud 2004): the study showed a relatively high open quotient (duration of the open-glottis phase relative to the glottal cycle) at the end of tones D1 and D2. This finding hints at high airflow (the relationship between high airflow and high open quotient was established by a study combining airflow and electroglottography: Rothenberg and Mahshie 1988). Airflow data on tones D1 and D2 appears useful, however, as electroglottography does not provide a measurement of airflow at the glottis (Kochanski and Shih Chilin 2003 offer a means to reconstruct glottal airflow from electroglottography and an array of microphones, but the proposal remains controversial). Figure 9 shows oral airflow curves averaged over 141 syllables read in isolation. The curves for condition R, condition E, and isolated syllables with initial /t/ are essentially similar. Table 5 provides data for all 391 syllables.

reading condition	tone	mean position of the oral airflow peak (on	average of airflow peak values, in cm ³ /s; in brackets:
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		a 1-100 scale)	standard deviation
R (50 syllables)	B2	50	136 (142)
	D1	87	332 (305)
	D2	82	288 (250)
E (58 syllables)	B2	76	117 (117)
	D1	88	368 (366)
	D2	83	422 (404)
in isolation, no initial (141 syllables)	B2	57.5	203 (206)
	D1	83	403 (412)
	D2	82	427 (439)
in isolation, initial /t/ (142 syllables)	B2	17	243 (243)
	D1	42	391 (396)
	D2	50	375 (367)

Table 5. Quantified data on oral airflow on the target syllables.

The oral airflow measurements reported here confirm that there is a strong difference in airflow between tone B2 on the one hand, tones D1 and D2 on the other. The contrast between glottalised tone B2 (with nasal finals) and nonglottalised tones D1 and D2 (with final obstruents) is stronger under condition E than under condition R, confirming the observation that differences of voice quality across tones are slightly enhanced under emphatic reading (Michaud 2004:130).

Oral airflow increases steadily in the course of D1- and D2-tone rhymes, getting close to the range of breathy voice given by Henton et al. 1992, who report values of 120 cm³/s for modal voice and 500 cm³/s for breathy voice (for a male subject phonating with a subglottal pressure of 8 cm H₂O). By the lower standard proposed by Catford 1977:99 (airflow on the order of 300 to 400 cm³/s for breathy voice), the present airflow data for tones D1 and D2 gets into the range of breathy voice.

Lastly, standard deviation of airflow is considerably higher than standard deviation in open quotient measurements (reported in Michaud 2004: same syllables, 4 speakers), suggesting that vowel articulation has a stronger influence on airflow than on voice quality. This could be predicted from the fact that the impedance of the oral tract varies greatly across vowels: the impedance of the oral tract has a direct bearing on nasal airflow (see, in particular, Lass 1995).

4. Discussion and conclusion

The tone system of Vietnamese is the epitome of the **contour-plus-voice quality** type, which opens challenging perspectives for theories of tone; to mention a few: to our knowledge, tone sandhi and floating tones (reported in some Tibeto-Burman languages) are entirely absent in Mon-Khmer, and in Austroasiatic at large; the analysis of contour tones into sequences of level tones, and of the syllable rhyme into *morae*, which clarifies greatly the description of contour tones in many Sub-Saharan languages (see, e.g., Odden 1995), has not clearly proved its usefulness in the study of

Austroasiatic tone languages. The detailed experimental description of Vietnamese takes on special significance in light of these theoretical issues. The present research aimed to make a contribution towards a fuller understanding of Vietnamese tone and its interaction with segments in the present state of the language. The salient findings are as follows. The airflow measurements confirm that final oral stops in Vietnamese are not orally released, and that nasal release often takes place some time after the stop closure, resulting in a short voiceless nasal. Nasal airflow during the vowel does not distinguish successfully between nasal-final rhymes carrying tone B2 and obstruent-final rhymes. However, as airflow measurement does not relate to acoustic nasalisation in a straightforward way, this observation does not rule out the possibility that the degree of acoustic nasalisation of the two sets of syllables differs. By contrast, oral airflow brings out a clear difference between these two sets of rhymes: tone B2 has low oral airflow; tones D1 and D2 have relatively high oral airflow, getting close to the range of breathy voice. The results support a hypothesis set out by Michaud 2004 on the basis of acoustic analysis, electroglottographic measurements and recognition tests: that nasal-final rhymes carrying tone B2 and obstruent-final rhymes carrying tone D2, which have similar pitch and are similar from the point of view of supraglottal articulation, do not contrast by nasality (*vs.* lack of such) so much as by their voice quality.

The next step will be to conduct perception tests on these rhymes, playing the stimuli to trained phoneticians without any knowledge of Vietnamese.

From a technical point of view, the study confirms that several exploratory techniques usefully complement one another to obtain a full picture of phenomena of nasalisation.

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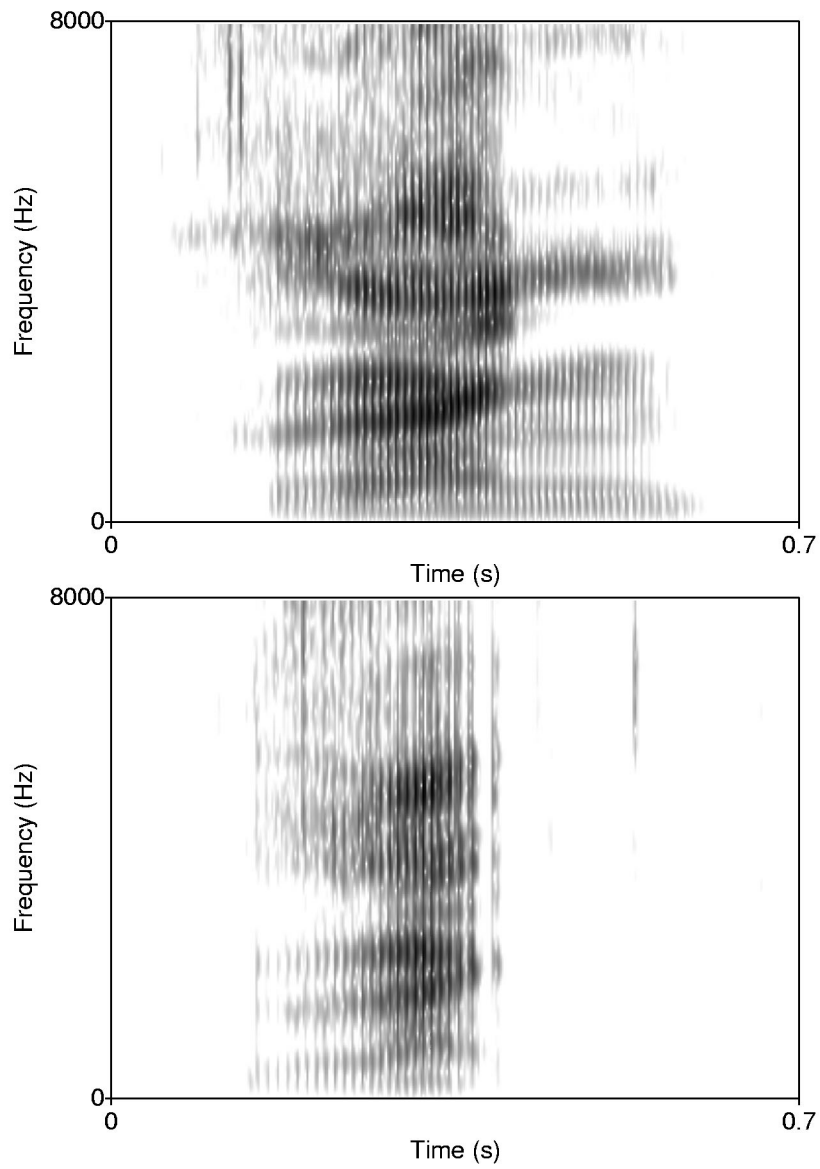


Figure 1. Syllable /yɛŋ/, under tone A1 (top) and B2 (bottom), illustrating the loss of visible nasal under tone B2.

Audio (top), nasal airflow (middle), derivative of nasal airflow (bottom).

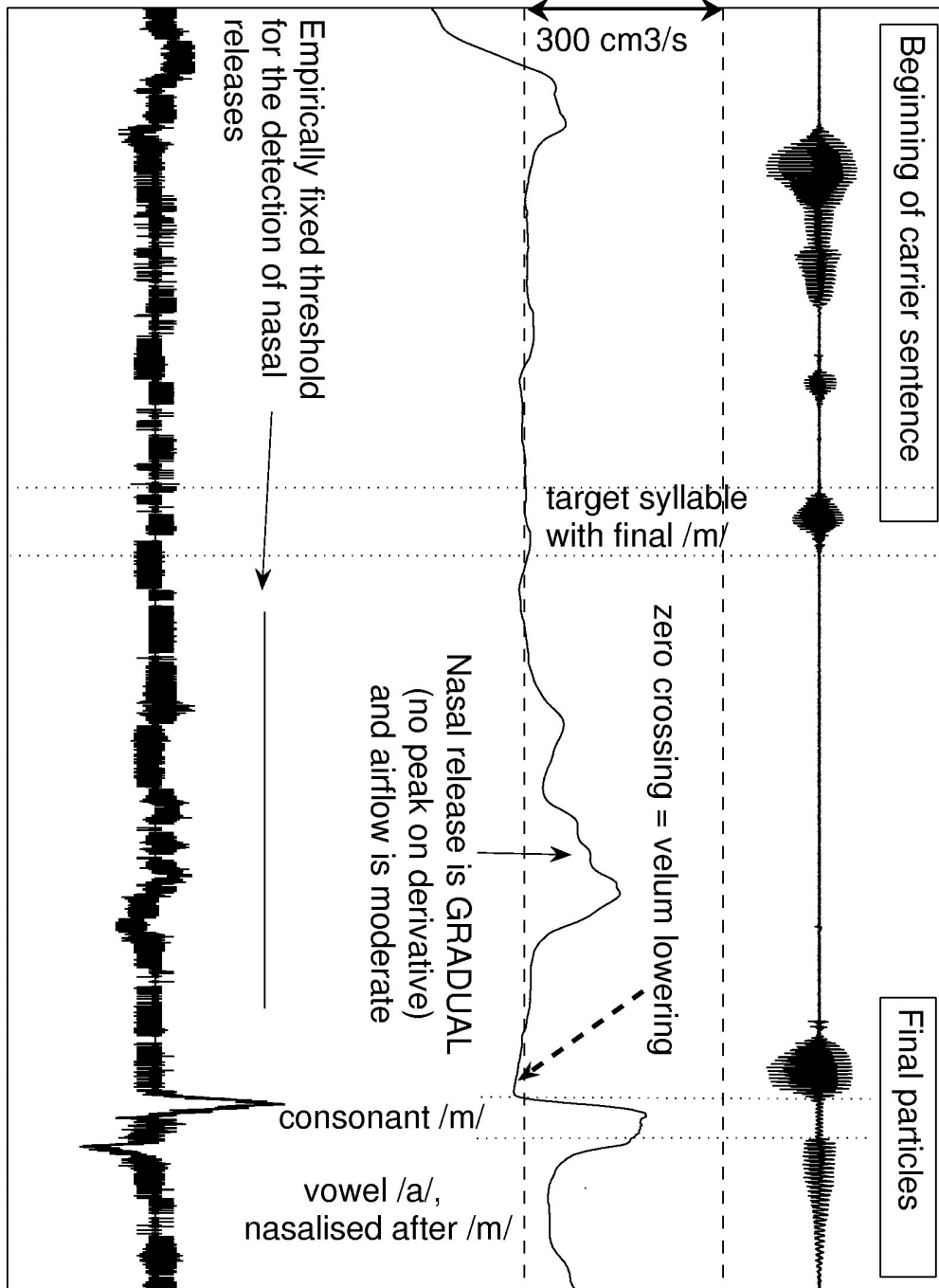


Fig. 2. An example of non-abrupt nasal release after a nasal (/m/). Window: 2520 ms.

Audio (top), nasal airflow (middle), derivative of nasal airflow (bottom).

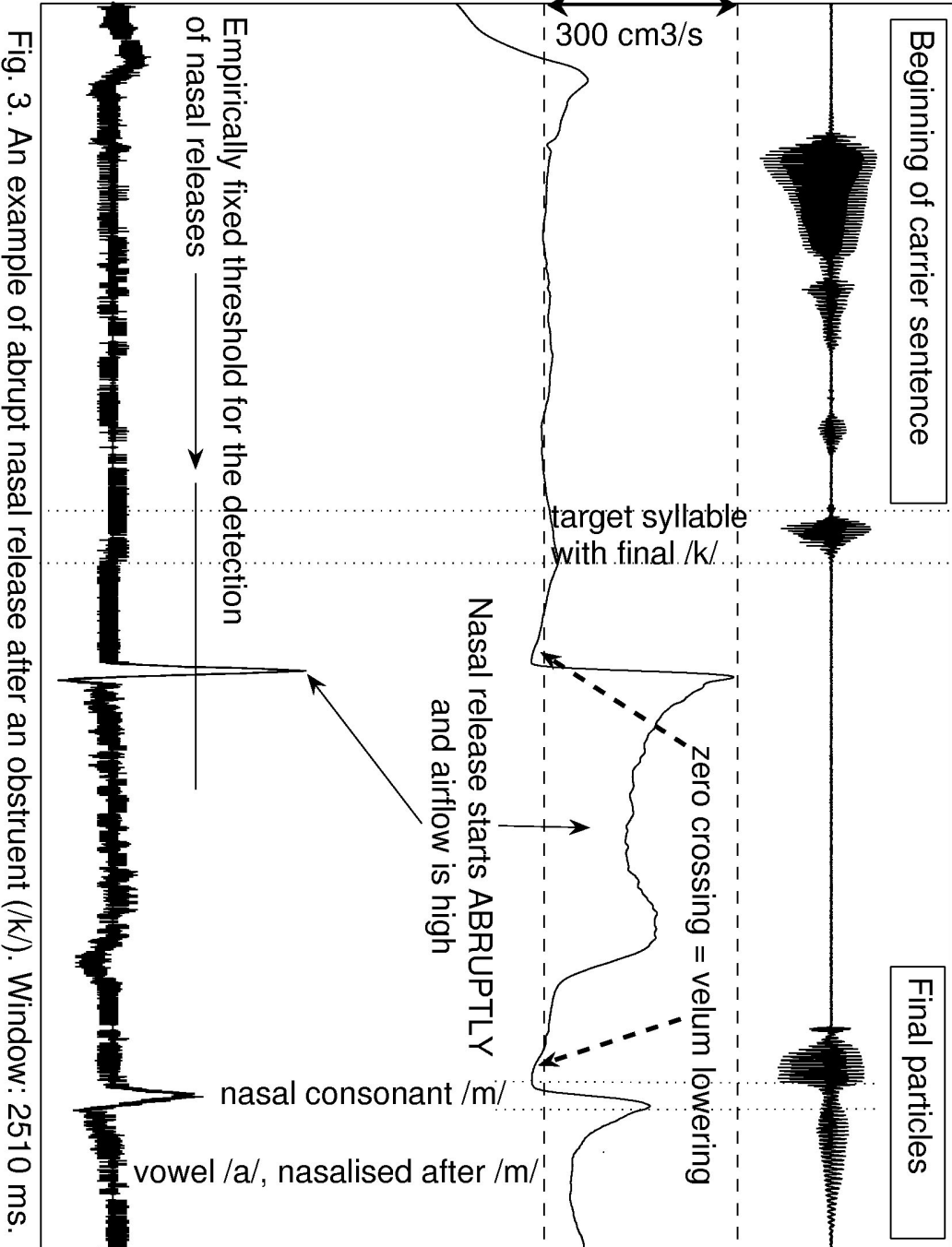


Fig. 3. An example of abrupt nasal release after an obstruent (/k/). Window: 2510 ms.

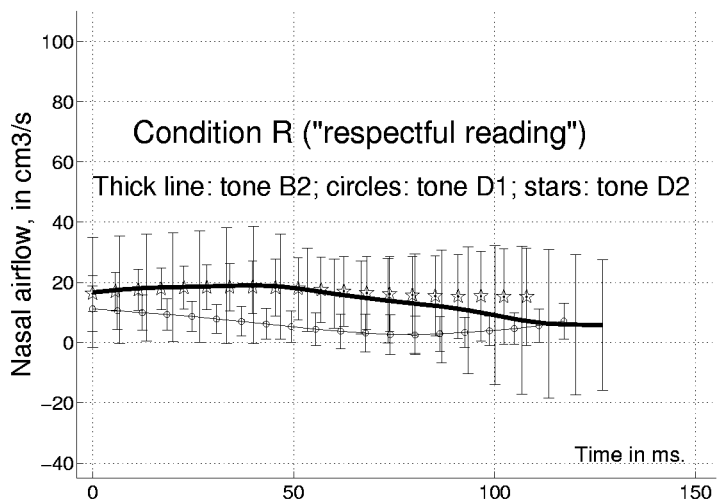


Fig. 4. Nasal airflow values averaged over 50 items, condition R.

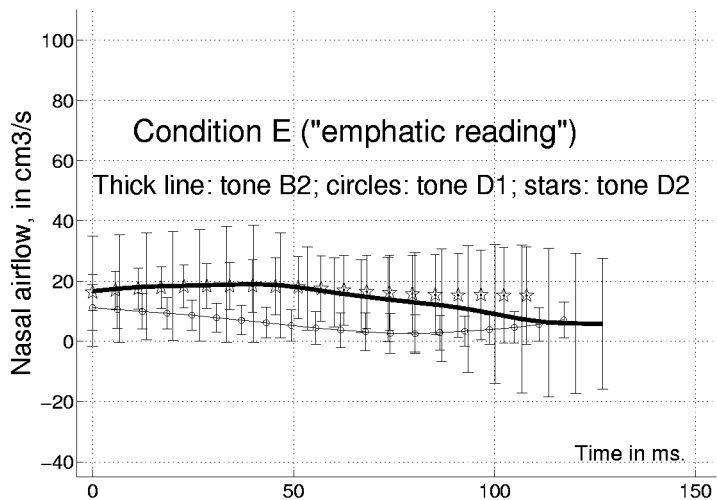


Fig. 5. Nasal airflow values averaged over 58 items, condition E.

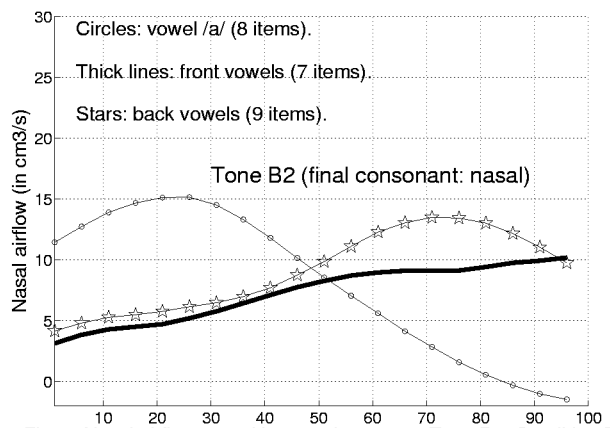


Fig. 6. Nasal airflow sorted by vowel category. Tone B2. Condition E.

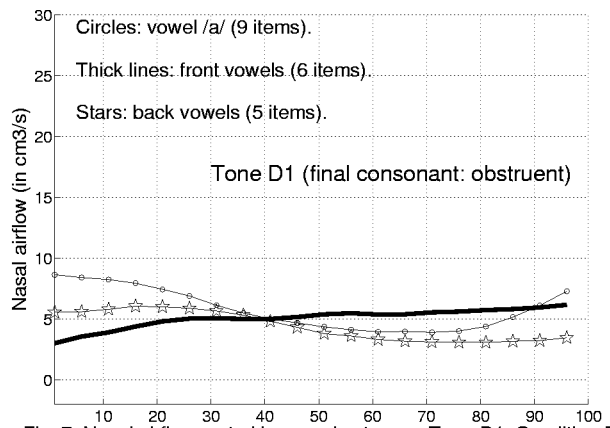


Fig. 7. Nasal airflow sorted by vowel category. Tone D1. Condition E.

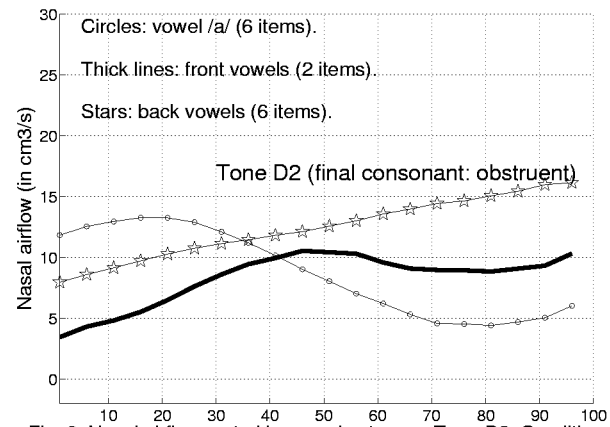


Fig. 8. Nasal airflow sorted by vowel category. Tone D2. Condition E.

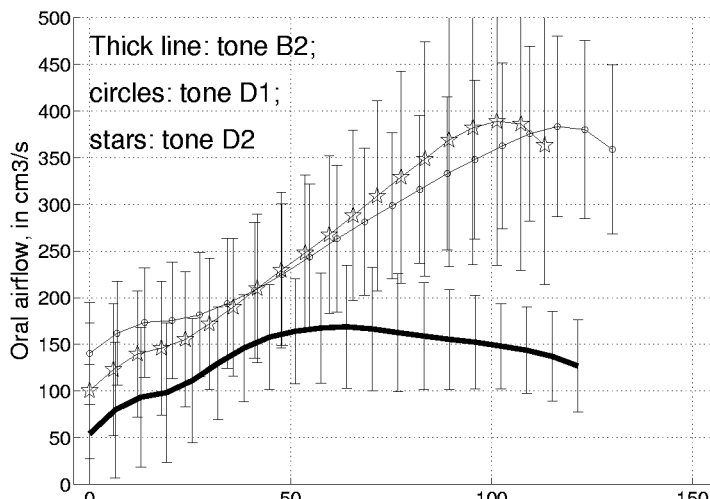


Fig. 9. Oral airflow averaged over 141 syllables read in isolation. Time in ms.