Ultrasound and nasometric evidence for controlled high vowel nasalization in Montreal French

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High vowel nasalization

- High vowels in French typically subject to greater rates of contextual nasalization than mid & low vowels (Basset et al., 2001; Delvaux et al., 2008; Dow, 2014; Rochet and Rochet, 1991; Spears, 2006)
- Is this a controlled property of French? Perhaps:
    - Proportionality of velic height to vowel height ⟶ low vowels tolerate nasal "leakage" & require greater effort to nasalize (Ohala, 1975)
    - High vowels rapidly perceived as nasal and with much smaller degrees of nasal coupling than low vowels (Maeda, 1982)

Complications

- As perception of nasality improves with increased vowel duration (Lintz and Sherman, 1961; Whalen and Beddor, 1989), low nasal(ized) vowels can be preferred (Hajek and Maeda, 2000)
- Percentages of nasalization may be covertly inflated on high vowels:
  - More susceptible than low vowels to spontaneous nasal coupling from aerodynamic (Hajek, 1997) and acoustic (House and Stevens, 1956; Maeda, 1993) perspectives
  - High vowels the shortest of peripheral vowels (e.g., Lehiste 1970) and often uniquely subject to lenition processes in French (Cedergren and Simoneau, 1985; Fagyal and Moisset, 1999), especially Laurentian French

Today's presentation

- How can we tell what vowels, if any, are *targeted* for regressive nasalization?
- We examine the link between nasality and vowel quality (height) with respect to...
  - Vowel duration (nasometry) and
  - Maximum tongue height (ultrasonography)

  in Laurentian French as spoken in Montreal.

Outline

1. Introduction
2. Background: Nasal coupling & duration, influence of intraoral gestures
3. Methodology
4. Results
5. Discussion
6. Future work & conclusion

Duration

- Role of nasalization can be revealed as function of speech rate/vowel duration (Solé, 1992, 2007):
  - Mechanical: Duration of nasal phase remains stable, and/or percentage decreases proportionate to overall vowel duration
  - Controlled: Duration of nasal phase increases, and/or percentage remains stable proportionate to overall vowel duration

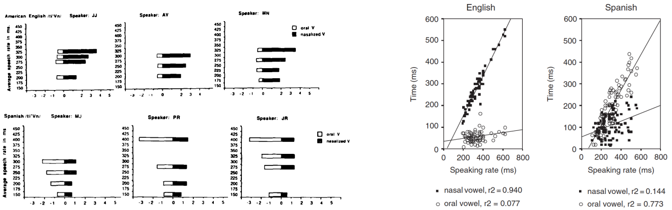


Fig. 1: Controlled (English) vs. mechanical (Spanish) nasalization in Solé 1992 (left) and Solé 2007 (right)

Intraoral gestures

- Centralizing F1 effect of nasal coupling: lowered for low vowels, raised for high vowels (e.g., Feng and Castelli 1996)
- Tongue height (among others) of nasal(ized) vowels can be manipulated to. . .
  - Distinguish certain oral-nasal congeners, e.g., tongue lowering of European French [ɛ̃] ⟶ higher F1 vs. [ɛ] (Carignan, 2014) = *enhancement*
  - Resituate vowels in formant space, e.g., tongue raising of Am. English [ĩ] (Carignan et al., 2011) = *compensation*

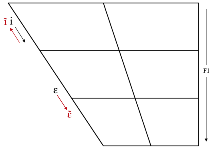


Fig. 2: Rough schematic of F1 changes due to nasal coupling (black) and tongue height (red). Anteriority doesn't mean anything here!

Main questions

Q: When we employ a Solé-esque approach, does regressive nasalization of high vowels in QF decrease significantly with duration or not?

A: It would appear *not to* for /i/ for 3 of 4 speakers examined here. Variable for /y, u/.

Q: Do QF speakers manipulate maximal tongue height to enhance or compensate contextually nasalized vowels?

A: Yes and no, depending on the person and the vowel. Lots of follow-up work to do.

Materials & task

- 10 QF speakers from greater Montreal area (7 women, 3 men), between 19 & 28 years old (mean = 23.3)
- Reading list of oral (/a, e, ø, o, i, y, u/) and nasal (/ã, ẽ, õ, œ̃/) vowels constructed; 'C' = non-nasal consonant, 'N' = nasal consonant, '#' = word edge
  1. Oral in non-nasal settings: _CV, _#, _C# (e.g., *ce **pa**radis perdu, des pap**a** poules, des vis**a**ges pâles*)
  2. Nasal in non-nasal settings: _CV, _# (e.g., *la **san**té publique, des **agents** terribles*)
  3. Oral in pre-nasal settings: _NV, _N# (e.g., *des **cam**arades, la **femme** pressée*)
- Variable rate task: 2-3 times casually, 1-2 times more slowly and once more quickly
- 4 speakers' data analyzed here

Instrumentation & Procedure: Ultrasound

- MC4 convex ultrasound transducer with a 20mm radius and the Articulate Assistant Advanced (AAA) software package
- Ultrasound probe held in place using custom-made helmet
- Subjects asked to drink water for initial task to approximate hard palate, alveolar ridge and teeth
- For vowels, automatic tracking function employed to trace the tongue contours (hand corrected if necessary)
- Splines for the individual vowels (N=812, contrastive nasal vowels not included) were analyzed in AAA's Spline Workspace

Instrumentation & Procedure: Ultrasound, cont.

- Maximum height for each vowel defined as the highest midsagittal point of the tongue body, normalized across speakers as percentage of distance between centre of ultrasound probe and alveolar ridge

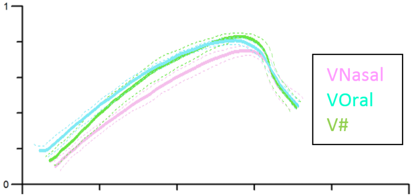


Fig. 3: Tongue splines for [i] before nasal consonants (VNasal) and oral consonants (VOral), and word finally (V#)

- Single-factor pairwise ANOVA performed using RStudio statistical software package, with an independent variable of context and a dependent variable of tongue height

Instrumentation & Procedure: Nasometric

- Glottal Enterprises NAS-1 SEP Clinic handheld nasometer with separator plate
- Recordings performed in Praat (44.1 kHz sampling frequency) in stereo (nasal microphone = left channel, oral microphone = right channel)
- Vowel energy readings extracted at 5 ms intervals within each channel (N=1164)

Instrumentation & Procedure: Nasometric, cont.

- Extreme outliers thrown out and min-max normalization performed within speaker, energy channel and phoneme
- Differential Energy Ratio (DER; Dow 2014) returns nasality of 0-100% (x = oral energy and y = nasal energy):

$$\text{DER} = 100 \times \frac{|\sum_i \min(x_i - y_i, 0)|}{|\sum_i \min(x_i - y_i, 0)| + \sum_i \max(x_i - y_i, 0)}$$

- Speaker-specific linear regressions performed for DER with respect to duration and vowel identity, with an interaction between the two; /a/ as baseline

Ultrasound

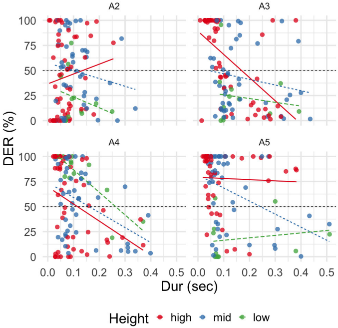
- Significant difference between non-pre-nasal and pre-nasal contexts for all vowels for all speakers, except speaker A4 [a, ø]
- Direction of effect (i.e., in which context tongue is higher) inconsistent
- Focussing on high vowels in pre-nasal position
  - A2: [i] lower ($p<0.001$)
  - A3: all high vowels higher ([i]: $p<0.01$, [y]: $p<0.05$, [u]: $p<0.001$)
  - A4: [i] lower ($p<0.05$); [y] ($p<0.01$) and [u] ($p<0.05$) higher
  - A5: all high vowels lower ([i, u]: $p<0.01$, [y]: $p<0.001$)

red = enhancement, *black = compensation*

NB: Pairwise comparisons of VN vs. VC and VN vs. V# were performed separately but made no difference in the results presented here.

Nasometry

- Pre-nasal vowel average DER: low (35.7%) < mid (52.7%), high (58.4%)
- Caveat: mid & high vowels not internally homogeneous, especially with respect to variation and behaviour over time (cf. Appendix)



Acoustic regressions

- A2: no significant nasalization
- A3: [i] ($p<0.01$) and [y] ($p<0.001$) nasalization , but significant fall for [y] over time ($p<0.01$), ns for [i] ($p=0.074$)
- A4: baseline [a] significantly nasal ($p<0.001$) but falls significantly over time ($p<0.01$); [i] ($p<0.01$) and [u] ($p<0.05$) less nasal but [i] significantly rises in nasality over time ($p<0.05$), ns for [u] ($p=0.433$) ≈ [i] nasalization
- A5: [i, y] ($p<0.001$) and [u] ($p<0.01$) nasalization, insignificant fall over time ([i]: $p=0.46$, [y]: $p=0.91$, [u]: $p=0.84$)

Summary (high vowels)

Table 1: Tongue height displacement and significant nasalization, with predicted effects; '*' = DER remaining or becoming significantly nasal over time

Speaker	Tongue height		DER	
A2	[i] ↓	F1↑	—	—
A3	[i, y, u] ↑	F1↓	[i]*, [y]	F1↑
A4	[y, u] ↑	F1↓	[i]*	F1↑
	[i] ↓	F1↑		
A5	[i, y, u] ↓	F1↑	[i, y, u]*	F1↑

Synthesis

- Evidence for enhancement of nasalized [i] in speaker A4 and of all high vowels in A5
- Evidence for compensation for nasalized [i] in speaker A3
- Less clear cases:
  - A2: lower pre-nasal [i] without significant nasalization
  - A3: higher [y] which falls in nasality, higher [u] without significant nasalization

Future work

- Take into account preceding & following (where applicable) segments
- Disentangle high vowel laxing and phonotactics (distribution of mid vowels)
- Compare results with actual, relative formant values
- Look at anteriority and more nuanced tongue contours
- Synthesize results for individual tokens!

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Nasometry: Individual vowel means

V	A2	A3	A4	A5
a	22.4	23.3	78.5	17.8
e	65.5	45.9	52.6	86.1
ø	41.1	16.9	29.4	24.0
o	43.9	52.8	64.7	71.6
i	33.8	58.0	61.8	85.9
y	60.4	62.5	51.6	78.7
u	32.3	65.7	41.3	65.7

Table 2: Pre-nasal vowel average DER, by target & speaker

Nasometry: Individual vowels vs. duration

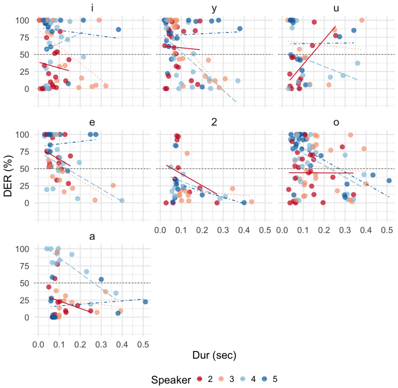

Fig. 5: Pre-nasal vowel DER vs. duration, by target & speaker

- Fall on /a/ (A4) and most mid vowels (save A5 /e/)
- Stability/rise on certain speakers' high vowels (but note also variation)