ULTRASOUND AND NASOMETRIC EVIDENCE FOR CONTROLLED HIGH VOWEL NASALIZATION IN MONTREAL FRENCH

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ABSTRACT

We examine ultrasound and nasometric data in a variable rate task to quantify the influence of vowel quality, duration, and intraoral gestures on regressive nasalization in Montreal French. Acoustic results suggest that, while on average high and mid vowels are heavily nasalized in this context, only certain high vowels remain significantly nasal as duration increases, for the majority of speakers. We interpret these results as indicative of high vowel nasalization as a controlled property of production, à la Solé [31, 32]. The ultrasound data (maximum tongue height), meanwhile, show no unidirectional or group-wide tendencies, but suggest certain speakers modulate tongue height in order to increase the salience of [i]-nasalization, or to undo height displacement of nasalized [i] in the formant space. Finally, certain speakers show significant nasalization without changes in tongue height.

Keywords: Nasality, laboratory phonology, French

1. INTRODUCTION

The majority of phonetic studies on regressive nasal coarticulation in French find high vowels to be the most nasal ([10, 3]), exceeding 50% nasality at times ([28, 33, 11]), whereas mid vowels are less nasalized and low vowels the least. High vowel nasalization (HVN) is rarely qualified as a controlled property of French, however, characterized at most as passive laxing of oral-nasal contrast [33, 10], given its lack of contrastive high nasal vowels. Meanwhile, others (e.g. [8]) deny the possibility that any contextual nasalization in French may be intentional.

The large body of phonetic evidence suggesting a height parameter, wherein high vowels more readily achieve significant nasal coupling than low, and with smaller degrees of velopharyngeal port opening (VPO), complicates the question of whether HVN may be deliberate. Acoustic modeling studies [18, 23] show that the formant structure of high vowels is more propitious to nasal coupling at smaller degrees of VPO. These observations are mirrored by the aerodynamic literature (see [14] and references therein), in that the higher degree of intraoral pressure on high vowels necessitates a smaller VPO area to direct air through the nasal cavities. Finally, in perceptual studies, high vowels are more quickly judged as more nasal than low [16, 1], and more than twice the magnitude of nasal coupling is required for [a] to reach the same perceived degree of nasalization as [i], once nasal coupling begins [22, 23].

From an articulatory point of view, the lower velic position on low vowels [17] does not make them easier to nasalize as originally thought [7], and intended acoustic outputs appear to take precedence [25]. As such, intraoral articulators can be manipulated in reaction to the centralizing acoustic consequences of nasalization, with respect to both F1 and F2 [13]. In particular, tongue retraction and/or lowering often distinguishes oral-nasal congeners in French, beyond nasal coupling [4]. Such differences serve to heighten the salience of nasality of nasal vowels. Meanwhile, in American English, tongue body raising accompanies HVN, counteracting F1 raising though not undoing nasal coupling [5].

At the same time, the interaction among vowel height, duration and nasalization suggests low nasal(ized) vowels may be preferred. Specifically, nasality is better perceived with increased vowel duration, regardless of a vowel's proportion of nasalization [21, 34]. Moreover, theoretically (e.g. [20]) and experimentally (see [15] for references), a length parameter favouring low vowels emerges. Taken together, low nasal vowels may be the least marked, especially at slower rates.

All in all, due to (a) the differentiation of vowel heights in French nasal coarticulation, (b) the possibility that elevated percentages in HVN are merely due to shorter duration, and (c) the consensus that high vowels are nasalized easily, we question whether HVN in French is covertly mechanical, or indeed an active part of its grammar. We thus look at the relationship between nasality (using nasometry) and duration for individual vowel qualities of Montreal French in a variable-rate speech task, as an extension of Solé's methodology [31]. Given that lingual position may further reveal speakers' intentions to produce a certain acoustic output, we also utilize ultrasound imagery to compare tongue height of individual vowel qualities according to the nasality of its context. We predict that in pre-nasal contexts, high vowels' rates of nasality should stay consistent or rise with duration and, in order to increase this salience, show tongue body lowering in these same contexts. Meanwhile, non-high vowels should be less nasal with time and show either no tongue body modulation or gestures potentially diminishing nasal salience (according to their height).

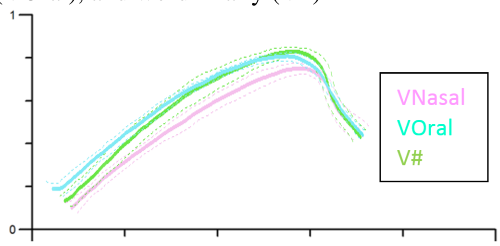
2. METHODOLOGY

Ten native speakers of Quebec French (7 women, 3 men; age range 19 to 28, mean = 23.3) native to the greater Montreal area participated in the study. No participants reported any diagnosed language or auditory impairments, nor did any claim to be suffering of allergies or diseases affecting the nasal cavities.

A reading list of French expressions was created for the first task of this experiment. The 7 major oral vowel categories of Quebec French, /a, e, ø, o, i, y, u/ ([±ATR] distinctions conflated), and its 4 contrastive nasal vowel categories /ã, ẽ, õ, œ̃/, hereafter *targets*, were placed into various *contexts* according to French phonotactics, namely (a) oral vowels in non-nasal settings, (b) oral vowels in nasal settings and (c) nasal vowels in non-nasal settings. This design yielded 56 target-context sequences. Each participant read this list in a randomized order 2 or 3 times (depending on time constraints) at a self-directed, normal speaking rate. An expanded list including words from the previous task was created for a second task. Participants were asked to read a randomized version this list first at a slower rate than usual, taking care to string together syllables. Participants then read the list, newly randomized, at a faster than usual rate, though still comprehensible.

Ultrasound data were registered using an MC4 convex ultrasound transducer with a 20mm radius and the Articulate Assistant Advanced (henceforth AAA) software package. Subjects were asked to drink water for the initial task to approximate the hard palate, alveolar ridge and teeth. For the vowels, an automatic tracking function was employed to trace the tongue contours. Splines for the individual vowels (N=812) were analyzed in AAA's Spline Workspace. Maximum height for each vowel was defined as the highest midsagittal point of the tongue body. In order to compare height measures across subjects who have different vocal tract sizes and tongue lengths, the values for maximum height were normalized by applying a ratio whereby the distance between the center of the probe and the maximum tongue height was divided by the distance between the center of the probe and the subject's hard palate/alveolar ridge along the same fan line. This renders height as a percentage of the distance between the center of the ultrasound probe (0) and the hard palate/alveolar ridge (100, or 1, as depicted in Figure 1). After exporting data from the AAA software, single-factor pairwise ANOVA were performed in R [26] using the RStudio statistical software package [29], with an independent variable of context and a dependent variable of tongue height.

Figure 1: Tongue splines for [i] preceding nasal consonants (VNasal), preceding oral consonants (VOral), and word finally (V#)



Acoustic data were obtained using a Glottal Enterprises NAS-1 SEP Clinic nasometer, consisting of two equally spaced, pre-calibrated microphones separated by one of three plates (depending on the subject's anatomy) pressed against the upper lip. Nasal and oral channels were thus recorded separately but simultaneously. Participants were instructed to keep plate contact and the nasometer's angle constant during recordings, which were performed in Praat at a sampling frequency of 44.1 kHz in stereo (nasal microphone = left channel, oral = right). These recordings were automatically segmented by WebMAUS Basic [30, 19] with standard French settings. The resulting textgrids were manually inspected and corrected by two independent judges. The stereo channels were then split, and energy readings of each target vowel were taken from each channel at 5 ms intervals. Vowel duration was also extracted.

Outliers were defined as points whose raw energy, within their respective channels, (a) exceeded $3\times$ the interquartile (IQ) range + Q3 or (b) was beneath $Q1 - 3\times IQ$. This was performed on a speaker-internal basis, for each channel and individual target. These readings (N=1,021/27,823) were discarded, and the remaining energy values were min-max normalized within each channel by speaker and target. Finally, the Differential Energy Ratio (DER) [11], a formula similar to nasalance-based formulae but modeling more directly rates of change in energy, was applied to the normalized data to obtain each vowel's nasality as a percent. Namely, after calculating the differential energy of each point by subtracting nasal energy from oral energy, DER is expressed as the ratio of the absolute value of the sum of negative (i.e., nasal) differential energy to total differential energy. This paper analyzes 1,164 vowels from speakers A2, A3, A5 (female) and A4 (male).

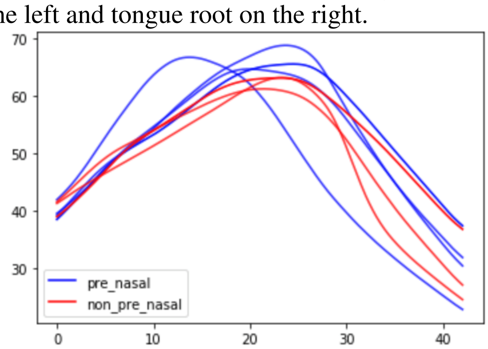
In addition to DER averages and duration, linear regressions were performed for each speaker in R using the RStudio software package to predict nasality of pre-nasal vowels based on phoneme identity and duration, with the vowel [a] as a baseline.

3. RESULTS AND DISCUSSION

3.1. Ultrasound results

All contrasts between the pre-nasal and non-pre-nasal contexts were significant (p<0.05) for all speakers except for A4 (though the direction of the effects was not consistent), who showed insignificant differences between the pre-nasal and non-pre-nasal contexts for [a, ø]. However, only for Speaker A3 were results consistent with the predicted direction of the effects (i.e., high vowels should be higher than their non-pre-nasal counterparts). Figure 2 illustrates the vowel [i] in all pre-nasal and non-pre-nasal contexts produced by Speaker A3.

Figure 2: Ultrasound tongue images of oral [i] for speaker A3 in pre-nasal (blue splines) and non-pre-nasal (red splines) contexts. Tongue tip is on the left and tongue root on the right.



For Speaker A2, [i, o] are significantly lower in the pre-nasal context, in pairwise comparisons with pre-oral and word-final contexts ([i] p<0.001 for both, [o] p<0.01 for both). Only in the case of [a] did the pre-nasal context exhibit higher tongue height values, significantly so (p<0.001 for both). Results for Speaker A4 were similar to those of Speaker A3 in that the pre-nasal context showed significantly (p<0.01 for both) higher mean tongue heights for [y] and [u], but not for [i] or [o]. In fact, mean tongue height for [i] in the pre-nasal context was considerably lower than in the non-pre-nasal context (approximately 5% lower). For Speaker A5, only [o] had a higher mean maximum tongue height in the pre-nasal context than in the non-pre-nasal context.

Against our prediction, we find no unidirectional effect within high vowels. Tongue body raising of [a] in A2's data, which may lower F1 and thus increase nasal salience, seems to go against our hypotheses, though as we will see, this vowel is not significantly nasal. In general, our interpretations must be taken cautiously at this stage, as jaw lowering due to vowel laxing, again common in QF [24, 12], may skew results for tongue height, and other articulators affecting F1 are not considered here. In particular, pharyngeal constriction or expansion (raising or lowering F1, respectively) and various labial configurations have been shown to interact with F1 in French [6, 4]. Additionally, formant values, tongue retraction (affecting F2, an important percept in nasal coupling), and potential diphthongization must be considered in the future.

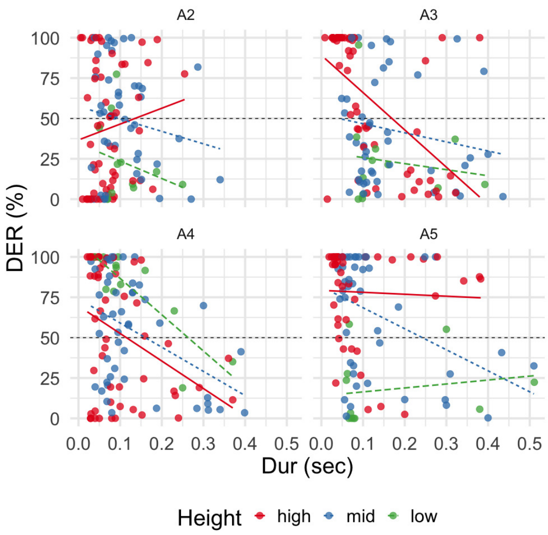
3.2. Acoustic results

Average DER rates of pre-nasal vowels are lowest for low vowels (35.8%), in comparison with mid (52.7%) and high (58.4%). Within controls, contrastive nasal vowels are on average at least 83.2% nasal, while non-high oral vowels are at most 2.6% in non-nasal settings. High vowels have slightly elevated DER means in these same settings ([i, y, u] = 11.5%, 5.8%, 17.2%) due to occasional diminished or turbulent oral energy which may dip beneath these vowels' consistently low nasal energy. Post-voiceless obstruent vowels were particularly affected, suggesting high vowel devoicing, a common process in QF (inapplicable next to nasal consonants) [12]. The failure of nasometry to accurately account for voiceless segments is a known problem [2] and may, in the future, be controlled for.

The relationship between nasality and vowel duration of all VN tokens is plotted in Figure 3 for individual speakers. The dashed horizontal lines indicate 50% nasality. Point colour and line style of linear regressions differentiate vowel heights.

Speaker A2 shows no significant effects of nasality, potentially due to task-induced hypercorrection. Speaker A3's front high vowels are, in general, significantly nasal (p<0.01 for [i], p<0.001 for [y]), though nasality falls significantly for [y] as duration increases (p<0.01). Nasality equally falls for [i], but not significantly (p=0.73). Speaker A4's low vowel, which, again, served as his regression's baseline, is significantly nasal (p<0.001) with an average DER of 78.4%, though this nasality falls significantly with duration (p<0.05), being on average 35.1% at its longest rates. Vowels [ø, i, y] are significantly less nasal than his low vowel (p<0.01, p<0.01, p<0.05,

Figure 3: % nasality (DER) vs. duration, by height and speaker; VN context



respectively), though [i] increases significantly in nasality over time ($p<0.05$). Finally, speaker A5's vowels [e, o, i, y, u] are significantly nasal ($p<0.01$ for [u], $p<0.001$ for the rest). These vowels do not fall significantly in nasality over time, with the exception of [o] ($p<0.01$). In summary, save for A2, all speakers appear to control [i]-nasalization, and speaker A5 additionally seems to target [y, u, e].

These results are reminiscent of Solé's [31] findings that nasal phase duration increased proportionately to overall vowel duration duration in English, yet remained constant in Spanish, which is reflective of a difference of grammatical function of nasalization in the two (controlled in the former, mechanical in the latter). Both types are present in our acoustic data, according to vowel and speaker. Specifically, even at more deliberate speech rates, most speakers' pre-nasal high front vowels either remain within the range of nasality demonstrated on phonemic nasal vowels in French [27, 9] or increase in nasality with duration; mid and low vowels generally do not.

Table 1 synthesizes the tongue height displacement and nasometric results for each speaker's pre-nasal vowels, along with the predicted acoustic effects of each (all other things being equal). Asterisks indicates a vowel whose DER either remains significantly high or increases significantly with duration.

Speaker A3's general raising and subsequent F1 lowering may appear contradictory with her controlled [i]-nasalization, which should also raise F1. However, this profile is suggestive of nasalized [i]-raising in American English, which is argued not to mitigate undesirable lowering of the vowel in formant space [5]. Meanwhile, speaker A4's be-

Table 1: Tongue height displacement and significant nasalization, with predicted effects

	Tongue height		DER	
A2	[i, o] ↓	F1↑	—	—
	[a] ↑	F1↓		
A3	All ↑	F1↓	[i]*, [y]	F1↑
A4	[y, u] ↑	F1↓	[i]*	F1↑
	[i] ↓	F1↑		
A5	[o] ↑	F1↓	[i, y, u, e]*, [o]	F1↑

haviour is more in line with our hypotheses; namely, tongue lowering on [i] reinforces its controlled nasal salience, while raising of [y, u], which are not significantly nasal, may either diminish residual nasal percepts (in contrast with A3's strongly nasal yet raised [i]) or resituate the vowels closer to their acoustic, oral targets. This same analysis applies to [o] in speaker A5's data; tongue height does not interact with her controlled, nasalized high vowels and [e].

4. CONCLUSION

This paper examined whether regressive high vowel nasalization, prominent in the literature, constitutes a deliberate process in French. We identified two confounding factors: (1) the relative shortness of these vowels potentially inflating percentages, and (2) the ease of nasal coupling on these same vowels. We utilized ultrasound and nasometric instruments to investigate the relationship between tongue height position and the acoustic consequences of nasal coupling, and between nasality and duration. Consideration of duration allows for circumvention of (1), while use of ultrasound imagery clarifies (2), given evidence that speakers may subconsciously manipulate articulators for specific acoustic targets.

We presented acoustic evidence that nasalization is controlled only for high front vowels (save for one conservative speaker). Ultrasound results were mixed, in that speakers' lingual movements (when differentiating at all) may serve either to increase nasal salience of [i] or to undo displacement of its height percepts due to nasal coupling. We reserve judgment until additional articulatory factors effecting formant structure, such as tongue anteriority and lip rounding, are examined and compared against our vowels' actual acoustic outputs.

5. ACKNOWLEDGEMENTS

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