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Ultrasound and Corpus Study of a Change from Below: Vowel Rhoticity in Canadian French

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Abstract
While phonetically-motivated change from below is a fundamental concept in contemporary approaches to phonology and variation, empirical data is sparse (Cedergren, 1973; Trudgill, 1974; Labov 2001), partly because changes usually go unnoticed until long after their inception, and because articulatory data (which can shed light on phonetic motivations) is often unavailable. This paper documents the inception of a change from below using corpus data and ultrasound imaging of the tongue. The variable under investigation is the rhoticity with which some speakers of Canadian French produce the vowels /ø/, /œ/ and /œ˜/, making them sound like English [ɹ] (i.e., heureux, docteur, and commun sound like [ɻʀɻ], [dɔktʌɹʀ] and [kɔmɻ˜]. When asked, native speakers are completely unaware of the difference between rhotic and non-rhotic pronunciations, suggesting that rhoticity is a change from below. Previous reports of retroflex-sounding variants of Canadian French vowels date back to the early 1970s in Montreal (Dumas 1972, 100, Sankoff, p.c.) and a retroflex-sounding variant of /ö/ has also been observed (Sankoff and Blondeau, 2007), but there has been no previous articulatory study of these sounds. North American English /ô/ can be produced with various tongue shapes, including bouched and retroflex variants (Delattre and Freeman, 1968) raising the question of whether French rhotic vowels are also produced with these categorically different tongue shapes.

Ultrasound and Corpus Study of a Change from Below: Vowel Rhoticity in Canadian French

Jeff Mielke*

1 Introduction

Some speakers of French in Canada produce the vowels /ø/, /œ/, and /œ̃/ with a rhotic perceptual quality, much like English [ɹ], leading *heureux*, *docteur*, and *commun* to sound like [ɹ̩ʁɹ̩], [dɔktaɹʁ], and [kɔmɹ̩̃]. The earliest report of rhotic vowels was by Dumas (1972:100), who observed a retroflex-sounding variant of /ø/ in the early 1970s in Montreal, in final open syllables exclusively among men. This study uses corpus data to examine the development of rhoticity in apparent time, and articulatory data to see whether rhotic vowels, like English /ɹ/, are produced with a range of categorically different of tongue shapes such as bunched and retroflex.

Acoustically, American English /ɹ/ is characterized by low F1, low F2, and especially low F3 (Delattre and Freeman 1968, Alwan et al. 1997, *inter alia*). Rhotic vowels are produced with lower F3 than their non-rhotic counterparts, as seen in the representative spectrograms in Figure 1, where arrows identify F3 during the target vowel.

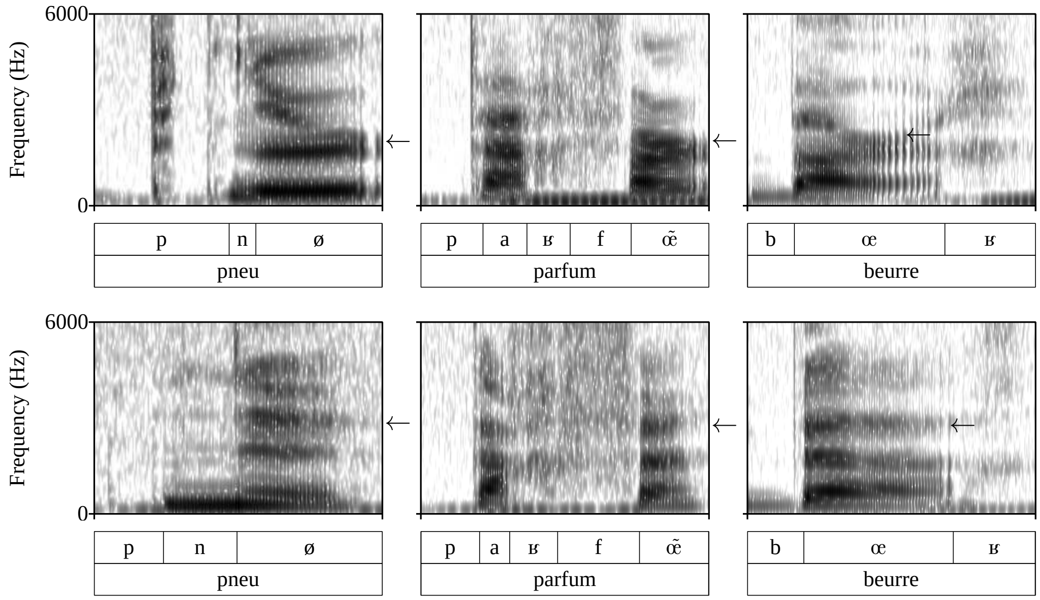

Figure 1: Representative spectrograms and phonemic transcriptions for words with rhotic vowels (top) and non-rhotic vowels (bottom). Arrows identify F3.

The rhotic vowels (in the top row) show a lowering of F3 and very little difference between F3 and F2, whereas the non-rhotic speaker's vowels show comparatively even spacing between the formants. The spectrogram for rhotic version of *beurre* shows a typical situation for /œ/, which occurs most often before /ʁ/: the uvular /ʁ/ is still present following the rhotic vowel, which is

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diphthongized, meaning a phonetic transcription of this word as spoken by a rhotic speaker would be [baɪʁ] (with two consecutive rhotic sounds at different places of articulation. Further evidence that the rhoticity of the vowel is not due to the following uvular fricative is that the F3 minimum is typically achieved prior to the end of the vowel.

A contact-based explanation for rhotic vowels is appealing, considering the similarity with English /ɹ/ and the contact between French and English in Canada. However, the evidence that is available points to change from below. When asked, native speakers typically are unaware of the difference between rhotic and non-rhotic pronunciations, and this observation is supported by a perception experiment (Lamontagne and Mielke 2013) showing that rhoticity is less salient to native speakers of Canadian French than it is to English speakers with no French exposure. Rhoticity also does not appear to be more frequent among speakers with more English exposure. While phonetically-motivated change from below is a fundamental concept in contemporary approaches to phonology and variation, empirical data is sparse (Cedergren 1973, Trudgill 1974, Labov 1994), partly because changes usually go unnoticed until long after their inception. Rhotic vowels present an important opportunity to investigate the production of a change from below in progress.

2 Corpus Methods

The development of rhoticity was investigated using two conversational French corpora involving speakers from Gatineau, Quebec.[1] These include the *Corpus du français parlé à Ottawa-Hull* (adults from Ottawa and Gatineau, recorded in 1982; Poplack 1989) and the *Corpus du français de l'Outaouais au nouveau millénaire* (students and teachers recorded in the last decade; Poplack and Bourdages 2010). Data from 75 speakers was analyzed, including 42 females and 33 males, of which 26 are working class, 25 are middle class, and 24 are upper class. Birth years range from 1893 to 1991.

Forced alignment was performed using using a system developed by Milne (2011), who adapted the Penn Phonetics Lab Forced Aligner (Yuan and Liberman 2008) to work with French. 10–25 minutes of speech aligned for each of 75 speakers. The segmentation of the target vowels /ø œ̃ œ/ was hand-corrected, yielding 5837 tokens at least 50 ms long. 10,980 tokens of /a i u/ were used for normalization. The normalization vowels were not hand-corrected, but bad measurements were removed using EM clustering. Since rhoticity is associated with low F3 values, F3 was measured at the location of the F3 minimum. F1 and F2 were measured at the vowel midpoint.

3 Corpus Results and Discussion

The minimum F3 of the mid front rounded vowels /ø œ̃ œ/ across segmental contexts is shown in Figure 2. The figure excludes speakers who did not produce these vowels with low F3 in any context. /ø/ (as in *d**eux***) has the lower F3 word-finally than before consonants. /œ̃/ (as in ***un***) does not show this pattern, but for a special reason: most tokens of /œ̃/ are the word *un*, and the contexts __C and __# reflect whether the final /n/ was produced or not. For /ø/, these contexts reflect different groups of lexical items. For the vowel /œ/ (as in *c**oeu**r*), which only occurs before consonants, F3 is lowest before /ʁ/.

Figure 3 shows speaker F3 means for the three mid front rounded vowels in the contexts where rhoticity is observed. LOESS curves are shown for all three formants in the lower plot. F3 values for all three vowels are lower among speakers born after after 1965, and F2 shows a steady decline throughout most of the 20th century. Linear Mixed Effects regressions were performed for each of the three vowels, with normalized F3 minimum as the dependent variable, birth year, sex, and class as fixed factors, and speaker as a random factor. Birth year is significant for all three vowels [/ø/: Estimate= -5.765, $t = -2.669492$, $p = 0.0095$; /œ̃/: Estimate= -5.470, $t = -2.916455$, $p = 0.0048$; /œ/: Estimate= -4.110, $t = -2.3945593$, $p = 0.0194$]. Main effects of class and sex are not significant when interactions with birth year are included.

[1] Gatineau is a city in Quebec that is located directly across the Ottawa River from Ottawa, Ontario. It was formed in 2001 as an amalgamation of smaller municipalities including Hull and Aylmer.

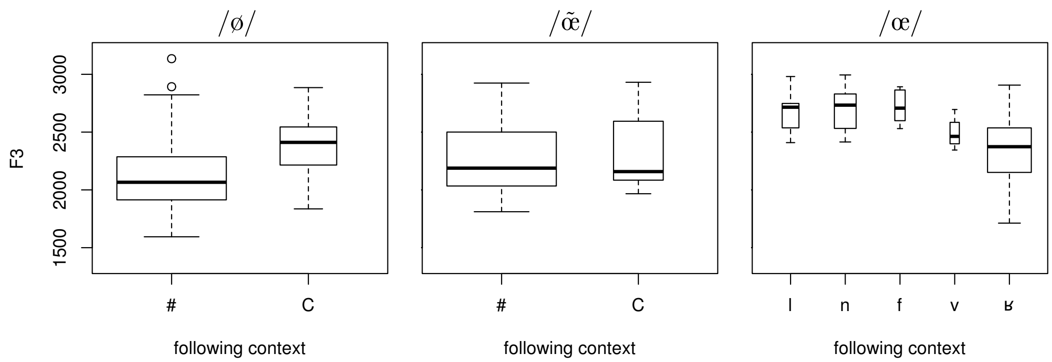


Figure 2: /ø œ̃ œ/ F3 by context.

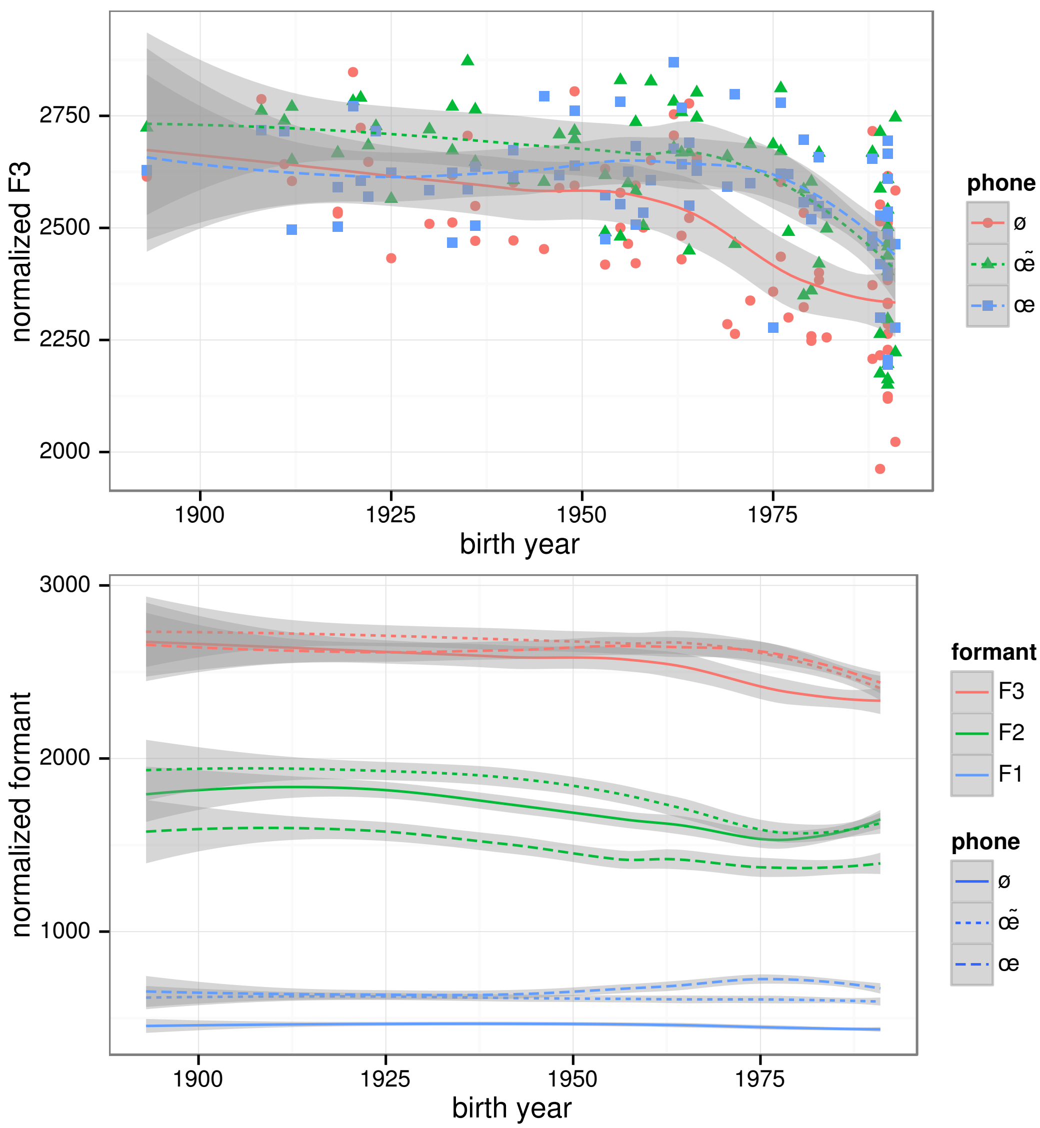


Figure 3: Top: F3 by birth year (speaker means); Bottom: F1, F2, and F3 by birth year.

Rhoticity is apparent only in speakers born after 1965, showing that it is a change in progress. The absence of significant social factors other than age is consistent with other indicators that it is a change from below. Rhoticity developed first in word-final /ø/, and later in its nasalized counterpart /œ̃/ and in /œ/ before /ʁ/. Before there was rhoticity, there was backing and/or unrounding, seen in the fall of F2 over time. The F2 drop is the shallowest for /œ/, which began with the lowest F2 and which also involves an increase in F1, associated with the development of [œː] into a diphthong. Dumas (1981) transcribes the resulting diphthong as [aʸ], and the rhotic version has been transcribed in this paper as [aɹ].

Several topics remain for future research, including the role of backing/unrounding and diphthongization in the development of rhotic vowels. Another apparently relevant factor is the development of rhoticity in Montreal, which was already under way in 1972 when it was described by Dumas. While Dumas reports rhoticity only among men and only word-finally, there is no sex effect in the Gatineau data, and word-final rhoticity is quickly followed by rhoticity before /ʁ/.

The way rhotic vowels are articulated is of particular interest because of the resemblance to English /ɹ/, which is known to be produced with multiple distinct tongue postures. Articulatory variability has the potential to shed light on the development and spread of rhoticity in Canadian French.

4 Ultrasound Methods

Ultrasound imaging was used to generate mid-sagittal video of tongue movements of 27 speakers of Canadian French as they read a word list containing the target vowels. Data from 23 participants was usable for analysis. Participants were aged 18–38 at the time of recording (median = 20), i.e., born 1973–1993. There were 16 females and 7 males. Twelve were from Quebec, nine were from Ontario, and two were from New Brunswick. The stimuli consisted of between 107 and 143 words, including target words containing /œ/, /œ̃/, and /ø/ (listed in the appendix), target words for another experiment on high vowels (Dalton 2012), and fillers. Each word was repeated three times, twice in the carrier phrase "Je dis ___." and then once in the carrier phrase "Je dis ___ encore." Each speaker produced 90–105 tokens of potentially rhotic vowels.

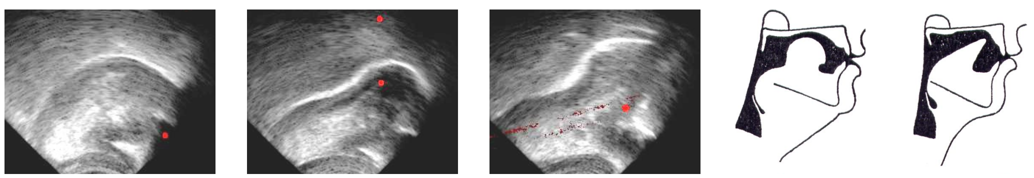
Participants were seated in an optometry chair inside a sound-proof booth. A Terason t3000 ultrasound machine with a 8MC4 ultrasound transducer and Ultraspeech (Hueber et al. 2007) was used to generate mid-sagittal ultrasound video at 30 frames per second. A closed-circuit TV camera was used to capture side-view video of the participant's face. Audio was recorded at 44.1kHz/16 bits using a Shure MX412/C Gooseneck Condenser cardioid microphone mounted close to the participant's mouth and connected via a Sound Devices USBPre microphone preamp and A/D converter to a PC running Audacity 1. The Palatron system (Mielke et al. 2005) was used to correct for head movement: the participant faced wore a pair of sunglasses or ski goggles to which was attached a small lightweight wooden rod with white dots at each end, for tracking changes in head position and head angle. A similar wooden rod was attached to the ultrasound transducer as a reference.

The speech was segmented in Praat TextGrids using forced alignment and hand correction. The TextGrids were used as the basis for automatic extraction of formant values and ultrasound and video frames. Each token was coded auditorily by the author as rhotic, non-rhotic or ambiguous. For each target word, a single ultrasound/video frame was selected at a typical F3 minimum location (averaging across each speaker's repetitions of the same phone). The tongue surface and lips were traced using Palatoglossatron software (Baker 2005), and transformed to correct for head and/or transducer movement (Mielke et al. 2005), i.e., to put all of the tongue traces in the same head-centric coordinate system.

Articulatory analysis involved Smoothing-Spline ANOVA comparisons (Gu 2002, Davidson 2006) for broad comparisons of tongue shapes. Since the tongue surface approximates an arc more closely than it approximates a horizontal line, SSANOVAs were calculated using polar coordinates and then plotted in Cartesian coordinates. The key differences between the tongue shapes associated with English [ɹ] and a typical tongue shape used to produce a mid front vowel are the concavity in the tongue dorsum that results from simultaneous pharyngeal and postalveolar constrictions, especially in bunched /ɹ/, and the tongue blade raising that occurs in tip-up and blade-up tongue shapes such as retroflex. Tongue dorsum concavity was measured by finding the largest polygon bounded by a subsection of the tongue contour and a segment connecting its endpoints. To ensure that the concavity was along the tongue dorsum, the polygon was restricted from occurring near the tongue root or tongue tip. The quantity used for analysis was the square root of the area of the polygon divided by the square root of the area of the tongue, represented by the polygon bounded by the tongue trace and a vertical line passing through the most anterior point of the trace and a horizontal line passing through the most posterior point of the trace. Tongue blade angle was measured by defining a line through the tip-most tongue point and the fourth point in from the tip, and calculating the angle between this line and the horizontal.

5 Ultrasound Results and Discussion

The articulatary results include non-rhotic vowels articulated with typical vowel tongue shapes, rhotic vowels articulated with the bunched tongue shape commonly observed in English /ɹ/, and rhotic vowels articulated with a raised tongue tip/blade, similar to retroflex /ɹ/. Figure 4 shows sample ultrasound images for the /ø/ in *pn**eu***, as spoken by three participants, alongside x-ray tracings for two types of English [ɹ] (Delattre and Freeman 1968).



Non-rhotic **Bunched rhotic** **Retroflex rhotic** **Bunched [ɹ]** **Retroflex [ɹ]**

Figure 4: Ultrasound images for rhotic and non-rhotic vowels, with x-ray tracings for English [ɹ].

Figure 5 shows SSANOVA plots for three representative participants. A non-rhotic female speaker from Hull is depicted in Figure 5a-b, which shows tongue shapes that are similar across /ɛ/ and the other vowels, the main differences being in the tongue root position, which is most advanced for /ø/, consistent with it being classified as a tense vowel. It is reasonable to expect these vowels to have similar tongue shapes in the absence of rhoticity, because they are all mid front rounded vowels that are distinguished primarily by lip rounding and nasality. There is a significant difference at the tongue dorsum between the two pre-/ʁ/ vowels, which may be related to their timing relative to the uvular constriction of the following consonant.[2]

A rhotic female speaker from Aylmer is depicted in Figure 5c-d, which shows a classic bunched tongue shape. The tongue root is retracted for all of the target vowels, including /ø/, whose non-rhotic version is traditionally classified as tense (consistent with tongue root advancement, as seen in Figure 5(a–b), instead of retraction). The tongue body is raised for /ø/ and /œ̃/, and between the posterior and anterior constrictions is the concavity characteristic of bunched /ɹ/, and at this point on the tongue dorsum, /œ̃/ is the same as /ɛ/ and /ø/ is significantly lower. While /ø/ and /œ̃/ both show bunching, the constriction is more anterior for /ø/ than for /œ̃/. In /œ/, the tongue dorsum is raising for the following uvular consonant, but the concavity is still visible.

A rhotic male speaker from Ottawa is depicted in Figure 5e-f. The rhotic vowels again have significantly more tongue root retraction and tongue front raising than /ɛ/, but the anterior constriction is made by tip/blade raising instead of tongue bunching. This is the only speaker in the study to use this strategy to articulate rhotic vowels. The tongue blade is raised above horizontal for /ø/ and /œ̃/, and both vowels show concavity, which is characteristic of English bunched /ɹ/, but

[2]The images for /ɛ/ were extracted at the vowel midpoint, whereas the images for the target vowels were extracted at the point of the speaker's typical F3 minimum for that vowel. Since the F3 minimum for /œ/ before /ʁ/ (which is often diphthongized) is often late in the vowel, it makes sense that the tongue dorsum would be higher for /œ/ without this being a distinctive property of the vowel.

also observed in conjunction with retroflexion in English. The tongue posture is markedly different for /œ/, which shows less raising and little concavity. This speaker shows the greatest difference between /ɛ/ and the rhotic vowels.

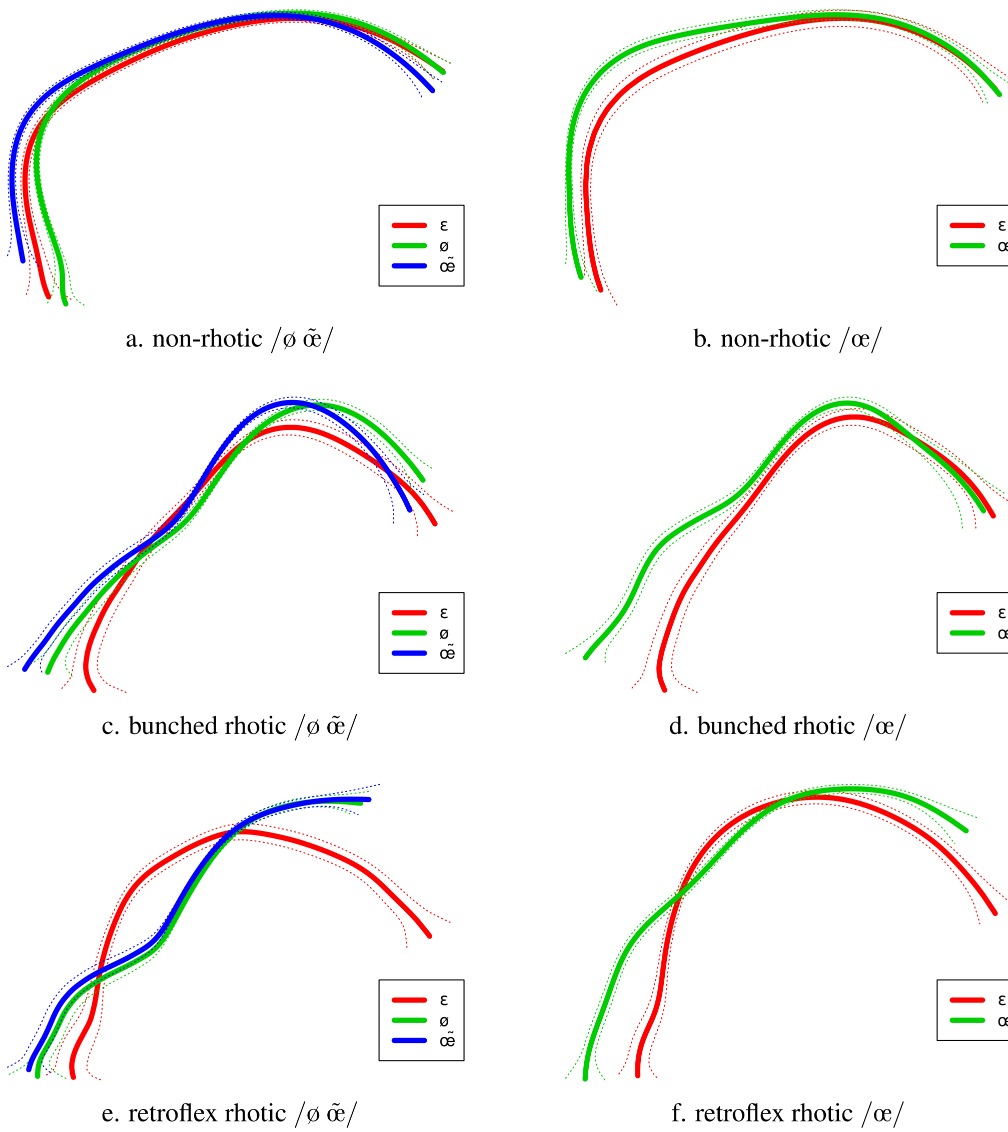


Figure 5: SSANOVA comparisons: Top: a non-rhotic speaker from Hull (frr11); Middle: a bunched rhotic speaker from Aylmer (frr3); Bottom: a retroflex rhotic speaker from Ottawa (frr4).

The key articulatory features of rhotic vowels observed in Figure 5 are tongue dorsum concavity and tongue blade raising. Measurements of these features are summarized for all of the participants in Figure 6. These plots show the relationship between each speaker's mean F3, rate of rhoticity, and the two articulatory features. Each speaker is represented by an identifying number, and circles represent the amount of rhoticity. The filled gray circle represents tokens coded as rhotic, and the unfilled circle represents tokens classified as rhotic or ambiguous. Participants frr4 and frr28 have almost exclusively rhotic tokens, participant frr12 has no rhotic tokens, and participant frr24 has a large number of ambiguous tokens in addition to some rhotic tokens. The same relationship between low F3 and rhoticity is seen in all of the figures. /ø/ shows the most linear relationship between low F3 and tongue dorsum concavity. Only frr4 exhibits tongue blade raising.

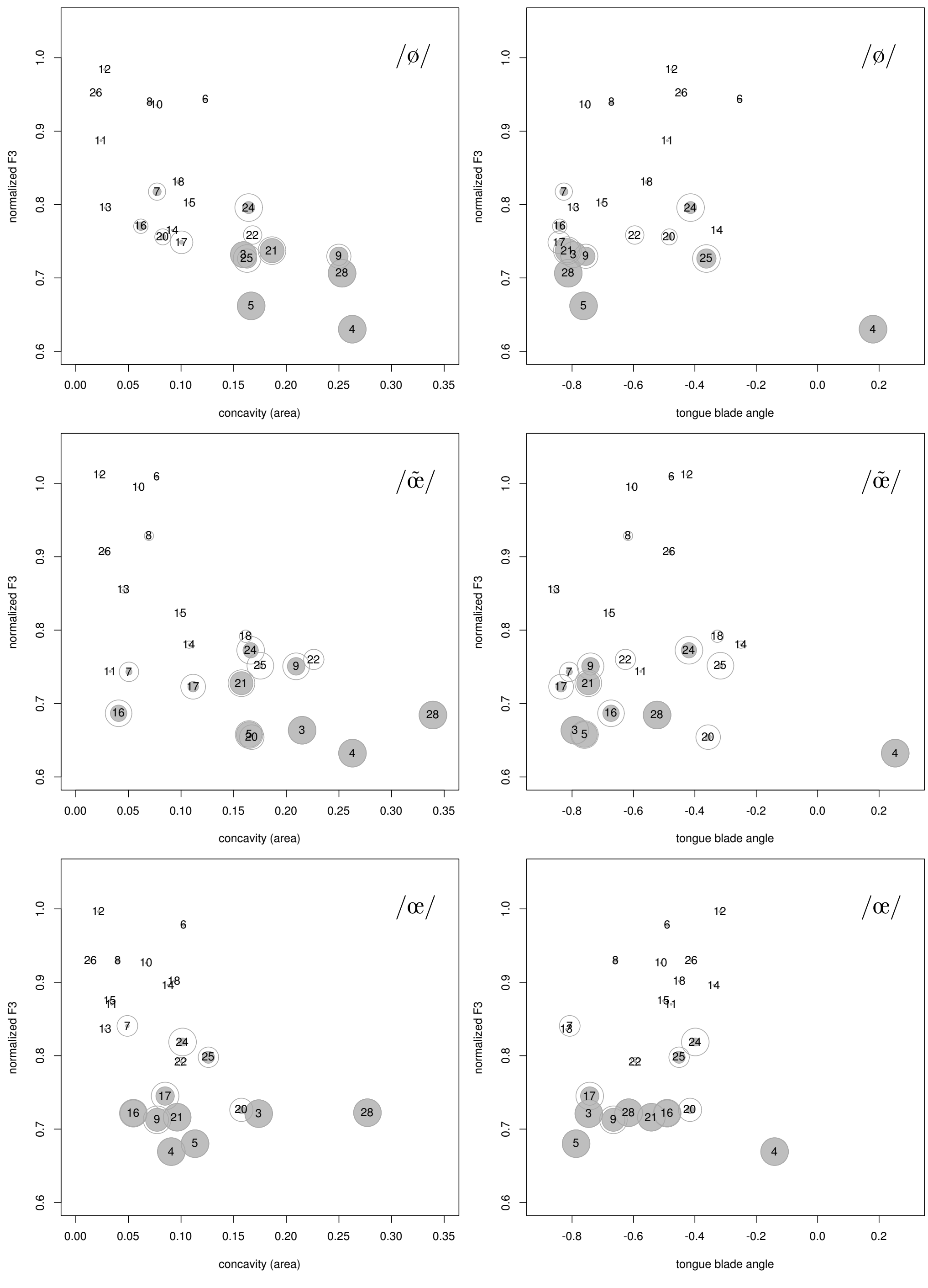


Figure 6: Rhoticity and F3 by concavity and blade angle by speaker.

Figure 7 shows the relationship between F3 and concavity and blade angle on a token-by-token basis. The relationship between tongue dorsum concavity and low F3 is apparent in rhotic and non-rhotic tokens for /ø/ and /œ̃/, but /œ/ shows very little concavity, probably because of the uvular constriction of the following /ʁ/. Blade raising is correlated with low F3 only for rhotic tokens, and only because of the rhotic tokens produced by the one participant who employs a tip/blade raising strategy (frr4).

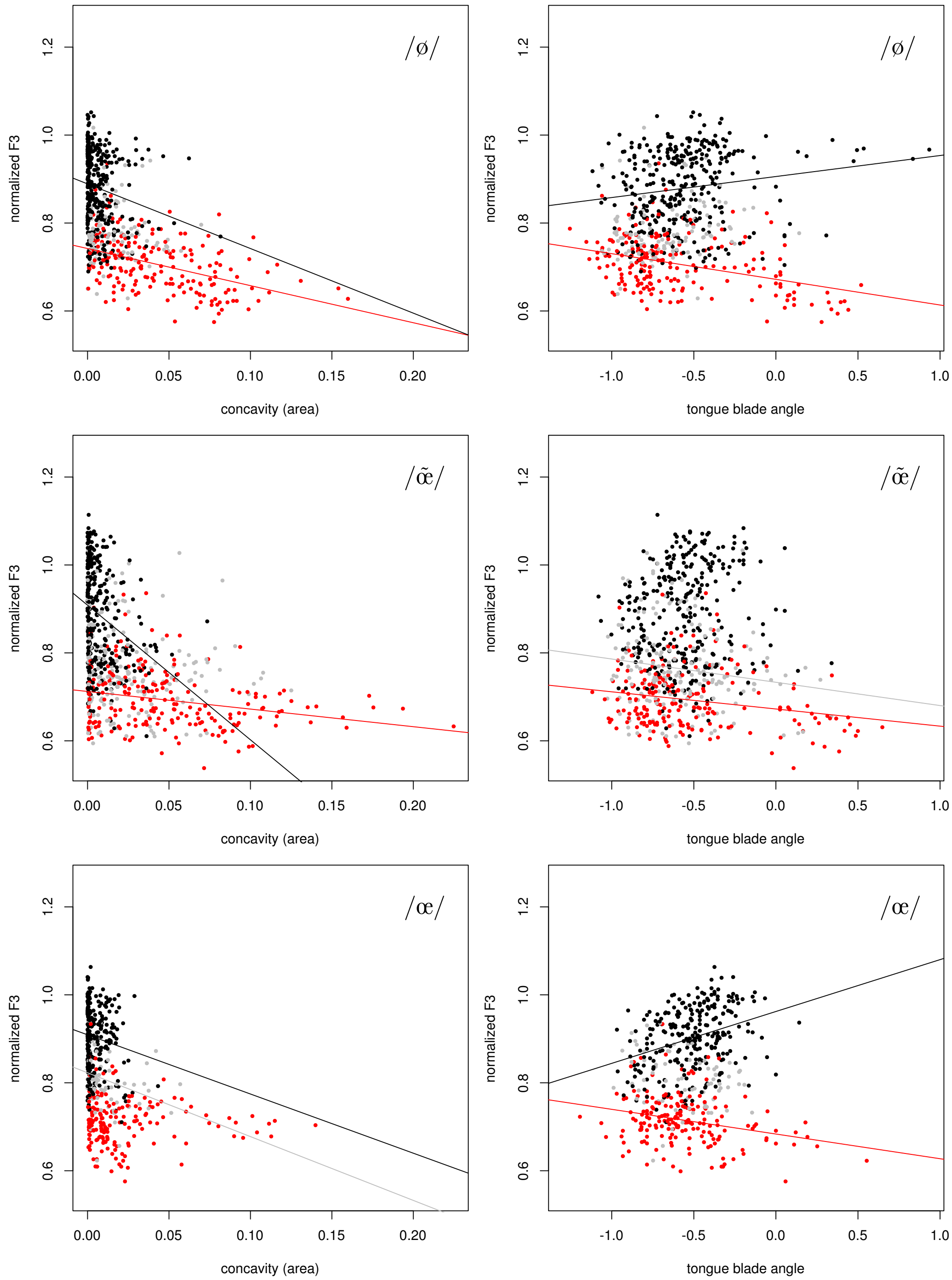


Figure 7: Rhoticity and F3 by concavity and blade angle by token. Dot color indicates auditory coding: black=non-rhotic, gray=ambiguous, red=rhotic.

6 General Discussion

The relationship between rhoticity/low F3 and tongue dorsum concavity in non-rhotic tokens suggests a gradual path from front vowel to bunched /ɹ/, i.e., a gradual increase in the bunching of the tongue and the retraction of the tongue root achieves a gradual increase in rhoticity. This is consistent with the bunched rhotic vowel tongue contours above in Figure 5c, which resemble the contour for /ɛ/ but with the addition of bunching and retraction. A bunched rhotic vowel could have arisen due to gradual exaggeration of low F3 in front rounded vowels, perhaps in conjunction with the gradual exaggeration of low F2.

The retroflex rhotic vowel (Figure 5e-f, above), on the other hand, bears little resemblance to /ɛ/, and there is no indication of anything gradual about the use of tip/blade raising to achieve rhotic vowels. Rather, there is one speaker who adopts a different strategy for producing rhotic vowels. This is consistent with the idea that the gradual emergence of rhoticity involved bunching, and that retroflexion appeared abruptly as an alternative strategy. The retroflexion rate among the speakers with the most rhoticity is comparable to the retroflexion rate in American English. In a study of 27 American English speakers, Mielke et al. (2010) found retroflexion rates of approximately 15% for the /aɹ#/ context (comparable to French /œʁ/) and 7–15% for the /ɚ/ context (comparable to French /ø/). Most of the inter-speaker variability in retroflexion occurs in prevocalic contexts, which are not found in Canadian French, since rhotic vowels are only observed in syllable rhymes. If it is correct that there is no gradual path to retroflexion, then the development of retroflexion is due to the perceptual similarity between the retroflex vowel and the bunched vowel, which does have a gradual path from a non-rhotic vowel. Therefore, retroflexion may be diagnostic for the change moving beyond its initial phonetic motivation.

7 Conclusions

The rhotic perceptual quality of Canadian French /ø œ̃ œ/ is associated with low F3, tongue root retraction, and either tongue bunching or retroflexion. Rhoticity appeared in Gatineau in speakers born after 1965, and its distribution does not appear to involve social factors other than age. It remains to be seen whether rhoticity in Gatineau was transmitted or diffused from Montreal, but internal and social factors do not match those anecdotally reported for Montreal in the early 1970s. The corpus and articulatory data are consistent with perceptual evidence that rhoticity is a change from below in progress. Rhoticity occurred first in word-final /ø/, which is the vowel that shows the clearest evidence of a correlation between degree of bunching and degree of rhoticity, and this may have been associated with the exaggeration of an ongoing drop in F2. Rhoticity later spread to the nasalized vowel /œ̃/ and to /œ/ before word-final /ʁ/. The articulatory data for /œ̃/ and /œ/ show less evidence that the degree of bunching is correlated with the degree of rhoticity. This is consistent with rhoticity in these vowels being the result of generalization from word-final /ø/. Similarly, there is no articulatory evidence that retroflexion could emerge gradually, which is consistent with the idea that the occurrence of retroflex vowels is due to their perceptual similarity to bunched vowels rather than directly from coarticulation.

A Stimuli for the Ultrasound Experiment

Word-final			**Word-internal**	
/ø/	**/œ̃/**	**/œ/**	**/ø/**	**/œ̃/**
bl**eu**	auc**un**	b**eu**rre	h**eu**reux	h**um**ble
d**eux**	br**un**	chauff**eu**r		l**un**di
f**eu**	chac**un**	dépann**eu**r		
heur**eux**	comm**un**	doct**eu**r		
joy**eux**	opport**un**	fl**eu**r		
p**eu**	parf**um**	h**eu**re		
pn**eu**	quelqu'**un**	hum**eu**r		
vingt-d**eux**	**un**	maj**eu**re		
y**eux**	vingt-et-**un**	pêch**eu**rs		

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