Laboratory Phonology
Journal of the Association for Laboratory Phonology

Lipari, M., & Sonderegger, M. (2025). A new perspective on the development of Quebec French rhotic vowels. *Laboratory Phonology: Journal of the Association for Laboratory Phonology*, 16(1), pp. 1–44. DOI: https://doi.org/10.16995/labphon.11678

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A new perspective on the development of Quebec French rhotic vowels

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Quebec French is reportedly developing rhoticity, with low F3 resulting from a bunched or retroflexed tongue (like English /ɚ/), in some or all of the front mid rounded vowels /ø, œ, œ̃/. The source of this rare, understudied sound change is unclear from previous work: contact with English and contrast enhancement have been suggested, and phonologization of coarticulation is typologically plausible. We examine this issue, investigating the apparent time change in the F3 trajectories of the three vowels using generalized additive mixed models on a corpus of parliamentary speech (106 speakers from across Quebec). We observe rhoticity in /ø/ and /œ̃/: men begin with low F3 in these vowels, and women show change in progress. Conversely, there is less clear evidence of change in /œ/. We suggest these findings are best explained by analyzing rhotacization as a two-phased change, originally due to borrowing and subsequently spreading through contrast enhancement. Rhoticity, we argue, is the combined product of intensive exposure to English (which led to frequent nonintegration of bunched/retroflex segments in loanwords) and an exceptionally large vowel inventory. It thus results from the unique interplay of social and phonological factors in Quebec French, which is consistent with such changes being cross-linguistically rare.

1. Introduction

Quebec French is undergoing a sound change whereby three front mid rounded vowels—the high- and low-mid oral vowels /ø/ (as in *jeu*, 'game') and /œ/ (as in *coeur*, 'heart'), as well as the nasal vowel /œ̃/ (as in *brun*, 'brown')—are reportedly developing rhoticity. That is, these vowels increasingly resemble the English rhotic /ɹ/ or /ɚ/ both articulatorily and acoustically, in which a bunched or retroflexed articulation combines with secondary lip rounding, tongue root retraction, and/or tongue dorsum concavity to produce the signature low third formant (Espy-Wilson et al., 2000). This phenomenon, first observed over 50 years ago (Dumas, 1972) and since reexamined only by Mielke (2013a, 2013b, 2015), has remained understudied, especially *qua* sound change. Because rhotic vowels are rare crosslinguistically, occurring in less than 1% of languages (Maddieson, 1984), opportunities to study their emergence in progress are scarce. A better understanding of the particulars of the change in Quebec French may ultimately help understand why the development of rhotic vowels is so constrained, as well as the broader issue of how rare sound changes actuate and spread within a language.

In this paper, we bring new acoustic results to bear on rhotacization in Quebec French, making use of a large-scale corpus of speech constructed from publicly-available data: parliamentary proceedings of the National Assembly of Quebec. We provide the most complete acoustic description of the phenomenon to date, using generalized additive mixed models (GAMMs) to track the evolution of F3 trajectories over apparent time for each of the three front mid rounded vowels. We evaluate several hypotheses about where, when, and how rhotacization might have begun, critically examining two kinds of potential sources for the change which have been previously proposed (contact with English and contrast enhancement), as well as another which is typologically motivated (phonologization of coarticulation). Ultimately, we suggest that a hybrid account best reconciles the patterns in our data with those found in previous work: the early stages of the change are more consistent with borrowing, while its later spread is best explained through internal pressures to enhance weak phonological contrasts.

We begin by summarizing the sociolinguistic situation and the relevant phonological features of Quebec French, and reviewing previous findings surrounding rhotacization in that language in Section 2. Possible sources of the change and their predictions are then sketched in Section 3, along with our operationalized research questions in Section 4. The presentation of the corpus and of the statistical methods used here follows in Section 5. The predicted effects of social and phonological factors (age, gender, place of birth, segmental environment, and speech rate) for each of the vowel categories are shown in Section 6, and inform our evaluation of the different hypotheses as to the source of the change in Section 7.

2. Background

2.1. Social and linguistic dynamics in Quebec

The French spoken in Quebec is traditionally divided into two main regional varieties: one in the west, centered around Montreal (the largest city), and one in the east, centered around Quebec City (the capital). The primary phonetic difference between the two lay historically in the realization of the rhotic consonant phoneme /R/[1] (Dolbec & Ouellon, 1999). Whereas in the East this sound has long been dorsal, an apical realization was characteristic of the West until a sound change in the second half of the 20th century, now virtually complete, made the posterior variant the predominant community norm there too (Sankoff & Blondeau, 2007; Tousignant, 1987a, 1987b, 1987c). The exact location of the East-West divide (including the /R/ isogloss) is unclear, however (cf. Côté & Saint-Amant Lamy, 2023; Saint-Amant Lamy, 2016), resulting in a transitional area around Trois-Rivières (Lavoie & Verreault, 1999). This central zone may be grouped with areas only recently (around 1900) settled by francophones (e.g., the area around Sherbrooke), where migration from both East and West gave rise to a mixing of language varieties (Côté & Saint-Amant Lamy, 2023). While these regional divisions (illustrated in **Figure 1**) are well-motivated historically, they have become increasingly obscured over the past decades as Quebec French has seen rapid dialect levelling (Dolbec & Ouellon, 1999).[2]

Quebec French has a centuries-long history of contact with English, owing to the presence of a sizable anglophone minority ever since the British conquest of Quebec in 1760. The English-speaking community is largely concentrated in Montreal and to its west in an area along the border with Ontario (including the area surrounding the city of Gatineau, across the river from the Canadian capital of Ottawa). Although historical attempts to forcefully assimilate the francophone population were largely unsuccessful, English long enjoyed a privileged social position due to its role as the language of business and industry—sectors historically dominated by anglophones (Gossage & Little, 2013, ch. 4–5; Linteau, 2017, ch. 7–8). A broad social and political movement took roots in the 1960s, culminating in the Quebec government establishing legal protections surrounding the use of French in the workplace, in state institutions and in the public sphere by the end of the 1970s (Martel & Pâquet, 2010). The second half of the 20th century was more widely a period of major social change in Quebec: universal public schooling and healthcare systems were established, access to higher education improved, female

[1] This phonetically abstract notation of the rhotic consonant phoneme is common in the Quebec French literature (cf. Santerre, 1982; Tousignant, 1987a, 1987b; Tousignant, 1987c, *inter alia*), and is used throughout this paper.

[2] This paragraph describes the varieties spoken in Quebec of what is increasingly commonly dubbed 'Laurentian French' (Côté, 2020), and which also includes the French spoken in Ontario and Western Canadian provinces. A closely related but distinct variety, Acadian French, is also spoken by a minority of speakers in Quebec, mostly concentrated along the Baie des Chaleurs, on the Îles-de-la-Madeleine and in the Basse-Côte-Nord (which are all in the East). In this paper, we use the term 'Quebec French' to refer inclusively to both the Laurentian and Acadian French spoken in Quebec.

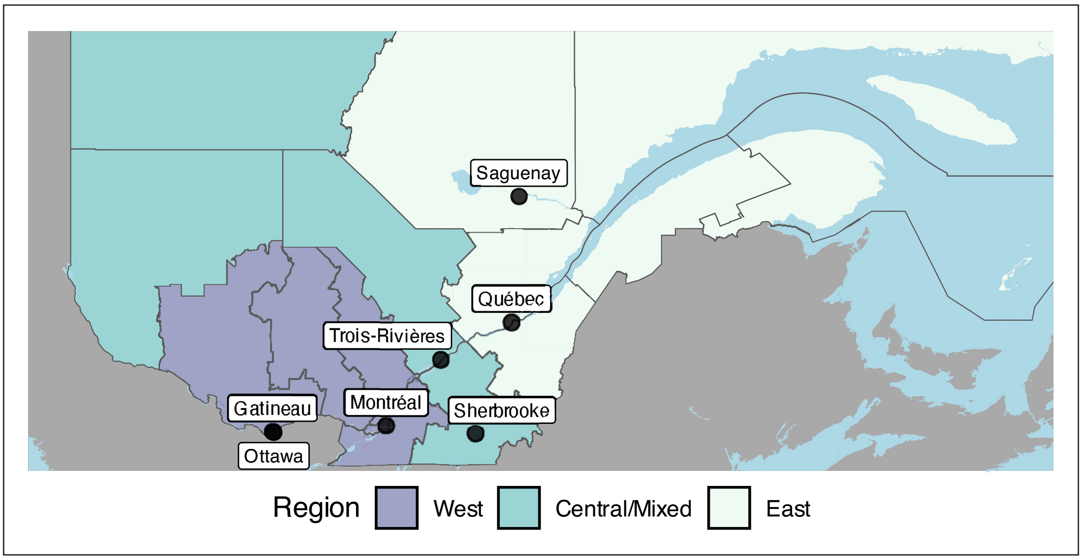

Figure 1: Map of southern Quebec (in colour), showing the approximate extent of the three major linguistic zones and the locations of major cities (as well as Ottawa, in neighbouring Ontario).

participation in the labour force increased sharply, and rapid economic development and decreases in poverty ensued, associated with the shift from a manufacturing-based to a service-based economy (Gossage & Little, 2013, ch. 10–11; Sarra-Bournet, 2015). Unsurprisingly, then, it was also marked by extensive language change, including in the vowel system (cf. MacKenzie & Sankoff, 2010; Saint-Amant Lamy, 2020, 2022; Yaeger-Dror, 1996).

2.2. The Quebec French vowel system and mid vowel contrasts

Quebec French has a large vowel inventory, even compared to other varieties of French: while the exact number of phonemes is debated, the set of 13 oral vowels (front unrounded /i, e, ɛ, ɜ, a/, front rounded /y, ø, œ, ə/, and back /u, o, ɔ, ɑ/) and 4 nasal vowels (/ɛ̃, œ̃, ɔ̃, ɑ̃/) is fairly uncontroversial (although see Côté, 2012; Dumas, 1981). Eleven of these are classified as mid vowels (/e, ɛ, ɜ, ø, œ, ə, o, ɔ, ɛ̃, œ̃, ɔ̃/). Additional vowel qualities result from two allophonic lengthening rules, which in turn feed a process of diphthongization (primarily word-finally): to a first approximation, the high-mid oral vowels /e, ø, o/ and the nasal vowels become long in closed syllables, and most other vowels become long in syllables closed by a voiced fricative (/R, v, z, ʒ/) or the cluster /vR/. Moreover, high vowels are subject to laxing in (most) closed syllables, producing allophones /ɪ, ʏ, ʊ/ which are very close or identical in height (and in their acoustics) to the corresponding high-mid vowels (Dumas, 1981). There is thus considerable crowding in the mid vowel space—especially at the front.

The height contrast in mid oral vowels is marginal in French, including in Quebec: the high-mid vowels tend to occur in open syllables and the low-mid vowels (/ɛ, ɜ, œ, ɔ/) in closed ones.

Unlike in other varieties (e.g., those of Southern France) where this rule is fully general and the phonemic distinction has been neutralized (Walker, 1984, p. 28), its rigidity varies in Quebec French by vowel pair and by phonological context. The distribution of /ø/ and /œ/ in word-final syllables, for example, is entirely predictable save for a few lexicalized exceptions (e.g., *jeûne* /ʒøn/, 'to fast (1S)' vs *jeune* /ʒœn/, 'young'). Only /ø/ is found in open syllables (e.g., *jeu* /ʒø/, 'game') and syllables closed by /z/ (e.g., *heureuse* /øRøz/ 'happy, fem.'), and only /œ/ is found elsewhere (e.g., *soeur* /sœR/, 'sister'; *seul* /sœl/, 'alone'). (Neither can occur before tautosyllabic /ʒ/.) In the 20th century, /ø/ also surfaced as a stylistic variant of /œ/ before /R/, at least in colloquial Montreal French (Dumas, 1972, 1974), but this usage has all but disappeared (Saint-Amant Lamy, 2022). Despite the low functional load of the contrast, the high- and low-mid vowels nevertheless remain distinct acoustically in Quebec French. This is also true of the distinction between /ɛ̃/ and /œ̃/, which has been lost in standard Metropolitan French (Walker, 1984). While there was once a tendency for /œ̃/ to delabialize and merge with /ɛ̃/ in vernacular Quebec French as well (Gendron, 1966, pp. 100–101; Charbonneau, 1971, p. 223),[3] it was subject to strong negative social evaluations and was ultimately reversed.

2.3. Rhotacization in Quebec French

Rhotic-sounding realizations of front mid rounded vowels in the native phonology of Quebec French were first documented by Dumas (1972), in a study of 17 working-class Montrealers aged between 25 and 35. Rhoticity is found in some tokens of /ø/ and /œ/ before word-final /R/, and more rarely also in (especially word-final) open syllable /ø/—both "almost exclusively" (p. 220) amongst men. The rhotic allophone of /ø/ and /œ/ before /R/ is labelled a diphthong, and is variably transcribed as [ɚɻ], [œ˞], [aœ˞], [ɐœ˞], [œːɻ], or [ɐœɻ]; conversely, open-syllable rhotic /ø/ is rendered as a monophthongal [ø˞]. Although Dumas impressionistically judges these productions to be retroflex, a bunched tongue articulation seems equally plausible. Rhotacization appears to have been incipient at this time: no evidence of rhotic gestures in these vowels can be seen in Charbonneau's (1971) earlier x-ray imaging study of a working-class male Montrealer born in 1913. Neither is rhoticity reported amongst the list of features distinguishing Quebec French from Metropolitan French compiled by Gendron (1966) in his study of 17 educated speakers from the Montreal and Quebec City areas (born between 1922 and 1936).

The phenomenon has largely flown under the radar in subsequent decades. Standard references for the phonology of Quebec French (Ostiguy & Tousignant, 2008; Walker, 1984), for instance, make no mention of rhotic vowels. More recently, Séguin's (2010) laboratory study of the front mid rounded oral vowels (in nonfinal open syllables) showed lowered F3 (with

[3] Note however that Dumas (1972) does not go as far, claiming that although delabialization does occur in some cases (most notably, in a stylistic variant of the indefinite article *un* /œ̃/), /œ̃/ nevertheless remained alive and well at the time of his study even in colloquial speech.

a high degree of variance) in /ø/ across 30 younger speakers (both male and female) from Quebec and Ontario, and for a select few (mostly male) speakers in /œ/ too; however, this is ascribed to increased lip rounding rather than rhoticity. Conversely, Saint-Amant Lamy's (2020, 2022) corpus study of vowels before /R/, which includes 153 male speakers from across Quebec, exhibited little evidence of F3 lowering in /œ/.

The most extensive work on Quebec French rhotic vowels to date was undertaken by Mielke (2013a, 2013b, 2015). In a corpus study of 75 speakers from the Gatineau-Ottawa region (which straddles the Quebec-Ontario border, approximately 150 km west of Montreal), a clear decrease in F3 is found in /ø/, /œ/, and /œ̃/. The first of these vowels begins to change in speakers born in the mid-1960s and the other two vowels lag 10–15 years behind. Amongst speakers judged perceptually to (at least occasionally) use rhotic vowels, F3 is on average lowest in word-final /ø/ (near 2100 Hz), with /œ̃/ being next lowest; in /œ/, F3 is only lowered before word-final /R/ (and to a lesser degree, /v/). Although speakers could lie anywhere on a continuum from negligible to near-categorical rhotacization, this variation does not appear to be conditioned either by gender (*contra* Dumas) or by socioeconomic class.

Mielke further provides a detailed articulatory analysis of the three front mid rounded vowel phonemes through ultrasound tongue imaging. 23 participants (born between 1973 and 1993) from Quebec, Ontario, and New Brunswick read a word list and their productions of /ø/, (pre-rhotic) /œ/, and /œ̃/ were perceptually coded for degree of rhoticity. This annotation is well correlated with low F3, and speakers are found to employ a diverse set of articulatory strategies for achieving this acoustic effect—just as has been previously observed for English (Mielke et al., 2010). Tongue root retraction and lip rounding are the most common means of lowering F3, but the greatest degree of rhoticity is achieved by speakers who use bunching or retroflexion (along with dorsum concavity). Mielke transcribes the rhotic variants of /ø/ and /œ̃/ as [ɚ] and [ɚ̃], respectively, suggesting complete rhotacization; rhotic /œ/, however, is rendered as [aɹ], suggesting (similarly to Dumas) that only the offglide is rhotacized in that vowel. Nevertheless, even the most rhotic speakers did not produce F3 of these vowels as low as observed for English /ɚ/: a subset of the participants (French-English bilinguals) also read an English word list, and produced rhotic vowels with significantly lower F3 in English than in French.

3. Possible sources of rhotacization in Quebec French

3.1. Borrowing from English

Because of the previously mentioned (Section 2.1) prolonged history of language contact in Quebec, English is commonly pointed to as the source of the distinctive features of Quebec French, sometimes without much evidence (as shown by Poplack et al., 2012). Still, contact is an intuitively appealing explanation for rhotacization: after all, rhotic vowels are present in English and otherwise typologically rare. There are also many documented cases of retroflexion diffusing areally, at least in consonants (Bhat, 1973). The transfer of a rhotic (retroflex/bunched) feature or a rhotic vowel phoneme would constitute a case of structural borrowing, which is claimed to typically be mediated by lexical borrowing (King, 2000; Winford, 2010)—although see Blevins (2017) for an opposing view. English loanwords have indeed been common in Quebec French since the 19th century (Paradis & Lacharité, 2008), and have been responsible for other phonological changes: notably, a marginal contrast between tense and lax high vowels in final closed syllables (e.g., *coule* /kʊl/ vs. *cool* /kul/, Côté, 2012).

Dumas (1972, pp. 102–105) proposes just such an account of rhotacization in Quebec French. He points to the variable realization of loanwords such as *toaster* and *jumper*. Although they are otherwise adapted to the native phonology, /ɚ/ is only sometimes replaced with (nonrhotic) /øR/, /œR/, or /ø/: it often instead faithfully preserves its bunched/retroflex articulation. This old and well-documented phenomenon (Friesner, 2009; Paradis & Lebel, 1994; Poplack et al., 2020) may be especially common in areas with greater community-level exposure to English, such as Montreal (Côté, 2021). The resulting alternations would have allowed [ɚ] in loanwords to be reanalyzed as a pre-rhotic allophone of /ø/ or /œ/, leading to its spread to the native vocabulary as well; this realization could then have been generalized to other phonological contexts. Such a process, Dumas writes, would have been aided by the phonetic and phonological similarities between English /ɚ/ and Quebec French /ø, œ/ (which are all labialized and nonperipheral), and perhaps also by the strong tendency for coda /R/ to lenite (often vocalize or outright delete) in Quebec French, especially word-finally (Lancien et al., 2023; Saint-Amant Lamy, 2022; Tousignant, 1987a, 1987b, 1987c). A subtly different explanation along the same lines is also possible here. While English /ɚ/ is historically associated with a rhotic coda, this may not have been transparent to a speaker of Quebec French with exposure to but little knowledge of (and especially, no literacy in) English. Indeed, if no /R/ was heard, /ɚ/ could instead have been heard as an open-syllable /ø/. The resemblance between the English agentive/instrumental suffix *-er* and the French suffix *-eux* /-ø/ (as in *violoneux* 'fiddler') may have favoured such misperception.

Dumas (1972) takes his finding that rhotacization is led by men as further evidence that it is induced by borrowing: at the time, exposure to English would have primarily occurred through the workplace, where women were still markedly underrepresented. The change is in his view socially motivated (p. 105): "l'usage de la rétroflexion prend en montréalais une valeur stylistique propre, celle de l'affirmation de soi par référence à l'anglais, qui est sans doute perçu comme 'argument d'autorité'" ["use of [rhoticity] takes on a stylistic value in Montreal French—one of self-affirmation through reference to English, which is without a doubt perceived as an 'argument from authority'"]. This suggests rhotacization is a *change from above*—a kind of change typically "introduced by the dominant social classes, often with full public awareness" which involves "borrow[ing] from other speech communities that have higher prestige in the view of the dominant class" (Labov, 1994, p. 78). The claim, then, is that speakers use rhoticity to deliberately sound more English-like, and therefore more authoritative, as a means of increasing their social mobility.

The predictions of Dumas' borrowing account of rhotacization can be summarized as follows. The change should have begun with /ø/ and /œ/ before /R/ and then spread to other phonetic environments; development of rhoticity in other phonemes (notably, /œ̃/) would not be directly accounted for and would require further explanation. Rhotacization must additionally have taken hold in areas and in social groups where knowledge of and/or exposure to English was sufficiently high, suggesting an origin with men from Montreal. To the extent that borrowing of rhoticity is a deliberate act intended to be salient to the listener, it is expected to be more prevalent in careful, listener-oriented speech—or *hyperspeech*, in the terminology of Lindblom (1990). The slight modification of Dumas' story that we detail above in most ways makes identical predictions, except that the change should have instead begun in open-syllable /ø/ and then spread to the pre-rhotic context.

3.2. Contrast enhancement

Conversely, Mielke rejects a borrowing-based explanation for the development of rhotic vowels in Quebec French. One reason is that he does not find individuals' level of exposure to English to be predictive of the degree of rhoticity in their speech, seemingly at odds with a contact-based account. Mielke, moreover, does not observe a significant effect of gender (contrary to Dumas), or even of social class, suggesting that rhoticity is in fact not socially salient. Indeed, he notes that most speakers of Quebec French—even those who regularly produce rhotic vowels—seem entirely unaware that they do so.[4] Evidence of this is found in a pilot perception study (Lamontagne & Mielke, 2013), wherein a phonetically-trained French-English bilingual speaker (who uses rhotic vowels in their own speech) and a monolingual English speaker judged the rhoticity of over 7,500 tokens of the three front mid rounded vowels: the former coded markedly fewer tokens (0.3%) as rhotic than the latter (~10%).

In Mielke's view, rhotacization is thus a *change from below*: this kind of "systematic" change, which "appear[s] first in the vernacular, and represent[s] the operation of internal, linguistic factors," is "[a]t the outset, and through most of [its] development, […] completely below the level of social awareness" (Labov, 1994, p. 78). He does not elaborate on what exactly might be its source, but suggests it may be related to the slow, steady decrease in F2 over much of the 20th century also seen in his data. This change (also noted for /œ/ before /R/ by Saint-Amant Lamy, 2020, 2022) is indicative of backing and/or increased rounding.[5] Both changes would

[4] This has also been our experience when mentioning rhoticity to native speakers. For convergent anecdotal evidence, see the two examples of social media threads (from February 2023) where native speakers discuss rhoticity in Quebec French included in this paper's Supplemental materials.

[5] Mielke (2013a, p. 144) writes "backing and/or unrounding", but this appears to be a typo. Lip compression (creating a constriction at an air displacement antinode) and lip protrusion (lengthening the vocal tract) are both expected to lower formants (Chiba & Kajiyama, 1941; Lindblom & Sundberg, 1971), and so unrounding would have the opposite effect.

have served to increase the perceptual distance between the front mid rounded vowels and their unrounded counterparts /e/, /ɛ/ and /ɜ/, and /ɛ̃/: low F3 has been argued to be an important cue to rounding in front vowels in several languages (including Metropolitan French, Vaissière, 2007), and a gradual development of tongue root retraction and/or tongue dorsum concavity would serve to enhance this effect. These changes would have thus together helped counteract the general instability of rounding contrasts in front vowels cross-linguistically.

There are at least two reasons this contrast may have been especially threatened in Quebec French. First, Gendron (1966, p. 34) notes a lesser degree of rounding in Quebec French compared to Metropolitan French. Second, when diphthongized, the initial portion of /œ/ and /œ̃/ is typically not rounded, and indeed similar to that of a diphthongized /ɜ/ (Dumas, 1981). To be sure, the functional load of each of these contrasts is low, which might suggest merger rather than enhancement as a resolution to the problem of confusability (cf. Wedel et al., 2013). In models of sound change like that of Kirby and Sonderegger (2015), however, the effects of low functional load are constrained by a (speaker- and/or language-specific) *categoricity bias*, which disfavours changes to the phonological system that would reduce the number of categories or their distinctness.[6] Social factors could help explain a relatively high categoricity bias in Quebec French: the stigma surrounding the merger of /ɛ̃/ and /œ̃/ in the vernacular (noted in Section 2.2), for example, might have favoured enhancement as an alternative.

A slightly different enhancement account, which instead sees rhotacization as a solution to crowding amongst the front mid rounded vowels, can also be sketched, since several of the contrasts in this region are weak. The acoustic similarity between /ø/ and /ʏ/ (the lax allophone of /y/), for one, was already mentioned in Section 2.2. For another, the /œ ∼ œ̃/ contrast may be threatened in Quebec French due to two particular properties of nasal vowels in this variety: the degree of nasality is reportedly lesser than in Metropolitan French (Gendron, 1966, p. 98), and velum lowering occurs substantially after the onset of the vowel, leaving only a relatively short portion at the end of the vowel fully nasalized (Charbonneau, 1971, ch. 4; Delvaux, 2006). (The extensive coarticulatory nasalization of oral vowels observed in Quebec French by Charbonneau further compounds these issues.) As for the /ø ∼ œ/ contrast, the association of the alternation of these vowels before /R/ with the vernacular (also noted in Section 2.2) could have created pressure to enhance the distinction between them in more formal speech.

We may thus distinguish two versions of the contrast enhancement hypothesis for the source of rhoticity: enhancement of rounding or enhancement within the front mid rounded vowel space. These differ in terms of which phonemes are expected to have been affected by rhotacization: the whole natural class /ø, œ, œ̃/ should have changed in relative lockstep in

6 See also Bouchard-Côté et al. (2013, especially Figure 3), where even at low values of functional load, where merger is certainly more likely, nonmerger is shown to remain very much possible.

the former, whereas only a subset of these may have undergone the change in the latter for any relevant contrasts to be enhanced. These accounts otherwise share predictions. Most notably, the greatest degree of enhancement, and thus rhoticity, should by definition be seen in hyperspeech: enhancement is fundamentally at odds with the target undershoot characteristic of hypospeech (Lindblom, 1990). Most sound changes, including changes from below, are found to be female-led (Labov, 1990): this should be the default expectation here, even though counterexamples are attested (cf. D'Arcy, 2013). Finally, although a change like the one described in this section may in principle have begun anywhere in Quebec, there is an established tendency in Quebec French for sound changes to spread outwards from influential population centers—especially Montreal, but perhaps also Quebec City (Friesner, 2010; Saint-Amant Lamy, 2016).

3.3. Phonologization of coarticulation

While borrowing and contrast enhancement provide reasonable explanations for the development of rhotic vowels in Quebec French, neither account finds broader cross-linguistic support. We are not aware of any other purported examples of rounding contrasts in front vowels being enhanced by rhoticity, nor of direct borrowing of rhotic vowels from one language to another—the closest such case being that of Kalasha, where rhotic vowels developed through coarticulation with a borrowed retroflex *consonant* (Heegård & Mørch, 2004; Hussain & Mielke, 2021; Mielke et al., 2023). The phonologization of coarticulation with a following (or more rarely, preceding) rhotic and/or retroflex consonant is in fact the typical pathway for rhotacization cross-linguistically—English is a notable example (Wells, 1982), and Bhat (1973) lists several cases amongst languages of South Asia and Australia.

Indeed, coarticulation is also a plausible source of rhoticity in Quebec French. Dumas (1972) suggests that for /ø/ and /œ/ before /R/, there is a trading relationship between the strength of the consonant and the degree of r-colouring on the vowel. His transcriptions reflect this observation, as tokens where final /R/ is retained to some degree are typically rendered as having only a rhotic off-glide, whereas ones where /R/ is fully deleted are often transcribed as monophthongal and rhotacized throughout. This is reminiscent of Beddor's (2009) account of the development of phonological vowel nasality in some varieties of American English: the duration of the nasal consonant and the extent of vowel nasalization trade off, as the velum lowering gesture is variably timed but incompressible. The variable strength of the coarticulatory source makes it an unreliable cue to the contrast, favouring phonologization of the coarticulatory effect.

A coarticulatory account of rhotacization in Quebec French may even suggest a relationship with the roughly contemporaneous change from a coronal to a dorsal rhotic consonant in Western Quebec (cf. Section 2.1), driven by speakers between approximately 1930 and 1970 (Saint-Amant Lamy, 2016; Sankoff & Blondeau, 2007). Rhotics with different places of articulation differ substantially in their acoustics: whereas low F3 is a property of coronal rhotics, uvular ones are instead associated with high F3 (Engstrand et al., 2007; Harrington, 2010, p. 84). Despite these differences, however, the lenition of coda /R/ may have impeded listeners' reconstruction of its place of articulation. If a weakened coronal rhotic were to be misperceived as dorsal, any F3 lowering on the previous vowel would thereby no longer be attributable to coarticulation, and would have to be reanalyzed as an inherent property of the vowel. Rhotacization would thus be an instance of hypocorrection of a coarticulatory effect, in the style of Ohala (1993).

Amongst coronal rhotics, bunched rhotics are expected to be the most coarticulatorily aggressive under Recasens' (1984) model due to their especially large degree of tongue dorsum involvement, a prediction borne out at least in Scottish English (Lawson et al., 2013). Several authors (Dumas, 1972; Santerre, 1979, 1982; Tousignant, 1987c) note the existence of a so-called 'English' rhotic in 20th century Quebec French, often labelled retroflex but described as bunched by at least Tousignant—both articulations may have coexisted, like in current-day American English (Mielke et al., 2010). This variant, either an English borrowing (per Dumas and Tousignant) or an intermediate variant that emerged in the change from apical to dorsal /R/ (cf. Graml, 2006; Santerre, 1979), is found by Dumas and Tousignant to occur disproportionately often before word-final front rounded vowels—including /ø/ and /œ/, in which Dumas observes rhoticity. This 'English' rhotic may thus also have contributed to producing the right conditions for the phonologization of coarticulation.

Some parts of this account are admittedly speculative, but the typological evidence in favour of coarticulation being the primary means through which rhotic vowels develop justifies its consideration here. Naturally, it directly explains only change before a rhotic consonant[7]—and thus only change in /ø/ and /œ/, since /œ̃/ does not occur in this context in Quebec French. It also clearly predicts that rhotacization must have originated in Western Quebec, since /R/ was overwhelmingly dorsal in the East by the early 20th century, and thus unable to produce the necessary coarticulatory effect.[8] Insofar as coarticulation is a consequence of target undershoot, rhoticity should be more prevalent in hypospeech (cf. Gay, 1981): once phonologization has occurred and rhoticity has become a target on the vowel, however, the effect should reverse (Solé, 1992). Finally, although coarticulation can in its early stages be thought of as an automatic process tied to speech rate that is not expected to be conditioned by social factors such as gender, its later phonologization would be a change from below that (for the same reasons as in Section 3.2) we may by default hypothesize to be led by women.

[7] While it is in principle also possible for a *preceding* rhotic consonant to induce a coarticulatory effect which then becomes phonologized, Bhat (1973) in practice finds that situation to be very rare. We thus do not pursue this possibility further here.

[8] Although the small pockets in Quebec where Acadian French are spoken are in the East, this variety actually also maintained an apical realization of /R/ through much of the 20th century. Because this concerns relatively few speakers, however, we ignore this detail here.

4. Research questions and hypotheses

The discussion in Section 2.3 and Section 3 showed that there remain many open questions about rhotacization in Quebec French as a sound change, primarily because the focus in Dumas and Mielke's work lies elsewhere (on the social factors surrounding rhotacized vowels and on their articulation, respectively). Moreover, the aforementioned authors' findings diverge on several key points—notably, which vowels are affected and whether rhoticity is socially salient—which leaves the ultimate source of the change unclear. Also of note is that most of their results concern only two metropolitan areas in Quebec (Montreal and Gatineau), which are in the same linguistic region (Western Quebec) and show similarly high degrees of English contact. Not much is known, then, about whether, when, and how rhoticity may have arisen elsewhere: this information, however, is crucial in determining how rhoticity developed in Quebec French.

Accordingly, this study is an apparent time acoustic investigation of rhotacization in the three front mid rounded vowels /ø/, /œ/, and /œ̃/ of Quebec French over the course of the second half of the 20th century. Its first aim is to offer a more complete description of the chronology of the change, with particular consideration given to expanding the geographical area under study and to determining the role of social factors (gender and region of origin) and phonological factors (segmental environment and degree of articulatory effort). This will serve the second aim of determining how well the potential sources of the change hypothesized in Section 3 (borrowing, contrast enhancement, and phonologization of coarticulation) explain the observed patterns. The various predictions made by each account are summarized in **Table 1** (with weaker predictions indicated by parentheses). Note that the different sources are not necessarily mutually exclusive: it is possible for rhotacization to have taken place in several phases, each with a different cause.

	Borrowing		**Contrast enhancement**		**Coarticulation**
	Version 1	**Version 2**	**Version 1**	**Version 2**	
Vowels	/ø, œ/	/ø/	all FMRVs	1-2 FMRVs	/ø, œ/
Environment	pre-/R/ first	open syll. first	—	—	pre-/R/
Hyperspeech	more rhotic		more rhotic		less rhotic
Gender effect	men lead		(women lead)		(women lead)
Region effect	Montreal/Gatineau lead		(Montreal or Quebec leads)		West leads

Table 1: Predictions for each account of the origin of rhoticity in Quebec French.

For the purposes of this study, degree of rhoticity is operationalized through F3, both because a low F3 is the most reliable acoustic correlate of tongue bunching and retroflexion and for comparability with Mielke (2013a, 2013b, 2015). Other studies (e.g., Lawson et al., 2013) use the difference between F3 and F2 instead as a measure of the degree of auditory integration of the two formants, which may be more important than the value of F3 itself in creating the percept of rhoticity (Heselwood, 2009; Heselwood & Plug, 2011). The frequency of the integrated formant, however, also matters (Heselwood et al., 2010): both measures would have to be examined simultaneously, which would considerably complicate the analysis. *F3 – F2* may also be difficult to interpret here due to the possible concurrent lowering of F2 noted by Mielke (2013a). In any case, Mielke (2015) finds that the three categories of perceptual coding he uses for the Quebec French front mid rounded vowels (nonrhotic, moderately rhotic, or most rhotic) are well-separated by F3, but not by F2 or F1 (see his Figure 6). It is thus a reasonable simplification to use F3 as our sole measure of rhoticity, with the caveat that this risks confounding potential changes in other articulatory gestures (e.g., rounding) with rhotacization.

5. Data and methods

5.1. The expanded *AssNat* corpus

The archives of national parliaments are fruitful sources of data for research on phonetic variation and change, as they typically contain large amounts of orthographically transcribed, good-quality recordings covering long periods of real and apparent time. Moreover, elected bodies inherently tend towards a certain level of geographic and social diversity. In this study, we use the Quebec portion of Milne's (2014) *AssNat* corpus, which consists of recorded proceedings of the National Assembly of Quebec produced in May 2011 and includes 8.5 hours of data across 62 speakers.[9]

Information about speaker gender, year of birth and place of birth was collected from online sources (when available, directly from the National Assembly website). This revealed a marked underrepresentation of women and speakers born after 1970 in the corpus, posing a problem for our study (given the need to accurately determine the effect of gender here and the timeline of the change observed by Mielke, 2013a). We thus collected more than 15 additional hours of National Assembly data (using sessions from between May 2005 and March 2022)[10] from a convenience sample of 66 speakers (including some overlap with the original 62), bringing the total number of speakers up to 113. Parliamentarians born outside Quebec, who sounded obviously nonnative or nonfluent,[11] or for whom age information was unavailable were excluded. This left 106 speakers (42 female, 64 male) born between 1941 and 1992 (with a median birth year of 1968, IQR = 20.75). The total length of aligned recordings is broken down by speaker in **Table A1**. **Figure 2** shows a map of speakers' places of birth, with the size of each point representing the number of speakers from that location.

[9] The corpus also contains a similarly-sized Metropolitan French component, built from proceedings of the French parliament, which is not used in our study.

[10] Note, however, that for most speakers, the time span covered was relatively small, with in many cases all the data coming from a single day: this precluded examining change over the lifespan, as in e.g., Sankoff and Blondeau (2007) and Sankoff (2018), in the present study.

[11] As judged by the first author, a near-native speaker of Quebec French.

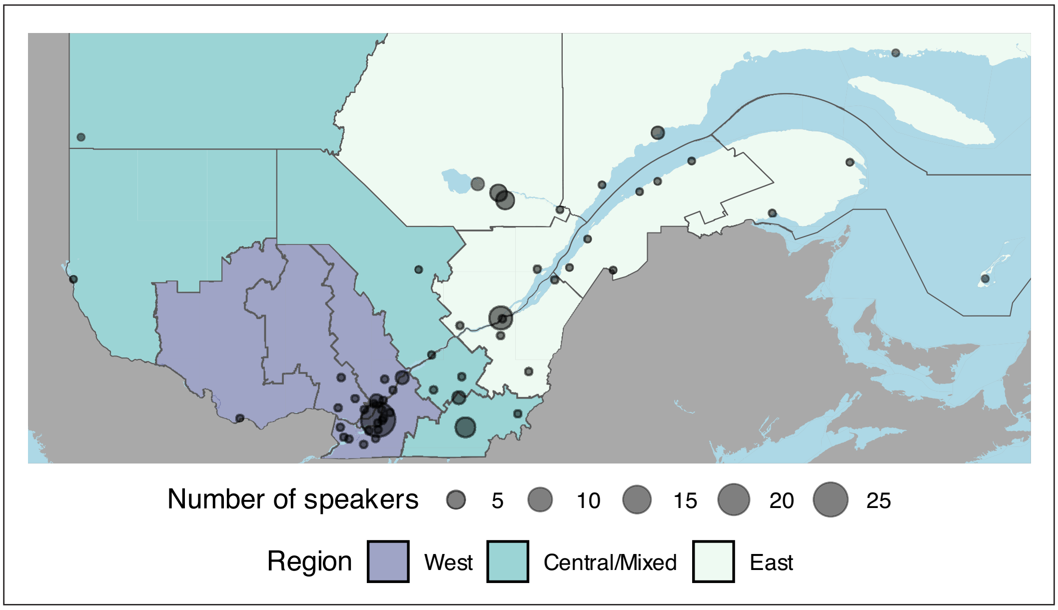

Figure 2: Map of birthplaces of speakers included in the study, with the number of speakers per location.

5.2. Phonetic alignment

For the original corpus, we used forced alignments generated by Milne using a custom aligner and pronunciation dictionary (adapted from *Lexique*, New et al., 2004), with an acoustic model trained on the same data. To prepare the new data for forced alignment, recordings were manually split into individual speaker turns, with longer turns further broken down into chunks no longer than about 100 seconds, to increase speed and accuracy. The orthographic transcripts were (also manually) chunked accordingly, and small inaccuracies were simultaneously corrected (e.g., by adding disfluencies and removing elided words). The *Montreal Forced Aligner* (MFA, McAuliffe, Socolof, et al., 2017) was then used, in combination with the MFA French acoustic model and its associated pronunciation dictionary (McAuliffe & Sonderegger, 2022a, 2022b), as no Quebec French-specific tools were available. The model is trained on 1,900 hours of speech across multiple varieties of French (seemingly predominantly Metropolitan French). Fromont et al. (2023) achieve good performance with MFA aligning data from one language variety (*r*-less child New Zealand English) using a sufficiently large acoustic model trained on a substantially different variety (*r*-ful adult American English). Here, manual spot checking confirmed that the alignment was generally successful.

Some transcription inconsistencies resulted between the original and new data, notably because the French MFA pronunciation dictionary fails to mark the /ɛ̃ ~ œ̃/ contrast (which is crucial for our study), and only sporadically marks the /a ~ ɑ/ contrast. Moreover, neither set of alignments distinguish /ɜ/ from /ɛ/. Postprocessing scripts were thus written to automatically ensure that all three contrasts were consistently reflected, using a manually-annotated word list.

Note that none of the alignments distinguish between /œ/ and /ø/ before /R/, with all tokens labelled /œ/ despite the stylistic alternation mentioned in Section 2.2: this was not changed, as the significant overlap between the acoustic distributions of these phonemes makes determining which was produced challenging.

Note also that because of lenition of coda /R/ (discussed in Section 3.1), the location of the boundary between the vowel and the consonant in a /V + R/ is often arbitrary. We thus decided to treat tautosyllabic /œ + R/ sequences as a single unit (cf. Plug & Ogden, 2003; Sóskuthy & Stuart-Smith, 2020), automatically deleting the boundary between the two segments using a script and measuring acoustics across the entire sequence. This prevents spurious effects due to differences in how the boundary is drawn between forced aligners and between speakers.[12]

5.3. Data preparation and final dataset

The data were loaded into the corpus management tool *PolyglotDB* (McAuliffe, Stengel-Eskin, et al., 2017), which ultimately calls *Praat* (Boersma & Weenink, 2024) to measure F1, F2, and F3 values every 10 ms for each vowel token, later interpolating tracks to 21 equidistant points. *PolyglotDB* implements the 'refinement' algorithm described in Mielke et al. (2019),[13] which attempts to minimize the Mahalanobis distance between the measured values for each token and the distribution for the associated phoneme. At the first iteration, the process uses user-inputted prototype acoustic measures for each vowel phoneme (mean formant frequency and bandwidth measures, along with the associated covariance matrix). Prototypes for /ø/, /œ/, and /œ̃/ were generated by randomly sampling 100 tokens of each phoneme from the corpus and manually measuring formant values in *Praat* (excluding any problematic tokens); for the other vowels, a set of first-pass (unrefined) formant measurements obtained from the original *AssNat* corpus via *PolyglotDB* were used instead. The algorithm selects the optimal candidate amongst a series of alternatives obtained by setting the formant ceiling frequency to 5500 Hz and varying the number of linear predictive coding coefficients. Once measures for all tokens are extracted for a given speaker-phoneme pair, a new prototype distribution is calculated for that combination and used in the next iteration. The entire process is repeated until convergence or until a maximum of 20 iterations is reached.

Data cleaning involved discarding all tokens from certain stop words (mostly various kinds of filled pauses) and loanwords. This includes English borrowings containing /ɚ/, the variable realization of which was noted in Section 3.1: while these would have been interesting to examine in light of the discussion surrounding the contact account, there were unfortunately not enough

[12] We initially ran the analysis without combining /œ/ with the following rhotic. The change was motivated by a concern that the forced aligner could ascribe a low F3 during the vocalic portion of an /œ + R/ sequence to the rhotic, thus obscuring rhotacization in that phoneme. We obtained very similar results in both cases, but nevertheless report the result from the combined tracks, as this approach seemed more theoretically sound for the reasons discussed in the text.

[13] Here, however, the formant dropping component of the algorithm was disabled, as prototypes with formant amplitude measures were not available.

observations (approximately 300, predominantly of a single word) to make such an analysis feasible. Tokens with a duration of less than 50 ms (too reduced) or more than 500 ms (possible alignment errors) were also removed, leaving a total of 8,629 tokens: 2,959 of /ø/, 2,910 of /œ/, and 2,760 of /œ̃/. Formant measures were subsequently normalized using a version of the Nearey2 method (Nearey, 1978), where a speaker-specific, formant-extrinsic reference value is subtracted from the log-transformed raw formant frequencies. The implementation used here (from Voeten et al., 2022) is adapted for imbalanced data: using all 17 vowel categories listed in Section 2.2, reference values are calculated by first computing by-speaker means for each combination of vowel, formant, and time point, and then averaging across these. Nearey2 is also chosen by Mielke (2013a, 2015), in part due to concerns that a formant-intrinsic procedure like Lobanov (1971) would perform poorly on bimodally-distributed F3 values, as may result in a language with rhotic vowels. In any case, Voeten et al. (2022) find that both these methods perform similarly well in reducing anatomically-derived differences between speakers while preserving key sociolinguistic variation.

The final dataset was obtained by making two further restrictions. First, all 496 tokens from non-word-final syllables were discarded: these vowels are generally unaccented in French, and an optional process of tense/lax harmony affecting mid (and high) vowels in this position makes their quality unpredictable (Riverin-Coutlée & Gubian, 2024; Walker, 1984). Second, only open-syllable tokens of /ø/ and /œ̃/ were retained, due to the small number of observations in other phonological contexts—99 and 6, respectively. In the end, a total of 8,028 tokens of the three vowels remain: 2,591 of /ø/, 2,688 of /œ/ (2,102 before /ʁ/, 150 before the other lengthening consonants /v/ or /vR/,[14] 436 before a nonlengthening consonant), and 2,749 of /œ̃/. The number of tokens of each vowel per speaker, summarized in **Table A1**, is highly variable: the range is 0–178 for /ø/ (IQR = 25.25), 0–166 for /œ/ (IQR = 27.25), and 0–177 for /œ/ (IQR = 23.5). There are a total of 320 unique words in the dataset, with 80 for /ø/ (1–966 observations per word, IQR = 14.25), 231 for /œ/ (1–314 obs./word, IQR = 7.00), and 19 for /œ̃/ (1–2,375 obs./word, IQR = 27.00—with the vast majority of tokens coming from the word *un*).

5.4. Statistical methods

In Mielke (2013a, 2015), a static acoustic measure is used: the minimum F3 value observed over the vowel, as an index of the point of greatest rhoticity. This makes for a simple and easily interpretable analysis, but loses potentially relevant detail lying in the shape of trajectories—notably, information about the timing of rhoticity, which both Dumas and Mielke find differs across vowels. Mielke (2013b) instead fits logistic curves to formant trajectories, in particular to examine the relationship between rhotacization and diphthongization in Quebec French. A more flexible approach along these lines is to use *generalized additive mixed models*, or GAMMs (Wood, 2017), which are increasingly popular in phonetic research (cf. Sóskuthy, 2017; Wieling, 2018):

[14] Recall that in French /œ/ is not phonotactically licit in final open syllables or before tautosyllabic /z/ or /ʒ/.

these models allow fitting of arbitrary nonlinear functions while automatically estimating the degree of wiggliness needed, through the inclusion of *smooth terms*. *Parametric terms*, which allow for simple linear effects and interactions, may also be specified.

Our study uses GAMMs, with one model for each of the vowels /ø, œ, œ̃/ fitted in R (R Core Team, 2024) with the `bam()` function of the `mgcv` package (Wood, 2017) version 1.9.1. The following terms were included in all models. A parametric term for GENDER (reference level = FEMALE) accounts for a possible difference in average F3 between men and women. A smooth term for MEASUREMENT allows F3 to vary nonlinearly over the course of the vowel. Additionally, a smooth over YEAR OF BIRTH (YOB) captures nonlinear change over (apparent) time in average trajectory height. A tensor interaction between the smooths over MEASUREMENT and YOB permits change in the shape of the F3 trajectory over time. Each of these three smooth terms is made to vary by GENDER. DURATION is used as a measure of local speech rate, which serves as a proxy for the hyper–hypospeech continuum (cf. Lindblom et al., 2009): it is log-transformed in order to achieve an approximately normal distribution and centered within each phoneme. The potentially nonlinear effect of DURATION is captured via a smooth over this predictor, which is allowed to interact with the smooths over MEASUREMENT (i.e., to affect different points in the vowel in different ways) and YOB (i.e., so that it can change over apparent time). Finally, by-speaker random smooths over MEASUREMENT are included to account for variation between individuals, and by-word random smooths over both MEASUREMENT and YOB are included to account for lexical effects. In `mgcv` syntax, this gives the following formula:

```
F3 ~ GENDER + s(MEASUREMENT) + s(MEASUREMENT, by=GENDER) + ti(MEASURE-
MENT, YOB) + s(LOG DURATION) + ti(MEASUREMENT, LOG DURATION) + ti(YOB,
LOG DURATION) + s(YOB) + s(YOB, by=GENDER) + s(MEASUREMENT, SPEAKER,
bs='fs') + s(MEASUREMENT, WORD, bs='fs') + s(YOB, WORD, bs='fs')
```

The model for /œ/ contains additional terms to account for effects of the following phonological CONTEXT, for which there are three levels: /R/ (the reference level), /v, vR/ (the two other phonotactically licit lengthening contexts for this vowel), and OTHER C. Parametric terms for CONTEXT and its interaction with GENDER are included. The smooths over MEASUREMENT, YOB, and DURATION, as well as the tensor interactions between MEASUREMENT and YOB, are also allowed to vary by CONTEXT. (Note that DURATION is centered separately for each level of CONTEXT for this vowel: this is important because we have included the following consonant in the formant tracks for pre-rhotic /œ/, whereas the other levels include only the vowel). These additions extend the formula as follows:

```
+ CONTEXT + CONTEXT:GENDER + s(MEASUREMENT, by=CONTEXT) + s(YOB, by=CO-
NTEXT) + s(LOG DURATION, by=CONTEXT) + ti(MEASUREMENT, YOB, by=CONTEXT)
```

All factor contrasts employ treatment coding, where the first level is used as a reference value with which subsequent levels are contrasted. All smooth terms use cubic regression splines. Smooths involving YOB use 5 knots, as a larger figure sometimes led to undersmoothing (since the number of speakers is unevenly distributed across years of birth). Random smooths are limited to 4 knots for faster fitting (and in testing, using a higher number of knots did not markedly affect results). All other smooths use the default number of knots (10 for regular smooths, 25 for tensor interactions). Models are fitted with discretized covariates and use the 'fREML' criterion in order to further speed up computation. Finally, AR1 error models are used to capture correlations between residuals from adjacent MEASUREMENT points within trajectories: the value of ρ is estimated from the equivalent GAMM lacking an error model (cf. Sóskuthy, 2017).

Full model summaries are given in Appendix B. For ease of interpretability, estimated marginal means—predictions calculated at specific levels of one or more predictors of interest, averaging over all other predictors—are used for visualizations (cf. Ting et al., 2025): these are computed using the `emmeans` package (Lenth, 2023) version 1.8.9, always using 21 equidistant MEASUREMENT points. To facilitate interpretation and comparison with Mielke's findings, we first present results in terms of minimum F3 (taken from predicted trajectories), and only subsequently examine formant dynamics. Unless otherwise specified, predictions for /œ/ always involve setting CONTEXT to the level /R/, since this is representative of the overwhelming majority of tokens of this vowel (and averaging over levels of CONTEXT here is not meaningful, due to the vowel and consonant having been combined into a single formant track for pre-rhotic observations only). Figures are generated using `ggplot2` (Wickham, 2016).

Notably absent from these models are any terms corresponding to speaker place of birth. This is because the most appropriate way to code this variable for our study is not obvious. The three-way REGION distinction laid out in Section 2.1, while appropriate for examining the coarticulatory (and to some extent, the contrast enhancement) hypothesis, does not correlate with community-level exposure to English well enough to fairly evaluate the contact hypothesis: though English contact is highest in the West, it is especially concentrated within certain parts of this region (Montreal and Gatineau), and nevertheless present to some extent in the East and Central/Mixed areas (including in other formerly industrial towns and cities).[15] Moreover, there are relatively few localities are represented in our data and they only sparsely cover the territory, which precludes including spatial terms (smooths over geographic coordinates) directly in the models. We thus rely on post-hoc analysis of by-speaker predictions, computed using `mgcv::predict.gam()`, to make inferences about geographic patterns.

[15] An earlier version of the analysis did include REGION terms in the model, but these consistently showed negligible and/or nonsignificant effects—in part due to the small number of speakers from Central/Mixed areas.

6. Results

6.1. Empirical summaries

Speaker means of each formant and for every vowel category (at vowel midpoint) were calculated after normalization, using all tokens in the dataset. The vowel space, which lies approximately within the ranges of [–0.4, –1.4] for F1 and [0.55, –0.25] for F2, is shown in **Figure 3**. Phoneme labels correspond to the mean of speaker means and the ellipses represent a confidence level of 68%. It closely resembles the vowel spaces depicted in MacKenzie and Sankoff (2010) and in Riverin-Coutlée and Roy (2022). The front mid rounded vowels are all centralized and clearly distinct on the F2 dimension from their unrounded counterparts. /ø/ and /œ/ are well separated by F2, and also to a lesser degree by F1 (which is lower in the former than the latter), as expected; /œ̃/ lies between the two, overlapping somewhat with /œ/ but not /ø/. In terms of vowel height, /œ/ may seem especially low at a first glance: this is likely due to pre-/R/ tokens comprising a large majority of the data for that vowel (cf. the acoustics of the long allophone of /œ/ in MacKenzie & Sankoff, 2010).

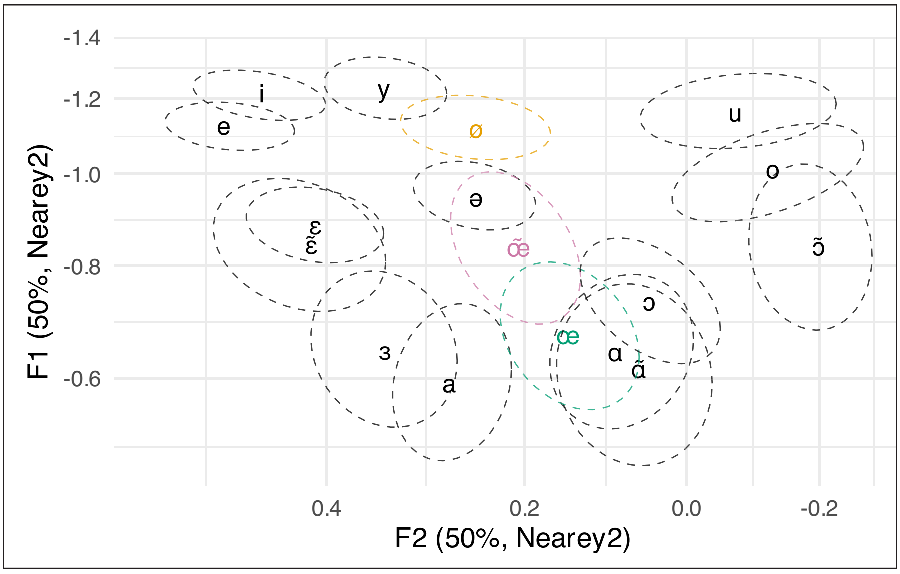

Figure 3: Normalized F1–F2 space for all vowels (measured at midpoint), with grand means and 68% confidence ellipses of speaker means. An exponential transform has been applied to both axes (but not to the values themselves) to undo the distortion caused by the normalization procedure.

By-speaker empirical means for F1 (at midpoint), F2 (at midpoint), and F3 (minimum) in the front mid rounded vowels as a function of speaker YEAR OF BIRTH (YOB) are given in **Figure 4**. There is evidence of a decrease in F3 over the whole apparent time window affecting /ø/ and /œ̃/, whereas the pattern is much less obvious for /œ/. There is also an F2 decrease in /ø/ and /œ̃/ (as observed by Mielke), perhaps a sign of backing or rounding, which stabilizes around

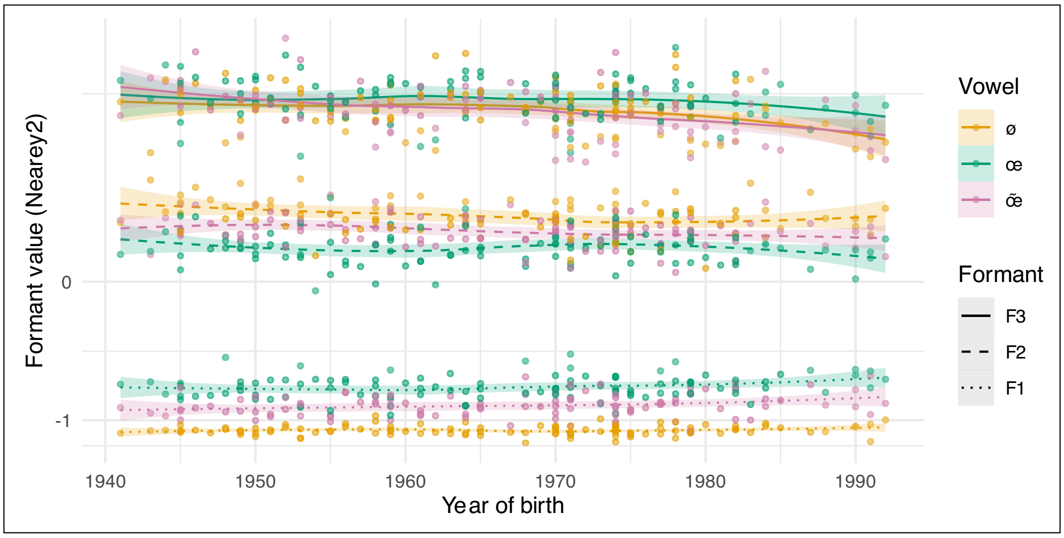

Figure 4: Empirical speaker means of the first three formants for /ø/, /œ/, and /œ̃/, with LOESS regression lines over speaker YEAR OF BIRTH. F1 and F2 are measured at vowel midpoint, whereas F3 is measured at its minimum. An exponential transform has been applied to the *y*-axis (but not to the values themselves) to undo the distortion caused by the normalization procedure.

1970; there is, however, no clear change in this formant in /œ/. Finally, F1 may begin increasing in /œ/ and /œ̃/ (but not /ø/) around 1970, consistent with increased pharyngeal constriction: any effect, however, is small.

6.2. Model predictions: Overall trends and social effects

We now turn, for the rest of Section 6, to presenting results from the GAMMs. The predicted change in minimum F3 over time for each of the front mid rounded vowels, marginalizing over other predictors, is given in **Figure 5**. (Recall that no model terms correspond directly to these effects due to the contrast coding used and because minimum F3 is not predicted directly.) Points correspond to predicted values for individual speakers. At the beginning of the observed period, /ø/ exhibits the lowest F3 of the three vowels: it decreases slowly until around 1975, and somewhat more rapidly afterwards. In comparison, F3 in /œ/ (pre-/R/) is slightly higher towards 1940, and shows no clear evidence of change (except perhaps after approximately 1980). The sharpest F3 lowering is seen in /œ̃/: although it begins at a similar value to /œ/ amongst the oldest speakers, it reaches the level of /ø/ by 1975 and continues to decrease in lockstep with it afterwards.

Although the average F3 does not differ significantly by GENDER in any of the three vowels, significant differences in the YOB effect by GENDER are found for /ø/ ($rdf = 2.76$, $p = .013$) and /œ̃/ ($rdf = 1.29$, $p < .001$). This is reflected in **Figure 6**. In both vowels, clearer evidence of change is seen in female speakers than in males. For /ø/, the model predicts two periods of decreasing F3 for men (one before 1955 and one after 1980), with a relatively stable period between the two where men may be more advanced in F3 lowering than women (although this

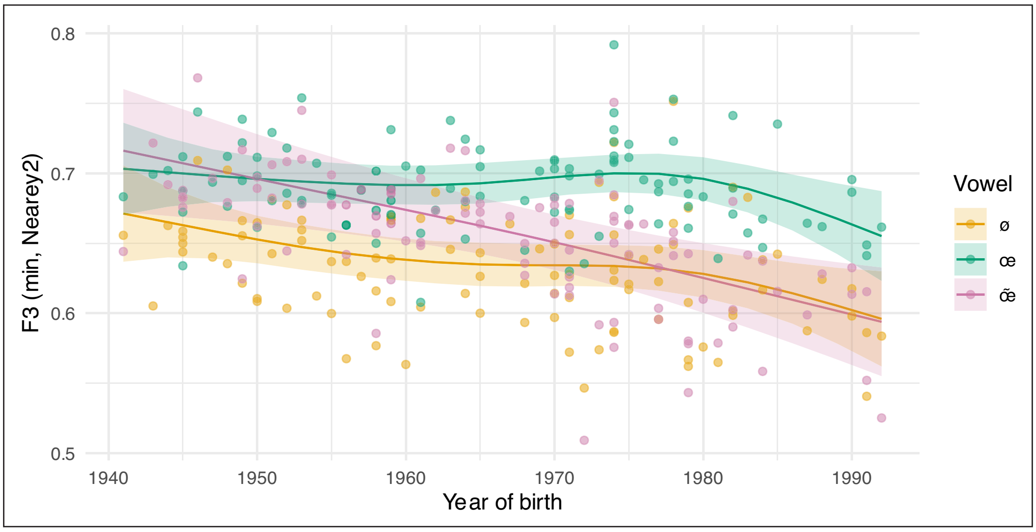

Figure 5: Predicted change over time in minimum F3 for each vowel.

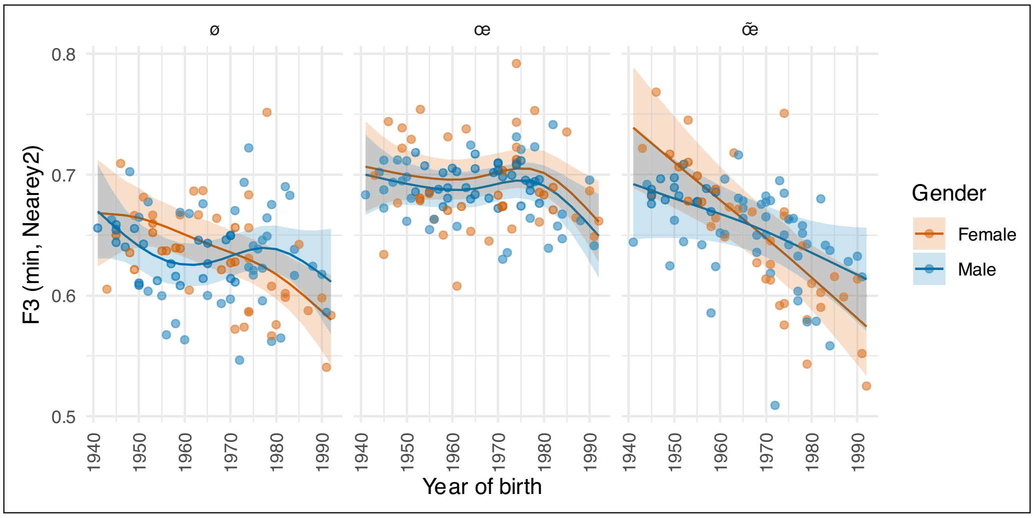

Figure 6: Predicted change over apparent time in minimum F3 for each vowel by GENDER.

effect is not very certain); for women, F3 decreases monotonically throughout the entire time range, such that they may overtake men by around 1970. Men appear to lead women in the change in /œ̃/ as well: both groups show a linear pattern of F3 lowering over apparent time, but due to a steeper slope for women the trajectories intersect around 1965. As for /œ/, the YOB trends for men and women are qualitatively identical.

Next, we examine regional variation after marginalizing over other predictors. To this end, we calculate the equivalent of a by-speaker random intercept (by taking the average value of the by-speaker random smooth) from the model predictions, which serves as an indicator of how advanced or conservative a given speaker is compared to the average speaker of their

GENDER group and YOB.[16] We consider the lowest 25% of values of this "random intercept" to be especially low (indicative of advanced rhotacization), the middle 50% to be average, and the highest 25% to be especially high (indicative of conservatism with respect to rhotacization). The coordinates of speakers' places of birth are used to generate the map of this index in **Figure 7**. Any geographic patterns are subtle at best, since all regions have a mix of innovative, average,

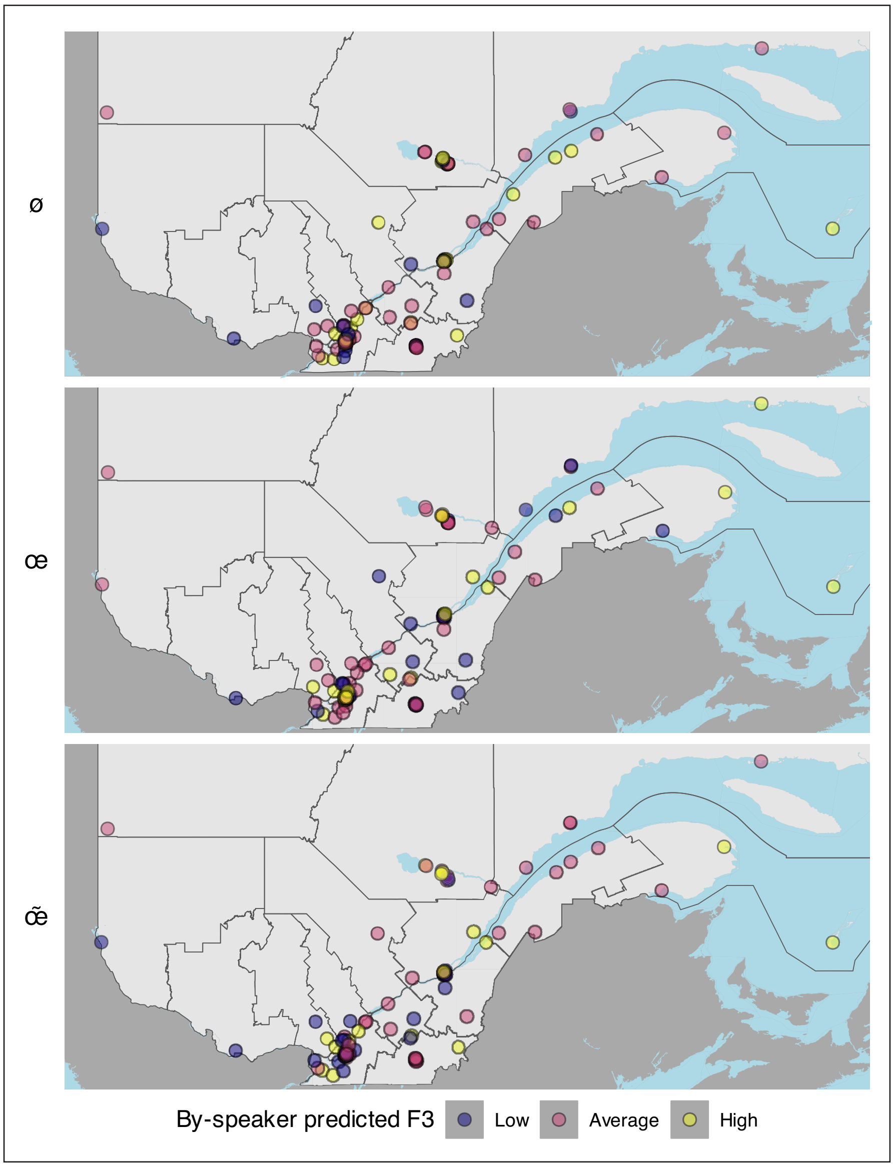

Figure 7: Predicted mean values of individual speakers' random smooths for each vowel, binned into three groups according to by-vowel quartiles (low = 1st quarter, average = 2nd & 3rd quarters, high = 4th quarter).

[16] Note that one speaker is excluded from this part of the analysis due to their place of birth information being missing.

and conservative speakers. For /ø/ and especially /œ̃/, however, there does appear to be a greater concentration of innovative speakers in Western Quebec, particularly in the areas with greater exposure to English (specifically, around Montreal), than elsewhere.

Figure 8 shows the evolution of formant trajectory shape in apparent time. All three vowels show clearly nonlinear F3 contours over MEASUREMENT. In /ø/ and /œ/, both endpoints have higher F3 than the middle of the vowel; conversely, in /œ̃/, F3 lowers over the first half of the vowel before essentially plateauing from around the midpoint until the end. The interaction between MEASUREMENT and YOB is only significant in /ø/ ($rdf = 7.21, p < .001$): this is the result of greater F3 lowering over apparent time at the middle of the vowel than at the edges. The change over apparent time in /œ̃/ manifests as uniform lowering of the entire trajectory, and there is no qualitatively meaningful (or significant) change in /œ/. Women may have a slightly shallower F3 trajectory than men in /ø/ (as seen in **Figure 9**), but this effect is not significant. In the other two vowels, the effect of GENDER on trajectory shape is both negligible and nonsignificant.

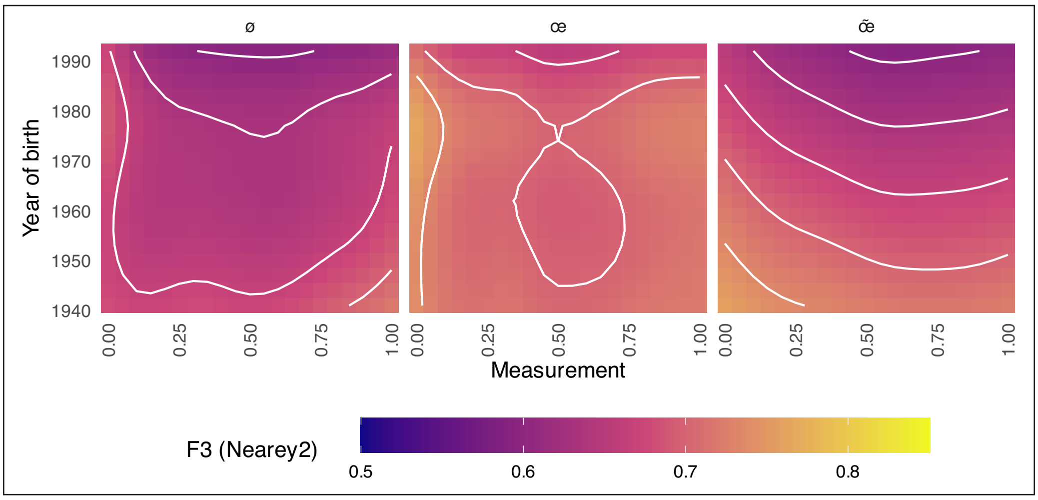

Figure 8: Predicted change over apparent time in F3 trajectories for each vowel.

6.3. Model predictions: Effect of phonological context

Breaking down the change in /œ/ by CONTEXT, as in **Figure 10**, reveals little in the way of differences between /R/ and /v, VR/. The overall difference between these levels is negligible and nonsignificant ($\hat{\beta} = -0.005$, $p = .681$), as is the difference in YOB trends ($rdf = 1.00$, $p = .912$). While the parametric term for the /R/ versus nonlengthening contrast is similarly small and not significant ($\hat{\beta} = 0.002$, $p = .854$), these levels do differ in terms of their YOB effects ($rdf = 3.58, p = .026$): this is due to F3 being slightly higher in nonlengthening contexts at the very beginning and very end of the observed period (YOB between 1940 and 1950 and between 1980 and 1990), although this effect is not very robust. GENDER has no significant effect on F3 for any level of CONTEXT.

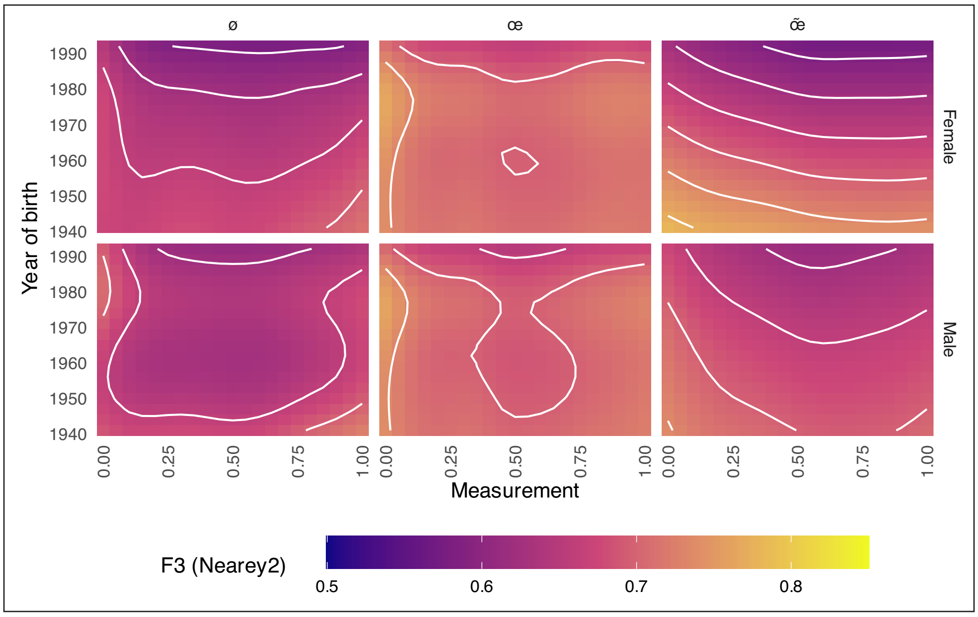

Figure 9: Predicted change over apparent time in F3 trajectories for each vowel by GENDER.

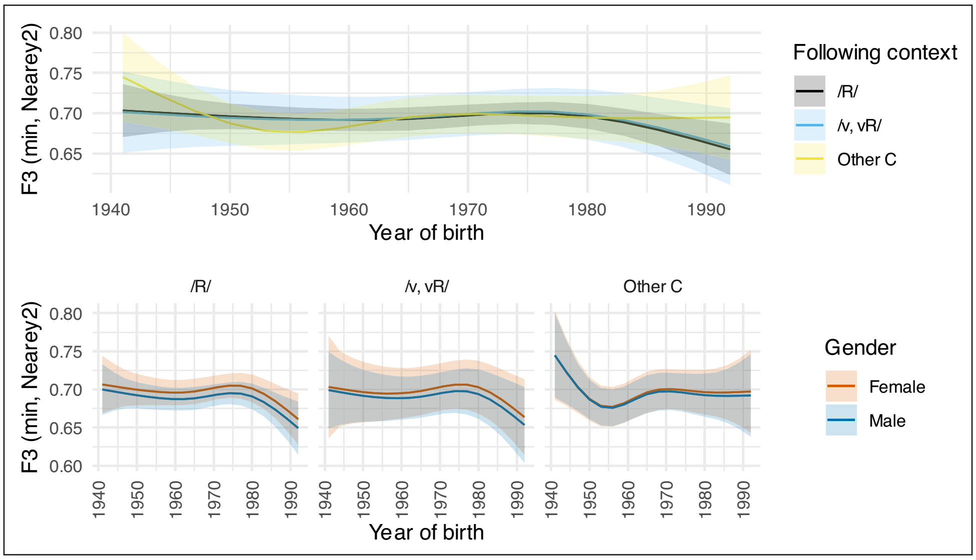

Figure 10: Predicted change over time in minimum F3 for /œ/ by FOLLOWING CONTEXT.

As for the shape of trajectories by CONTEXT, seen in **Figure 11**, we see that /R/ once again does not pattern significantly differently from other lengthening consonants (*rdf* = 1.00, *p* = .981). /R/ does differ significantly from nonlengthening codas (*rdf* = 5.35, *p* = .007), seemingly due to the latter context having a slightly steeper drop in F3 over the course of the vowel (although here too the effect is minute). The model does not predict a significant change in trajectory shape over time for any level of CONTEXT.

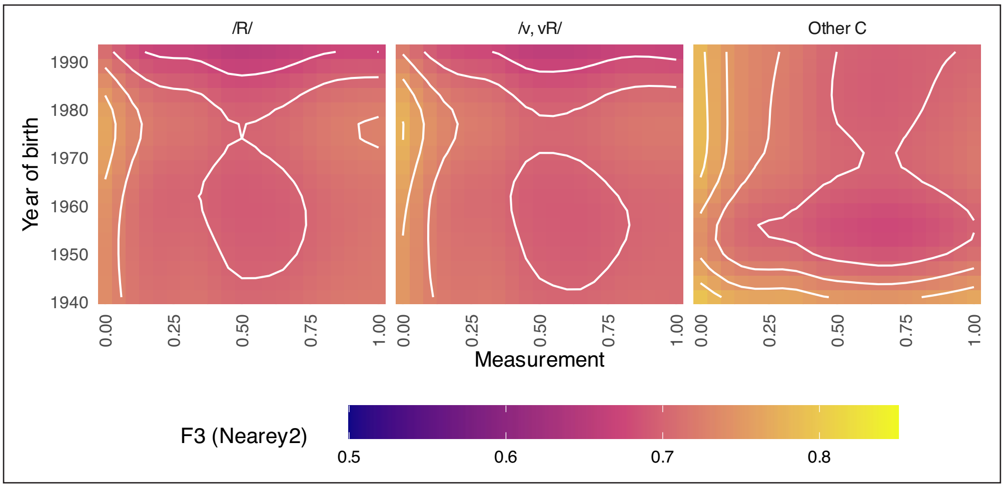

Figure 11: Predicted change over time in F3 trajectories for /œ/ by FOLLOWING CONTEXT.

6.4. Model predictions: Effect of duration

Figure 12 shows how the effect of DURATION (our proxy for hyper- vs. hypospeech) changes over the course of an observation and across years of birth. The vowels /ø/ and /œ̃/ both show significant overall effects of DURATION (*rdf* = 6.31, $p < .001$ for the former; *rdf* = 2.76, $p < .001$ for the latter), with longer durations being associated with lower F3; in (pre-/R/) /œ/, however, there is no significant effect (*rdf* = 1.03 $p = .154$). All three vowels show an effect of the interaction between DURATION and MEASUREMENT (*rdf* = 14.23 for /ø/, 10.02 for /œ̃/, 7.21 for /œ/, $p < .001$ for all three terms), which is the result of greater F3 lowering near the midpoint of the vowel than at the edges. Combined, these terms suggests that the lowering effect of duration on minimum F3 is greatest in /ø/, somewhat smaller in /œ̃/, and smallest in /œ/. Similarly, the interaction between YOB and DURATION is significant for all three vowels (/ø/: *rdf* = 10.52, $p < .001$; /œ/: *rdf* = 9.86, $p < .001$; /œ̃/: *rdf* = 6.45, $p = .027$). This seems to be because the DURATION effect is small in early years and becomes gradually stronger over apparent time (although note some noise in this pattern at the earliest YOB values in /œ̃/ and at the latest YOB values for /œ/).

7. Discussion

7.1. Summary of main findings

Let us briefly summarize the main results that emerged from Section 6, in line with our objective of providing a thorough acoustic description of the development of rhotacization in Quebec French. We find evidence of lowered F3 (both in terms of overall trajectory height and of minimum F3) in two front mid rounded vowels, /ø/ and /œ̃/, the phenomenon appearing more advanced in the former (as also observed by Mielke, 2013a). Through the first half of the apparent time window examined in our study, rhoticity appears to be most advanced in men: notably, marked rhoticity is already visible in /ø/ amongst a cohort of men born between 1950

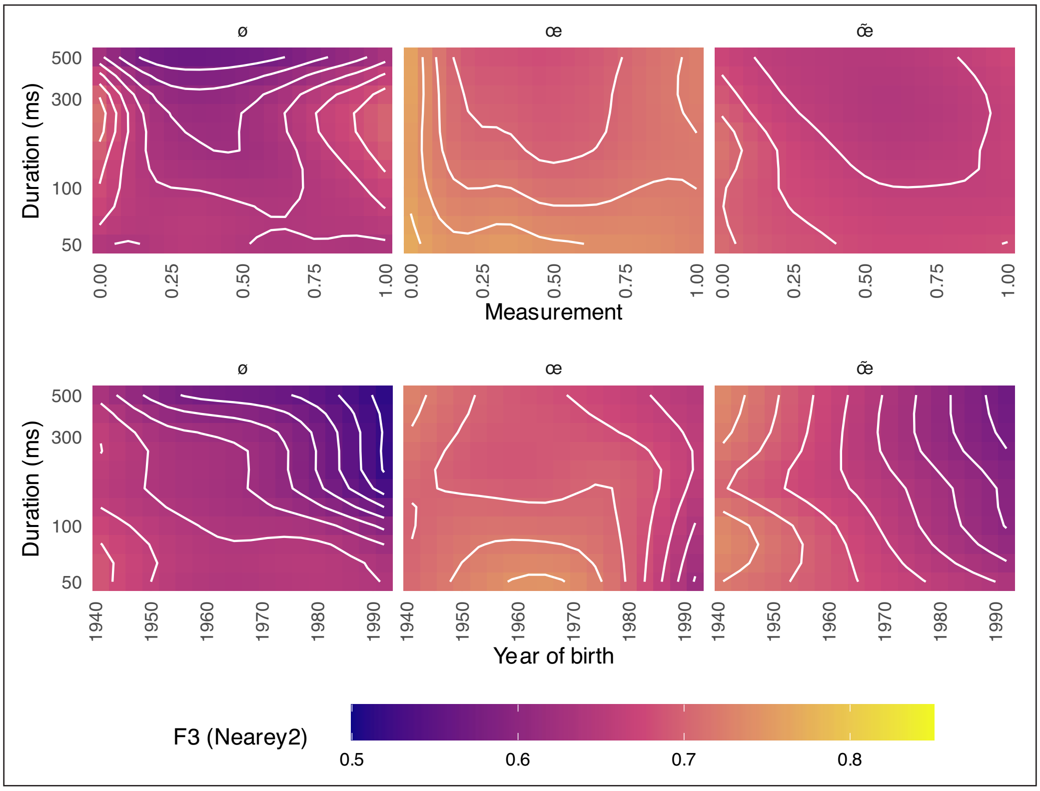

Figure 12: Top: predicted interaction of DURATION and MEASUREMENT by vowel. Bottom: predicted interaction of DURATION and YOB by vowel.

and 1960 (who are only slightly younger than the speakers in Dumas, 1972). For women, who at first have higher F3 than men in both vowels, rhoticity progresses steadily over the entire period: women eventually catch up with (or perhaps even overtake) men some time between approximately 1965 and 1975. Although the youngest speakers in our study are born in the 1990s, our results seem to suggest that rhotacization continues beyond this point. There is some evidence of a greater concentration of speakers exhibiting rhoticity in Western Quebec—especially in Montreal—than elsewhere, but it is not definitive. Finally, hyperspeech (longer vowel duration) is associated with more rhoticity, a tendency seen throughout the apparent time window but which strengthens over the years.

Surprisingly, we see little evidence of rhoticity in /œ/, in contrast to the findings of Dumas (1972) and Mielke (2013a; 2013b; 2015): this is true of both male and female speakers, of all phonological contexts, and of all regions. However, there is some suggestion that F3 is lowering in the youngest speakers in our study (those born after 1980), although there is not enough statistical power to ascertain this effect. It is also worth noting that rhoticity does not appear to be more prevalent in hypospeech in this vowel.

7.2. Implications for the origin of rhotacization

We now turn to the second aim of this study: examining what these findings suggest about the source of the change and about rhotacization as a sound change more broadly. Immediately, it is clear that our results clash with two of the accounts sketched in Section 3. Contrary to what is predicted from a typological perspective, there is an accumulation of evidence against the coarticulatory account—there is little indication of change in /œ/ before /R/, and especially not in hypospeech. The absence of clear change in /œ/ is also a mark against the version of the English contact account that suggests loanword [ɚ] gets reanalyzed as a prerhotic allophone of /œ/.

As for the three remaining accounts, none neatly explains all the observed facts. To be sure, the finding of greater rhoticity in hyperspeech is consistent with each account; the remaining results, however, conflict in favouring different explanations. That the earliest evidence of rhoticity is seen in /ø/ amongst men, and that many speakers who are advanced with respect to rhoticity are from Montreal (where exposure to English is especially high), both point to a contact explanation whereby loanword [ɚ] is reanalyzed as an allophone of /ø/. This would, however, fail to explain how the change subsequently spreads to /œ̃/, whereas both contrast enhancement accounts capture this neatly. Enhancement, moreover, is more consistent with the observation that women show the strongest evidence of rhoticity (perhaps even exhibiting greater rhoticity than men in years of birth after around 1970) than deliberate borrowing (since women would not have had the same level of exposure to English as men, per Section 3.1). It is nevertheless not obvious why men would be especially advanced in the early stages of an enhancement change ultimately led by women. The contrast enhancement account also fails to explain the delay between the change in /ø/ and in /œ̃/. More fundamentally, the question remains of why enhancement would lead to rhotacization in Quebec French uniquely, as we are not aware of any reports of such a change in any other language or even in any other varieties of French.

One way to reconcile these findings is to posit two distinct phases of rhotacization, each with a different underlying motivation. First, rhoticity (tongue bunching/retroflexion) is introduced into Quebec French as a feature by men through borrowing of the sound /ɚ/, which comes to be associated with the phonetically, phonologically, and phonotactically similar native vowel /ø/. This feature is later free to be repurposed in a contrast enhancement change led by women. Such a hybrid account is undoubtedly *ad hoc*, suggesting a unique pathway for rhotacization just for Quebec French, but captures all our findings in a way no other account considered here can. In any case, the particular combination of sociolinguistic and phonological forces at play in Quebec French may just be unusual enough to warrant such an idiosyncratic explanation. For one, that Quebec French experienced such intensive and prolonged exposure to rhotic vowels due to the privileged social position enjoyed by English is already quite exceptional. This is likely the reason that /ɚ/ (and its nonsyllabic counterpart /ɹ/) is borrowed at all in Quebec French: it appears to be more common for languages to substitute a native vowel and/or rhotic in English loanwords than to borrow this phoneme. Compare, for example, with other varieties of French, where words like *toaster* or *red* are rendered as [tostɛʁ] and [ʁɛd].[17] For another, few languages have a vowel inventory as crowded as Quebec French, which stands out even amongst varieties of French (cf. Section 2.2). The combination of these factors is surely exceedingly rare cross-linguistically, and thus this particular pathway for change would be equally exceptional. A two-phased change may also help explain the discrepancies between Dumas' and Mielke's findings (i.e., on whether there is a gender effect and on the timing of change in /œ/), under the assumption that Dumas only observes the first phase and that Mielke's results primarily bear on the second.[18]

It is worth recalling that there are good reasons why a change in Quebec French driven by borrowing from English would lose steam in the 1970s, and why a change from below led by women would take off around the same time. As seen in Section 2.1, this is precisely when English began to lose its dominant status in Quebec through social and legal efforts to promote the use of French in the public sphere. It is likely that in this context, the deliberate use of an English-associated variant as a sign of authority would come to be seen as old-fashioned and fall out of favour.[19] Simultaneously, the proportion of women in the (increasingly francophone) workplace rapidly and dramatically increased: having previously had little direct exposure to English, women hearing rhoticity in /ø/ may not have as directly associated the phenomenon with English, and thus have been less hesitant than men to expand its usage (including to other phonemes). Examining this suggestion more thoroughly would require a more careful sociolinguistic analysis than has been undertaken here, and is left for future investigation.

Note that our results do not truly allow us to distinguish between the two contrast enhancement accounts—enhancement of the height (/ø ~ œ/, /ø ~ ʏ/) and/or nasality (/œ ~ œ̃/) contrasts versus enhancement of the rounding distinction in front vowel. Telling these apart would require resolving the mystery of /œ/, for which we fail to find change despite incontrovertible articulatory

[17] As an anonymous reviewer correctly points out, the lack of /ɚ/ in loanwords in e.g., Metropolitan French could also be due to that variety having historically primarily been in contact with an *r*-less variety of English (namely, Standard Southern British English). This would not explain the failure to borrow /ɹ/ even in onsets, however. In any case, this still speaks to the particularity of the contact situation of Quebec French, since rhotic vowels are so rare cross-linguistically.

[18] The absence of a gender effect in Mielke (2013a), contrary to our findings, would be surprising if this is the case. Note, however, that Mielke specifically claims that there is no *main* effect of GENDER, which is actually also true of our models (where the YOB by GENDER interaction produces the effect). It is thus possible this particular finding of Mielke's is not especially robust. Selecting and reporting the optimal model may not have been a priority, given the secondary nature of the corpus study in his work.

[19] Supporting evidence of this may be found in Tousignant (1987c), where the bunched/retroflex allophone of /R/ is noted to be declining in apparent time—assuming, of course, that that variant is indeed an English borrowing. Note, however, that if it were instead an intermediate stage in the change from apical to dorsal /R/, the same decline would be predicted.

evidence of rhoticity in this vowel from Mielke. There are at least two possible reasons for this discrepancy. One explanation lies in that three of four speakers coded as 'most rhotic' in Mielke (2015), and five of nine coded as 'moderately rhotic',[20] are actually from Ontario (where French is a minority language) rather than Quebec. Séguin's (2010) finding of low F3 in /œ/, moreover, is essentially limited to her male speakers, who too are overwhelmingly Ontarian. Conversely, Saint-Amant Lamy's (2020, 2022) work, which predominantly examines speakers from Quebec, shows no evidence of F3 lowering in this vowel. Rhoticity in /œ/, then, may specifically be a property of Ontario French rather than Quebec French, with enhancement operating differently in each. Alternatively, our negative result for /œ/ may simply be a consequence of lack of power, as there are relatively few speakers in the corpus at the later end of the apparent time window: after all, we do find some evidence of change in /œ/ after around 1980. Indeed, the participants in Mielke's articulatory study (where the clearest evidence of rhotic /œ/ is seen) and Séguin's study are born around 1990, which is at the very end of the range of years of birth examined here. (This would, however, leave the lack of change found by Saint-Amant Lamy to be explained.) In this case, enhancement of the rounding contrast would also be driving rhoticity in Quebec French, but the lag between change in /œ̃/ and /œ/ would need explanation. More work is required to resolve these issues.

7.3. Open questions and future directions

One point that has not yet received attention is how the kind of speech examined here—parliamentary speech (which skews more formal and more towards hyperspeech)—compares to the sociolinguistic interviews (which skew more informal and more towards hypospeech) or to the laboratory data (perhaps the most formal and hyperarticulated) used in previous studies of rhotic vowels in Quebec French. Differences in speaking style or in clarity of speech may be responsible for some of the discrepancies noted between our results and those of preceding studies. For example, style may account for part of our failure to find clear change in /œ/ where Mielke does. It is plausible that enhancement-driven rhoticity is negatively connoted in /œ/ in a way that it is not in other vowels: diphthongization is both especially socially salient and stigmatized in /œ/ (including compared to /ø/ and /œ̃/), and Mielke (2013b) finds a positive association between rhoticity and diphthongization in this vowel. Conversely, if rhoticity pre-/R/ and in open syllables are different (but highly related) phenomena (as Dumas at times seems to suggest), the former due to coarticulation and the latter solely to borrowing, differences in average articulatory effort between his data and ours may prevent us from observing the change in the prerhotic context. Careful consideration of these questions would require the effects of

[20] Including one from Bourget, which is incorrectly listed as being in Quebec, but is actually on the Ontario side of the Ottawa River.

style and clarity to be teased apart (which is unfortunately not currently possible with our data), a potentially fruitful direction for future work.

We briefly draw attention to three further open questions concerning rhotacization in Quebec French which are worth following up on. The first is the status with respect to the change of /y/ (the remaining front rounded vowel) and of /ə/ (which is acoustically and articulatorily similar to the front mid rounded oral vowels). Dumas (1972, p. 62) actually suggests that /y/ may rhotacize as well before /R/, although only a weak rhotic offglide is transcribed. Conversely, both /y/ and /ə/ are shown to have on average higher F3 than even nonrhotic /ø, œ, œ̃/ in Mielke (2015, Figure 6), and Saint-Amant Lamy (2020, 2022) notes stability (or a slight increase) in F3 over the 20th century in pre-rhotic /y/. Anecdotally, we have indeed heard rhotic-sounding realizations of /y/: this would be a new development in the change, and merits further inquiry. The second issue to consider is the role of other formants in cueing rhoticity, particularly F1 and F2 (as briefly alluded to in Section 4). Examining patterns of covariance between all three formants could reveal additional signal, including by elucidating potential interactions with diphthongization. Multivariate methods for dynamic data (such as multivariate GAMMs or multivariate functional principal components analysis) thus offer a promising way to extend our study. Third, given the important role played by rhoticity in loanwords on the account of rhotacization we argue for here, a targeted study of /ɚ/ and /ɹ/ in English borrowings is in order. The social dynamics surrounding the integration or nonintegration of these phonemes at the time when rhoticity began to develop in the native phonology, as well as the resulting range of acoustic variation, should be documented: this could, for example, shed further light on our hypotheses as to why rhoticity came to primarily be associated with native /ø/ in particular (rather than first effecting change in e.g., /œ/).

Finally, we return to the issue of the initiation of rhotacization and of rare sound changes more broadly. We have defended the view that only a complex interplay of language-internal and language-external forces can lead to the actuation of change (cf. Baker et al., 2011)—and that this is especially true of unusual developments like the recruitment of vowel rhoticity in contrast enhancement. The rarity of a change like the one discussed here is a direct consequence of the rarity of the combination of factors needed to give rise to it: situations of intensive contact with a language possessing bunched/retroflex segments and cases of exceptional vowel inventory crowding are uncommon individually, let alone together in a same language. However, this leaves unanswered the question of *why* rhoticity is particularly dispreferred as a strategy for contrast enhancement cross-linguistically. The phonetic and/or cognitive constraints on rare sound changes such as this one remain to be determined.

Appendix

A. List of speakers

ID	Gender	YOB	Origin	Amount of speech		# tokens		
				Original	New	ø	œ	œ̃
52046	M	1941	Saint-Lambert-de-Lauzon	—	19m	39	52	18
15538	F	1943	Montréal	< 1m	—	2	2	1
18317	M	1944	Val-Paradis	3m	—	5	3	3
66831	F	1945	Québec	4m	—	6	9	5
45938	M	1945	Rivière-Bleue	1m	—	2	3	1
89478	M	1945	Québec	< 1m	—	5	1	2
46675	M	1945	Chicoutimi	41m	—	44	79	98
76718	F	1946	Sainte-Thérèse	—	6m	10	9	15
51010	M	1947	Montréal	5m	—	5	10	7
34326	F	1948	Saint-Constant	1m	—	3	1	0
77464	M	1948	Jonquière	5m	17m	59	46	47
36024	F	1949	Lachute	< 1m	—	1	5	0
95075	F	1949	Québec	5m	—	7	13	11
98601	M	1949	Danville	—	15m	32	40	24
18122	M	1950	Montréal	—	14m	44	22	13
15476	M	1950	Saint-Georges	8m	—	6	27	14
80983	M	1950	Chicoutimi	8m	3m	22	26	21
59967	F	1951	Mont-Joli	—	8m	11	5	9
59145	M	1951	Sherbrooke	—	13m	18	8	28
66281	M	1952	Îles-de-la-Madeleine	< 1m	—	3	2	2
63116	M	1952	Montréal	1h 19m	1m	178	166	177
10162	F	1953	Saint-Roch-des-Aulnaies	25m	—	30	72	33
44661	F	1953	Montréal	2m	—	2	3	6
46224	F	1953	Trois-Rivières	34m	—	40	52	54
63023	M	1954	Québec	< 1m	—	2	7	0
69953	F	1955	Montréal	12m	—	17	11	29

(Contd.)

ID	Gender	YOB	Origin	Amount of speech		# tokens		
				Original	New	ø	œ	œ̃
99765	M	1955	Saint-Gilbert	4m	—	7	6	6
11288	M	1955	Petit-Saguenay	2m	—	0	2	5
93238	F	1956	Sault-au-Mouton	16m	3m	47	37	52
97310	M	1956	Chicoutimi	3m	—	15	14	10
89604	M	1957	Alma	7m	—	8	13	13
77650	F	1958	Montréal	2m	—	1	3	12
73049	M	1958	Montréal	3m	—	8	4	13
96194	M	1958	Sherbrooke	5m	2m	16	15	9
66902	F	1959	Havre-Saint-Pierre	1m	5m	10	17	8
33483	F	1959	Coteau-Station	7m	—	18	13	11
38679	M	1959	Montréal	9m	2m	36	20	19
68585	M	1959	Châteauguay	1m	—	2	1	2
76485	M	1960	Montréal-Est	—	12m	25	11	18
22095	F	1961	Sherbrooke	—	3m	9	13	6
24488	M	1961	Québec	2m	—	0	6	4
35429	M	1961	Lavaltrie	—	37m	71	80	81
50550	F	1962	Montréal	1m	—	3	3	4
93404	F	1963	Salaberry-de-Valley-field	2m	18m	25	42	34
30352	M	1963	Rivière-du-Loup	1m	—	3	3	0
27626	F	1964	La Tuque	2m	—	2	4	3
91526	M	1964	Montréal	12m	—	32	23	30
49178	M	1964	Jonquière	—	43m	73	89	89
91294	M	1965	Sorel	4m	—	8	7	14
36683	M	1965	Montréal	13m	26m	74	49	49
62953	M	1965	Drummondville	33m	—	42	38	66
34408	F	1967	Lévis	2m	—	4	0	5
98588	F	1968	Maria	2m	—	3	6	3

(Contd.)

ID	Gender	YOB	Origin	Amount of speech		# tokens		
				Original	New	ø	œ	œ̃
28553	M	1968	Verdun	21m	—	49	47	69
55890	M	1968	Chicoutimi	2m	—	0	0	2
90245	M	1969	Saint-Philippe-de-Néri	—	20m	55	52	86
63101	F	1970	Joliette	—	23m	20	34	39
57055	M	1970	Alma	—	12m	25	29	24
82538	M	1970	Montréal	1m	9m	21	26	18
95581	M	1970	Sorel	1m	—	2	4	1
20409	M	1970	Jonquière	—	18m	66	30	22
89010	F	1971	Rimouski	—	17m	32	24	20
64968	F	1971	Québec	—	13m	30	29	27
18111	F	1971	Sherbrooke	—	22m	24	23	64
25012	M	1971	Victoriaville	—	15m	23	28	36
62741	M	1971	Howick	10m	15m	82	69	82
51369	M	1972	Montréal	2m	15m	44	36	32
48329	F	1973	Terrebonne	—	10m	21	52	27
99121	M	1973	Lac-Mégantic	—	10m	20	14	5
23400	F	1974	Baie-Saint-Paul	—	9m	15	17	21
56492	F	1974	Saint-Rémi	—	4m	7	8	12
98330	F	1974	Montréal	—	13m	17	46	24
57403	F	1974	Montréal	—	9m	15	32	25
20978	F	1974	Jonquière	—	8m	30	21	23
30893	M	1974	Montréal	—	18m	32	30	27
52260	M	1974	?	—	10m	19	13	22
48311	M	1975	Matane	8m	—	7	24	26
95698	M	1975	Québec	11m	—	34	33	17
85377	M	1975	Montréal	—	22m	41	35	37
51427	M	1976	Saint-Jérôme	—	18m	27	35	31

(Contd.)

ID	Gender	YOB	Origin	Amount of speech		# tokens		
				Original	New	ø	œ	œ̃
58291	M	1977	Chicoutimi	—	20m	38	37	46
65232	M	1977	Baie-Comeau	—	11m	30	34	25
66087	M	1977	Sainte-Agathe-des-Monts	—	15m	26	21	27
61332	F	1978	Danville	—	15m	20	36	25
51296	M	1978	Le Gardeur	—	<1m	3	1	1
57239	M	1978	Sherbrooke	3m	40m	102	84	103
20923	F	1979	Montréal	—	17m	44	35	44
13539	F	1979	Sainte-Marthe	—	9m	8	25	25
53703	M	1979	Montréal	—	7m	8	10	9
57487	M	1979	Montréal	—	14m	26	28	26
20189	F	1980	Baie-Comeau	—	9m	25	16	29
78385	M	1981	Quyon	—	10m	24	17	29
20488	F	1982	Québec	—	6m	21	8	20
38811	F	1982	Greenfield Park	—	20m	49	33	52
76572	M	1982	Québec	—	6m	13	12	19
93789	M	1983	Longueuil	2m	16m	44	45	29
41246	M	1984	Mascouche	—	18m	41	31	40
19478	M	1984	Mascouche	<1m	—	3	5	1
14401	F	1985	Montréal	—	10m	16	23	16
94076	F	1987	Sherbrooke	—	11m	14	34	16
28838	M	1988	Montréal	—	10m	30	29	23
92340	F	1990	Gaspé	—	11m	18	19	21
44263	M	1990	Montréal	—	10m	11	10	32
55473	F	1991	Duhamel-Ouest	—	8m	21	12	17
36431	M	1991	Montréal	—	19m	37	65	47
92098	F	1992	Sainte-Julie	—	15m	26	34	24
Total				7h 34m	15h 17m	2591	2688	2749

Table A1: List of speakers (by anonymous ID) and amount of data for each.

B. Model summaries

(a) Parametric terms				
Terms	**Estimate**	***SE***	***t***	***p***
(Intercept)	0.641	0.007	98.14	< .001
gender (male)	0.002	0.007	0.28	.781

(b) Smooth terms				
Terms	**edf**	**Ref. df**	***F*-score**	***p***
s(measurement)	8.27	8.73	16.55	< .001
s(measurement):gender (male)	4.37	5.58	2.38	.028
ti(measurement,yob)	6.11	7.21	5.10	< .001
s(duration)	5.28	6.31	8.98	< .001
ti(measurement,duration)	12.22	14.23	28.83	< .001
ti(yob,duration)	8.24	10.52	10.36	< .001
s(yob)	2.18	2.27	13.57	< .001
s(yob):gender (male)	2.69	2.76	5.10	.013
s(measurement,speaker)	250.98	409.00	6.00	< .001
s(measurement,word)	91.14	320.00	2.64	< .001
s(yob,word)	79.74	184.00	1.75	< .001

Table B1: Summary of parametric and smooth terms for the /ø/ model.

(a) Parametric terms				
Terms	**Estimate**	***SE***	***t***	***p***
(Intercept)	0.709	0.006	121.08	< .001
gender (male)	–0.006	0.006	–1.01	.315
context (/v, vR/)	–0.005	0.012	–0.41	.681
context (other C)	0.002	0.009	0.18	.854
gender (male):context (/v, vR/)	0.001	0.009	0.13	.894
gender (male):context (other C)	0.005	0.006	0.88	.378

(b) Smooth terms				
Terms	**edf**	**Ref. df**	***F*-score**	***p***
s(measurement)	8.18	8.70	13.81	< .001
s(measurement):context (/v, vR/)	1.03	1.06	2.29	.134
s(measurement):context (other C)	4.10	5.35	3.13	.007
s(measurement):gender (male)	4.75	5.98	1.44	.172
ti(measurement,yob)	6.68	8.41	1.10	.334
ti(measurement,yob):context (/v, vR/)	1.00	1.00	0.00	.981
ti(measurement,yob):context (other C)	1.01	1.01	1.90	.169
s(duration)	1.02	1.03	1.99	.154
s(duration):context (/v, vR/)	4.29	5.19	2.32	.035
s(duration):context (other C)	3.65	4.51	1.63	.192
ti(measurement,duration)	5.51	7.21	6.26	< .001
ti(yob,duration)	7.72	9.86	4.28	< .001
s(yob)	2.92	3.04	2.44	.055
s(yob):gender (male)	1.00	1.00	0.06	.814
s(yob):context (/v, vR/)	1.00	1.00	0.01	.912
s(yob):context (other C)	3.58	3.82	3.10	.026
s(measurement,speaker)	221.72	411.00	3.54	< .001
s(measurement,word)	192.32	917.00	0.54	< .001
s(yob,word)	259.77	498.00	1.62	< .001

Table B2: Summary of parametric and smooth terms for the /œ/ model.

(a) Parametric terms				
Terms	**Estimate**	***SE***	***t***	***p***
(Intercept)	0.669	0.010	63.93	< .001
gender (male)	–0.001	0.007	–0.19	.847

(b) Smooth terms				
Terms	**edf**	**Ref. df**	***F*-score**	***p***
s(measurement)	5.84	7.10	3.07	.003
s(measurement):gender (male)	3.71	4.74	1.78	.134
ti(measurement,yob)	2.75	3.38	0.67	.474
s(duration)	2.20	2.76	10.19	< .001
ti(measurement,duration)	7.58	10.02	4.37	< .001
ti(yob,duration)	5.06	6.45	2.33	.027
s(yob)	1.01	1.01	18.58	< .001
s(yob):gender (male)	1.25	1.29	9.98	< .001
s(measurement,speaker)	212.80	401.00	3.59	< .001
s(measurement,word)	16.69	74.00	0.87	< .001
s(yob,word)	31.16	51.00	4.05	< .001

Table B3: Summary of parametric and smooth terms for the /œ̃/ model.

Data accessiblity statement

All data and analysis code, along with instructions for accessing the expanded *AssNat* corpus, can be found on the OSF page for this paper: https://osf.io/egd7p/.

Acknowledgements

This work was funded by FRQSC B1Z award #321056 to ML, as well as SSHRC grant #435-2017-0925 and NSERC grant RGPIN-2023-04873 to MS. We are grateful to Peter Milne for providing access to the original *AssNat* corpus. A preliminary version of this study was presented at the 20th *International Congress of Phonetic Sciences* (Lipari, 2023). We thank audiences at *Les français d'ici 2024*, ICPhS 20, the Canadian Linguistic Association 2023 Conference, the 2023 Montreal-Ottawa-Toronto-Hamilton Phonology/Phonetics Worksop, and McGill for feedback. We thank Meghan Clayards and Charles Boberg for crucial comments on early drafts, as well as Jeff Mielke, Jane Stuart-Smith, Alexandra Pfiffner, and especially Irene Smith for fruitful discussion and advice.

Competing interests

The authors have no competing interests to declare.

Author contributions

ML: Conceptualization, methodology, investigation, data curation, formal analysis, software, visualization, validation, writing – original draft, writing – review & editing.

MS: Conceptualization, methodology, formal analysis, writing – review & editing.

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