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RESEARCH

The *loi de position* and the acoustics of French mid vowels

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This paper reports the results of two experiments on the acoustics of French mid vowels in a variety in which close-mid vowels ([e], [ø], [o]) occur in open syllables and open-mid vowels ([ɛ], [œ], [ɔ]) in closed syllables, according to the *loi de position*. Open-mid allophones have consistently higher F1 realizations and more central F2 realizations than their close-mid counterparts, but are not consistently shorter. These results are problematic for accounts of the *loi de position* as a pattern of vowel reduction, with mid-vowel lowering and centralizing being caused by shortening. F1 and F2 distances between close-mid and open-mid allophones vary across different prosodic and consonantal contexts and these variations can be analyzed as resulting from duration-based undershoot. More broadly, the results have implications for the typology of closed-syllable vowel laxing: they suggest that tense and lax realizations cannot generally be derived from the same acoustic target via closed-syllable vowel shortening but have distinct acoustic targets.

Keywords: French; mid vowels; *loi de position*; syllable; closed-syllable vowel laxing; undershoot

1 Introduction

This study investigates the acoustics of mid vowels in a French variety in which mid vowels follow the *loi de position*. The *loi de position* is the name given by French phonologists to the allophonic distribution of mid vowels observed in Southern French varieties, in which close-mid vowels are reported to occur in open syllables not followed by schwa and open-mid vowels in open syllables followed by schwa and in closed syllables (Lyche 2003; Moreux 2006; Coquillon & Turcsan 2012; Eychenne 2014). Table 1 shows words illustrating the *loi de position* in word-final syllables and in penultimate syllables before schwa (i.e., in stressed syllables).

In word-final syllables, close-mid vowels are characterized by lower F1 values than their open-mid counterparts, [e] by a higher F2 value than [ɛ], and [o] by a lower F2 value than [ɔ] (Delattre 1969; Gottfried 1984; Calliope 1989; Gendrot & Adda-Decker 2005; Ménard, Schwartz & Aubin 2008; Boula de Mareüil, Adda-Decker & Woehrling 2010).This study aims to better establish the acoustic correlates of the open-mid/close-mid distinction in and beyond word-final syllables and to investigate how the *loi de position* interacts with the prosodic and consonantal contexts in which vowels occur. The *loi de position* plays an important role in French phonology. However, it has not been studied thoroughly from a phonetic perspective. In particular, three important questions have not been investigated experimentally yet:

(i) whether the *loi de position* holds both in word-final and non-word-final syllables;
(ii) whether the *loi de position* is a pattern of vowel reduction induced by shortening;
(iii) whether only mid vowels follow the *loi de position*.

Table 1: Allophonic distribution of close-mid and open-mid vowels in Southern French varieties. Mid vowels in word-final syllables and in penultimate syllables before schwa.

Open syllable		**Closed syllable**
Not followed by schwa	**Followed by schwa**	
ses [se] 'his' ceux [sø] 'those' veau [vo] 'veal'	selle [sɛlə] 'saddle' seule [sœlə] 'alone' (fem) vole [vɔlə] 'flies' (ind 3d sg)	sel [sɛl] 'salt' seule [sœl] 'alone' (masc) vol [vɔl] 'flight'
	verre [vɛʁə] 'glass' meure [mœʁə] 'dies' (subj 3d sg) more [mɔʁə] 'mora'	vert [vɛʁ] 'green' meurs [mœʁ] 'die' (ind 1st sg) mort [mɔʁ] 'dead'
	laisse [lɛsə] 'leash' bosse [bɔsə] 'hump'	
	cette [sɛtə] 'this' (fem) meute [mœtə] 'herd' vote [vɔtə] 'vote'	

The distribution of close-mid and open-mid vowels in French is also relevant from a cross-linguistic perspective, as a case of closed-syllable vowel laxing (Féry 2003). Closed-syllable vowel laxing refers to a tendency for languages to have tense vowels in open syllables and lax vowels in closed syllables. This pattern has been described in Germanic languages (Lindau 1987; Ladefoged & Johnson 2010: Chapter 4; Botma & van Oostendorp 2012) and Austronesian languages (Blust 2013) among others. The tense/lax distinction is often characterized as involving at least one of the three following acoustic dimensions: F1, F2, duration. Lax vowels have typically higher F1 values, more central F2 values, and shorter durations than tense vowels (e.g., Adisasmito-Smith 1999 on Indonesian). However, studies on tense vs. lax vowels do not always provide information about all three dimensions. For instance, acoustic studies of French mid vowels generally focus on vowel quality. As a consequence, it is not clear whether all three dimensions always play a role and whether the tense/lax distinction primarily affects vowel quality or duration. Also, studies investigating the effect of syllable structure on vowels rarely control for the effect of co-articulation with neighboring consonants. For instance, vowel formants and durations are averaged across consonantal contexts in Adisasmito-Smith's (1999) study of Indonesian. The effect of syllable structure is therefore potentially confounded with the effect of the consonantal context.

The present study contributes to the research question on the acoustic correlates of the tense/lax distinction by providing a detailed analysis of a closed-syllable laxing language and carefully controlling for co-articulation. In the remainder of this introduction, the relevance of questions (i)–(iii) for French phonology and for the typology of closed-syllable vowel laxing is motivated.

1.1 The loi de position in non-word-final syllables

Answering question (i) is crucial both to a better understanding of the *loi de position* and to the task of transcribing French vowels. The existence of distinct close-mid and open-mid allophones is clear in penultimate syllables before schwa and in word-final syllables in Southern French varieties (see Table 1). However, it is still debated whether the *loi de position* holds beyond these contexts in Southern French (Lyche 2003: 351).

Since vowels are shorter in non-word-final syllables than in word-final syllables in French (Delattre 1966; O'Shaugnessy 1984; Bartkova & Sorin 1987) and shorter vowels are more subject to co-articulation with neighboring consonants (Lindblom 1963), the *loi* *de position* could be overridden by co-articulatory effects in non-word-final syllables. For instance, Tranel (1987) claims that mid vowels are systematically realized as open-mid before non-word-final coda [ʁ] but can be realized as close-mid or open-mid before other non-word-final coda consonants. Vowel-to-vowel co-articulation in V_1CV_2 sequences has also been claimed to override the effect of syllable structure word-medially in French, with mid vowels in V_1 being realized as open-mid before non-high vowels in V_2 (Tranel 1987). However, Nguyen and Fagyal (2008) did not find this effect in Southern French and it will not be further investigated in the present study.

1.2 The loi de position and mid vowel duration

Answering question (ii) is crucial to our understanding of the mechanism relating vowel quality and the syllabic/segmental context in the *loi de position* and more generally in closed-syllable laxing languages. Some phonological accounts take the *loi de position* to be a pattern of vowel reduction, with the relationship between mid-vowel quality and the syllabic/segmental context being mediated via vowel moraicity or duration (Féry 2003; Lyche 2003). However, this is still controversial, as some authors hold that the difference between close-mid and open-mid vowels is fundamentally a difference in aperture (Eychenne 2014: 238). The duration-based analysis was also proposed by Botma and van Oostendorp (2012) to account for the pattern of laxing in closed syllables cross-linguistically.

Lyche (2003), extending Féry's (2003) duration-based analysis of Standard French, derives the complementary distribution of close-mid and open-mid vowels in Southern French from the following hypotheses: (i) close-mid vowels are bimoraic, (ii) open-mid vowels are monomoraic, and (iii) rimes are bimoraic. By (i) and (iii), close-mid vowels are predicted to occur only as nuclei of open syllables. By (ii) and (iii), open-mid vowels are predicted to occur as syllable nuclei only if a coda consonant provides the second mora needed to form a well-formed rime, namely in closed syllables. The fact that open syllables followed by schwa pattern with closed syllables is not predicted under this approach but can be derived with special assumptions about the syllabification of schwa (Anderson 1982) or about feet in French (Durand 1976; Selkirk 1978). Schwa will not be discussed further in this paper.

There are several empirical problems with these hypotheses. First, while close-mid round vowels have been shown to be longer than their open-mid counterparts in positions where they contrast in Standard French (e.g., *côte* [kot] vs. *cote* [kɔt]; see Gottfried & Beddor 1988), it is unclear whether this durational difference extends to contrastive unrounded mid vowels in Standard French (e.g., *thé* [te] vs. *taie* [tɛ]), and to French varieties where close-mid and open-mid vowels are in complementary distribution.

Second, while lowering of mid vowels is reported to happen across consonant types in word-final closed syllables in *loi de position* dialects, Bartkova and Sorin's (1987) study of vowel duration in VC# contexts suggests that the effect of C is consonant-specific and can be either a shortening or a lengthening effect depending on the consonant. This means that rimes probably do not have identical durations across the board and therefore the claim that all rimes are bimoraic is problematic. Hypothesis (iii) can be maintained if moraicity is disconnected from duration (Scheer 2006), but this move makes the use of moraicity to explain the *loi de position* less appealing.

Hypotheses (i) and (ii) are also conceptually problematic. The hypothesis of an inherent relationship between vowel shortening and vowel lowering is at odds with the observation that vowels with higher F1 tend to be longer cross-linguistically (Lehiste 1970). Open-mid vowels have higher F1 values than close-mid vowels in French: if anything, open-mid vowels are expected to be inherently longer than their close-mid counterparts. Also, this hypothesis is not supported by the evidence available on patterns of vowel undershoot in

French. Gendrot & Adda-Decker (2005) found that, on average, French vowels are more centralized along F2 when shorter, but not necessarily lower. The average pattern of F1 undershoot is height dependent: with decreasing duration, high vowels have slightly higher F1 values, close-mid vowels do not vary along F1, and open-mid vowels and [a] have lower F1 values. Since close-mid vowels do not have higher F1 values when they become shorter, it is mysterious why shortening of mid vowels in closed syllables should be accompanied by an increase in F1.

Finally, the evidence available on the history of French does not suggest that the syllable-based distribution of mid vowels is related to a distinction in vowel duration (Spence 1988). For instance, the front rounded mid vowel is always pronounced as [ø] in word-final open syllables regardless of whether the vowel was historically long (e.g., the suffix *-eux*) or short (e.g., *peu* 'few') and the front unrounded mid vowel is always pronounced as [ɛ] before consonants word-finally regardless of whether it was historically long or short, open-mid or close-mid.

1.3 The loi de position and non-mid vowels

A complete typology of closed-syllable vowel laxing should include a description of which vowels it applies to. A quick survey reveals that languages differ in allowing different subsets of their oral vowel inventories to have tense/lax allophones. Some languages are reported to have tense/lax allophones for all their oral vowels. For instance, Kuteb (Niger-Congo) has /ieaou/ vs. /ɪɛɐɔʊ/ (Koops 2009). In some languages, the tense/lax distinction only applies to vowels of a specific height, for instance to mid vowels only in Selaru (Austronesian; Coward 1990) and Sri Lanka Malay (Austronesian; Nordhoff 2009), to non-low vowels only in Chamorro (Austronesian; Topping 1973) and Kairiru (Austronesian; Wivell 1981), to non-mid-vowels only in Hiligaynon (Austronesian; Wolfenden 1971). In other languages, subsets that cannot be characterized only in terms of height have tense/lax allophones: all oral vowels except [y] and [u] in Dutch (Trommelen 1983), only [i]/[ɪ], [e]/[ɛ], and [o]/[ɔ] in Paluai (Austronesian; Schokkin 2014), only high vowels and [o]/[ɔ] in Hinuq (Forker 2013). Turkish is an extreme case in this typology, as only the front mid vowel [e]/[æ] is reported to have tense and lax allophones in open vs. closed syllables (Göksel & Kerslake 2005).

French varieties with the *loi de position* belong to the set of languages with a height restriction on vowel laxing. However, to my knowledge, there is no acoustic study comparing the effect of syllable structure across oral vowels in these varieties. Since Québec French has high vowel laxing in closed syllables, characterized by an increase in F1 and F2 centralization (Martin 2002; Côté 2012), one may wonder how high vowels pattern in other French varieties, and in particular in *loi de position* varieties.

1.4 Experiments and hypotheses

In this paper, I report the results of two production studies that examine whether and how syllable structure affects oral vowel quality and duration across a range of consonantal and prosodic contexts in a variety of French in which mid vowels are reported to follow the *loi de position*. Experiment 1 looks at the realization of oral vowels before onset and coda [ʁ] and [l] in word-medial and word-final positions. Experiment 2 looks at the realization of oral vowels before onset and coda [s] in word-medial and word-final positions. The choice of phonetic correlates of mid vowel quality was guided by prior research on French mid vowels. F1 and F2 are the main dimensions along which close-mid and open-mid vowels have been found to differ. Duration has also been argued to distinguish close-mid and open-mid vowels in the phonological literature.

The main hypotheses which were tested in this study are summarized in H1 and H2:

H1.	The *loi de position* (increase in F1 and centralizing of F2 in closed syllables) exists for mid but not other vowels in word-final and -medial positions.
H2 (weak).	The *loi de position* is accompanied by closed-syllable vowel shortening.
H2' (strong).	The *loi de position* is synchronically driven by closed-syllable vowel shortening.

H2' entails H2: for H2' to hold, H2 must hold and, in addition, the realization of vowels in open and closed syllables must be derivable from a single acoustic target for each vowel via duration-based undershoot. H2' will not be tested statistically but through an exploratory analysis of vowel-consonant co-articulation. If H2' holds, it is expected that differences in vowel quality in open vs. closed syllables are entirely predictable from duration. In these analyses, it will also be explored whether variations in the magnitude of the effect of syllable structure on mid-vowel formants across prosodic contexts can be explained as resulting from co-articulation.

Section 2 presents the materials and methods used in Experiments 1 and 2. Section 3 presents the results. Section 4 concludes with a discussion of the results and their consequences for accounts of the *loi de position* and the typology of closed-syllable vowel laxing.

2 Materials and methods

2.1 Participants

20 speakers from Clermont-Ferrand, Auvergne (12 males, 8 females; aged 21–76, mean = 48 years, sd = 18 years) participated in Experiment 1 and 8 speakers from the same city (6 males, 2 females; aged 19–59, mean = 26 years, sd = 13 years) in Experiment 2. The distribution of mid vowels follows the *loi de position* in the variety of French spoken in Auvergne. For instance, the name of the central square in Clermont-Ferrand, *Jaude*, is typically pronounced as [ʒɔd], instead of the more standard [ʒod].[1]

Participation was voluntary. At the time of the recordings, all participants had been living in the Clermont-Ferrand area for more than twenty years except three of them, who were in their late twenties and were born and lived in Clermont-Ferrand until around the age of 20.

2.2 Stimuli and recordings

Participants in Experiment 1 were recorded pronouncing each of the seven oral vowels V in {i, y, u, e/ɛ, ø/œ, o/ɔ, a} in |Syllable|*|Consonant|*|Position| = 8 conditions, with Syllable = {open, closed}, Consonant = {ʁ, l}, and Position = {medial, final}. [ʁ] and [l] were chosen because they are typical coda consonants in French and have different F1 and F2 targets: a higher F1 target and a lower F2 target for [ʁ] than for [l] (Delattre 1959; Chafcouloff 1985). Medial syllables were used rather than initial syllables for the non-word-final syllable condition because they are shorter (Bartkova & Sorin 1987) and thus provide a wider range of durations together with word-final syllables. Nonce words were used as stimuli in order to have a better control over the segmental context and to have a fully crossed design. Based on previous research, the pre-vocalic consonant is not expected to interact with the *loi de position*. Therefore, a unique consonant, [k], was used in pre-vocalic position.

[1] Schwas are generally not pronounced in this variety of French (Walter & Martinet 1982), in contrast with other Southern French varieties.

The nonce words had the following shapes: [bakV{ʁ,l}a] (medial open syllable), [bakV#{ʁ,l}a] (final open syllable), [bakV{ʁ,l}ta] (medial closed syllable), [bakV{ʁ,l}#ta] (final closed syllable). The following spelling conventions were adopted: [i]: ⟨i⟩, [y]: ⟨u⟩, [u]: ⟨ou⟩, [e]: ⟨é⟩ in open syllables, ⟨e⟩ in closed syllables, [ø]/[œ]: ⟨eu⟩, [o]/[ɔ]: ⟨o⟩, [a]: ⟨a⟩, [k]: ⟨qu⟩ before front vowels, ⟨c⟩ before back vowels.

The nonce words were introduced as place names in the following carrier sentences: *La ville de __ vendait le sel* (medial open/closed syllable conditions), *La ville de __ rachetait le sel* (final open syllable condition), *La ville de __ taxait le sel* (final closed syllable condition). Each stimulus was repeated five times by each speaker, yielding a total of 20*5*7*8 = 5600 vowels.

Participants in Experiment 2 were recorded pronouncing each of the seven oral vowels {i, y, u, e/ɛ, ø/œ, o/ɔ, a} in |Syllable|*|Consonant|*|Position| = 4 conditions, with Syllable = {open, closed}, Consonant = {s}, and Position = {medial, final}. [s] was chosen because [sC] clusters are hetero-syllabic in French (Goslin & Frauenfelder 2000) but have properties that set them apart from other hetero-syllabic clusters. In particular, they can occur in word-initial position in French. Also, they do not trigger laxing of preceding high vowels in Québec French (Marie-Hélène Côté, personal communication). This raises the question of how they behave with respect to the *loi de position* in European French.

Nonce words were used as stimuli for the same reasons as in Experiment 1. The nonce words had the following shapes: [bakVsa] (open medial syllable), [bakV#sa] (open final syllable), [bakVsta] (medial closed syllable), [bakVs#a] (final closed syllable). The same spelling conventions were used as in Experiment 1. Nonce words were introduced as place names in the following carrier sentences: *Les gens de ___ vivaient dans les montagnes* (medial open/closed syllable conditions), *Les gens de __ s'adonnaient à l'opium* (final open syllable condition), *Le pays de ___ abondait de diamants* (final closed syllable condition). Each stimulus was repeated three times by each speaker, yielding a total of 8*3*7*4 = 672 vowels.

The recordings were made in a quiet room in Clermont-Ferrand with a table-mounted Shure SM58 connected to a computer via a Shure X2u XLR-to-USB signal adapter. The recordings were made using the Audacity software, with 44 kHz/16 bit sampling. The distance (approximatively 30 cm) and orientation of the participants to the microphone was held constant across all recording sessions.

2.3 Phonetic analyses

The recordings were first automatically segmented using the McGill Prosodylab text-to-speech aligner (Gorman, Howell & Wagner 2011). The segmentation was manually corrected to correspond to the criteria chosen in the study. All acoustic analyses were performed using the Praat software (Boersma & Weenink 2014). Measures of vowel duration included the vocalic segment only and not the initial burst associated with consonant release. The end of the vowel was identified by the last periodic oscillation when the vowel was followed by an aperiodic sound (e.g., [s]) and by a change in intensity or formant trajectory otherwise (e.g., with [l] and some instances of [ʁ]). Measurements of vowel first and second formants were made at vowel midpoint using a Praat script. The ceiling of the formant search range was set to 5500 Hz for female speakers and 5000 Hz for male speakers.

Among the 5600 vowels recorded in Experiment 1, ninety-nine were excluded from the analysis, either because they were misread (e.g., *bacura* was sometimes read as [bakura] instead of the expected [bakyra]) or formants could not be measured reliably. For one speaker, word-medial [i] tended to palatalize the preceding consonant and was not realized as a full vowel. For a handful of vowels, the formant measure at vowel midpoint was not reliable and another point close to the vowel midpoint was chosen instead. Among the 672 vowels recorded in Experiment 2, 11 were excluded from the analysis for the same reasons.

2.4 Statistical analyses

R (R Core Team 2013) and lme4 (Bates, Maechler & Bolker 2014) were used to perform linear mixed effects analyses of the relationship between the response variables (F1, F2, Duration) and the categorical predictors (Height, Syllable, Position, Consonant) and their interactions in Experiments 1 and 2. The logarithm of vowel duration was used as dependent variable in the models instead of duration because duration was logarithmically distributed. In all models, the response variables were normalized by speaker (using the R function *scale*), as it helped model convergence. P-values were obtained using the lmerTest package (Kuznetsova, Brockhoff & Christensen 2015).

Height (a variable with 3 levels: high, mid, low) was used instead of Vowel (a variable with 7 levels) in the models. This is motivated by the hypotheses which are explicitly about height. This is also motivated by the finding that vowels of the same height have very similar F1 values within speakers in French (Ménard, Schwartz & Aubin 2008) and are expected to have similar durations since vowel duration is highly correlated with F1 (Lehiste 1970; Escudero et al. 2009). *Post hoc* comparisons showed that the effects on F1 and duration which held for a group of vowels with the same height also held for each vowel individually, confirming that vowels of the same height are affected similarly by syllable structure.

For F2, separate models were run on three subsets of the data, {i, e/ɛ, a}, {y, ø/œ, a}, and {u, o/ɔ, a}. This was done because the effect of syllable on F2 is expected to go in different directions for front unrounded vowels (lowering of F2) and back rounded vowels (raising of F2). In a single F2 model with Height as a variable, the two effects would cancel each other out and it would be impossible to assess the presence of any effect.

In the F1 and F2 models, the formants of high vowels in open syllables before word-medial [l] (Experiment 1) and word-medial [s] (Experiment 2) served as the baseline for comparison. This choice was motivated by the hypothesis that the effect of Syllable is the smallest in that context (see section 1.1) and to allow for a direct comparison between high and mid vowels. In the duration model in Experiment 1, the duration of high vowels in open syllables before word-final [ʁ] was taken as the baseline. This choice was motivated by the *post hoc* observation that there is no significant effect of syllable on vowel duration in open syllables before word-final [ʁ] and therefore this context provides a natural baseline for comparison.

There were two external sources of non-independence in the data: data came from different speakers and each nonce word was repeated several times by each speaker. One approach is to control for these effects by having by-subject and by-subject/by-repetition random intercepts and random slopes for all the predictors and their interactions (Barr et al. 2013). However, the models with full random effect structures did not converge. The random structure was chosen so as to both control for the effects of theoretical interest (in particular the effect of Syllable on Height) and to allow for model convergence. The by-speaker random effect structure included subject-specific intercepts and random slopes for the effect of Consonant, Position, Syllable, Height, and the interaction of Syllable and Height.

The effect of repetition is expected to mainly affect vowel duration, if subjects speak faster as the experiment proceeds, and secondarily vowel formants, as a consequence of duration-induced vowel undershoot. However, models allowing for different speakers to have different mean vowel durations and formant values across the different repetitions were not found to improve model fit as compared to models without these effects. Therefore, no by-subject/by-repetition random effect was included in the models.

3 Results

3.1 Experiment 1

Figure 1 summarizes the distribution of the seven oral vowels over the F1 × F2 space in final/medial open/closed syllables across speakers in Experiment 1. The results are comparable with previous studies for word-final syllables. In addition, the vowel space is smaller word-medially than word-finally (Delattre 1969; Gendrot & Adda-Decker 2005; Meunier & Espesser 2011), attracted to the top left corner before medial [l] and to the bottom right corner before medial [ʁ], in accordance with previous studies on the influence of [l] and [ʁ] on neighboring vowels (Delattre 1969; Chafcouloff 1985).

F1

The results for F1 are shown in Figure 2. The output of the statistical model for the syllable effect is shown in Table 2. High and mid vowels have significantly higher F1 values in closed than in open syllables in all contexts except word-medially before [l] for high vowels. The effect of syllable is larger for mid vowels than for high vowels in all contexts. The effect of syllable is modulated by the coda consonant and by word-position: it is smaller in word-medial than in word-final position, and before [l] than before [ʁ]. The low vowel patterns differently from high and mid vowels: its F1 value is not increased in closed syllables.

F2

The results for F2 are shown in Figure 3. Only peripheral mid vowels [e] and [o] have systematically different F2 values in open and closed syllables. Tables 3 and 4 show the

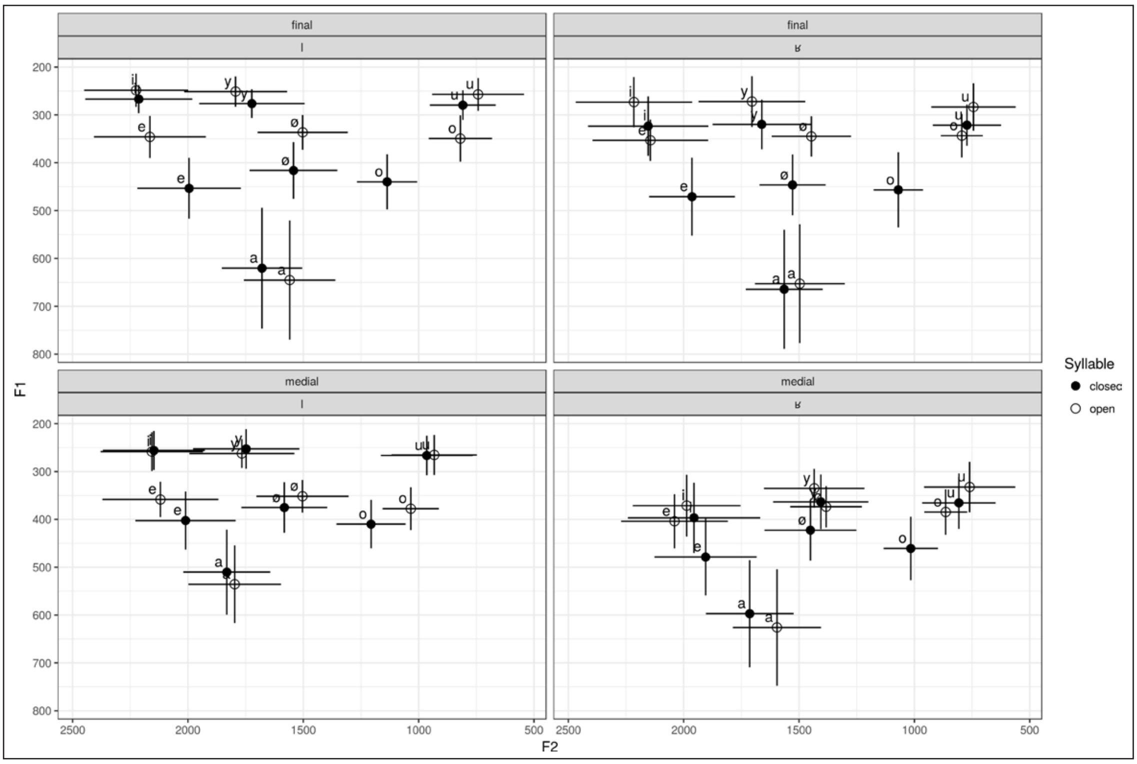

Figure 1: Mean vowel F1 and F2 in Hz (with standard deviations) in final/medial open/closed syllables before [l]/[ʁ] across speakers.

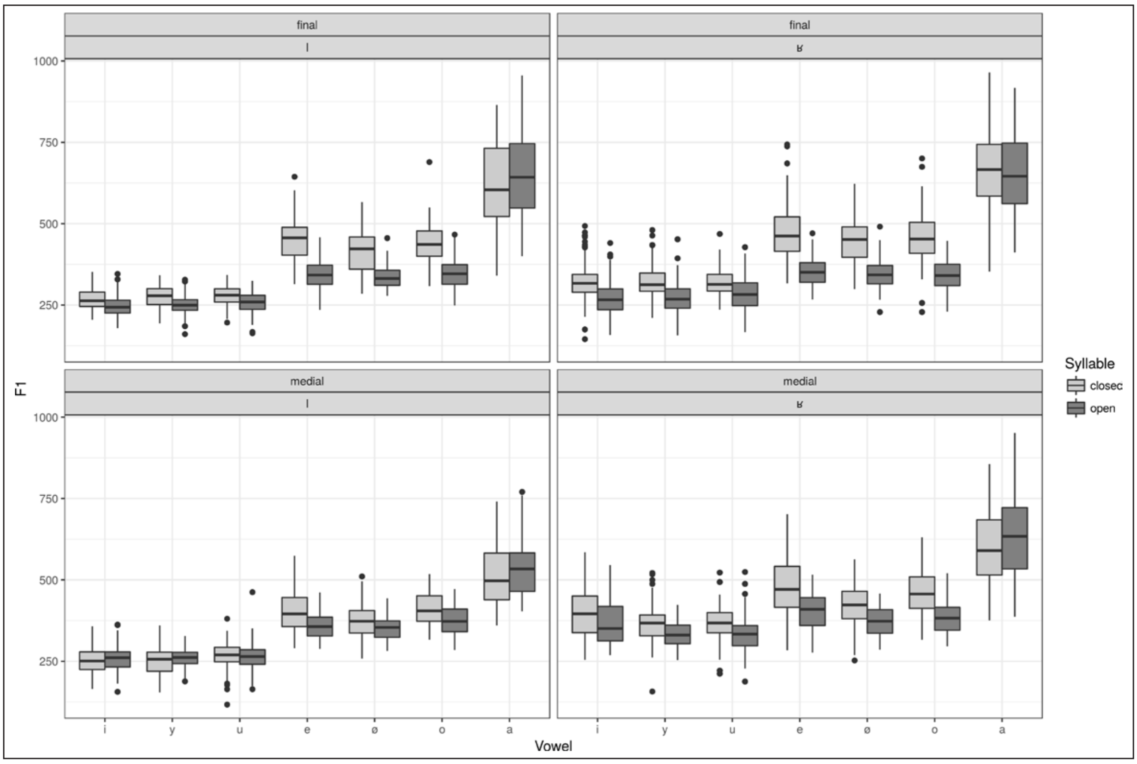

Figure 2: Vowel F1 (in Hz) in final/medial open/closed syllables before [l]/[ʁ] across speakers. Inside each plot, the boxes indicate the inter-quartile range (IQR), the range between the first and third quartile. The horizontal line indicates the median. The whiskers indicate the range, up to 1.5 times the IQR away from the median. Dot outside the whiskers lie more than 1.5 times the IQR away from the median and are potential outliers.

Table 2: Effect of syllable on vowel F1 (F1 values centered by subject). The effect Syllable (in the first row) indicates the increase in F1 for high vowels in closed syllables compared to open syllables word-medially before [l]. Interactions in subsequent rows show how the effect of syllable differs in the context appearing as the rightmost element in the interaction and in the corresponding baseline context. Significant effects are boldfaced.

	Estimate	**Standard Error**	**t value**	**p-value**
Syllable	−0.04	0.04	−1.07	0.29
Syllable:Mid	0.3	0.05	5.95	<0.01
Syllable:Low	−0.2	0.07	−3.05	<0.01
Syllable:Consonant	0.31	0.04	7.61	<0.01
Syllable:Consonant:Mid	0.01	0.06	0.11	0.91
Syllable:Consonant:Low	−0.29	0.08	−3.7	<0.01
Syllable:Position	0.25	0.04	6.28	<0.01
Syllable:Position:Mid	0.27	0.06	4.85	<0.01
Syllable:Position:Low	−0.2	0.08	−2.46	0.01
Syllable:Position:Consonant	−0.12	0.06	−2.05	0.04
Syllable:Position:Consonant:Mid	−0.04	0.08	−0.56	0.57
Syllable:Position:Consonant:Low	0.37	0.11	3.26	<0.01

effect across the four contexts for these vowels only, compared to high vowels [i] and [u], respectively. Front unrounded mid vowels have significantly lower F2 realizations and back rounded mid vowels have significantly higher F2 realizations in closed syllables than in open syllables across medial and final positions before [l] and [ʁ]. The distances between allophones are larger word-finally than word-medially.

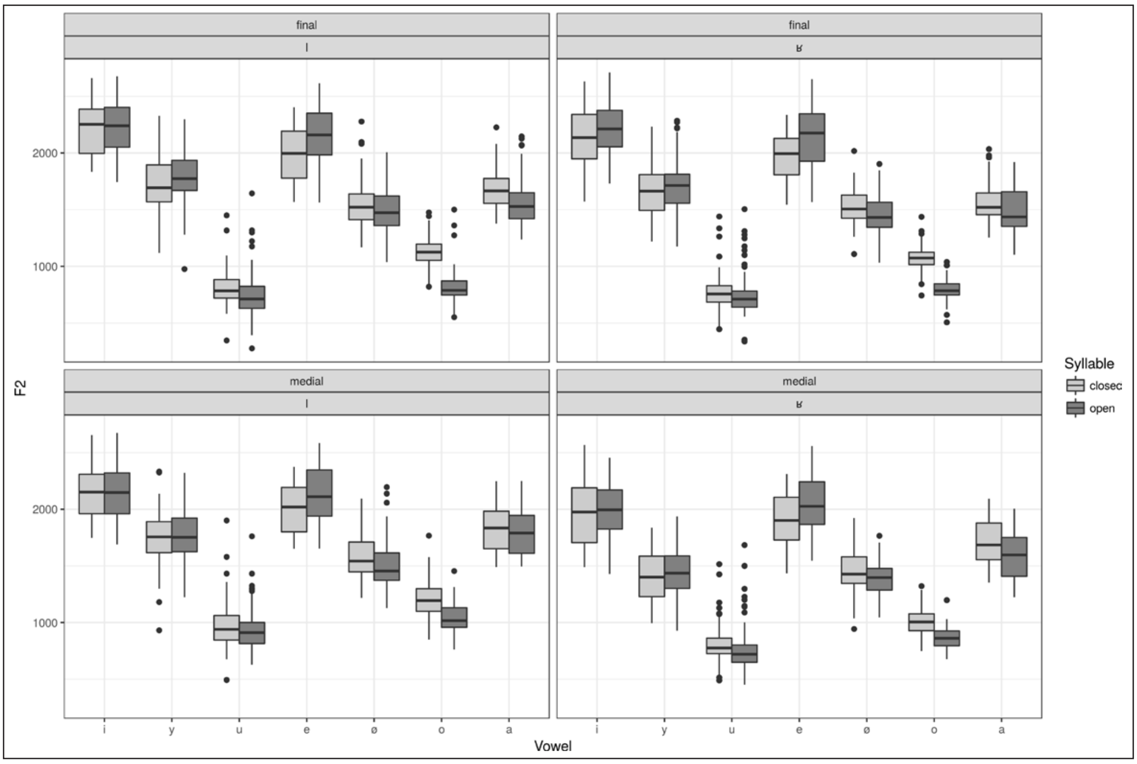

Figure 3: Vowel F2 (in Hz) in final/medial open/closed syllables before [l]/[ʁ] across speakers.

Table 3: Effect of syllable on peripheral high and mid front unrounded vowels' F2 (F2 values centered by subject). The estimate in the first row (Syllable) indicates the increase in [i]'s F2 in closed syllables compared to open syllables word-medially before [l].

	Estimate	Standard Error	t value	p-value
Syllable	–0.05	0.05	–1.15	0.26
Syllable:Mid	–0.16	0.05	–3.13	<0.01
Syllable:Position	0.02	0.04	0.48	0.63
Syllable:Position:Mid	–0.16	0.05	–3.04	<0.01
Syllable:Consonant	–0.04	0.04	–0.96	0.34
Syllable:Consonant:Mid	–0.04	0.05	–0.76	0.45
Syllable:Position:Consonant	–0.05	0.05	–1	0.32
Syllable:Position:Consonant:Mid	0.12	0.07	1.58	0.11

Table 4: Effect of syllable on peripheral high and mid back rounded vowels' F2 (F2 values centered by subject). The estimate in the first row (Syllable) indicates the increase in [u]'s F2 in closed syllables compared to open syllables word-medially before [l].

	Estimate	Standard Error	t value	p-value
Syllable	0.08	0.05	1.7	0.1
Syllable:Mid	0.28	0.06	4.74	<0.01
Syllable:Position	0.08	0.05	1.78	0.08
Syllable:Position:Mid	0.22	0.06	3.46	<0.01
Syllable:Consonant	0.02	0.05	0.41	0.68
Syllable:Consonant:Mid	–0.06	0.06	–0.92	0.36
Syllable:Position:Consonant	–0.11	0.06	–1.75	0.08
Syllable:Position:Consonant:Mid	0.06	0.09	0.69	0.49

Duration

Figure 4 shows the effect of syllable on vowel duration across the four contexts. The model output is shown in Table 5. Vowels are consistently shorter in closed syllables than in open syllables except in word-final position before [ʁ]. The shortening effect is the largest in medial position before [ʁ]. In word-medial position, the shortening effect is larger on non-high vowels than on high vowels.

Summary

Mid vowels are lower and peripheral mid vowels are more central in closed than in open syllables across the four contexts in Experiment 1, in accordance with (H1). High vowels

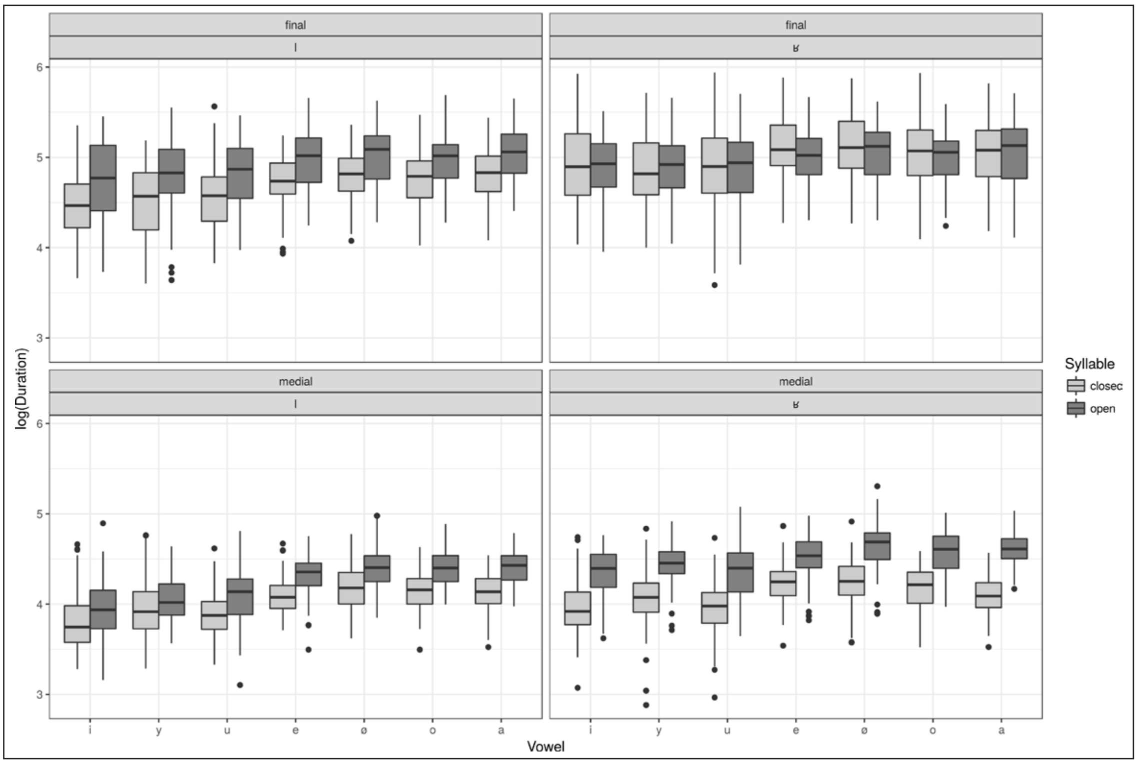

Figure 4: Vowel duration (in ms) in final/medial open/closed syllables before [l]/[ʁ] across speakers.

Table 5: The effect of syllable on vowel duration (log ms centered by subject). Syllable (in the first row) indicates the increase in duration for high vowels when going from open to closed syllables word-finally before [l].

	Estimate	Standard Error	t value	p-value
Syllable	−0.57	0.06	−9.5	<0.01
Syllable:Mid	0.1	0.06	1.75	0.08
Syllable:Low	0.1	0.08	1.28	0.2
Syllable:Position	0.25	0.05	4.59	<0.01
Syllable:Position:Mid	−0.33	0.08	−4.26	<0.01
Syllable:Position:Low	−0.39	0.11	−3.58	<0.01
Syllable:Consonant	0.5	0.05	9.13	<0.01
Syllable:Consonant:Mid	0.12	0.08	1.57	0.12
Syllable:Consonant:Low	−0.12	0.11	−1.13	0.26
Syllable:Position:Consonant	−1.05	0.08	−13.6	<0.01
Syllable:Position:Consonant:Mid	0.15	0.11	1.35	0.18
Syllable:Position:Consonant:Low	0.09	0.15	0.58	0.56

were also found to have higher F1 values in closed syllables than in open syllables, except word-medially before [l]. However, this effect is smaller than for mid vowels and it does not affect high vowels' F2, contrasting with the Québec French pattern of high vowel laxing where both F1 and F2 are affected and the effect of syllable structure is larger.

Vowels are generally shorter in closed syllables than in open syllables, in accordance with H2, except word-finally before [ʁ]. As pointed out by a reviewer, the fact that word-final [ʁ] patterns differently could be due to a difficulty to measure vowel duration in this context. In Standard French, the rhotic tends to be realized as a voiced fricative word-finally and as a voiceless fricative word-initially (Laeufer 1987 via Fougeron 2007). The presence of voicing word-finally would tend to make vowel duration harder to measure (consistent with the higher variability for this condition in Figure 4) and would likely result in closed-syllable measurements including more of the following consonant than open-syllable measurements (where the following consonant is word-initial and voiceless). This could help explain why this particular condition is different from the others in durational terms. An inspection of the spectrograms revealed that this hypothesis is plausible: word-final [ʁ] tends to be voiced and word-initial [ʁ] voiceless, resulting in a clearer boundary between the vowel and the following [ʁ] with word-initial [ʁ] than word-final [ʁ].

In the next section, I explore whether the different realizations of mid vowels in open vs. closed syllables and across prosodic and consonantal contexts can be analyzed as resulting from co-articulation, assuming fixed F1 and F2 targets for mid vowels across the board. Although small F1 differences were found for high vowels in open vs. closed syllables in most contexts, it will be assumed that high vowels have the same F1 target in open and closed syllables.

Exploratory analysis of co-articulation

If variations in the realizations of mid vowels in open vs. closed syllables are driven by closed-syllable vowel shortening (at least in the contexts where closed-syllable vowel shortening is clear, i.e. in all contexts except word-finally before [ʁ]), it is expected that differences in vowel quality disappear when duration is controlled for. In a given consonantal and prosodic context, close-mid and open-mid allophones should converge to the same vowel target as duration increases and the relation between duration and vowel quality should be continuous and monotonic across the two sets of allophones. If variations in the realizations of vowels across prosodic contexts result from vowel undershoot, word-medial and word-final vowels should converge to the same target in a given consonantal context and the relation between duration and vowel quality should also be continuous and monotonic across the two sets of allophones. If variations in the realizations of vowels across consonantal contexts also result from vowel undershoot, pre-[ʁ] and pre-[l] vowels should converge to the same target as duration increases. Also, vowels' F1 and F2 realizations are expected to become closer to the F1 and F2 targets of the following consonant as vowel duration decreases. The targets for [ʁ] and [l] were not estimated, but [ʁ] is known to have a larger F1 target and a smaller F2 target than [l] (Delattre 1959; Chafcouloff 1985).

Figure 5 shows how vowel F1 varies as a function of vowel height, vowel duration, vowel position in the word, and the following consonant. Mid vowels in open syllables and in closed syllables are distinguished as close-mid vs. open-mid.

The relationship between vowel duration and vowel quality for mid vowels across syllable types is not consistent with an undershoot account: close-mid and open-mid vowels clearly point to different F1 targets as vowel duration increases and the two sets do not lie on a continuum. This speaks against H2' and suggests that mid vowels have not only different F1 realizations but also different F1 acoustic targets in open and closed syllables.

However, the relationship between vowel duration and vowel F1 across prosodic and consonantal contexts is consistent with an undershoot account, where vowels have the same

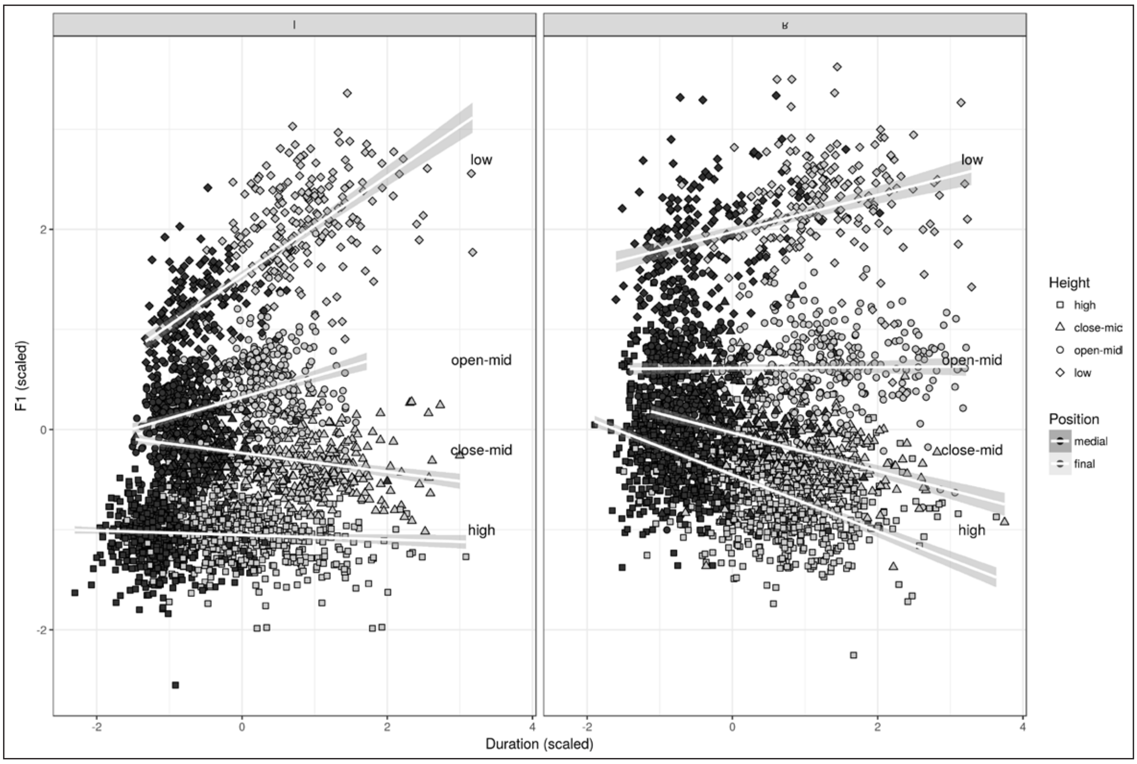

Figure 5: Vowel F1 as a function of vowel duration, vowel height, vowel position, and following consonant. F1 and Duration are scaled by speaker. The lines indicate the trends for each level of height. Vowels in medial syllables are shown in dark gray, and vowels in final syllables are shown in light gray.

F1 targets across consonantal and prosodic contexts. Vowels are shorter in word-medial than in word-final syllables. Vowel F1 converges toward a smaller value before [l] than before [ʁ] as vowel duration decreases and this trend is visible among medial vowels and among final vowels and for each height. This is compatible with a co-articulatory effect since [l] has a lower F1 target than [ʁ]. Also, vowels with F1 targets further away from the consonant target are more co-articulated (the slope is steeper) than vowels with closer F1 targets: [a] undershoots more its target in the [l] context and high vowels undershoot more their targets in the [ʁ] context. This is also consistent with a co-articulatory effect of [l] and [ʁ] on vowel F1. Vowel F1 converges to the same value for each level height across consonants, suggesting that there is a single vowel F1 target for each height level in both cases. These facts suggest that mid-vowel allophones are closer to each other in non-word-final syllables because they are more affected by co-articulation.

Figure 6 shows how vowel F2 varies as a function of vowel identity, vowel duration, and the following consonant. To improve readability, only the linear trends (with standard errors) are shown.

As for F1, the relationship between vowel duration and vowel F2 for peripheral mid vowels across syllable types is not consistent with an undershoot account: peripheral close-mid and open-mid vowels clearly point to different F2 targets as vowel duration increases and the two sets do not lie on a continuum. This also speaks against H2’ and suggests that peripheral mid vowels have not only different F2 realizations but also different F2 acoustic targets in open and closed syllables.

However, the relationship between vowel duration and vowel F2 across consonantal and prosodic contexts is consistent with an undershoot account. As vowel duration decreases, vowel F2 converges to a larger value with [l] than with [ʁ], except for [a], whose F2 value varies in a similar way in the two contexts. As in the case of F1, excluding [a], slopes

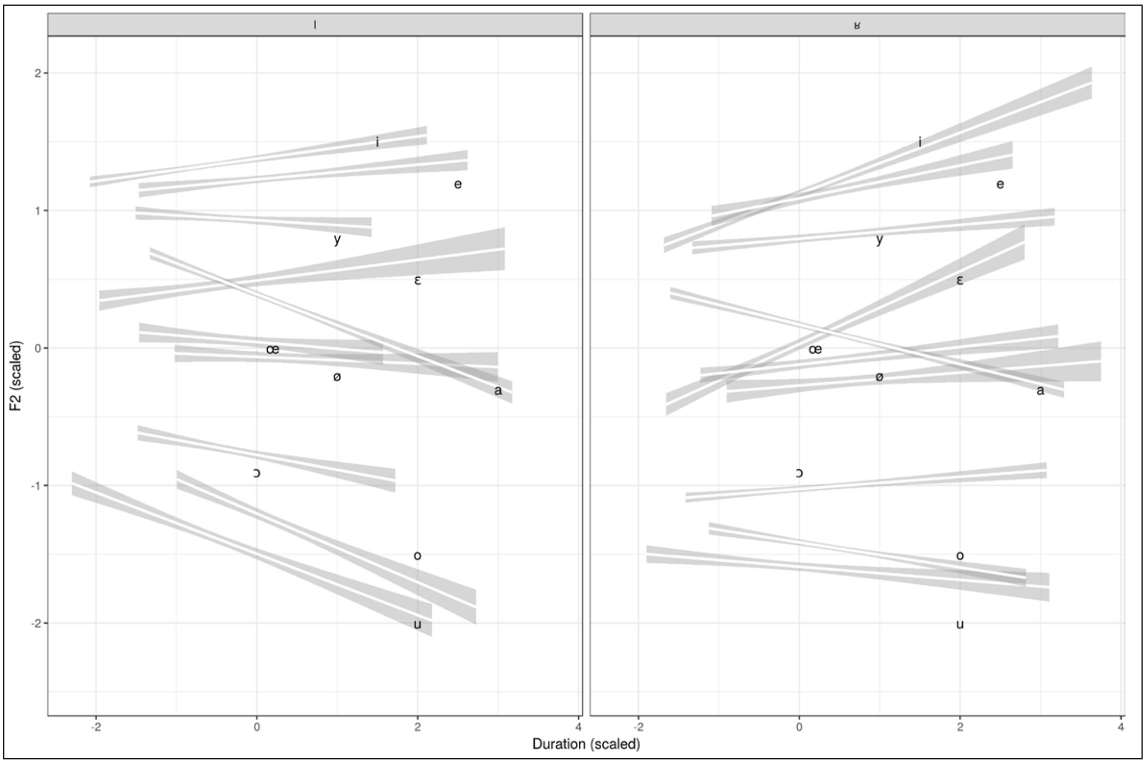

Figure 6: Vowel F2 as a function of vowel duration, vowel identity, and following consonant. F2 and Duration are scaled by speaker. To improve readability, only the linear trends (with standard errors) are shown.

are generally steeper for vowels which are further away from the consonantal target everything else being equal. For instance, the slope for [u] is steeper than the slope for [i] in the [l] context and the slope for [i] is steeper than the slope for [u] in the [ʁ] context. This is consistent with a co-articulatory effect of [l] and [ʁ] on vowel F2, at least for non-low vowels. Vowel F2 converges to the same value for each vowel across consonants, suggesting that there is a single vowel F2 target for each vowel in both cases.

3.2 Experiment 2

Figure 7 summarizes the distribution of the seven oral vowels over the F1 × F2 space in final/medial open/closed syllables across speakers in Experiment 2. The general distribution of the vowels is comparable with the results in the pre-[l] context in Experiment 1: vowels with high F1 values or low F2 values word-finally show less extreme formant realizations word-medially.

F1

The results for F1 are shown in Figure 8. The output of the statistical model is shown in Table 6. Mid vowels have higher F1 values in closed than in open syllables before [s] both word-medially and -finally, and the distance between mid-vowel allophones in open and closed syllables is larger word-finally. High vowels have higher F1 values in closed syllables than in open syllables only word-finally and the effect is smaller than for mid vowels. As in Experiment 1, the low vowel patterns differently from high and mid vowels: its F1 value is not increased in closed syllables.

F2

The results for F2 are shown in Figure 9. Only peripheral mid vowels have significantly different F2 values in open and closed syllables. The outputs of the statistical models for

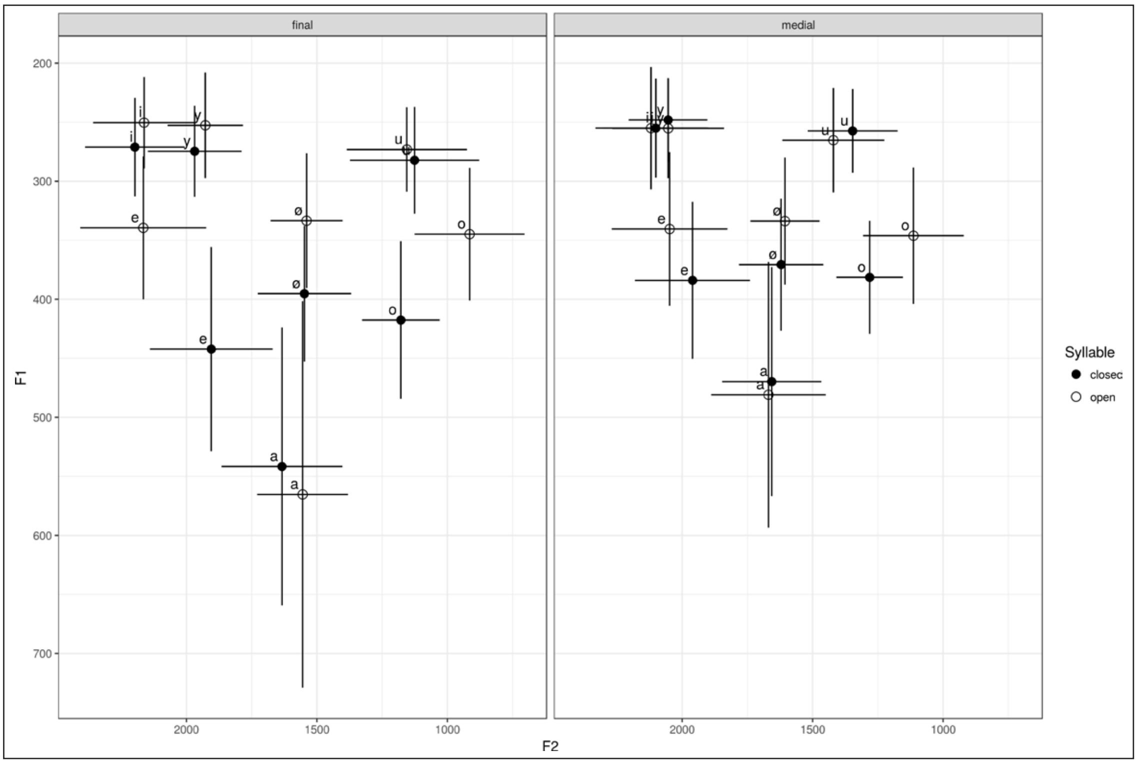

Figure 7: Mean vowel F1 and F2 in Hz (with standard deviations) in final/medial open/closed syllables before [s] across speakers.

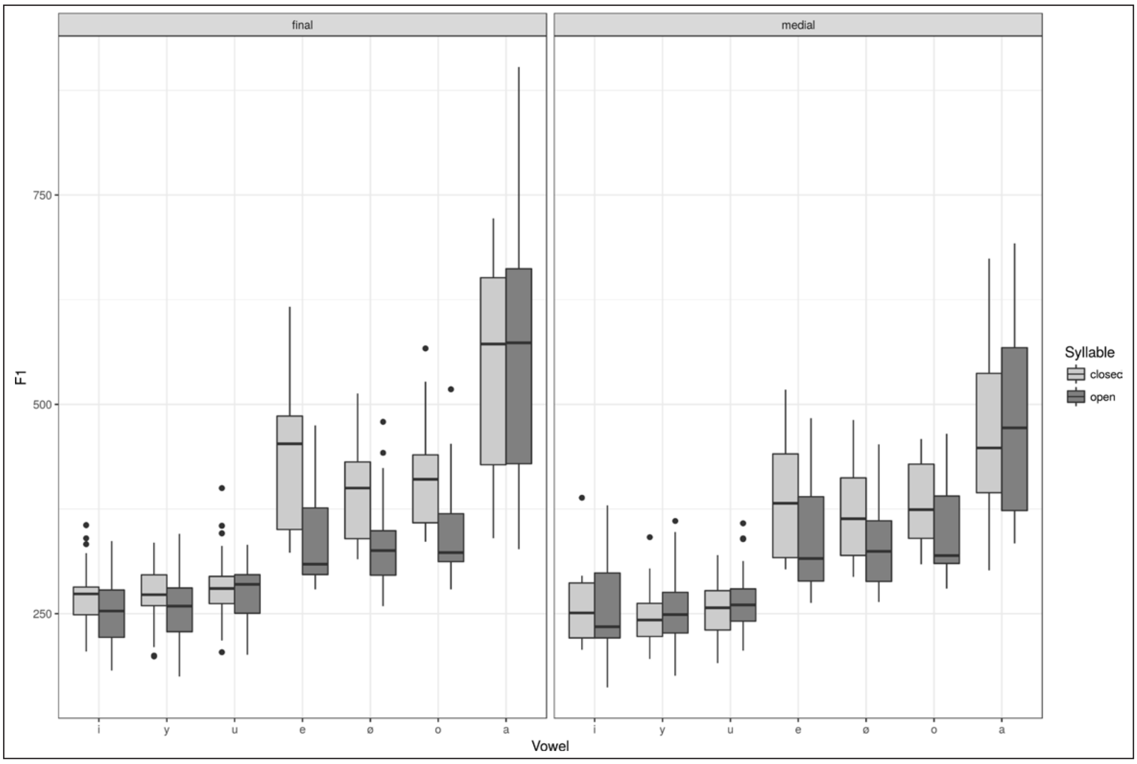

Figure 8: Vowel F1 (in Hz) in final/medial open/closed syllables before [s] across speakers.

front unrounded and back rounded vowels are shown in Table 7 and Table 8, respectively. Peripheral mid vowels have significantly more central F2 realizations in closed than in open syllables across medial and final positions. The F2 realizations of other vowels are

Table 6: Effect of syllable on vowel F1 (F1 values centered by subject). The estimate in the first row (Syllable) indicates the increase in high vowels' F1 in closed syllables compared to open syllables word-medially. Interactions in subsequent rows show how the effect of syllable differs in the context appearing as the rightmost element in the interaction and in the corresponding baseline context.

	Estimate	Standard Error	t value	p-value
Syllable	−0.04	0.06	−0.79	0.44
Syllable:Mid	0.47	0.09	5.46	<0.01
Syllable:Low	0.06	0.22	0.27	0.79
Syllable:Position	0.24	0.07	3.3	<0.01
Syllable:Position:Mid	0.14	0.1	1.38	0.17
Syllable:Position:Low	−0.39	0.14	−2.75	0.01

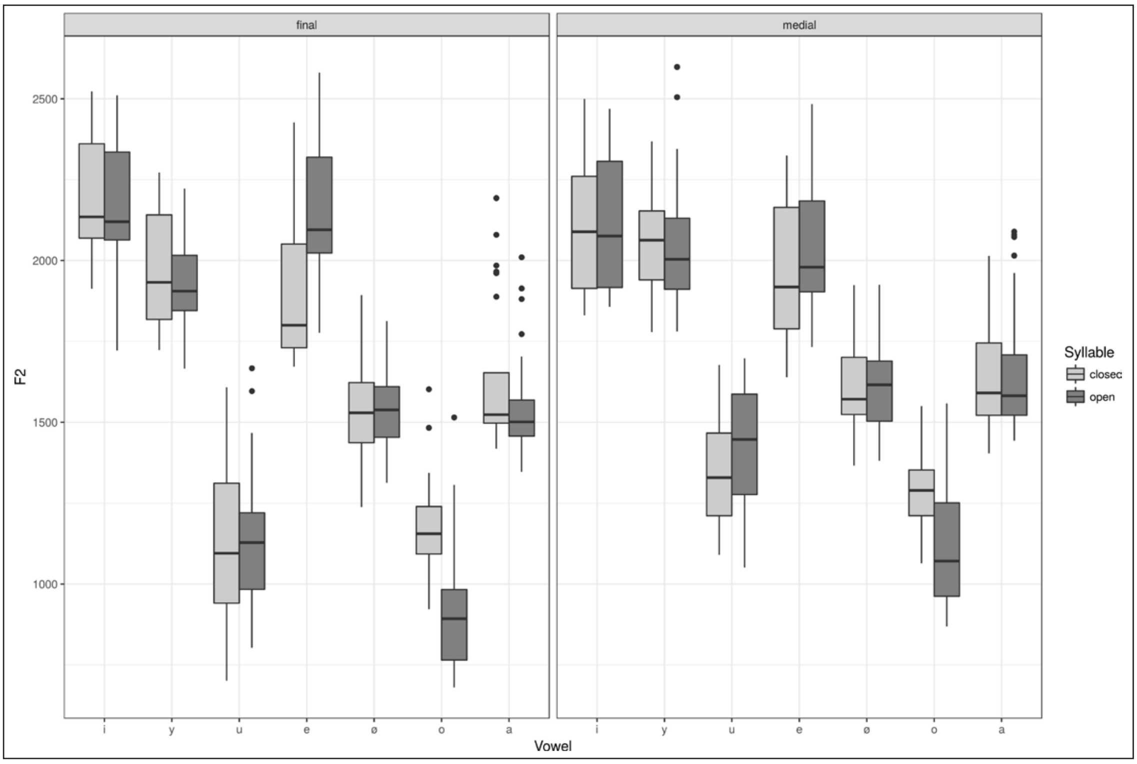

Figure 9: Vowel F2 (in Hz) in final/medial open/closed syllables before [s] across speakers.

Table 7: Effect of syllable on peripheral high and mid front unrounded vowels' F2 (F2 values centered by subject). The estimate in the first row (i.e., Syllable) indicates the increase in [i]'s F2 in closed syllables compared to open syllables word-medially.

	Estimate	Standard Error	t value	p-value
Syllable	−0.05	0.06	−0.73	0.47
Syllable:Mid	−0.2	0.08	−2.58	0.02
Syllable:Low	0.02	0.08	0.25	0.8
Syllable:Position	0.09	0.07	1.27	0.2
Syllable:Position:Mid	−0.58	0.1	−5.84	<0.01
Syllable:Position:Low	0.11	0.1	1.12	0.26

not significantly affected by syllable structure. The F2 distance between [e] and [ɛ] is significantly larger word-finally than word-medially.

Duration

The results for duration are shown in Figure 10. No vowel was found to have a significantly different duration in open and closed syllables word-medially or word-finally. A likelihood ratio test was performed and showed that adding syllable structure as a fixed effect does not significantly improve model fit ($\chi^2 = 13.47$, df = 14, p = 0.49).

Summary

Mid vowels have consistently higher F1 values and peripheral mid vowels have consistently more central F2 values in closed than in open syllables before [s], in accordance with H1. Mid vowels are never shorter in closed than in open syllables, against H2. Because H2' entails H2, these results speak also against H2'. These results are consistent with the results of Experiment 1, with the following difference: coda [s] does not trigger vowel shortening in word-medial or in word-final syllables. As in Experiment 1, the F1 and F2 distances between close-mid and open-mid allophones tend to be larger word-finally than word-medially. In the next section, I explore whether these variations can be analyzed as resulting from co-articulation.

Table 8: Effect of syllable on peripheral high and mid back rounded vowels' F2 (F2 values centered by subject). The estimate in the first row (Syllable) indicates the increase in [u]'s F2 in closed syllables compared to open syllables word-medially.

	Estimate	Standard Error	t value	p-value
Syllable	–0.2	0.17	–1.16	0.28
Syllable:Mid	0.61	0.23	2.65	0.03
Syllable:Low	0.18	0.19	0.93	0.37
Syllable:Position	0.09	0.12	0.77	0.44
Syllable:Position:Mid	0.17	0.17	1.01	0.31
Syllable:Position:Low	0.1	0.17	0.61	0.54

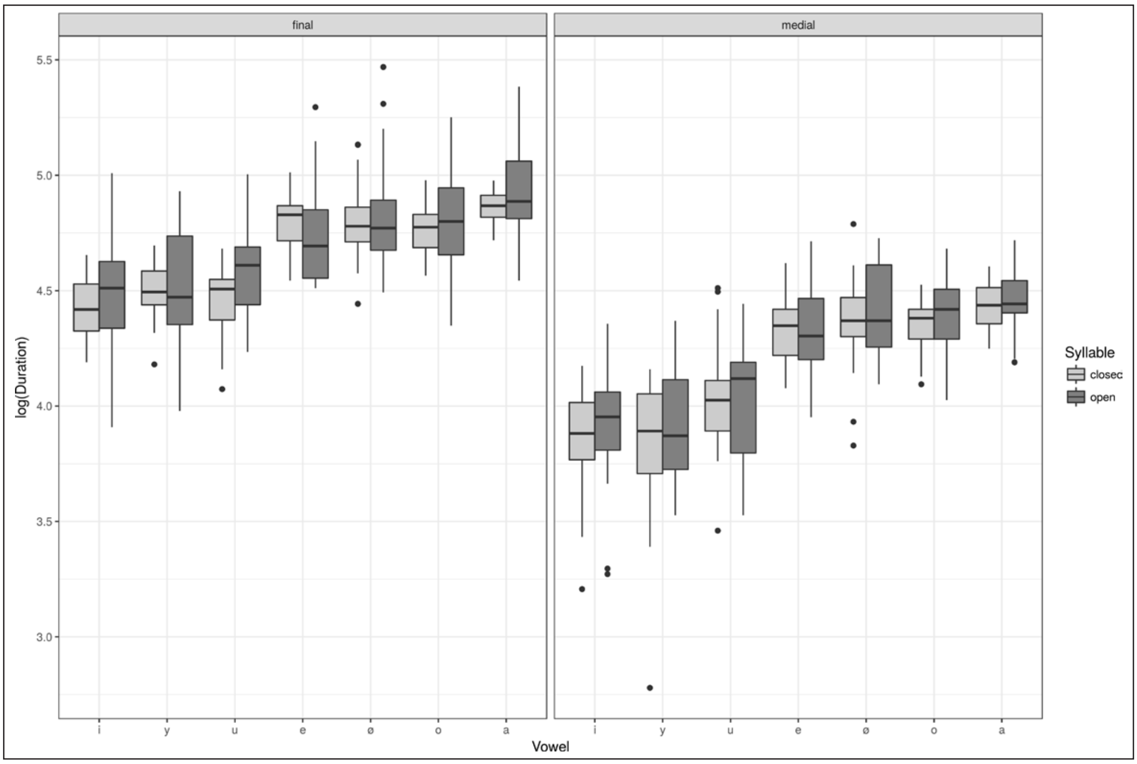

Figure 10: Vowel duration (in ms) in final/medial open/closed syllables before [s] across speakers.

Exploratory analysis of co-articulation

As a dental fricative, [s] is expected to have a relatively small F1 target and a relatively high F2 target. Figure 11 shows how vowel F1 varies as a function of vowel height, vowel duration, and vowel position in the word before [s].

The relationship between vowel duration and vowel F1 for mid vowels across syllable types is not consistent with an undershoot account: close-mid and open-mid vowels clearly point to different F1 targets as vowel duration increases and the two sets do not lie on a continuum. This speaks specifically against H2'.

However, the relationship between vowel duration and vowel F1 across word-medial and word-final positions is consistent with an undershoot account. Vowels are shorter in medial than final syllables. F1 values converge toward a relatively low value and become more similar with decreasing duration. This trend is visible among final and medial syllables. [a] undershoots more its target than other vowels. These results are consistent with a pattern of undershoot. This is consistent with vowels having the same F1 target across word-medial and word-final contexts.

Figure 12 shows how vowel F2 varies as a function of vowel identity and vowel duration in the word before [s].

As vowel duration decreases, F2 values converge to a high region in F2. Slopes are generally steeper for vowels with more extreme formant values (e.g., for [o] and [u]). This is consistent with a co-articulatory effect of [s] on vowel F2. This is consistent with vowels having the same F2 target across word-medial and word-final contexts.

4 General discussion

4.1 Acoustic correlates of the close-mid/open-mid distinction

One of the major results of this study is that mid-vowel lowering and centralizing do not entail mid-vowel shortening in French. This is at odds with phonological accounts of the *loi de position* as a phenomenon of vowel reduction. These accounts further assume

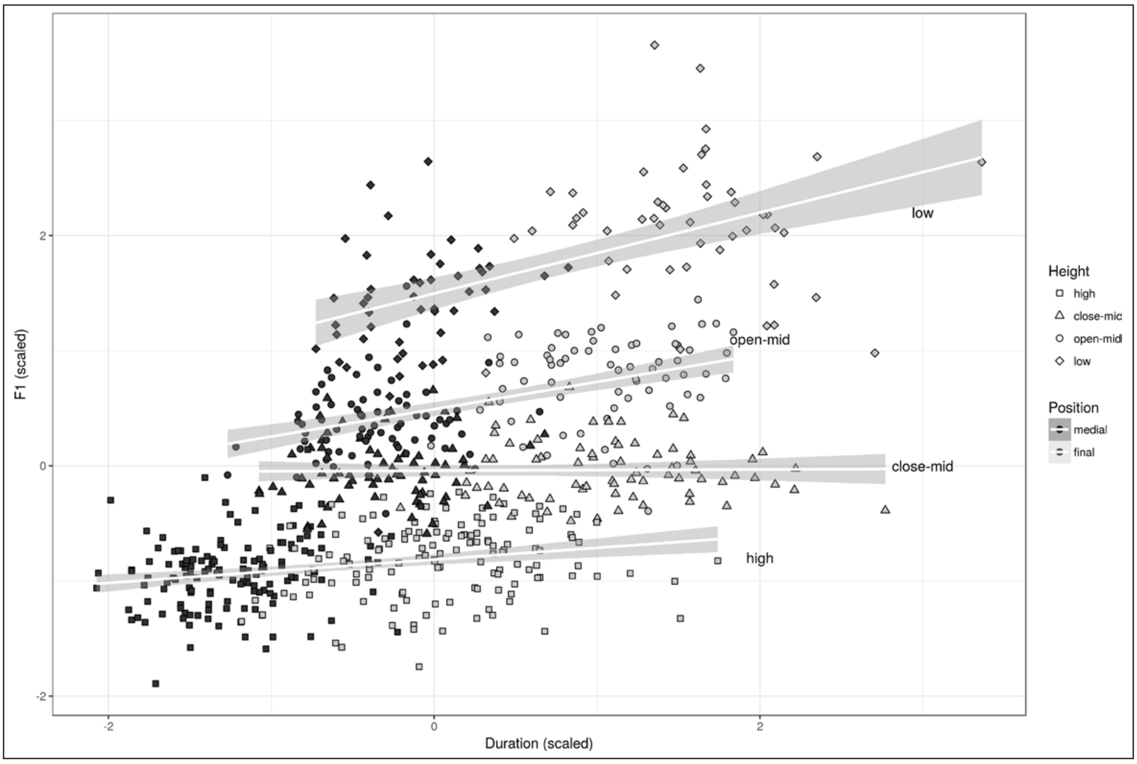

Figure 11: Vowel F1 as a function of vowel height and vowel position before [s]. F1 and Duration are scaled by speaker.

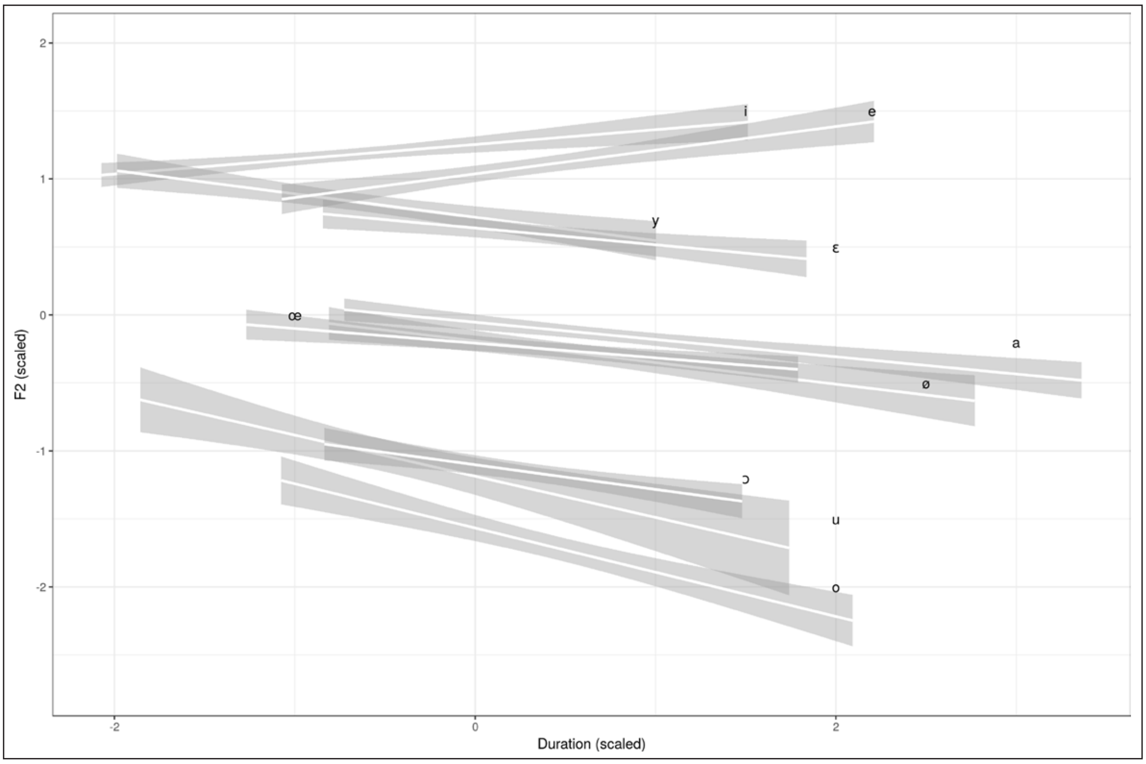

Figure 12: Vowel F2 as a function of vowel height and duration before [s]. F2 and Duration are scaled by speaker.

that there is an inherent relation between shorter duration and laxing, understood as an increase in F1 and F2 centralizing. However, the patterns of vowel undershoot observed in French in Gendrot and Adda-Decker (2005) and in the present study cast a doubt on this connection. The present study showed that the patterns of undershoot vary by consonant, as expected under Lindblom's (1963) model, and do not necessarily involve an increase in F1 (this only happens with [ʁ]). Also, close-mid and open-mid vowels do not converge to the same acoustic targets as vowel duration increases.

The results are compatible with close-mid and open-mid vowels having different F1 and F2 targets, but not necessarily different durational targets, at least in French varieties obeying the *loi de position*.[2] [ø] and [œ] were not found to have different F2 targets. This is consistent with other studies which only report an effect of syllable structure on the F2 of peripheral mid vowels. High vowels were found to have a higher F1 value in closed syllables than in open syllables, except in word-medial positions before dental segments ([s] and [l]). This is also the context where the F1 distances between mid-vowel allophones were the smallest. This suggests that the *loi de position* also affects high vowels. However, the effect on high vowels is smaller than for mid vowels and does not affect F2. Syllable structure was found to have a very different effect on [a] vs. non-low vowels. In particular, [a] was sometimes found to have a lower F1 value in closed than in open syllables. This happens in particular in contexts with closed-syllable vowel shortening in Experiment 1, suggesting that the raising of the low vowel in closed syllables can be due to vowel undershoot.

The *loi de position* can probably not be reduced to an increase in F1 while analyzing the centralizing of F2 for peripheral mid vowels as a by-product of this increase, due to the

[2] Standard French has close-mid/open-mid vowel contrasts in penultimate syllables before schwa and these contrasts involve duration, with [o] and [ø] being longer than [ɔ] and [œ] respectively (Gottfried & Beddor 1988). Therefore durational targets must be specified for close-mid and open-mid vowels in this variety of French.

bell shape of the vowel space. The space of vowels which can be produced by the human vocal tract is assumed to display a front-back asymmetry (Liljencrants & Lindblom 1972). If F2 centralizing followed from an increase in F1 alone, the F2 distance between [o] and [ɔ] would probably be smaller than the F2 distance between [e] and [ɛ]. But the centralizing effect does not appear to be asymmetric between front and back in this way.

4.2 Vowel duration

The results suggest that vowel duration is determined by vowel height, with duration(high) < duration(mid) < duration(low), and by the context in which vowels occur. The effect of the context appears to be largely independent of vowel height: vowels are shorter in word-medial than in word-final positions and vowels are shortened before coda liquids (setting aside the case of the word-final rhotic) but not before coda [s]. These findings are consistent with previous research on the role of height (Lehiste 1970; Escudero & Boersma 2009), word-position (Delattre 1969; O'Shaugnessy 1984), and coda-consonant manner (Katz 2012) on vowel duration. Katz (2012) showed a similar asymmetry between liquids and obstruents in English: English vowels followed by a liquid-voiced obstruent cluster (e.g., [dɪlb]) are shorter than those followed by a singleton liquid (e.g., [dɪl]) but this cluster-driven compression does not obtain for similar pairs containing obstruents (e.g., [dɪs] vs. [dɪsp]) in place of the liquid.

4.3 Co-articulation

Another important result of this study is that the open-mid/close-mid distinction holds across different consonantal contexts and both word-medially and word-finally. Together with Nguyen and Fagyal's (2008) finding that vowel co-articulation does not override the effect of the *loi de position* in Southern French, the results of this study suggest that co-articulation is in general not strong enough to neutralize the allophonic distribution of close-mid and open-mid vowels.

The exploratory analysis of co-articulation suggests that it is likely that the differences in the allophonic distances between mid-vowel allophones in medial and final syllables can be explained in terms of vowel undershoot. It is possible that differences across consonants are to be explained this way as well. As long as consonants have different F1 and F2 targets and different effects on vowel duration, it is expected that patterns of vowel undershoot will vary across consonants. For instance, the F1 target for [l] appears to be between the F1 targets for close-mid and open-mid vowels whereas the F1 target for [ʁ] appears to be similar to the target for open-mid vowels. This alone could explain why F1 distances between close-mid and open-mid allophones are smaller before [l] than [ʁ] word-medially: in the case of [l], both close-mid and open-mid vowels are moving closer to each other when assimilating to [l], whereas in the case of [ʁ], only the close-mid vowels will shift towards the open-mid vowels. Another fact that could explain the difference between [l] and [ʁ] word-medially is the overall longer duration of vowels before medial onset [ʁ] than medial onset [l].

The patterns of co-articulation described in this study might be responsible for the uncertainty reported in the phonological literature as to whether the *loi de position* holds word-medially. Because F1 and F2 distances between close-mid and open-mid vowels are generally smaller word-medially, the allophonic distribution should be harder to detect by ear in that context. Also, I found that close-mid vowels and open-mid vowels may have similar realizations in different consonantal contexts due to co-articulation: for instance, the F1 of open-mid vowels before coda [l] was found to be similar to the F1 of close-mid vowels before onset [ʁ] (see Figure 2). Failing to carefully control for the consonantal context when assessing the close-mid vs. open-mid quality of a word-medial vowel might therefore lead to overlook the actual effect of syllable on mid vowels.

4.4 The phonology and phonetics of the loi de position

In this section, I present a sketch of a rule-based analysis accounting for the main qualitative patterns observed in this study. The allophonic distribution of close-mid and open-mid vowels is derived in a SPE phonological grammar operating on discrete representations (Chomsky & Halle 1968). Close-mid vowels, specified as [–low, +mid], are part of the inventory of input segments whereas open-mid vowels, specified as [+low, +mid], are not. This ensures that mid vowels will surface as close-mid by default. By the lowering rule in (1) (Dell 1985), any input vowel specified as [–low, +mid] is mapped to an output vowel specified as [+low, +mid] if it occurs in a closed syllable or before a syllable containing a schwa in the output.

(1) Lowering rule: [–low, +mid] → [+low, +mid] / _{C., *Cə}

A phonetic grammar assigns numerical acoustic targets to the segments output by the phonological grammar. The F1 and F2 targets depend on the featural specifications of the output vowels. Durational targets are determined based on the specific context in which mid vowels occur. For instance, vowels have longer durational targets in word-final syllables than in word-medial syllables, vowels have shorter durational targets in closed syllables than in open syllables before medial [ʁ], etc. The realizations of the F1 and F2 targets for mid vowels in a specific context are affected by their durational targets in that context according to Lindblom's (1963) model of vowel undershoot: mid vowels undershoot their formant targets by a proportion of the distance to the formant targets of the following consonant, and this proportion increases as vowel duration decreases. As a consequence, mid vowels generally deviate more from their targets and become more similar to the following consonant in medial syllables, resulting in smaller acoustic distances between close-mid and open-mid allophones in this context.

4.5 Consequences for the typology of closed-syllable vowel laxing

The patterns of vowel reduction documented in the present study and elsewhere (e.g., Gendrot & Adda-Decker 2005) do not point towards an inherent relationship between shortening and laxing (understood as F1 raising and F2 centralizing). As vowel duration decreases, vowel formants assimilate more to the consonantal context. Because most consonants have high F1 targets, like [l] and [s], vowel reduction for mid vowels in closed syllables should not result in an increase in F1 in most coda contexts. Assuming that patterns of co-articulation are qualitatively similar across languages and roughly follow Lindblom's (1963) model, this means that laxing is unlikely to be due to shortening, even in languages in which closed-syllable laxing is always accompanied by closed-syllable shortening.

5 Conclusion

The primary goal of this paper was to better establish the role of F1, F2, and duration in the close-mid/open-mid distinction in a French variety in which mid vowels follow the *loi de position*. The results indicate that mid vowels are consistently lower and peripheral mid vowels more central in closed syllables than in open syllables, but not shorter. Allophonic distances between close-mid and open-mid vowels vary in different prosodic and consonantal contexts and these variations are compatible with an undershoot analysis. From a typological perspective, the results indicate that closed-syllable vowel laxing cannot be generally conceived as a pattern of vowel reduction and that vowel quality can be affected by syllable structure independently of vowel duration.

In addition to its implications for our understanding of the *loi de position* and of the typology of closed-syllable vowel laxing, this work provides a foundation for future work on phonological phenomena which involve mid vowels in French. In particular, it provides reference data to investigate the effects of phonological environments (e.g., the role of schwa on a preceding mid vowel, see Eychenne 2014) and morphological environments (e.g., the role of prefix-stem and stem-suffix boundaries, see Durand 1990) on mid vowels. It also has implications for the transcription of mid vowels in Southern French.

Abbreviations

C = consonant, F1 = first formant, F2 = second formant, HZ = Hertz, KHZ = kilohertz, MS = millisecond, SD = standard deviation, SPE = Sound Patterns of English, V = vowel

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Competing Interests

The author has no competing interests to declare.

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