Isogloss
Open Journal of Romance Linguistics

**Received**: 22-09-2024
**Accepted**: 01-04-2025
**Published**: 14-07-2025

# Reconsidering the mid vowel system of Parisian French: Phonetic and phonological factors

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**How to cite:** Griffiths, Joshua M. & Margaret E. L. Renwick. 2025. Reconsidering the Mid Vowel System of Parisian French: Phonetic and Phonological Factors. RLLT 25, eds. Adam McBride, James Law & Willis Fails. Special Issue of *Isogloss. Open Journal of Romance Linguistics* 11(5)/8, 1–21.
**DOI:** https://doi.org/10.5565/rev/isogloss.503

**Abstract**

The French mid vowel system exhibits a complex marginal phonological contrast. The distributions of three pairs of vowels (/e, ɛ/; /o, ɔ/; /ø, œ/) are neither completely contrastive nor allophonic, and their heights vary, leading to overlapping phonetic realizations. This paper explores the phonetic and phonological factors that determine mid vowel height in Parisian French. We especially explore the relative contributions of phonological grammar, including the tension between contrast maintenance and positional neutralization based on syllable structure alongside the phonetic factor of vowel duration. Results are formalized in Maximum Entropy Grammar (Goldwater & Johnson 2003) with constraint scaling (Coetzee & Kawahara 2013) to model the interplay of phonetics and phonology. We find that speakers of Parisian French do tend to realize these vowels more faithfully than in varieties in which the *loi de position* is consistently productive, but realizations are still highly variable, and although an effect of duration was observed, we find that vowel length may not play a role in helping speakers distinguish high- and low-mid vowels.

**Keywords:** French, mid vowels, phonetics, phonology, marginal contrast.

## 1. Introduction

Phonological theory has traditionally been predicated upon the notion of contrast, understood as the representational capacity of sounds to distinguish higher-level units within a language. Recent research in speech perception and production has shown that a binary conceptualization of contrast in which sounds are either fully contrastive or allophonic may not be entirely adequate. Contrasts may instead be gradient, leading to a marginal contrast between sounds that are neither robustly contrastive nor allophonic. The Romance languages contain many such marginal contrasts, especially in their mid vowels, exemplified by the minimal pairs in (1)–(3).

(1) Italian (Renwick 2024: 5)
foro /fo.ro/ 'hole' vs. foro /fɔ.ro/ 'forum'

(2) Portuguese (Veloso 2024: 26)
besta /beʃtɐ/ 'beast' vs. besta /bɛʃtɐ/ 'crossbow'

(3) Catalan (Nadeu & Renwick 2016: 36)
néta /netə/ 'granddaughter' vs. neta /nɛtə/ 'clean'

Height-based variation in these mid vowels may lead to overlapping phonetic realizations and partial neutralization of the phonemic contrasts shown above. Many of the vowel systems in question typify classic seven-vowel inventories with two pairs of mid vowels /e, ɛ/ and /o, ɔ/. French is unusual among Romance languages in that it contains a third pair of mid vowels in /ø, œ/ which arose from changes that took place during the transition from Old French to Middle French (Pope 1934; Martinet 1955).

The difference in height within the pairs /e ɛ/, /o ɔ/, and /ø œ/ is typically characterized as a distinction in *tenseness*, where the higher vowels are tense and the lower are lax. The vowels' rounding and backness historically derive from the quality and phonotactic conditions of their Latin etymons (for an overview see e.g. Pope 1934: 208–214; Alkire & Rosen 2010), but their tenseness is linked to syllable structures that developed within French and may have undergone subsequent systematic changes. A great deal of research on these vowels has examined whether and how they contrast phonologically, as well as factors conditioning their distributions, namely the *loi de position*, or the tendency under stress for the lax vowels to be realized in closed syllables and the tense vowels to be realized in open syllables. However, some degree of contrast between these pairs of vowels is evidenced by the minimal pairs in (4).

(4) French contrasts between tense and lax vowels
a. épée /epe/ 'sword' vs. épais /epɛ/ 'thick'
b. rauque /ʁok/ 'hoarse' vs. roc /ʁɔk/ 'rock'
c. jêune /ʒøn/ 'fast' vs. jeune /ʒœn/ 'young'

Bullock (1995: 273) attributes the maintenance of this contrast to the phonemicization of the mid vowels in particular lexical entries. Yet, regardless of the presence of structural contrast for these vowels, the pronunciations of the words listed in (4) are variable, and they may be distinct or homophonous. This is analogous to the behavior of similar vowels in other Romance languages and indicates the marginal nature of French tense/lax distinctions.

The distribution of tense vowels in open syllables, but lax vowels in closed syllables, is challenging to formalize and explain. In particular, since lax vowels are phonetically lower in the vowel space, increased articulatory effort and time should be required to achieve their lowered target; paradoxically, the restriction of lax vowels to *closed* syllables shortens their duration compared to tense counterparts. Expanding upon dispersion theory (Flemming 2004; Liljencrants & Lindblom 1972), Storme (2019) suggests that the distributions of lax vowels in closed syllables and tense vowels in open syllables serve as a means of contrast enhancement and that the phonological grammar plays a role in enhancing perceptual contrast. He argues that lax vowels, which are typically shorter than tense vowels, enhance distinctiveness among coda consonants due to the characteristics of their VC formant transitions. At the same time, tense vowels enhance distinctiveness in vowel contrasts due to increased vowel peripherality.

Building upon this perspective, we argue that variable realizations of the mid vowels can be modeled as a manifestation of the tension between maximizing consonant distinctions, via contrast enhancement (Stevens, Keyser & Kawasaki 1986) and vowel dispersion, which privileges phonetic differences even at the expense of surface contrast. The tension between these systemic constraints results in variable realizations of the mid vowels, a phenomenon not previously addressed in the contrast enhancement approach to the *loi de position* (Storme 2019). We further suggest that the realizations of the French mid vowels are at the interface of phonetics and phonology. They allow for an investigation into the extent to which a marginal contrast may be driven by phonetic factors and to what extent it may be driven by phonological factors. We proffer an analysis of the phonetic and phonological factors affecting the mid vowel system in Parisian French, a standard variety which has traditionally been described as maintaining both a contrast in the mid vowel system and synchronic alternations linked to syllable structure. We especially explore the relative contributions of phonological grammar, including the tension between contrast maintenance and positional neutralization based on syllable structure, as well as the phonetic factor of vowel duration. This interplay between phonetics and phonology is explored through a bipartite analysis comprised of (1) an acoustic analysis of corpus data; and (2) a formal analysis framed in Maximum Entropy Grammar (Goldwater & Johnson 2003) with constraint scaling (Coetzee & Kawahara 2013; Coetzee 2016). We argue that even in varieties that have been described as maintaining contrast in the mid vowel system, the tense/lax contrast is still marginal—albeit to a lesser degree than in Southern varieties. In the rest of the Introduction, we outline prior accounts of the French mid vowels and the phonetic and phonological factors that have been identified as affecting their realization.

## 1.1. Phonetic and phonological factors affecting mid vowel realization in French

A central goal of the present study is to understand how much of the mid vowels' realization is driven by the phonological grammar and how much of it is driven by non-grammatical phonetic factors. Previous accounts of the instability of the French mid vowels have examined the various factors at play affecting their realizations, which we discuss briefly. These include language-internal factors that may be phonetic

(Gendrot & Adda-Decker 2005; Boula de Mareüil, Adda-Decker & Woehrling 2010; Storme 2017), phonological (Nguyen & Fagyal 2008; Eychenne 2014), morphological (Durand 2014), and syntactic or semantic (Rochet 1980), as well as sociolinguistic factors, particularly regional variety (Detey et al. 2016: 59) and the individual speaker (Landick 2004). Such influences may not apply consistently, though, so any analysis of the mid vowels must observe to what degree non-phonological factors are relevant and how they interface with the phonological grammar.

Literature on French mid vowels has examined a tendency underlying their distributions in stressed syllables, known as the *loi de position*. Fouché (1935: 17) first describes the *loi de position* in absolute terms stating that it requires that the mid-close variants [e, ø, o] be realized in open stressed syllables while the mid-open variants [ɛ, ɔ, œ] are realized in closed stressed syllables, even if this does not match the lexical form or creates a homophone. The *loi de position* would therefore predict the realizations shown in (5).

(5) French *loi de position*
a. lait /lɛ/ → [le] 'milk' vs. laide /lɛd/ → [lɛd] 'ugly'
b. peau /po/ → [po] 'skin' vs. gnôle /ɲol/ → [ɲɔl] 'hooch'
c. jeûne /ʒøn/ → [ʒœn] 'fast' vs. jeune /ʒœn/ → [ʒœn] 'young'

Adherence to the *loi de position* varies across varieties, with its application being more productive in Meridional varieties, but even in varieties in which the *loi de position* is more readily applied there tend to be exceptions and a great deal of intra- and inter-speaker variability (Eychenne 2014). Scholars disagree on the exact underpinnings of the *loi de position*, with some accounts (Féry 2003; Lyche 2003) suggesting that it is a process of phonological reduction, while others argue that its application is driven by more phonetic factors, such as differences in aperture (Eychenne 2014) or as the result of duration-induced vowel undershoot (Storme 2017). Given the restriction of the *loi de position* to stressed syllables, the formal analysis presented in Section 3 examines only vowels in that context.

Vowel harmony is another phonological process affecting the realizations of mid vowels. Vowel harmony in French is a regressive assimilation process in which a mid vowel in an open pre-tonic syllable takes on the height features of the stressed vowel that immediately follows. Nguyen and Fagyal (2008) show that vowel harmony in French—like the *loi de position*—is highly variable, inconsistently applied, and can often result in the vowel taking on an intermediary height value between the low-mid and high-mid vowels. Our corpus lacks sufficient tokens where harmony was possible, so it will not be discussed further in the present analysis.

Trends in the durational patterns of French mid vowels can be considered in light of cross-linguistic phonetic tendencies, including as they occur in other Romance languages. They can also help us assess whether duration should be considered a grammatical or non-grammatical factor in a formal analysis. Two factors to consider are potential relationships between vowel tenseness and duration, and the link between vowel height and duration. In non-Romance languages like English and German, tense vowels are typically phonetically longer than lax vowels; however, in Italian, vowel duration distinctions are driven by their inverse relationship to vowel height (Esposito 2002). Stress, syllable structure, and position of the stressed syllable within the word also mediate duration (Farnetani & Kori 1986; D'Imperio & Rosenthall 1999), such that the longest vowels are stressed low vowels in penultimate open syllables. Under long durations, greater articulatory jaw movement is possible, leading to increased openness and greater first formant values. Recent corpus-based comparisons of Italian mid vowel durations found that such a correlation is stronger for low-mid [ɛ ɔ] than high-mid [e o], suggesting that duration is harnessed to phonetically enhance the mid vowel contrasts (Renwick 2024). In French, as in Italian, vowel length is not lexically contrastive. Its tense vowels are longer than lax vowels (Delattre 1959; Tranel 1987), and as in many languages, vowels are longer before voiced than voiceless consonants (Laeufer 1992). Despite these consistent patterns, French listeners do not use duration as a perceptual correlate of height (i.e., tenseness) for mid vowels, suggesting this property is not tied to the identification of phonological vowel category (Gottfried & Beddor 1988).

Turning to the issue of classifying duration as a grammatical vs. non-grammatical factor for French, we note that Coetzee (2016) treats speech rate (a duration-related parameter) as non-grammatical. In so doing, he draws on a traditional sociolinguistic treatment (Labov 1966; Guy 1991) which holds that the two types of factors are understood to be *independent*. Given evidence that duration does not directly assist vowel quality identification in French (Gottfried & Beddor 1988), where the latter is phonological in nature, these factors are independent. This motivates our present treatment of duration as a non-grammatical factor that nonetheless relates to and can help quantitatively predict phonetic height. Our treatment of vowel duration as non-grammatical aligns with findings (Storme 2019) that the influence of syllable structure on vowel quality is independent of duration.

The discussion above makes clear that several factors affect, and therefore cause variation in, the tenseness/height of French mid vowels. The *loi de position* is a potentially powerful phonological force encouraging the neutralization of contrast through contextual dependence on syllable structure. Mitigating against this process, however, is faithfulness to lexical specification, a force that acts to maintain contrast and retain lexical distinctions in phonetic form. In the acoustic analysis that follows in Section 2, this is codified explicitly according to the prescriptive quality of the stressed mid vowel in each word, corresponding to the input in the subsequent formal analysis. The output pronunciation is expected to reflect the extent to which grammatical factors like the *loi de position*, non-grammatical factors like duration, and additional parameters not manipulated in this dataset impinge upon the faithful realization of input forms.

Taking the above-mentioned factors into consideration, we propose a revised analysis of the mid vowel system of Parisian French in the rest of this paper. Our treatment has two parts. We first conduct an acoustic and quantitative analysis of corpus data, to estimate the rates at which mid vowels are realized as either tense or lax in French. These results are then input to a formal analysis framed in Maximum Entropy Grammar. Both components of this analysis serve to complement one another. Not only do they provide a more comprehensive picture of how this vowel system is realized, but they also offer a concise, quantifiable account of the interplay of phonetic factors and phonological grammar. In Section 2, we present the corpus that was subject to analysis as well as the acoustic analysis. This is followed in Section 3 by a description of the formal framework adopted here and its application to French mid vowel data. We conclude in Section 4 with a synthesis of the analyses presented in Sections 2 and 3 as well as their overall implications for French phonology.

## 2. Data & Acoustic Analysis

Data for this study come from the *Phonologie du français contemporain* corpus (PFC; Durand, Laks & Lyche 2002; Durand, Laks & Lyche 2005). The PFC is of particular interest as it was constructed for the analysis of variability in French phonology, and its wordlist was designed to elicit variable phenomena including the mid vowels in different phonological contexts. The wordlist tasks from three different survey points in the Metropolitan Paris region (Brunoy, Paris Centre ville, Puteaux-Courbevoie) were queried, outputting data from 26 different speakers—thirteen men and thirteen women—whose birth years range from 1918–1981. Paris was chosen for several reasons. First, many recent studies of the French mid vowel system have focused extensively on the (non-)application of the *loi de position* in Meridional varieties which are more likely to respect the *loi de position*. Parisian has long-been considered a standard variety of continental French that does not necessarily adhere to the *loi de position.* In a case study of a speaker of Parisian French, for instance, Hansen (2016: 129) notes that her speaker "to some extent follows *la loi de position*." Another reason for choosing the Paris wordlists was to avoid words in which a final schwa is realized. The realization of a word-final schwa, which is ubiquitous in Meridional varieties, opens a closed syllable, but those open syllables tend to pattern as if they were closed (the reader is referred to Eychenne 2014 for more information on the schwa and mid vowels). None of the data in the initial query of the Paris wordlists contained a realized final schwa, allowing for a more straightforward and transparent analysis. This query yielded a total of 2849 vowels from seventy-eight unique words which were subject to analysis.

### 2.1. Acoustic analysis

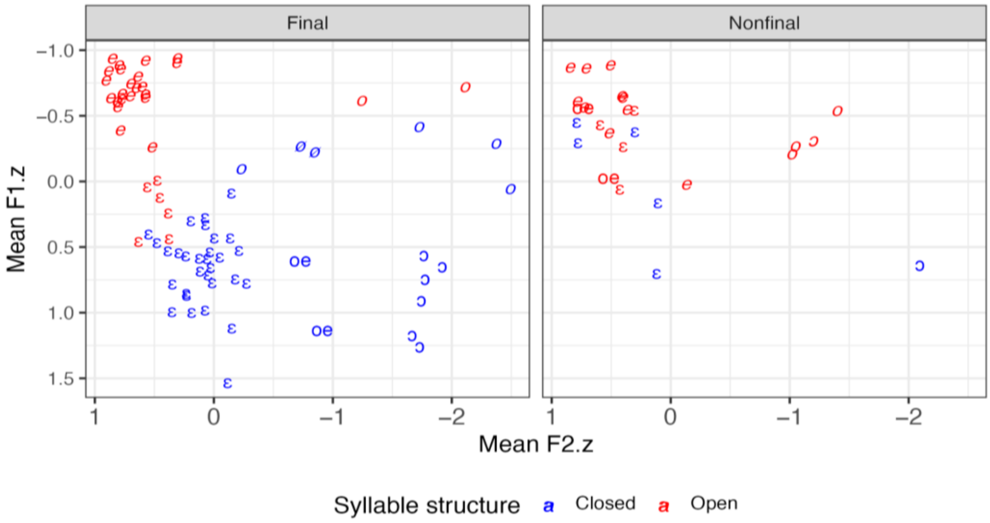
Acoustic analysis was adapted from the methodology employed by Renwick and Ladd (2016) and Nadeu and Renwick (2016) in studies of Italian and Catalan mid vowels respectively. The acoustic analysis serves several different roles in this study. First, the results of the acoustic analysis inform the identification of phonological constraints for the MaxEnt analysis by detecting phonetic and phonological factors that significantly predict mid vowel height. These factors are formalized as constraints in the grammar or as non-grammatical scaling factors used to adjust constraints' weights. The analysis also identifies the proportions of vowel tokens realized as [e, ø, o] and [ɛ, ɔ, œ] across open vs. closed and stressed vs. unstressed syllables. These proportions are input to the formal Maximum Entropy analysis detailed in §3.

The audio and text outputs of the PFC query were first force-aligned using WebMAUS (Kisler, Reichel & Schiel 2017) to create TextGrids annotated at the word and segment levels. Formant values (F1, F2) were then extracted at each vowel's midpoint in Praat[1] (Boersma & Weenink 2025), and vowel duration was measured. The data were visually checked for formant-measurement outliers using an F1 and F2 scatterplot, and 13 individual tokens of the vowel /e/ were excluded due to extreme F2 values. Additionally, the data of one male speaker were entirely excluded due to

[1] Formant extraction settings in Praat were the following: for female speakers, Praat's standard settings of tracking 5 formants with a ceiling of 5500 Hz were used; for male speakers, 5 formants were tracked with a ceiling of 5000 Hz.

interference from excessive background noise. Formant measurements were normalized to Z-scores (Lobanov 1971) at the level of the individual speaker. The data are displayed in Figure 1, where each point represents the average F1,F2 values for all tokens of a specific word in the dataset, with a symbol corresponding to the lexical quality of the mid vowel, colored according to syllable structure. Generally, Fig. 1 indicates that in this dataset, lexical quality is phonetically adhered to: tokens of lexical [e, o, ø] are phonetically higher and fronter than [ɛ, œ, ɔ]. Additionally, open syllable structure results in phonetically higher tokens, following the *loi de position*—particularly in lexical [ɛ] vowels, seen in final position.

**Figure 1.** Vowel spaces final vs. non-final vowels, labeled by lexical height




The clustered data were subject to descriptive statistics and then treated with mixed-effects linear regression models using the lmerTest package in R (Kuznetsova, Brockhoff & Christensen 2013). Models were constructed to predict the continuous dependent variable of Lobanov-normalized F1 values from a combination of categorical and continuous variables. Categorical predictors are syllable structure [open vs. closed], stress, lexical height based on dictionary specification (Robert, Rey-Debove & Rey 1967), and speaker sex; continuous variables are duration and log-year-of-birth.[2] The random effects of word and speaker were also tested (Baayen, Davidson & Bates 2008), but no model including the random effect of speaker would converge.

Effects in our linear regression are summarized in Table 1. We found a strong effect of lexical height, indicating a tendency for speakers to adhere to prescribed lexical specifications in pronunciation. An interaction between stress and syllable type was also found to be significant. Post-hoc analyses found no statistically significant differences between open and closed syllables in unstressed syllables, but a significantly lower normalized F1 value was observed in open syllables under stress.

[2] Additional predictors were tested but determined via model comparison not to significantly contribute explanatory power, resulting in their exclusion from modeling. These included syllable position within the word (strongly related to stress conditions), normalized F2 value, and log lexical frequency. Speaker year of birth is retained as a predictor because differences in how speakers realize the mid vowels have been observed across age groups (i.e., Lyche 2003: 357).

The results of this interaction are shown in Figure 2. Finally, the effect of duration, shown in Figure 3, found that as duration increased so did F1. While many of the factors found to be impactful on mid vowel realization are indeed phonological, the grammar that we present in Section 3 needs to be able to account for the non-grammatical phonetic factor of vowel duration. We believe that a theory of constraint scaling is capable of doing so.

**Table 1.** Regression Model Predicting F1

| Fixed Effects | Estimate | Std. Error | Df | *t*-value | *Pr*(>*t*) | Signif. |
|---|---|---|---|---|---|---|
| **(Intercept)** | –7.691 | 10.277 | 2792.282 | –0.748 | 0.454 | |
| **Duration** | 0.574 | 0.173 | 2791.697 | 3.328 | < 0.001 | *** |
| **Log(age)** | 0.928 | 1.355 | 2782.037 | 0.685 | 0.494 | |
| **Open Syllable** | –0.096 | 0.096 | 464.010 | –0.990 | 0.323 | |
| **Stressed Syllable** | 0.553 | 0.088 | 404.330 | 6.311 | < 0.001 | *** |
| **Low-mid Dict.** | 0.638 | 0.054 | 371.681 | 11.910 | < 0.001 | *** |
| **Stressed:Open** | –0.504 | 0.098 | 484.736 | –5.153 | < 0.001 | *** |
| **Random Effect** | ***s*** | ***s*²** | | ***n* Observed** | | |
| **Word** | 0.053 | 0.231 | | 78 | | |
| **Significance Codes**: *** <0.001; ** <0.01; * <0.05 | | | | | | |

**Figure 2.** Effect of interaction between Stress and Syllable Structure on Mid Vowel Realization

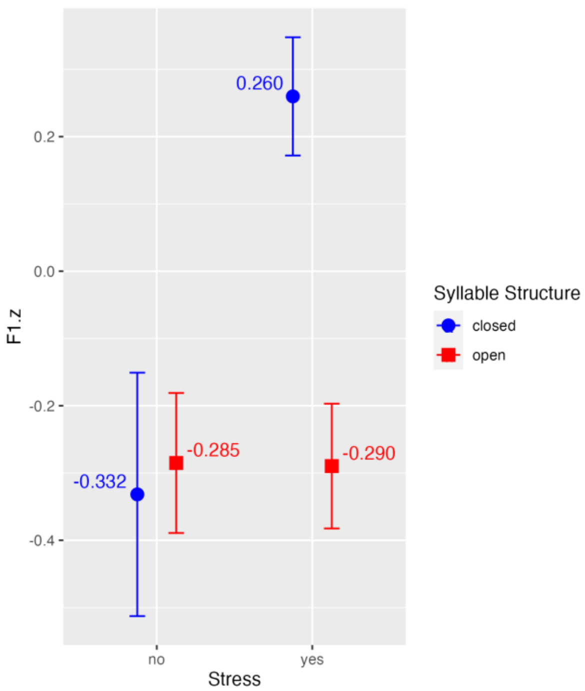
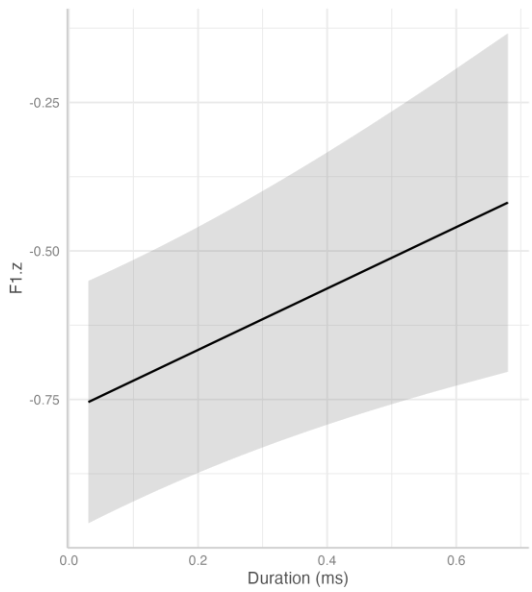


**Figure 3.** Effect of Duration on Mid Vowel Realization




To transition from an acoustic analysis of continuous variables to a constraint-based formalization, it is necessary to categorize each vowel token according to its phonetic height. For instance, while forced alignment provides a temporal link between segment-level transcriptions and the audio signal, the forced aligner's segment labels are not sensitive to variation in vowel height. Therefore, a *k*-means clustering analysis was applied, to automatically classify each token as a phonetically higher or lower vowel, according to its acoustic properties. The clustering analysis was conducted in R (R Core Team 2000) using the kmeans() function, which applies the Hartigan and Wong (1979) algorithm to automatically group each token into one of two clusters, based on normalized F1 and F2 values; we refer to these groupings as 'high-mid' or 'low-mid' assignments. This method categorizes each vowel in a way that is unbiased by human perception and intuition (see Renwick 2021 for an additional application to Italian), which further enables analysis of vowel height variation. In particular, since the *loi de position* describes a contextual dependence between vowel tenseness and syllable structure, we anticipate that tokens are more likely to be clustered as "high-mid" vowels in open syllables and as "low-mid" realizations in closed syllables.

## 3. Formal Analysis

### 3.1. Maximum Entropy Grammar

The results of the acoustic and clustering analyses described above provide the information necessary to formalize a grammar of mid vowel realization in Parisian French. We propose a formalization in Maximum Entropy Grammar (MaxEnt; Goldwater & Johnson 2003), a constraint-based theory of grammar similar to Optimality Theory (OT); however, unlike OT, which ranks constraints in a discrete hierarchy of strict domination, MaxEnt grammar proposes a gradient constraint ranking system, in which constraints are assigned a mathematical value (or *weight*) through a machine learning algorithm. MaxEnt grammar in particular makes use of multinomial logistic regression, and it has been used as a supplement to standard regression models (cf. Griffiths 2022). The gradience afforded by theories of weighted constraints like MaxEnt makes them particularly adept at handling instances of phonological variation (Coetzee & Pater 2011; Pater 2016). MaxEnt was chosen for the present analysis because it is driven entirely by probabilities and has been shown effective at capturing both intra- and inter-speaker variation (Bayles, Kaplan & Kaplan 2016).

The MaxEnt learner requires a series of Inputs, their respective Outputs and the probability of realization of each Output, a constraint set, and each Output candidate's violations of that constraint set. The inputs are provided by the clustering analysis in 2.1, which was used to determine the relative frequency of tense vs. lax vowel realizations for MaxEnt learning simulations. In particular, we consider the proportions of tokens realized as high-mid or low-mid vowels across closed and open syllables, for each of the six mid vowels. These are represented in Table 2 as specific candidates representing input-output pairs (e.g., lexical /e/ output as [e] vs. [ɛ] in an open syllable), with their corresponding probability of occurrence. The constraint set submitted to the learner is provided in (6)–(7).

(6) Markedness Constraints
  a. CV$_{\text{TENSE}}$: Assign one violation for each non-tense vowel in an open syllable.
  b. CVC$_{\text{LAX}}$: Assign one violation for each non-lax vowel in a closed syllable.
  c. *TENSE: Assign one violation for each tense vowel.
  d. *LAX: Assign one violation for each lax vowel.

(7) Faithfulness Constraints
  a. IDENT-F1[–BACK]: Assign one violation for each segment specified as [–Back] whose F1 value differs from Input to Output.
  b. IDENT-F1[+BACK]: Assign one violation for each segment specified as [+Back] whose F1 value differs from Input to Output.
  c. IDENT-F1[–ROUND]: Assign one violation for each segment specified as [–Round] whose F1 value differs from Input to Output.
  d. IDENT-F1[+ROUND]: Assign one violation for each segment specified as [+Round] whose F1 value differs from Input to Output.

The markedness constraints presented in (6) formalize the tendencies of the *loi de position*, namely the preference for lax vowels in closed syllables and tense vowels in open syllables. The constraints appealed to in (6a, b) enforce the positional preferences in a similar vein to the *[e]C constraint proposed by Féry (2003: 275) penalizing the realization of the tense vowel [e] before a syllable coda. These constraints, however, do not, by themselves, determine the overall distributions of vowel height and must be considered in tandem with those defined in (6c, d). While lax vowels are generally considered less marked than tense vowels typologically, their distributions and realizations are not entirely unmotivated, nor are lax vowels merely the default form. Instead of imposing a strict binary opposition, *TENSE and *LAX function as gradiently weighted markedness constraints that interact with the structural constraints defined in (6a, b) to shape the observed phonological patterns. If only

*Tense were included, the model would predict a broad dispreference for tense vowels without accounting for the systematic presence of lax vowels, failing to account for their phonotactic motivation. Appealing to all four markedness constraints allows the model to distinguish inherent markedness from distributional conditioning, ensuring that vowel realization is shaped by typological markedness and syllable structure. This approach accounts for the probabilistic nature of the *loi de position* where categorical phonotactic constraints alone are insufficient in predicting the observed variation. The inclusion of all four constraints accounts for the asymmetries observed in the mid vowel system while allowing for gradient well-formedness.

**Table 2.** Input-Output pairs given to MaxEnt by syllable type, with rate of occurrence for each form

| Syllable Type | Input | Output |
|---|---|---|
| CV σ | /pi.ke/ | [pi.ke] 0.91<br>[pi.kɛ] 0.09 |
| | /ʒa.lɛ/ | [ʒa.le] 0.39<br>[ʒa.lɛ] 0.61 |
| | /a.ɲo/ | [a.ɲo] 1.00<br>[a.ɲɔ] 0.00 |
| CVC σ | /fɛt/ | [fet] 0.16<br>[fɛt] 0.84 |
| | /pom/ | [pom] 0.81<br>[pɔm] 0.19 |
| | /pɔm/ | [pom] 0.18<br>[pɔm] 0.82 |
| | /ʒøn/ | [ʒøn] 0.88<br>[ʒœn] 0.12 |
| | /ʒœn/ | [ʒøn] 0.31<br>[ʒœn] 0.69 |

The faithfulness constraints defined in (7) account for the different rates of variability observed across each of the three pairs of mid vowels /e, ɛ/; /o, ɔ/; and /ø, œ/. Similarly to the need for considering both markedness constraints defined in (6c, d), considering all four faithfulness constraints outlined in (7) is necessary in maintaining a balanced and unbiased constraint set for the learner. Including all four constraints ensures symmetry in constraint structure by equally preserving features across roundedness and backness. The model would asymmetrically favor certain contrasts over others if any of these constraints were to be excluded. Moreover, including all four constraints allows for a more nuanced picture of mid vowel realization, preventing overly categorical predictions and enabling a degree of gradient well-formedness in the model.

MaxEnt learning was conducted in Praat's OT learning functionality (Boersma & Weenink 2025). The grammar was learned a total of one hundred times, and constraint weights were averaged across the repetitions. The initial weighting condition, shown in Table 3, found large effects of the $\text{CVC}_{\text{LAX}}$ and $\text{CV}_{\text{TENSE}}$ constraints suggesting an overall preference for penalizing markedness over faithfulness. The relatively high ranking of these two constraints lends credence to Storme's (2019) appeal to closed syllable laxing and open syllable tensing as means of contrast enhancement, particularly since this is a variety in which the *loi de position* has been described as less productive.

**Table 3.** Initial weighing conditions

| Constraint | *W* |
|---|---|
| IDENT-F1[−ROUND] | 1.010 |
| IDENT-F1[+BACK] | 0.970 |
| $CV_{TENSE}$ | 0.650 |
| IDENT-F1[−BACK] | 0.550 |
| IDENT-F1[+ROUND] | 0.510 |
| $CVC_{LAX}$ | 0.350 |
| *LAX | 0.300 |
| *TENSE | −0.300 |

The two highest-ranked constraints are faithfulness constraints penalizing changes in height for non-round vowels (/e, ɛ/) and for back vowels (/o, ɔ/). This suggests that faithfulness to the input vowel may predominate. However, depending on the vowel's other features, in particular its original height and the syllable structure in which it is found, the weight of markedness constraints could override the input height. The negative weighting of the *TENSE constraint has interesting implications for the grammar, which can be better explained by understanding how a constraint's weight impacts the realization of a particular candidate. A candidate's harmony score (*H*) is how well-formed it is within the context of the grammar. The higher a candidate's *H* score is, the more harmonious that candidate is. *H* is obtained by the formula in (8).

(8) $H(C) = \sum_{k=1}^{K} w_k \cdot s_k$
where $w_k$ is the weight of constraint *k* of the constraint set *K*, $s_k$ is the number of times that a candidate *C* violates *k* expressed as a negative integer.

Since *H* is the sum of the products of a constraint's weight and its violations, a constraint with a negative weight would result in a candidate's violation of that constraint being more harmonious. This would indicate a strong preference for lax vowels in this grammar since violating either *LAX or *TENSE would result in a preference for candidates containing the lax vowel.

## 3.2. Scaling the constraints

The preliminary version of the grammar presented in Table 3 is able to account for the impact of the phonological factors that influence mid vowel realization; however, phonetic factors like duration fall outside of the scope of the grammar, and the role they play in determining the realization of these vowels needs to be incorporated in some other way. The initial weighted grammar suggests that all mid vowels are equally subject to variation in height no matter their duration, but to adequately model the data, we must account for the fact that as duration gets longer, lower vowels tend to be preferred. This raises an issue posed by Storme (2019: 335), regarding the impact duration has on contrast enhancement and how this effect covaries with the role of vowel quality in contrast enhancement. In this analysis, we account for duration by scaling the weights of constraints learned by our preliminary MaxEnt grammar. Constraint scaling was introduced in a case study of lexical frequency by Coetzee and Kawahara (2013), who suggest that the weights of learned faithfulness constraints can be adjusted, allowing them to have a stronger effect on less frequent words than on more frequent words. While scaling incorporates non-grammatical factors into a formal phonological grammar, the model still remains grammar-dominant (Coetzee & Kawahara 2013: 77–79), meaning that the grammar defines what kinds of phonological patterns are possible, while the scaling factors determine how a particular structure can vary within the limits defined by the grammar. Scaling is typically only applied to faithfulness constraints, but a variety of factors have been used as scaling factors including lexical factors like frequency (Coetzee & Kawahara 2013), phonetic factors like place of articulation and speech rate (Coetzee 2016), and sociolinguistic factors like age and register (Griffiths 2022). Duration has been explicitly treated as a factor in a MaxEnt model by Lefkowitz (2017), where the durational properties of English vowels were learned according to their links with other phonological properties including tenseness, stress, phrase position, and phonotactics. The output of Lefkowitz's (2017) learner are candidate phonetic duration ranges in bins of 100ms. Such an approach, distinct from the scaling method adopted here, is appropriate for a *phonetic grammar* formalizing "speakers' knowledge of phonetics, as distinct from phonology" (Lefkowitz 2017: 1); our method, however, uses scaling to integrate the effects of phonetic properties within a more abstract phonological grammar.

Simply put, the scaling procedure involves generating new possible grammars, based on the original grammar (Table 3) but with slightly different weights, and then testing which set of scaled weights can provide predicted output proportions that most closely match the data under consideration. It is possible that the original grammar will be optimal and that scaling won't improve model fit. To scale the four faithfulness constraints in the grammar, a series of grammars were generated in Praat in which the weights of the faithfulness constraints in the initial weighting conditions were adjusted in increments of ±0.05. After the scaled grammars were generated, their output distributions were queried. This query provides a report, for each input in the grammar, of the proportional likelihood of each output candidate, given the grammar's weights. Each grammar's output distribution was queried 10 times following Coetzee (2016), and the resulting proportions were averaged together and transformed into values out of 100 at the level of individual output candidates.

The predictions of the scaled grammars were compared to the distributions of vowel tokens at *long* or *short* durations. The phonetic data gathered from PFC were divided into two durational bins based on the median duration value observed in the corpus (0.14 ms). Vowel realizations whose durations were longer than 0.14 ms (928 tokens) were grouped as *long*, while those with durations less than or equal to the median (1091 tokens) were grouped as *short*. Within each durational bin, the proportion of tokens clustered as high-mid vs. low-mid was calculated. These proportions were compared against the scaled grammars' outputs.

The output distributions of scaled grammars represent the models' predicted proportions of two possible surface realizations corresponding to the same input. The underlying base grammar was trained on distributions that were not separated according to tokens' durations, so the effect of scaling is to alter the outcomes of that base grammar by tuning the weights of faithfulness constraints up, or down. The best scaling factor is the one that best matches the vowel height distributions calculated for each durational bin. This is found by calculating the difference between observed and predicted outcomes and transforming it to Mean Squared Error (MSE). A reduction in MSE, representing an increase in the grammar's fit to the data, is achieved when a scaled grammar has lower MSE than the unweighted grammar (note that this method permits the best fit to have a scaling factor of 0). For short vowels, the greatest reduction in MSE occurred when the faithfulness constraints were scaled down by −0.05 (one increment), while for long vowels the greatest reduction in MSE occurred by scaling the faithfulness constraints up by +0.1 (two increments).

The modified weighting conditions for short and long vowels are presented in Table 4. The implications for the adjusted weighting conditions are elaborated upon in Section 4. Additionally, Table 5 presents a comparison of MSE values for long and short vowels according to the original weighting conditions vs. scaled conditions. The results demonstrate that small reductions in MSE were achieved for both short and long vowels.

**Table 4.** Scaled weighting conditions for faithfulness constraints, separated by short vs. long vowels

| **Constraint** | **Short duration (*N* = 1091) Scaling Factor: –0.05** | **Long duration (*N* = 928) Scaling Factor: +0.1** |
|---|---|---|
| IDENT-F1[−ROUND] | *w* = 0.960 | *w* = 1.110 |
| IDENT-F1[+ROUND] | *w* = 0.460 | *w* = 0.610 |
| IDENT-F1[−BACK] | *w* = 0.500 | *w* = 0.650 |
| IDENT-F1[+BACK] | *w* = 0.920 | *w* = 1.070 |

**Table 5.** Mean Squared Error (MSE) corresponding to differences in observed vs. predicted outputs based on original constraint weights vs. scaled constraint weights

| | **Initial Grammar** | | **Scaled Grammar** | |
|---|---|---|---|---|
| | ***Short vowels*** | ***Long vowels*** | ***Short vowels*** | ***Long vowels*** |
| **MSE** | 80.690 | 136.609 | 79.481 | 128.326 |

The observed rates of occurrence for tense vs. lax vowels are visually compared to their predicted rates of occurrence in Figures 4, 5, and 6. For each figure, the predicted proportions are derived in Praat from the scaled constraint weights presented in Table 5. Predicted values all lie within 10 percentage points of observed values. For front unrounded vowels (Fig. 4), the *least* accurate predicted rates are for underlying /ɛ/ in an open syllable at short durations, which are overpredicted to surface as [e] under the *loi de position*: the observed reality is more faithful to a lax quality. For front rounded vowels (Fig. 5), underlying /ø/ is predicted more closely than underlying /œ/, which at long durations is overpredicted to surface faithfully as [œ]; in fact, high-mid realizations are equally likely at long durations. Among back rounded vowels (Fig. 6), faithful outputs are slightly underpredicted for both /o/ in an open syllable, and for /ɔ/ in a closed syllable: the scaled, weighted grammar predicts slightly *more* variation towards unfaithful candidates than actually occurs. Nevertheless, the scaled results are more accurate to observed distributions than prior to scaling, and the overall predicted patterns of occurrence are a good match to the original data.

**Figure 4.** Front unrounded vowels: predicted proportions from MaxEnt analysis scaled by duration, vs. observed token counts, for tested input-output relations.

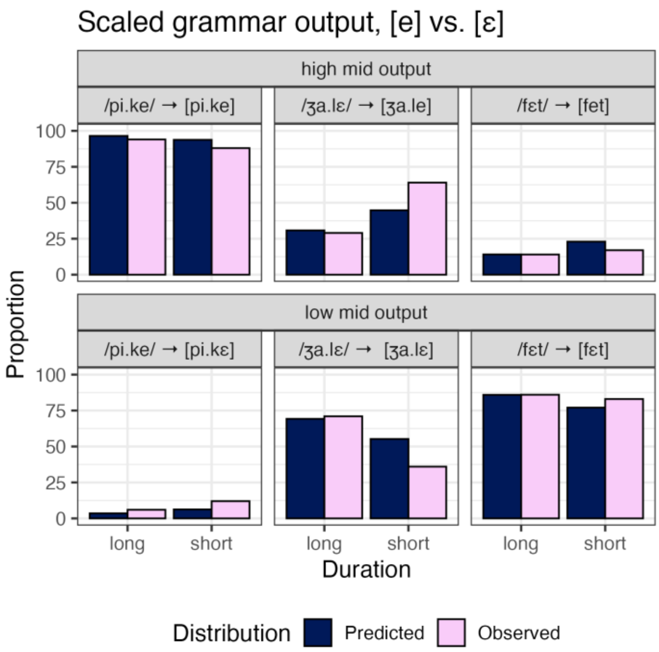



**Figure 5.** Front rounded vowels: predicted proportions from MaxEnt analysis scaled by duration, vs. observed token counts, for tested input-output relations.

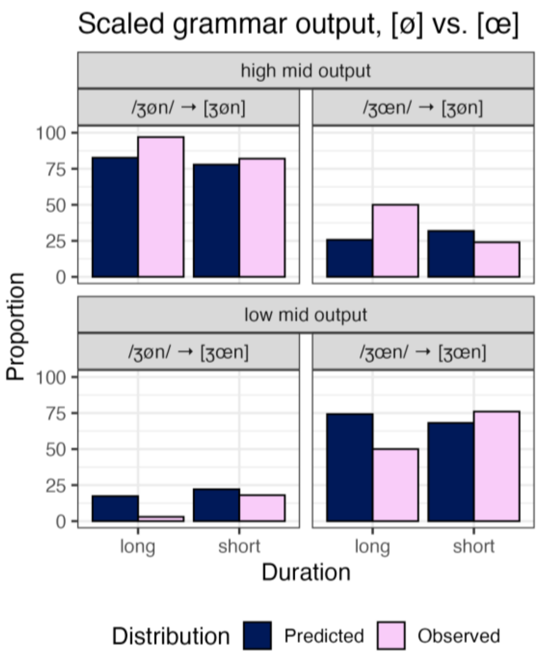
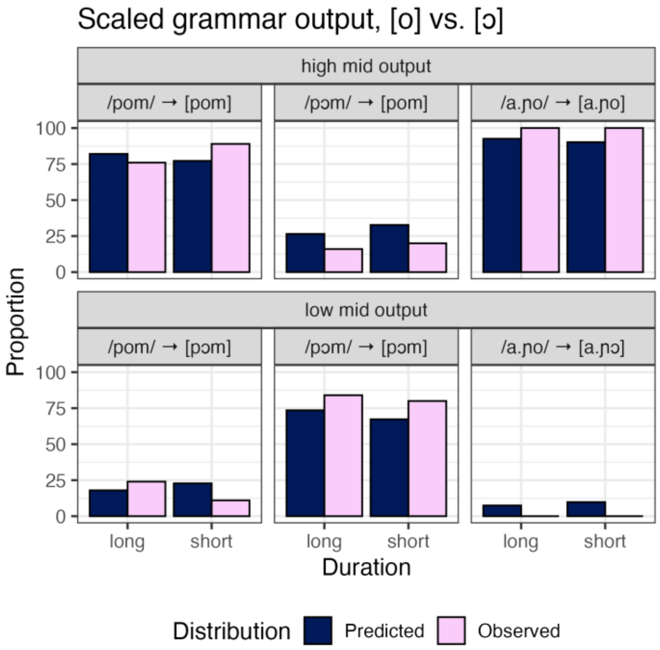


**Figure 6.** Back rounded vowels: predicted proportions from MaxEnt analysis scaled by duration, vs. observed token counts, for tested input-output relations.




## 4. Discussion and conclusion

The results of the present study offer insight into the phonetics and phonology of the French mid vowel system as well as on the growing body of literature on marginal contrast in mid vowel systems. We would like to begin by discussing the application of the *loi de position.* While Parisian French has traditionally been described as a variety in which the *loi de position* is not productive, some adherence to its tendencies can be observed, particularly in open syllables. However, the data still show strong adherence to lexically-specified vowel quality, exhibited by a significant effect for lexical height in our linear mixed-effects modeling and large weights for faithfulness constraints in the MaxEnt formalization. This adherence to lexical norms results in a higher likelihood of faithfulness than in Meridional varieties which are more likely to apply the *loi de position*. So, while it is clear that the *loi de position* is not as productive in Parisian French as it is in Southern varieties, it is still somewhat productive, falling in line with the observations made in Hansen's (2016) case study. This would suggest that although the contrast between the mid vowels in Parisian French is still marginal, it is less marginal than in Meridional varieties. Further research should attempt to measure how strong the orthographic effect is on the phonological representations as well as the output forms of these vowels.

Turning to the effect of duration, we find that a single trend of vowel height variation does not appear across tokens at long vs. short durations. With the exception of the /Cɛ/ context, faithfulness to vowel height predominates despite durational variation. This is in line with previous research on the mid vowels in Italian which exhibit a similar sort of marginal contrast (Renwick 2024). The findings do offer some insight into questions raised by Storme (2019: 335–336) concerning the role duration may play as a means of contrast enhancement and the co-occurrence of durational differences with differences in vowel quality. He hypothesizes that in languages in which tense-lax contrasts are signaled by differences in quality and duration, duration may serve as a secondary cue to enhance distinctions in vowel quality. While the contrast between tense and lax mid vowels in Parisian French is marginal, the formal analysis finds little variation in vowel height due to duration, evidenced by the small magnitude of the scaling factors. This suggests that for this variety, duration is unlikely to act as a secondary cue, in line with perceptual findings (Gottfried & Beddor 1988). This suggests that the lack of phonetic distinctions in vowel quality—already evidence for marginal contrast—is not compensated for with another acoustic cue. Further research is also necessary in understanding how the relationship between quality and duration may manifest in other languages that exhibit processes of closed-syllable laxing similar to the *loi de position*.

**Acknowledgments**

The authors appreciate the feedback from two anonymous reviewers of this manuscript, and they are grateful to the organizers and participants at the 54th Linguistic Symposium on Romance Languages in Provo, Utah.

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