The Shape of [u]:
Towards a Typology of Final Vowel Devoicing in Continental French

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ABSTRACT

Phrase-final vowel devoicing is a feature of Continental French in which utterance-final vowels variably lose their voicing and produce fricative-like whistles. Although the phenomenon is singularly referred to as "vowel devoicing," most research on the topic ignores the parameter of voicing loss in favor of a description of the emergent downstream fricative, a fact that is complicated even further when considering that the fricative by-product is not uniform in nature. In this study, we investigate the multiplicity of phonetic phenomena occurring under the heading of "final vowel devoicing" via an analysis of normalized measures of center of gravity. Six resulting COG profile shapes emerge: one describing literal vowel devoicing, the others describing five different energy profiles of fricative epenthesis. Results indicate an interaction of vowel and percent devoicing, suggesting that PFVD is a singular phenomenon with several allophonic realizations predicted by both vowel type and length.
Keywords: center of gravity, vowel devoicing, fricative epithesis, French, acoustic analysis

1. INTRODUCTION

Phrase-final vowel devoicing (PFVD) is a phenomenon in Continental French (CF) in which utterance-final vowels (i.e. the locus of stress in CF) variably lose their voicing and produce intense fricative-like whistles [8], as in (1).

(1) Mais oui_hhh. Je t'ai vu_hhh.

Much of the scholarship on PFVD has documented its phonological and pragmatic conditioning, pinpointing its most robust occurrence to the French high vowel series /i,y,u/ [7, 10, 13], read speech [3, 7], following stop consonants [3], intonation phrase-finally [7, 13], declarative phrase-finally [7, 12] and in words with high lexical frequency [3]. Although the phenomenon is singularly referred to as "vowel devoicing," most studies sidestep the parameter of voicing loss in favor of a description of some aspect of the emergent downstream voiceless fricative. [4, 5, 10, 13, 14] all report rates or durational/ratio measures of PFVD which only take into account tokens showing the presence of aperiodic energy, thereby eliminating the chance to observe more minimalist devoicing types that share in the loss of devoicing but not in the emergence of the downstream fricative. [1, 2, 6] follow a similar methodological practice, but remove some of the ambiguity by instead referring to PFVD as *épithèse fricative* 'fricative epithesis'.

The idea that not all PFVD is phonetically similar was present already at its initial documentation in the literature, as [8] speculated that PFVD's phrase-final whistles might correspond in some way to the identity of their host vowel, similar to *ich-Laut* and *ach-Laut* in German. [10] later observed three different types of vowel devoicing: 1) *syncope* (loss of vowel periodicity, harmonics, stable formants, replaced by noise >5000 Hz), 2) *complete devoicing* (loss of periodicity + intense noise with full formant structure or a weakening of noise >5000 Hz), and 3) *partial devoicing* (loss of periodicity at beginning of vowel with formants eventually appearing), however, he didn't examine the acoustic features shared between each devoicing type and the various host vowels. A center of gravity (COG) analysis of devoiced /i,y,u/ corroborated [8]'s speculations, reporting significant differences in each vowel's spectral energy during the first half of the segment [3], but neglected to used normalized COG measures or examine their longitudinal trajectory throughout the PFVD segment.

The literature reveals that the term "final vowel devoicing" is used to describe a multitude of phonetic processes, some of which exclusively contain devoiced vowels, others of which instead or additionally contain compensatory voiceless fricative by-products whose energy profiles are dependent on underlying segments. It is therefore the goal of this study to investigate the multiplicity of these variable phonetic phenomena via an analysis of both underlying segment and spectral trajectory, informed by normalized measures of the PFVD segment taken at multiple timepoints.

2. METHODS

2.1. Participants & Materials

31 native speakers of CF completed a reading task targeting 98 tokens of /i,y,u/ in phrase-final position. 30 of the speakers were recorded in France (4 in Paris, 26 in Strasbourg), and 1 was recorded in the United States. The 98 target words featured /i,y,u/ in mono-, bi- and tri-syllabic words preceded by every licit consonant and consonant cluster found in CF. Each sentence was read twice to yield 196 vowel tokens per participant (6,076 total).

2.2. Procedures

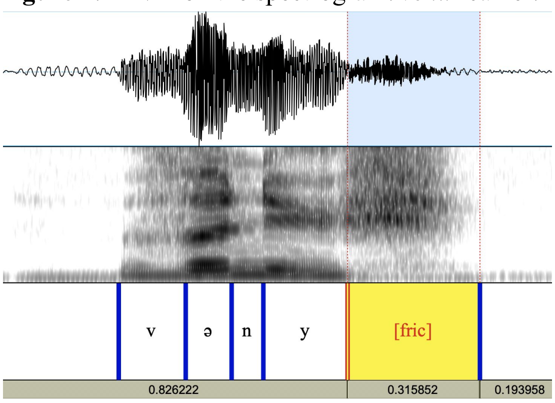
Speakers were recorded via a head-mounted unidirectional cardioid microphone (SHURE WH20) plugged into a solid-state digital recorder (Marantz PMD 660) digitized at 44kHz (16 bit). The task was self-paced and completed under the direction of the researcher.

3. ANALYSIS

3.1. Measurements

The final vowel of target words was examined for presence of PFVD, assessed via the loss of the voicing bar and/or the onset of high-frequency aperiodic energy, as depicted in Figure 1 with the label "fric." A Praat script was then used to measure the duration of each full vowel and any fricated PFVD segment. A measurement of percent devoicing was then derived by dividing the length of the frication by the overall length of the vowel including frication. A second Praat script measured fricated PFVD segments for COG at the 25%, 50% and 75% marks [5].

Figure 1: PFVD on the spectrogram: *venu* 'came'.



3.2. Normalization

To control for effects of vocal tract length, COG values were normalized according to a technique adapted from [15]. Normalization of frication was performed according to (2):

(2) $COG_{norm} = s_i \times COG$,

where the speaker-dependent coefficient s_i was calculated by (3):

(3) $s_i = 1/(COGi/COG_{ave})$,

where COG_i refers to the average COG value of participant *i*, and COG_{ave} refers to the average COG value across all participants.

3.3. Profile Shapes

Following normalization, the three COG measurements taken for each response were synthesized into a single variable, hereafter referred to as *profile shape*. First, frequencies were divided into three bins: 0-2000 Hz (low), 2000-4000 Hz (medium), and 4000-6000+ Hz (high). Each trial was then given a letter designation on the basis of its three COG levels (i.e. LMH, HMM, MLL). The 27 possible combinations were condensed into 6 final categories describing the level and continuing, growing or decreasing nature of its energy, as shown in Table 1:

Table 1: Profile shapes by COG designation

Profile	Categorical COG designations
Flat-low	LLL
Flat-high	MMM, HHH
Rising	LLM, LLH, LMM, LMH, LHH, MMH, MHH
Falling	MLL, MML, HLL, HML, HMM, HHL, HHM
Rise-fall	LML, LHL, LHM, MHL, MHM
Fall-rise	MLM, MLH, HLM, HLH, HMH

3.4. Statistics

Statistical analyses of profile shape were conducted in R [11]. A chi-square test of the relationship between *profile shape* and *vowel* was performed using *chisq.test()*. Using *multinom()* from package *nnet* [16], a multinomial logistic regression was also performed, with *profile shape* as the dependent variable, and *vowel* and *percent devoicing* as the independent variables. Visualizations were generated using the packages *corrplot* [17] and *effects* [9].

4. RESULTS

4.1. Vowel Type

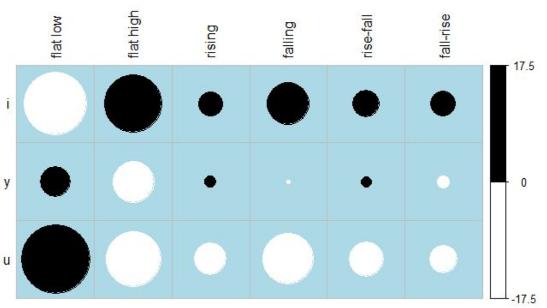
Counts of profile occurrence by vowel (Table 2) indicate that flat-low was the most common profile shape for /y/ and /u/, while falling and flat-high were the most common for /i/. Dynamic profiles were used less frequently than flat ones, but were more prominent for /i/ than for the other two vowels, with falling being the only well-represented dynamic profile type for /y/, and /u/ almost solely represented by flat-low.

Table 2: Counts *(percentages)* of profile shape by vowel

Profile	/i/	/y/	/u/
Flat-low	414 *(22.4)*	523 *(50.7)*	715 *(83.3)*
Flat-high	490 *(26.5)*	80 *(7.8)*	6 *(0.7)*
Rising	188 *(10.2)*	94 *(9.1)*	42 *(4.9)*
Falling	512 *(27.6)*	214 *(20.7)*	53 *(6.2)*
Rise-fall	189 *(10.2)*	85 *(8.2)*	34 *(4.0)*
Fall-rise	63 *(3.4)*	23 *(2.2)*	8 *(0.9)*
Total	1852 *(100.0)*	1032 *(100.0)*	858 *(100.0)*

A chi-square test revealed that the relation between *profile shape* and *vowel* was significant [$\chi^2 = 1004.2$, df = 10, $p<.0001$]. Examination of the residuals, as illustrated in Figure 2, indicates this was mainly due to the preference for flat-high and dispreference for flat-low by /i/, and the preference for flat-low and dispreference for flat-high by /u/.

Figure 2: Residuals of profile shape by vowel



As shown, the low-energy profile is preferred for /u/ and, to a lesser extent, /y/, and the high-energy profile for /i/. A COG analysis revealed different flat-low averages for /i/ and /u/ (787 and 866 Hz at midpoint) versus /y/ (1187 Hz), suggesting that although flat-low was common for /y/, its measure was not as diffuse as the flat-low of /u/.

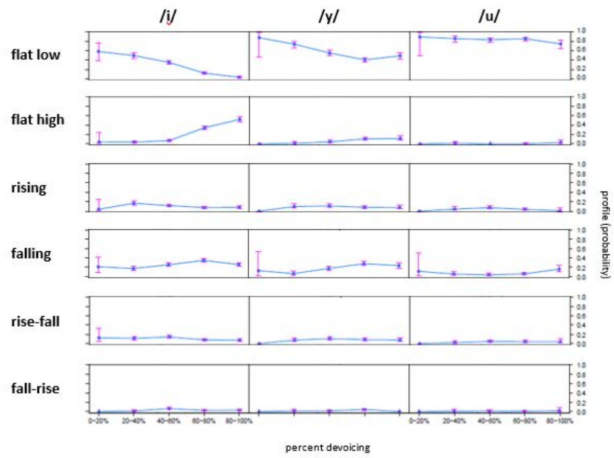
4.2. Percent Devoicing

Since profile shape was strongly governed by vowel quality, a multinomial logistic regression was fit for the effects of the interaction of *vowel* and *percent devoicing* on *profile shape*. Percent devoicing (PDV) was defined as the percent of vowel duration consisting of aperiodic noise, and binned into five categories with widths of 20%. The results of this model, presented in Table 3, indicated a significant interaction between *vowel* and *percent devoicing*, such that there were significant differences between all vowel-PDV pairs for every profile type except *falling*, which reported no significant differences. Main effects of *vowel* and *percent devoicing* were also present for all profile types except *falling*.

Table 3: Multinomial logistic regression (profile ~ vowel*percent devoicing)

COG Profile Type	Main Effects	Interactions
Flat-high	$p<.0001$	$p<.0001$
Rising	$p<.0001$	$p<.0001$
Falling	$.0688\leq p\leq .9283$	$.1538\leq p\leq .9110$
Rise-Fall	$p<.0001$	$p<.0001$
Fall-Rise	$p<.0001$	$p\leq .0007$

Figure 3: Effects of *vowel* × *percent devoicing*



The visualization of the above interactions (Figure 3) shows that /u/ exhibited high rates of flat-low profile across all PDVs, with a slight decrease at 80-100%. /i/ and /y/ both exhibited relatively high rates of flat-low at low PDVs, which decreased as PDV increased, with rates being higher overall for /y/. For the flat-high profile, /y/ and /u/ both showed low overall usage, while /i/ showed low usage from 0-60%, with a sharp increase from 60-100%. Finally, /i/ and /y/ exhibited similar trajectories for the falling profile, with modest, slightly increasing levels as

PDVs increased. The use of the falling profile for /u/ was low, but increased slightly at 80-100%. The other three profile types were used infrequently, with no clear pattern with respect to PDV.

5. DISCUSSION

5.1. Vowel Type

The predominance of flat-low and flat-high energy profiles for /u,y/ and /i/, respectively, suggest that at least two well-represented allophones can be identified for PFVD among the class of French high vowels: one with low aperiodic energy throughout (flat-low) and one with or attaining high aperiodic energy for some portion of its overall length (all other types). The results here suggest that lip rounding may be the relevant articulatory gesture preventing the attainment of high periodic energy, creating a dichotomy between the flat-low profile common of devoiced /u, y/ and the flat-high profile common of devoiced /i/. This finding supports [8]'s speculation that PFVD segments might be contextually conditioned by the features of their underlying host vowel à la *ich-Laut/ach-Laut*, but singles out lip rounding as the relevant conditioning feature instead of backness.

5.2. Percent Devoicing

Measures of PDV show that /u/ is realized with a flat-low profile, regardless of the PDV of the vowel it occurs in. /i/ and /y/ show similar behavior at PDVs $\geq$60%, but their behavior diverges at higher PDVs, with /i/ showing a marked preference for flat-high or falling, and /y/ instead showing a continued preference for flat-low or falling. This suggests that /u/ and /y/ are realized similarly with respect to PDV, the only difference occurring at higher PDVs where the falling profile can also be attested for /y/. Contrastively, while devoiced /i/ patterns like /y/ and /u/ at lower PDVs, it does so at a much lower rate, since it is also found exhibiting falling and rise-fall profile types at these levels. Interestingly, despite the fact that PFVD is a phenomenon attested throughout the full series of French vowels [14], the salient period of high-frequency aperiodic energy that has become associated with the devoicing phenomenon is the type most commonly found in devoiced /i/ at high PDVs (flat-high).

6. CONCLUSIONS

In this study, we examined the full-range of PFVD types as a function of underlying vowel, spectral trajectory and PDV to reveal two allophones of PFVD, flat-low and flat-high, that show preference for certain vowel types and percent devoicings. These findings add further evidence to the idea that phrase-final vowel devoicing in CF is not, phonetically speaking, a singular phenomenon. Whereas the typology of devoicing types proposed by [10] focused on differentiating whether the voicing bar occurs initially, finally or not at all with respect to the devoiced segment, the types observed in this study focused on characterizing the spectral trajectory of energy throughout the life of the devoiced segment. Vowel devoicing in the literal sense does appear to exist in this constellation of phonetic behaviors, but it does so predominantly in devoiced tokens of /u/ which produce a diffuse, [w]-like labialized frication that is not reliably audible in all speech conditions and thus may be equated with deletion. For this reason, we call for a terminological distinction to be made between "vowel devoicing" in its most literal sense and "fricative epithesis" [1, 2, 6], the latter of which is a more fitting phonetic description of the phenomenon observed when a burst of salient high-frequency aperiodic energy emerges phrase-finally. Since the devoicing phenomenon has been attested in all French vowels, further research should investigate the role of vowel height and nasality in determining the acoustic quality of the devoicing. Future studies should also examine the role of vowel frequency in the top 25% of French lexical items, as a means of determining if devoiced /i/ has become the canonical example of devoicing due to vowel frequency effects in the lexicon or the increased salience of its fricative energy at higher PDVs, or both.

The present work has far-reaching implications for studies of phonetics and sound change because it documents how a singular process can emerge phonologically, but, based on the acoustic nature of an emergent segment, proceed down different phonetic paths: one where tokens of diffuse devoiced /u/ may lead to wholesale deletion, and another where tokens of devoiced /i/ may lead to lexicalization or a laxing of the phrase-final domain, both of which have already been attested for this variable in the high-frequency word *oui* 'yes' [14].

7. REFERENCES

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