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Abstract

This paper examines the production of /ʁ/-clusters in a corpus of spoken French. We compare word-final Cʁ#, word-final ʁC#, and word-initial #Cʁ in the LOCAS-F corpus, which is one of the few French corpora with prosodic annotation [1]. Three production outcomes are compared (ʁ-deletion, schwa insertion, and canonical pronunciation of the clusters), as a function of the following factors: prosodic boundaries, post-lexical context, speech style, and word frequency. Results reveal that for word-final Cʁ#, 17% of the /ʁ/s are deleted, and 39% of the time a schwa is inserted. Post-lexical context, prosodic boundaries, speech style and word frequency all have significant impact on the realization of Cʁ# clusters. The presence of a major prosodic boundary significantly disfavours ʁ-deletion in word-final Cʁ#. For word-final Cʁ# and ʁC#, post-lexical consonantal contexts favour non-canonical realizations. Interestingly, for word-final ʁC#, epenthetic schwa is still observed in 20% of the cases, and post-lexical context has a significant influence on the insertions. In word-initial #Cʁ, the canonical pronunciation is systematically observed.

Index Terms: French /ʁ/-clusters, corpus study, prosodic boundary, variation

1. Introduction

In spoken language, final clusters are often simplified. Various factors may trigger cluster simplification or modification. For instance, in Catalan, when two consonants share the same place features, the second one can be deleted [2]. In English, the reduction of stops in word-final clusters is favored by the agreement in voicing between the two consonants [3]. /ʁ/ is the most frequently occurring consonant in French, and it exhibits multiple pronunciation variants [4, 5]. In the current study, we are interested in the variable production of two word-final /ʁ/-clusters in French. Following [6, 7, 8], among others, we investigate speech variation in a corpus of continuous speech, since the study of corpora of continuous speech grants us unique access to instances of variation that cannot be elicited in laboratory settings, but are crucial for identifying and quantifying variation patterns as they occur in everyday speech.

Previous studies show that native French speakers often tend to produce word-final Cʁ# in its non-canonical forms. [9] found that speakers delete /ʁ/ or insert schwa in Cʁ# clusters. The less formal the speech style is, the less they insert schwa (/Cʁ#/ produced as [Cʁə#]; e.g., quatre /katʁ/ produced as [katʁə], *four*) and the more they delete /ʁ/ (/Cʁ#/ produced as [C#]; e.g., quatre /katʁ/ produced as [kat], *four*). This result is consistent with earlier results. For example, [10] found that the deletion of /ʁ/ in final clusters is correlated with speech formality: the less formal the speech situation, the more /ʁ/ can be deleted. Moreover, [11] found that the Cʁ# cluster is affected by its right hand post-lexical context, and by the variety of French (French spoken in France vs. Swiss French vs. Belgian French).

Prosodic structure is known to have acoustic or articulatory effects, for instance, syllables at the ends of prosodic domains have longer durations [12, 13, 14, 15]. Such lengthening of final syllables increases gradually as a function of the hierarchical level of the following prosodic boundary (see [16, 17] for French, [18, 19] for English). However, as far as we know, there are no studies yet on how prosodic boundaries influence the realization of consonant clusters with /ʁ/ in French. The present study uses the LOCAS-F corpus (Louvain Corpus of Annotated Speech - French), which is one of the few French corpora with prosodic annotation, including the marking of major and intermediate prosodic boundaries. The following factors are considered in this study: prosodic boundaries, post-lexical context, speech style, and word frequency. We predict that:

- *Prosodic boundaries*: If the final-lengthening of a high-level prosodic boundary affects the realization of word-final /Cʁ/ and /ʁC/, the /ʁ/ within the clusters should be less likely to be deleted than that in other positions.
- *Post-lexical context*: Post-lexical context is expected to have an impact on the production of word sequences [20, 11]. Accordingly, when a Cʁ# cluster is immediately followed by a word starting with a vowel, few modifications are expected; when it is followed by a word starting with a consonant, epenthetic schwa or /ʁ/ deletion is expected.
- *Word frequency*: Previous studies show that frequent words are produced with more variability than less frequent ones [21, 22]. Thus, Cʁ# in frequent words should be more often modified than in infrequent words.
- *Speech style*: Speech style is known to influence speech production in various ways. [9] show that we are more likely to observe /ʁ/ deletion than schwa insertion in informal speech, and the opposite trend is observed for formal speech. The LOCAS-F corpus allows us to investigate speech style from the perspective of degree of preparation, from more carefully prepared non-interactive speech to more spontaneous, less prepared interactive speech. We expect to find more non-canonical realization of the clusters in the more interactive speech style.

2. Method

We test our predictions on the LOCAS-F corpus [1]. The corpus is composed of 42 sound tracks of 3-to-5-minute audio files,

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adding up to about 4 hours of speech. The audio files are accompanied with multilevel annotations of phones, words and prosodic levels. Besides linguistic annotations, metadata such as speech style is also available. There are 63 speakers in total in this corpus. The origin of the speakers is non-homogeneous, with a majority from France and Belgium.

For prosodic annotations, both major and intermediate prosodic boundaries are assigned [23]. This detection and annotation of boundaries is carried out semi-automatically and is based on the detection of prominent syllables according to their pitch, their relative duration, or the duration of the subsequent pause. A major prosodic boundary is identified when one of the following criteria is met, concerning the final syllable:

- the final syllable is followed by a silent pause lasting at least 200ms;
- it is lengthened (three times longer than the average duration of the preceding syllables);
- it has a salient rise for melodic contour (between 5 and 10 semitones).

Table 1: *Detailed levels for each examined factor.*

Factor	**Levels**
Prosodic boundary	non-boundary
	intermediate boundary
	major boundary
Post-lexical context	consonant (C)
	vowel (V)
	pause (P)
Speech style	interactive
	non-interactive
Word frequency	continuous variable

Cʁ# and ʁC# words were analyzed in this study. Detailed levels for each investigated factor can be found in Table 1. For words containing multiple /ʁ/-clusters, only Cʁ# in word final position was considered. For instance, for the word *apprendre* (/apʁɑ̃dʁ/, "learn"), /pr/ (in word-medial position) was not included in our analyses. The word *parce que* (/paʁskə/ or /paʁsəkə/, "because") was also excluded from our analyses because of its special status in terms of morphological structure, and its high frequency (64 occurrences in the corpus).

The presence and absence of /ʁ/ in word-final Cʁ# and ʁC# and schwa insertion right after these clusters were decided by comparing the phonological/reference transcription of the word, based on Lexique380 [24], with the transcription of the same word in LOCAS-F extracted from the annotation of the corpus. We also extracted word frequency measures for the words containing the target clusters.

3. Results

We report here the pronunciation variants of word-final Cʁ# and ʁC# in the corpus, their frequencies, and the role of several factors in these pronunciation variants.

Table 2 gives a summary of the occurrence of the consonant clusters with /ʁ/ at word boundaries in the LOCAS-F corpus. Word-initial #Cʁ is the most frequently occurring cluster in the corpus, followed by word-final Cʁ# and by word-final ʁC#.

Figure 1 shows the realizations of the clusters in the corpus. French native speakers tended to modify Cʁ# more often than the other two clusters. Only one out of 1717 tokens of word-initial #Cʁ was modified from its reference, canonical form. For

Clusters	Count
#Cʁ	1717
Cʁ#	419
ʁC#	198

Table 2: *The occurrence of the consonant clusters with /ʁ/ at word boundaries in the LOCAS-F corpus*

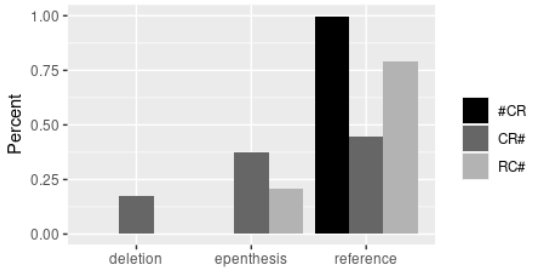


Figure 1: *Realization of #Cʁ, Cʁ#, ʁC# in the corpus*

word-final ʁC#, schwa was inserted after the cluster 20% of the time. No ʁ-deletion occurred, and the C of ʁC# was also never deleted in the corpus. In Cʁ#, speakers inserted a schwa after the cluster 39% of the time. The /ʁ/ in Cʁ# was deleted 17% of the time.

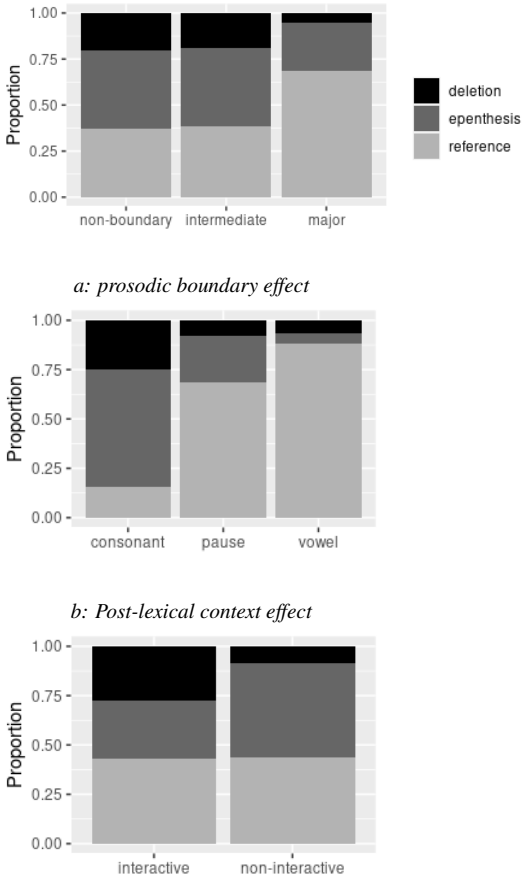
Bayesian multinomial logistic regression models were fitted to the 3-level realizations of Cʁ#: deletion, epenthesis and reference. The dependent variable was coded such that each level of the variable (deletion and epenthesis) was compared to the reference level (reference). The independent variables were *post-lexical context* (consonant, vowel, pause), *prosodic boundary* (major boundary, intermediate boundary, no-boundary), *speech style* (interactive vs. non-interactive) and *word frequency*. For multilevel categorical variables, the contrast coding was dummy coding (compare each level of the categorical variable to a fixed reference level).

Statistical analyses were performed using the MCMCglmm package, a package for fitting Generalised Linear Mixed Models using Markov chain Monte Carlo techniques in R. We report a 95% highest posterior density (HPD) interval for each coefficient and related p-values.

3.1. Cʁ#

Prosodic boundary effect: Figure 2.a. shows that the realization of Cʁ# not followed by a boundary is very similar to that preceding an intermediate boundary. Overall, fewer modifications were observed when Cʁ# preceded a major boundary. The multinominal logistic analysis revealed that when the cluster preceded a major boundary, the /ʁ/ in Cʁ# was less often deleted than before other prosodic boundaries ($deletion \times major\_boundary = -2.44$, 95% HPD $[-4.55, -0.42], p = 0.021$).

Post-lexical context effect: Figure 2.b. shows the realization of Cʁ# varying in different post-lexical contexts. The multinominal logistic analysis revealed that when the cluster was immediately followed by a word starting with a consonant, French native speakers tended to add a schwa after Cʁ#, or delete the /ʁ/ more often than when the cluster was followed by a word starting with a vowel ($deletion \times vowel = -3.52$, 95% HPD $[-4.58, -2.53], p < 0.0001$; $epenthesis \times vowel =$



a: prosodic boundary effect

b: Post-lexical context effect

c: Speech style effect

Figure 2: *Effect of prosodic boundary, post-lexical context, and speech style on the realization of Cʁ#*

-4.79, 95% HPD $[-5.88, -3.75], p < 0.0001$). When the cluster was followed by a pause, less epenthesis was produced than when the cluster was followed by a word starting with a consonant ($epenthesis \times pause = -3.1$, 95% HPD $[-4.59, -1.67], p < 0.0001$).

Speech style effect: Figure 2.c. shows that French native speakers produced Cʁ# differently between speech styles. The analysis shows that more epenthesis was produced and /ʁ/ was less often deleted in non-interactive speech than in interactive speech ($epenthesis \times non-interactive = 0.77$, 95% HPD $[0.16, 1.4], p = 0.015$; $deletion \times non-interactive = -1.1$, 95% HPD $[-1.82, -0.29], p = 0.006$).

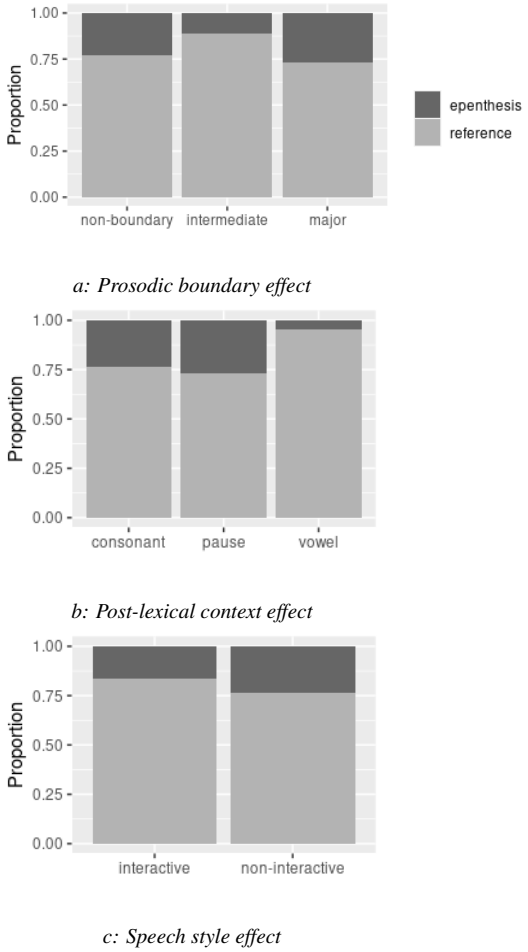
Word frequency effect: The production of Cʁ# across different levels of word frequencies was analyzed using the database Lexique380 [24]. The multinominal logistic analysis revealed that the /ʁ/ in Cʁ# tended to be deleted more often in high frequency words ($deletion \times frequency = 0.21$, 95% HPD $[0.04, 0.39], p = 0.017$). There was no significant difference between epenthesis and reference pronunciation.

3.2. ʁC#

To better understand the vocalic epenthesis after the cluster ʁC#, we conducted generalized linear models fitted to the two realizations: epenthesis and reference. As for Cʁ#, the independent variables were *post-lexical context* (consonant, vowel, pause), *prosodic boundary* (major boundary, intermediate boundary, no-boundary), *speech style* (interactive vs. non-interactive) and *word frequency*. For multilevel categorical variables, the contrast coding was dummy coding (compare each level of the categorical variable to a fixed reference level). Statistical analyses were performed using the function $glm()$ in R. P-values were generated using likelihood ratio test.

Post-lexical context: Figure 3.b. shows the realization of ʁC# varying across post-lexical contexts. The generalized linear model revealed that when the cluster was immediately followed by a word starting with a vowel, French native speakers produced an epenthetic vowel significantly less often after the cluster than when the cluster was followed by a word starting with a consonant, or by a pause ($\chi^2(4) = -16.03, p < 0.01$).

The other independent factors considered did not have a significant impact on the realization of the cluster ʁC#. However, Figure 3.d. shows that, similar to the result of Cʁ# under different speech styles, speakers tended to insert schwa more often in non-interactive speech than in interactive speech.



a: Prosodic boundary effect

b: Post-lexical context effect

c: Speech style effect

Figure 3: *Effect of prosodic boundary, post-lexical context and speech style on the realization of ʁC#*

3.3. Cʁ# vs. ʁC#

French native speakers inserted vowels after both Cʁ# and ʁC#. A generalized linear model revealed that more epenthetic

vowels were produced after Cʁ# than after ʁC# ($\chi^2(3) = 36.33, p < 0.001$). A Tukey's post-hoc test showed that such a difference of epenthesis between Cʁ# and ʁC# was due to the post-lexical segmental context. More vowels were inserted after Cʁ# when the cluster was immediately followed by a word starting with a consonant ($p < 0.0001$). But when the two clusters were followed by a word starting with a vowel or a pause, there was no difference.

4. Discussion

In the current study, we found that French native speakers often delete the /ʁ/ in Cʁ# or insert a schwa after word-final Cʁ#. They also tend to insert a schwa after word-final ʁC#, without consonant deletion. Canonical pronunciation is systematically observed in word-initial #Cʁ.

Word-finally, most of the modifications are found in Cʁ#. Our results showed that the cluster is modified more often when followed by a word starting with a consonant than with a pause or a vowel (45%, 6%, 3%, respectively). Cʁ# followed by a word starting with a consonant is always produced with simplification or schwa insertion. When the cluster is immediately followed by a pause, significantly less epenthesis is observed. It would be tempting to relate these findings to the Sonority Sequencing Principle (SSP) [25], following [26]. It can be argued that Cʁ# violates the SSP as a coda, and when it is followed by a vowel-initial word, the violation can be repaired by resyllabifying the cluster as an onset to the following vowel (e.g., quatre enfants [ka.**tʁ#ɑ̃**.fɑ̃], 'four children'.) This could explain why the cluster is rarely modified in this context (3%). It does not, however, explain why modifications are also rare in the prepausal position (6%). If anything, the modifications encountered in the pre-pausal position should be comparable to those in pre-consonantal position (45%), since the cluster cannot be resyllabified in either context.

It is clear that factors other than sonority also have an impact on the realization of Cʁ#. We observed that speakers still inserted a schwa 20% of the time after the cluster ʁC#, which does not violate the SSP in its canonical form. This is consistent with the Law of Three Consonants [27], which states that a schwa is (often) produced after a group of two consonants followed by a third, to avoid a three-consonant cluster. It is also worth mentioning that all final clusters in French, regardless of sonority shape, have been argued by many researchers to be actual onsets, based on empirical facts related to 'liaison' and final schwa (see [28, 29]; for a review, see [30]). The relevance of the SSP is therefore not entirely clear. Our results are too preliminary to pursue this question, but they do suggest that sonority alone cannot explain the data.

Prosodic boundary also plays a role in the realization of word-final Cʁ#. We found that the cluster tends to be simplified less often when it precedes a major boundary than before an intermediate, or no boundary. This finding allows us to hypothesize that the final lengthening that occurs in French [17] may favor a full, canonical realization of the cluster in this position. The initial result we report here clearly warrants an acoustic analysis that can verify whether syllables preceding a major boundary are produced with longer duration and/or more salient rise for melodic contour than in other positions in the LOCAS-F corpus. The acoustic properties of the clusters in this corpus will be examined in a future study.

Speech style also influences the type of modification in the realization of Cʁ#, but does not affect the proportion of canonical forms. Cluster simplification and schwa insertion are found under both speech styles: prepared non-interactive speech and less prepared interactive speech. More schwa insertion (39%) and less /ʁ/ simplification (17%) were produced overall. For ʁC# specifically, speakers tended to insert schwa more often in non-interactive speech than in interactive speech. This finding is consistent with [9, 10].

As expected, more simplification occurs in high frequency words in the production of Cʁ#. We did not find the same result in the realization of ʁC#. It should be noted, though, that we have fewer words with ʁC# than Cʁ#. This finding is therefore inconclusive, and the effect of word frequency on ʁC# should be re-analyzed with more data in the future.

5. Conclusions

This paper investigates the production of French /ʁ/-clusters (Cʁ#, ʁC# and #Cʁ) as a function of prosodic boundary, post lexical context, speech style and word frequency in the LOCAS-F corpus of spoken French. The LOCAS-F corpus was used for its detailed annotation of different linguistic levels, particularly the annotation of prosodic boundary. Building on findings in [9] on the production of Cʁ# as a function of different factors in continuous speech, we investigated Cʁ# and two additional /ʁ/-clusters, ʁC# and #Cʁ.

Each variation factor was investigated in terms of three possible production outcomes of the clusters: ʁ-deletion, schwa insertion, and canonical pronunciation. Results show that the production of post-consonantal word-final /ʁ/ (Cʁ#) is influenced by post-lexical context, prosodic boundaries, speech style and word frequency. Schwa insertion is observed more often than /ʁ/ deletion, which may be related to the distribution of /ʁ/ clusters in different speech styles of this corpus. Though no /ʁ/ deletion was observed for ʁC#, epenthetic schwa was still observed in 20% of cases. For word-initial #Cʁ only one non-canonical realization was observed.

The findings of this study allow us to have a better understanding of the variable production of clusters with /ʁ/ as a function of different factors. More importantly, they can provide the basis for testable predictions about their acoustic realizations, which will be verified in a future study.

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