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Reduction of word-final obstruent-liquid-schwa clusters in Parisian French

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Abstract: This corpus study investigated pronunciation variants of word-final obstruent-liquid-schwa (OLS) clusters in nouns in casual Parisian French. Results showed that at least one phoneme was absent in 80.7% of the 291 noun tokens in the dataset, and that the whole cluster was absent (e.g., [mis] for *ministre*) in no less than 15.5% of the tokens. We demonstrate that phonemes are not always completely absent, but that they may leave traces on neighbouring phonemes. Further, the clusters display undocumented voice assimilation patterns. Statistical modelling showed that a phoneme is most likely to be absent if the following phoneme is also absent. The durations of the phonemes are conditioned particularly by the position of the word in the prosodic phrase. We argue, on the basis of three different types of evidence, that in French word-final OLS clusters, the absence of obstruents is mainly due to gradient reduction processes, whereas the absence of schwa and liquids may also be due to categorical deletion processes.

Keywords: pronunciation variation, casual speech, content words, acoustic reduction, Parisian French

1 Introduction

In casual speech, words tend to be produced with fewer or lenited phonemes compared to their citation forms. In American English, the word *hilarious* [hɪlɛriʌs], for instance, may be pronounced as something like [hlɛrɛs] (e.g., Ernestus and Warner 2011; Johnson 2004). This phenomenon, called reduction, is highly frequent and has been studied in a number of languages, such as Dutch (e.g., Ernestus 2000), German (e.g., Kohler 1990), Finnish (e.g., Lennes et al. 2001), and Russian (e.g., Van Son et al. 2004). This study contributes to our knowledge of reduction by providing a detailed analysis of a reduction pattern

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in the Romance language French. We use the terms *reduction* and *reduced* to refer to both absence and weakening of segments. The term *absent* refers to segmental absence, that is, to a phoneme that is at best present in the details in the pronunciation of the neighbouring segments.

Previous studies have shown that reduction especially affects frequently occurring words (e.g., Pluymakers et al. 2005a; Bybee & Scheibman, 1999). For instance, in American English conversational speech (Johnson 2004), the percentage of phonemes in a word that deviates or is absent from those in the word's citation form is higher in high-frequency function words than in content words (20% deletion and 40% deviation for function words versus 10% deletion and 25% deviation for content words, respectively). Similarly, Greenberg (1998) reported that, in American English, pronouns, articles, conjunctions and modal/auxiliary verbs are most susceptible to phoneme reduction. Likewise, in Dutch, function words like articles, pronouns, and conjunctions are most prone to deletion (Van Bael et al. 2007). As a consequence of this, many studies on reduction have focused on high-frequency words. Bell et al. (2003), for instance, investigated the 10 most frequent English function words and Pluymakers et al. (2005b) studied occurrences of the seven most frequent Dutch words ending in the adjectival suffix *–lijk* [lək] *–able*. Less is known about reduction in content words of low to medium frequency.

Another restriction of most previous studies is that they focused on the reduction of single phonemes (consonants: e.g., Raymond et al. 2006; Bybee & Scheibman, 1999; vowels: e.g., Patterson et al. 2003). The few studies that have examined reduction of sequences of phonemes (e.g., Milne 2014; Côté 2004; Armstrong 2001) have mainly focused on the reduction of one of the cluster's phonemes. Côté, for instance, reported that liquid absence in French word-final obstruent-liquid-schwa (OLS) sequences is more constrained in Parisian varieties than in any other variety of French. Like Côté, Armstrong (2001) studied liquid absence in word-final obstruent-liquid sequences. The author demonstrated that/l/is often reduced before a consonant or a pause. Milne observed that word-final consonants are often completely deleted in clusters spanning the word boundary that violate the Sonority Sequencing Principle (SSP). Study of the reduction of all phonemes in a sequence may, however, provide important information about the processes underlying speech reduction. When the articulatory movements for a given phoneme are reduced, this may affect the articulation of the preceding and/or following phoneme, which may still be present, but acoustically weakened.

Furthermore, nearly all previous studies on reduction have focused on the presence versus absence of phonemes and on the duration of individual phonemes or words (e.g., Pluymakers et al. 2005a; Johnson 2004; Bybee &

Scheibman, 1999). Only a few studies have investigated more detailed phonetic characteristics of reduced word variants, showing that absent phonemes, which have durations of zero ms, are still cued by the detailed acoustic characteristics of neighbouring phonemes. Manuel (1991) reported, for instance, that English *s'pport* (the apostrophe marks the absence of schwa) differs from *sport* due to the presence of an oral (mouth opening) or glottal (vocal fold adduction) gesture for the underlying schwa. Ernestus and Smith (2018) studied the pronunciation of the Dutch discourse marker *eigenlijk* "actually", and showed that although the [l] frequently has a duration of zero ms, acoustic traces of [l] often remain in the neighbouring fricative, for instance as a dip in the second formant.

In sum, little is known about the influence of phoneme reduction on the (detailed) realisations of sequences of phonemes in (low frequency) content words. In this study, we aim to contribute to filling these gaps by examining obstruent-liquid-schwa (henceforth OLS) clusters at the end of spontaneously produced nouns[1] (e.g., [tʁə] in [ministʁə] *ministre* "minister") in Parisian French. We restricted our analyses to one word class, that is, nouns, because we aimed to investigate in detail a word class that, so far, has been shown to be least susceptible to phoneme reduction. We selected OLS clusters as previous studies (e.g., Brand and Ernestus 2015; Milne 2014; Laks 1977) have reported that these clusters are frequently reduced. The present study was set up to investigate the possible pronunciation variants of noun-final OLS clusters, their phonetic characteristics, the frequencies of the pronunciation variants, the predictors of these pronunciation variants, and the relationship between the reductions of the individual OLS phonemes.

Previous studies have investigated the absence of schwa in French. We only briefly discuss here some studies on Parisian French as we also study this variety of French (e.g., Bürki et al. 2011a; Racine and Grosjean 2002; Fougeron et al. 2001; Hansen 1994). These studies have shown that schwa in word-initial syllables is absent in more than 50.0% of spontaneously produced word tokens. The French word/pəluz/*pelouse* "lawn" is thus often pronounced as [pluz]. For our study, it is important to note that in word-final position, schwa has been reported to be absent in 35.0% of the word tokens in which it is preceded by one syllable, and in 90.0% of the word tokens in which it is preceded by several syllables (two, three, or more; Adda-Decker et al. 1999).

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1 We consider the obstruent and the liquid as well as the schwa, although according to some literature (e.g., Dell 1985), the schwa is always absent or only surfaces as the result of a process of schwa insertion.

Reduction of schwa in French has been shown to be influenced by many socio-indexical factors (e.g., regional accent, social status) and speech style (formal versus informal). Durand and Eychenne (2004) and Coquillon (2007), for instance, have shown that schwa deletion is more widespread in the North of France than in the South of France. Furthermore, Eychenne and Putska (2007) demonstrated that young educated speakers from the South of France are more likely to delete schwa in frequent verbs and/or specific constructions than their middle-aged or older counterparts. We studied words produced by young educated speakers from the North of France.

Context has been shown to influence the absence of a phoneme. Milne (2014), for instance, reported that schwa following a word-final consonant cluster is more often absent before a vowel-initial word (87.5%) than before a consonant-initial word (63.9%) or before a pause (69.7%). These results confirm those reported for other languages (e.g., Bybee 2015).

There are several studies that have examined the reduction of northern French single consonants. Examples are Milne (2014), Adda-Decker et al. (2008), Armstrong (1998), Su and Basset (1998), Dell (1995) and Laks (1977). Laks studied six adolescents from Villejuif (a commune in the southern suburbs of Paris) conversing with each other. He observed that the more formal the conversation and the higher the speaker's social status, the less likely [ʁ] was to be absent. Armstrong also examined liquids; he studied speech produced by French girls aged 11–12 years from Dieuze (north-eastern France), and also observed that the more formal the speech style, the less likely the liquid ([l] or [ʁ]) was reduced. Su and Basset studied spontaneously produced consonants produced by two male speakers and reported that only voiced fricatives and the lateral approximant [l] may be absent. This latter finding was confirmed in a corpus study by Adda-Decker, Gendrot, and Nguyen, who showed that in phone conversations, [l] is the most likely consonant to be absent (43.0%). Like schwa, the word-final consonant is more often absent in preconsonantal (44.2%) than in prevocalic (23.7%) or prepausal position (31.6%) (Milne 2014).

As noted above, most studies on reduction, including studies on reduction in French, have focused on the absence versus presence of phonemes. Only a few studies have examined the phonetic characteristics of reduced word variants. This also holds for Parisian French. One of these few exceptions is the corpus-based study by Bürki et al. (2011b). These authors reported that shorter schwas were more co-articulated than longer schwas and took on the spectral characteristics of the surrounding consonants, like the second formant. Another exception is the production study by Barnes and

Kavitskaya (2002),[2] who observed that the rounding gestures required for the articulation of schwa were still present when schwa was reduced. Interestingly, Côté and Morrison (2007) did not replicate these results in their study on Québec French. Finally, Meunier and Espesser (2011) and Adda-Decker et al. (2008) demonstrated that shorter vowels show more centralised formant values than unreduced vowels.

The studies by Bürki et al. (2011b) and Barnes and Kavitskaya (2002), among others, show that schwa can be strongly co-articulated. This co-articulation may result in the acoustic absence of schwa. Indeed, co-articulation forms one of the two types of main processes that may underlie the absence of phonemes. Gradient co-articulation leads to a continuum of pronunciations with the unreduced phoneme on the one extreme and the absence of the segment on the other. That is, there are (many) realisations of the word in which this phoneme is present, but where it is acoustically weakly to extremely reduced.

The results of an articulatory study on American English by Browman and Goldstein (1990) nicely illustrate this for a consonant. These researchers analysed realizations of the sequence *perfect memory*, either produced as two independent words in a word list (and thus with an intonation boundary between the two words), or produced as a grammatical unit in a fluent phrase. In the fluent phrase version, the final [t] of *perfect* was often not audible, but the alveolar closure gesture for the [t] was nevertheless always present, with almost the same magnitude as in the word list version, in which [t] was clearly audible. In the fluent phrase version, the alveolar burst was often completely overlapped by the closure of the following bilabial [m]. Hence, Browman and Goldstein assume gradient reduction to be the result of the retiming of articulatory gestures which results in stronger co-articulation. Other studies (e.g., Bybee 2002) propose that gradient reduction may also be stored as part of a word's lexical representation.

Second, the absence of phonemes may result not only from gradient reduction processes, but also from categorical processes, which result in the complete absence of phonemes without any acoustic traces. The categorical absence of a phoneme could be due to a phonological deletion rule (e.g., McCarthy and Prince 1993; Chomsky and Halle 1968) or the storage of a word pronunciation variant without the given phoneme in the mental lexicon (e.g., Bybee 1998). In the latter case, the categorical absence of a phoneme results from the selection of the word pronunciation variant without that phoneme.

Evidence for lexical storage of categorically distinct pronunciation variants is provided by, among others, Bürki and Gaskell (2012). Bürki and Gaskell

2 Barnes and Kavitskaya (2002) do not specify the variety spoken by their participant, but we can presume that it is Parisian French.

compared English words with schwa in poststress position (e.g., as in *mackerel*) to words with schwa in prestress position (e.g., as in *salami*). Previous studies (e.g., Kager 1997; Patterson et al. 2003) showed that reduced schwa variants of poststress schwa words (e.g., *mackerel* realized as [mækrəl]) are categorically distinct (word-medial schwa is either present or absent) from the corresponding schwa variants ([mækərəl]). In contrast, reduced schwa variants of prestress schwa words (e.g., *salami* realized as [slami]) show gradient schwa reduction. Bürki and Gaskell investigated the lexical representations underlying the production of categorically and gradient distinct English schwa words, by instructing participants to read aloud pseudohomophones (e.g., with pre-stress schwa: *b*/ə/*loone*; with post-stress schwa: *batt*/ə/*ree)* and pseudowords (e.g., with prestress schwa: *b*/ə/*leen*; with post-stress: *bott*/ə/*ree*) with and without schwa. The authors found shorter naming latencies for pseudohomophones than for pseudowords for both variants of poststress schwa words, but only for schwa variants of prestress schwa words. Based on these results, they assumed that both variants of poststress schwa words are lexically represented, while only schwa variants of prestress schwa words are.

Several methods have been used to determine whether phoneme absence only results from gradient or also from categorical processes. First, the phonetic properties of the phoneme sequences resulting from the absence of a phoneme have been studied in detail. Phoneme absence can be assumed to result from a categorical process when the phoneme is completely absent and has not left any traces in the acoustic signal. In contrast, the absence of a phoneme results from gradient reduction when the phoneme has left traces, for instance, in the durational or spectral properties of surrounding phonemes. In their analyses of French vowel reduction, Bürki et al. (2011b), Meunier and Espesser (2011), Adda-Decker et al. (2008), and Barnes and Kavitskaya (2002) observed residues of absent vowels in lip rounding and in durational and spectral characteristics of the acoustic signal.

A second method for attributing the absence of a phoneme to only gradient or also categorical processes is the inspection of the distribution of the duration of the phoneme (e.g., Bürki et al. 2007). If the distribution shows two clearly distinct peaks, one of which is around zero ms, representing the absent phoneme, absence of the phoneme is assumed to result from both a categorical and a gradient reduction process. If, in contrast, the distribution is unimodal, without a clear peak around zero ms, absence of the phoneme is assumed to result from gradient shortening. For the duration of French word-initial [s(e)] in *c'était* [sete] "it was", Torreira and Ernestus (2011) found a bimodal distribution, with one mode containing most tokens with [e] (38.0% of the tokens, mean duration: 37 ms) and the other containing most tokens without [e] (62.0% of the tokens in which [e] had a duration of zero ms). This pattern suggests that the absence of [e] in French *c'était* results from a categorical process rather than from extreme vowel shortening. Bürki et al. (2011b) showed that the distribution of the duration of French schwa in word-initial syllables (e.g., [ə] in [pəluz] *pelouse* "lawn") is close to normal, and that schwa duration varies from very short to very long. They therefore concluded that the absence of schwa, which is traditionally assumed to result from a categorical process of alternation, may especially be the result of a process of gradual phonetic reduction.

A third approach addressing the issue of gradient versus categorical reduction is to compare the variables predicting phoneme absence and those predicting phoneme duration. Perfect (or substantial) overlap in predictors would suggest that phoneme absence and duration are driven by the same processes, and that phoneme absence is the endpoint of gradient sound shortening (possibly as the result of co-articulation). In contrast, when phoneme absence and phoneme duration are affected by different variables, they are more likely to result from different processes, and the absence of a phoneme may then also result from a categorical process. In their study on Dutch informal speech, Hanique et al. (2013) found approximately the same phonetic variables to predict presence and duration of suffixal [t] in past participles (e.g., [t] in *gemaakt* "made"), indicating that the absence of [t] may simply be the extreme result of shortening. Torreira and Ernestus (2011) found evidence for categorical absence; they observed that the presence and duration of [e] in French *c'était* "it was" are conditioned by different variables, which suggests that presence and duration of [e] are determined by different processes, as was also suggested by the distribution of the duration (the second method).

In order to investigate the nature of the processes that underlie the reduction of the word-final OLS phonemes in French nouns, we applied all three methods to see whether their absence was mostly due to gradient or also to categorical reduction processes. Comparison of the results obtained with the three methods may not only provide more information about the underlying processes, but may also show what the best method for analysing reduction in corpus data is.

This chapter is structured as follows. We first provide a brief description of the procedure used to create our dataset. We then present our results in three parts. The first part of the results section discusses the different pronunciation variants of the OLS clusters that we observed at the phonemic level. In the second part, we focus on the phonetic properties of the OLS phonemes. In the third part, we present the distributions of the durations of the OLS phonemes and our statistical analyses of absence and duration of the OLS phonemes. In the general discussion, we summarize our results and discuss the implications of our findings for speech production models.

2 Methods

2.1 Materials

We extracted noun tokens from the Nijmegen Corpus of Casual French (NCCFr; Torreira et al. 2010). The NCCFr contains speech from 46 speakers (24 females, 22 males), who have completed the secondary education cycle in France and have been raised in central/northern France. Except for two female speakers, all speakers are university students, aged between 18 and 27 years. The speakers participated in pairs, coming to the laboratory with a third friend, who was a confederate. After adjusting the recording volume during the first two minutes of the conversation, the confederate was asked to come out of the sound attenuated room under the pretext that his/her microphone was not working properly. The two friends left in the room then spontaneously started a conversation. At this moment, the recording started. In the second part of the recording, the confederate was asked to go back to his/her friends and the three continued discussing topics raised in the first part of the recording. In the third part, the participants received a sheet of paper with several questions about politics and society. They were asked to negotiate unique answers for at least five questions. The corpus contains around 90 min of recorded conversation for every pair of speakers.

We selected noun tokens with citation forms ending in a voiceless OLS cluster. We restricted the analysis to clusters with voiceless obstruents because the acoustic analysis of these clusters is much easier than the acoustic analysis of OLS clusters containing voiced obstruents: the presence of an unreleased stop can be more easily detected if its closure is produced without vocal fold vibration. After we had excluded tokens that occurred in phrases containing laughter or overlapping speech or that occurred in fixed expressions (e.g., *par exemple* "for instance"), 291 noun tokens were left (212 singulars and 79 plurals, 41 lemmas; see Appendix). This selection of tokens includes one token ending in /flə/, seven in /fʁə/, 66 in /klə/, one in /kʁə/, 55 in /plə/, and 161 in /tʁə/. OLS clusters were preceded by one syllable in 147 word tokens and by two syllables in 144 tokens. They were produced by 43 different speakers (21 females, 22 males), aged between 18 and 50 years (mean age: 22.7).

2.2 Transcriptions

The first author annotated the acoustic signal of the OLS clusters of the 291 word tokens in Praat (Boersma and Weenink 2014). Segment boundaries were placed to indicate the presence, onsets, and offsets of the obstruents, liquids, and schwas,

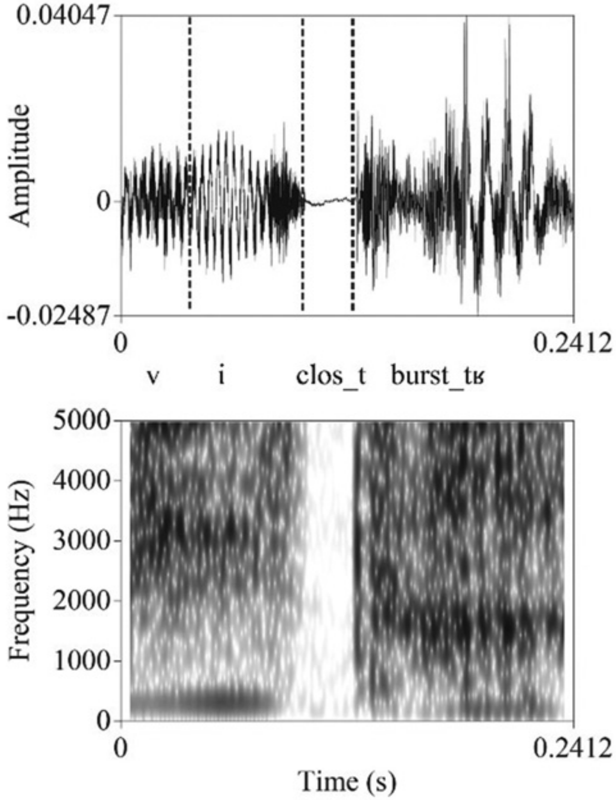

Figure 1: Example of a phonetic transcription of /vitʁə/ *vitre* 'window glass'. 'Clo_t' refers to the closure of the /t/ and 'burst_tʁ' refers to the burst of the /t/ and the /ʁ/.

based on the periodicity in and the acoustic intensity of the speech signal, as well as movements of the second formant in the spectrograms. Figure 1 gives an example of a phonetic transcription of [vitʁə] *vitre* "window glass".

The onset of the oral closure was considered as the onset of the voiceless stop ([k], [t] and [p]). Due to the high-frequency fricative noise, the beginning of the [f] could also be distinguished easily. On the basis of auditory inspection, two transcribers determined whether the obstruent was voiced or voiceless.

The release of the voiceless stop was not included in the stop segmentation, because it could rarely be distinguished from the following liquid, which was often voiceless (81.8% of the liquids was voiceless). The segmentation of the stop thus only includes its closure. Since liquids have neither a (complete) closure nor a turbulent obstruction of airflow (e.g., Ball and Rahilly 1999), segmentation of [l] and [ʁ] was also challenging after fricatives. The transcriber placed the boundaries between the fricatives and the liquids taking into account changes in the second formant and in the amplitude. Following previous literature, we also took into account the possibility of cluster-medial vowel epenthesis (e.g.,/kʁy/*cru* "raw" may be pronounced as something like [gəʁy], at least in Québec French, see Colantoni and Steele 2005, Colantoni and Steele 2007).

We considered an increase of energy (and the start of periodic waveforms if the liquid was voiceless) as cue(s) for the onset of the schwa. Schwa offset was considered to be indicated by a decrease in intensity.

The first author further annotated every word token for variables that were significant predictors of the presence of phonemes in previous studies (e.g., Bell et al. 2009; Gopal 1990; Klatt 1976): we annotated which phoneme followed and preceded each of the three phonemes, and specified its voicing, manner and place of articulation.

One hundred randomly selected tokens were also annotated by a second transcriber. No major disagreements were found with respect to the judgments on the presence versus absence of phonemes (95.0% agreement on presence of the obstruent and the schwa, 96.0% agreement on presence of the liquid). The mean between-transcriber difference in obstruent duration was 7.19 ms, in liquid duration 9.23 ms, and in schwa duration 10.36 ms Comparisons of the annotations further showed an agreement of 96.0% for the type of phoneme following the word and of 93.0% for the type of phoneme preceding the word. The phonemes on which the transcribers did not agree with respect to presence or duration (disagreement being quantified as a duration difference > 20 ms) were transcribed by a third transcriber, and we adopted the majority vote.

2.3 Variables in our dataset

We added the frequency of occurrence of the given word, based on the NCCFr (Torreira et al. 2010), to our dataset. Since previous studies have shown that a word's predictability influences its reduction and that of the preceding word (e.g., Pluymakers et al. 2005a; Bell et al. 2003), we also incorporated the bigram frequencies of the word with the following word and with the preceding word, with bigram frequencies also being derived from the NCCFr. All these frequency variables were logarithmically transformed.

Furthermore, we took the position of the word token in the prosodic phrase into account: we annotated whether it was in phrase-medial or phrase-final position. We also included the number of syllables of the word in its unreduced form. Finally, we incorporated speech rate, which we defined as the number of syllables in the utterance's citation form divided by the duration of the utterance. We defined the utterance following Torreira et al. (2010), that is as a stretch of speech with clear syntactic and semantic coherence that contains no pauses. Pauses, which could be filled (e.g., by "euh") or unfilled, were only annotated if they were minimally 200 ms, because this appears to be the standard threshold for perception (e.g., Zellner 1994; Grosjean and Deschamps 1975; Goldman-Eisler, 1968).

3 Results

3.1 Pronunciation variants

The majority of the OLS clusters (80.7%) lack at least one phoneme. Schwa is absent in 79.4% of all tokens, the liquid is absent in 42.9% of all tokens, and the obstruent is absent in 17.9% of all tokens. Our data show lower percentages of absence for the schwa, the liquid, and the obstruent than found in previous studies, which reported schwa absence rates of 90.0% for polysyllabic words (Adda-Decker et al. 1999), liquid absence rates of 58.0% (for mono- and polysyllabic words, Villeneuve 2010), and obstruent absence rates of 23.7–44.2%, depending on the following context (for mono- and polysyllabic words, Milne 2014). Our absence rates are probably lower because our dataset only contains nouns, and does not contain high-frequency verbs (e.g., *être* "to be") or conjunctions (e.g., *par exemple* "for example"), which are known to show particularly high reduction rates.

If the phonemes of OLS clusters can be absent independently from each other, we would expect to find eight pronunciation variants. Our data only show seven pronunciation variants, of which three occur only rarely. Table 1 lists these seven variants and their relative frequencies.

As mentioned above, the majority of word tokens are produced with reduced OLS clusters given that the citation form of the OLS cluster only occurs in 18.9% of the tokens. The variant without schwa has often been considered as the most frequent and thus canonical variant (e.g., Adda-Decker et al. 1999). This is also true for our dataset, where the most frequent variant of the OLS cluster is the OL variant. However, this variant only occurs in 35.7% of the tokens (out of which 21.7% had one syllable preceding the OLS cluster; and 14.1% had two preceding syllables), and the difference in frequency with the second most frequent variant is small. This second most frequent variant (27.1% of the tokens) is the variant in which both the liquid and schwa are

Table 1: Relative frequencies (percentages of occurrence) of the OLS pronunciation variants, illustrated with the variants of the word *ministre* "minister". Below the dotted line, we present the three "rare" variants.

Variant type	Obstruent	Liquid	Schwa	Example	Relative frequency
OLS	present	present	present	[ministʁə]	18.9%
OL	present	present	absent	[ministʁ]	35.7%
O	present	absent	absent	[minist]	27.1%
X	absent	absent	absent	[minis]	15.5%
LS	absent	present	present	[minisʁə]	1.4%
L	absent	present	absent	[minisʁ]	1.0%
OS	present	absent	present	[ministə]	0.3%

absent. Strikingly, the variant in which the entire OLS cluster is absent also occurs quite often (15.5%).[3]

Table 1 also lists three low-frequency pronunciation variants. In the first of these, only the obstruent is absent (LS), in the second, both the obstruent and schwa are absent (L), and in the third, only the liquid is absent (OS). In the LS and L variants, for instance in [minisʁə] and [minisʁ], the obstruent is absent, but the liquid is still present. In the OS variant, for instance in [ministə], the liquid is absent, but [ə] is still present. These variants thus display the following pattern: a phoneme is absent while at least one of the following phonemes is present.

We see a different pattern for the frequent reduced variants, those above the dotted line in Table 1 (OL, O, X). If a phoneme is absent, all following phonemes are absent as well. This difference between the high-frequency and low-frequency variants suggests that a phoneme is more likely to be absent if the following phoneme is also absent. This pattern is confirmed by two logistic mixed-effects models (Faraway 2006) (with word and speaker as random variables) showing that the absence of the obstruent and the absence of the liquid can be predicted as a function of the absence of the following phoneme ($ß = 2.69$, $z = 5.36$, $p < 0.001$; $ß = 4.50$, $z = 4.31$, $p < 0.001$, respectively).

Figure 2 shows the percentages of tokens with a "present" obstruent, the percentages of tokens with a "present" liquid, and the percentages of tokens

3 We tested whether the differences in frequency between the pronunciation variants are statistically significant. We conducted pairwise generalized mixed effects models with only the intercept as fixed effect and speaker and word as random effects for each pronunciation variant and the variant that was most similar in frequency. The model comparing the OL and O variants, the model comparing the O and OLS variants, and the model comparing the OLS and X variants showed no statistically significant difference.

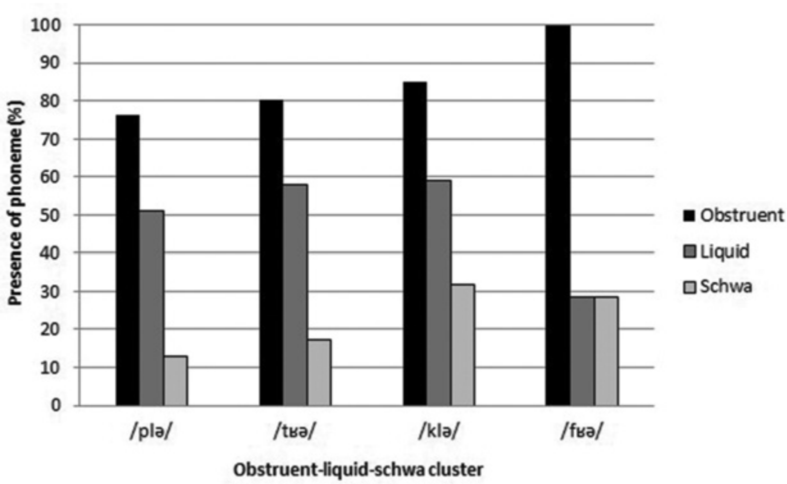

Figure 2: The presence of obstruents, liquids and schwas in different OLS clusters.

with a "present" schwa, split by type of OLS cluster. Since we only studied one token of/flə/and of/kʁə/, we did not incorporate these clusters in the figure.

Figure 2 shows that, across OLS cluster types, schwa is absent most of the time. Pearson Chi-squared tests show that schwa is more often present in the/klə/cluster than in the/plə/and/tʁə/clusters (differences with/plə/and/tʁə/, both *ps* < 0.05, which are also significant after Bonferroni correction). Furthermore, in/plə/and/tʁə/, the liquid is more often present than the schwa (also significant after Bonferroni correction: for/plə/$p < 0.01$; for/tʁə/$p < 0.001$; whereas for/klə/ $p > 0.05$; and for/fʁə/$p > 0.1$).

Regarding following-context effects, the whole cluster can be expected to be absent especially if the initial phoneme of the following word has the same place of articulation as the O, and that LS is especially absent if the following phoneme shares its place of articulation with the L. For instance, in the word sequence *peintre dans* "painter in", the [t] has the same place of articulation as the initial [d] of *dans* and this may increase the likelihood that [tʁe] is absent. Our data show that only 35.6% of the word tokens with a completely absent OLS cluster are followed by a word that starts with an obstruent with the same place of articulation as the O of the OLS cluster,[4] and that in only 41.2% of the tokens

4 We believe that the obstruent is missing rather than being merged with the following obstruent because if the two had merged we would have expected the following segment to be longer. That is, we then predict the following obstruent to be longer when the OLS obstruent seems absent than when the OLS obstruent is clearly present. This is not what we find. The

in which the liquid and the schwa are absent, the following word starts with a liquid. This shows that which phonemes in the OLS cluster may be absent is not only determined by the type of the initial segment of the following word, although this segment may have an influence.

Finally, the number of syllables preceding the OLS cluster does not seem to influence the likelihood of the absence of the word-final schwa (one versus two syllables preceding the OLS cluster: 78.9% versus 79.9%). In contrast, the two other cluster phonemes seem to be absent more often if the cluster is preceded by two syllables (obstruents: 26.4% versus 9.5%, Pearson Chi-squared test demonstrates $p < 0.01$; liquids: 49.3% versus 36.7%, but Pearson Chi-squared test demonstrates $p > 0.05$).

3.2 Phonetic properties

In this section, we discuss the phonetic properties of the different pronunciation variants of the OLS clusters in more detail.

3.2.1 Reduction of the stop closure

We first focus on the reduction of the stop closure. Figure 3 presents two pronunciation variants of *couple*/kuplə/“couple”.

In the variant on the left, which is followed by *depuis*, the final schwa is present. The relatively long closure of the [p] (i.e., 86 ms) is followed by the burst of the [p] and the [l], which together have a duration of 48 ms In the variant on the right, which is followed by *pour*, the schwa is absent. The relatively short closure of the [p] (i.e., 21 ms) is followed by the burst of the [p] and the [l], which together have a duration of 105 ms Data like these suggest that if the closure of the [p] is shorter, the total duration of the burst of the [p] and the [l] is longer. The shorter stop closure may be the result of a (partly) incomplete closure and thus of the weakening of articulatory gestures.

This duration pattern is reflected by a logistic mixed-effects model with word and speaker as random variables (Faraway 2006), which shows that, for the whole data set, the duration of the stop closure can be predicted as a function of the duration of the burst and liquid: the stop closure is shorter if the burst and liquid are longer ($ß = -0.136$, $t = -2.858$, $p < 0.01$).

mean duration of the following [d] is 26.5 ms when the obstruent is absent (N = 15), and 29.0 ms when the obstruent is present (N = 3). We cannot say anything about the absent [k] since absent [k] only once showed overlap with the place of articulation of the following segment.

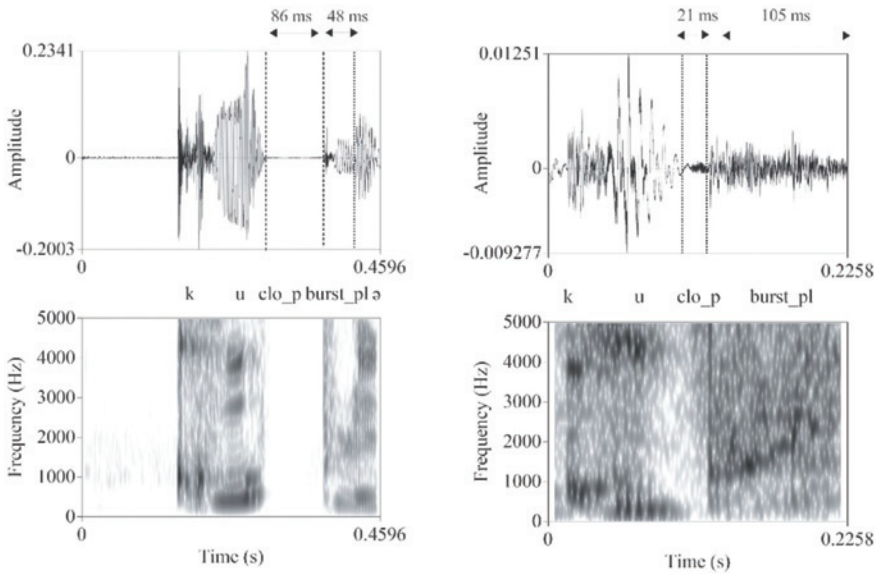

Figure 3: Two pronunciation variants of *couple* /kuplə/ 'couple'. In the variant on the right, which is followed by *pour*, the burst of the stop and the liquid together (burst_pl) are unexpectedly long compared to the duration of the stop's closure (clo_p) and to the duration of the preceding vowel. This is not the case in the variant on the left, which is followed by *depuis*.

3.2.2 Obstruent voicing

While the obstruent is voiceless in the citation forms of the words, it is often realized as voiced in our data. If the liquid and schwa are both absent and the obstruent is in word-final position, the obstruent is realized as voiced in 13.9% of the tokens (i.e., in 11 of the 79 word tokens). The question arises about the source of this voicing. In 18.2% of the tokens (i.e., in 2 of the 11 tokens) in which the OLS cluster is pronounced as the voiced variant of O, the word token was followed by a voiceless consonant. The voicing of the obstruent did thus not exclusively result from the voicing of the following *present* segment (i.e., regressive voice assimilation to the following *present* segment). In Figure 4, we see an example of the noun token *spectacle* "show" in which the OLS cluster/klə/is pronounced as [g] and the next word *c'est* starts with a voiceless [s].

Progressive voice assimilation, where a phoneme takes on the voicing properties of the preceding one, is not very common in French (e.g., Lodge et al. 1997) and, to our knowledge, progressive voice assimilation to French vowels has not been reported. Moreover, all voiced obstruents were in word-final position ([dʁ], [dʁə], [bl], [blə], [gl], [glə], [vʁ] and [vʁə] do not occur), which suggests that the

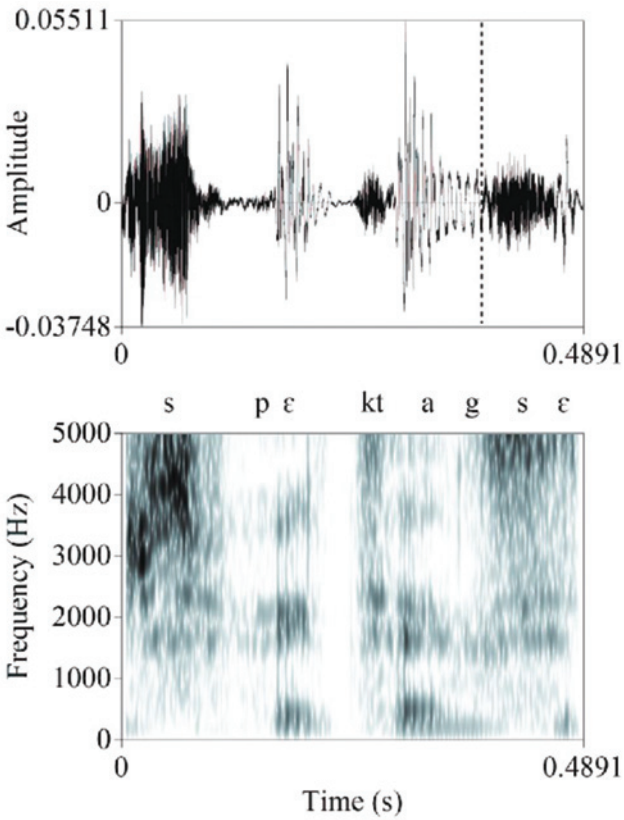

Figure 4: Token of *spectacle* 'show' in which the final OLS cluster is pronounced as the voiced variant of the obstruent. The next word starts with a voiceless /s/.

voicing of obstruents does not result from assimilation to the voicing properties of the vowels preceding the obstruents. This pattern of results also confirms our hypothesis formulated above that the voicing does not come from the following present sounds. Otherwise, the obstruents would also have been voiced if followed by the liquids or the schwa.

We propose that the voicing of the obstruents originates from the *absent* liquids. Since we showed that the obstruent is neither likely to be voiced as a result of progressive assimilation nor as a result of regressive assimilation to the surrounding *present* phonemes, obstruents, like [k] in Figure 4, are likely to be voiced as a result of co-articulation with the voicing properties of the segmentally absent liquid.

Figure 5 presents another token of a noun (*litres* "litres") in which the liquid and the schwa are absent and the obstruent is voiced. This noun token was followed

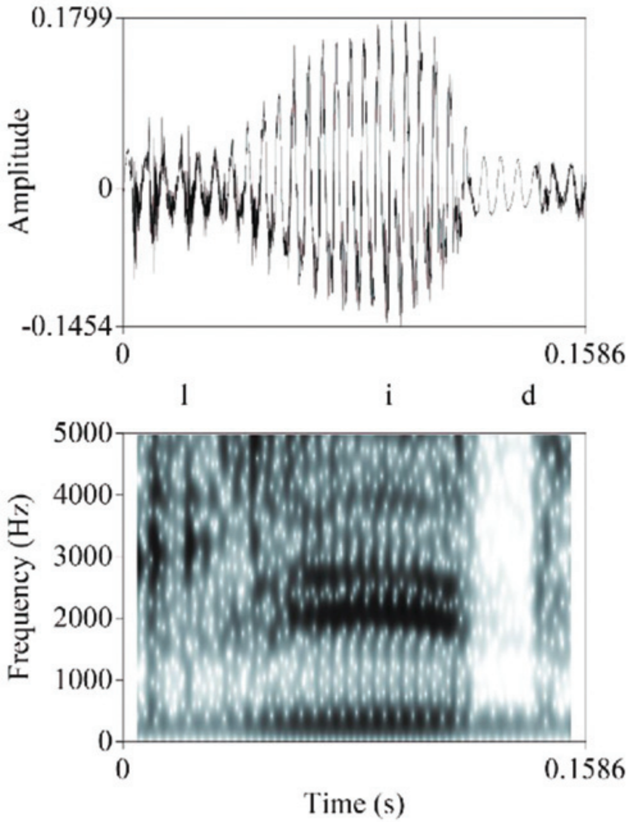

Figure 5: A token of *litres* /litʁə/ 'litres' pronounced as /lid/. The noun is followed by the /m/ of *mais*.

by a nasal from the following word (*mais* [mɛ] "but"), and the/t/may therefore be voiced as a consequence of regressive voice assimilation to this nasal as well. However, Hallé and Adda-Decker (2007) pointed out that nasals rarely induce voice assimilation processes in French, and we therefore believe that the absent liquid may have played a role in the voicing of the obstruent in the four O tokens followed by nasals.

3.2.3 Acoustic residues of velar obstruents

Figure 6 shows an example of a pronunciation variant of *articles* "articles" followed by *par* in which the [k] surfaces as a velar pinch in the vowel formant structure:

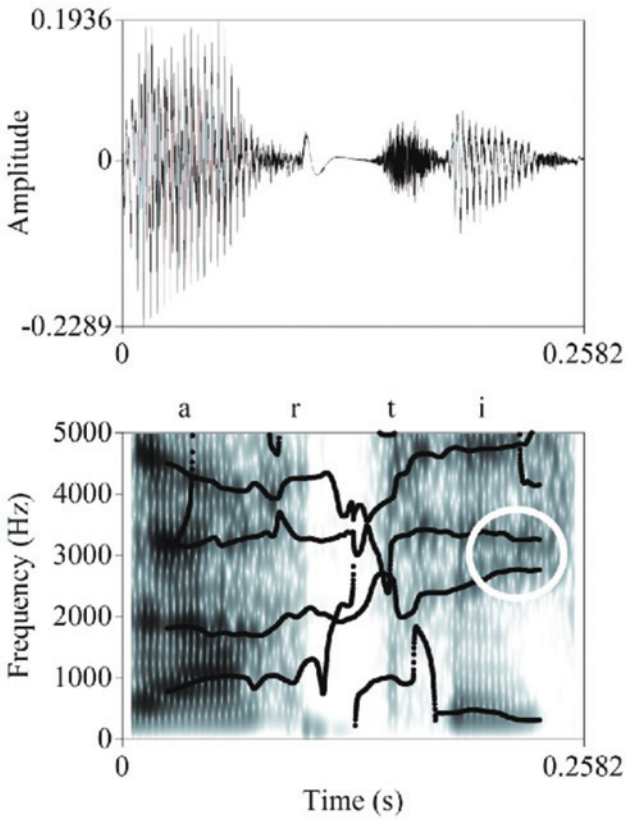

Figure 6: Example of a pronunciation variant of *articles* ‘articles’ in which the OLS cluster is completely absent. The variant is followed by *par*. The black lines in the spectrogram represent the formants. In the white circle, during the /i/, the second and third formants come very close to each other, which is typical for a velar context.

during the preceding vowel, the second and third formants come very close to each other, which is typical for a velar context. We observed a similar pattern in 62.5% of the tokens (i.e., for five of the eight tokens) in which/klə/seems completely absent.

3.2.4 Obstruent nasalisation

Twenty-one word tokens in our dataset have a nasalised vowel preceding the OLS cluster (e.g., *exemple*/ɛgzɑ̃plə/“example”). In 71.4% (15 out of 21) of these

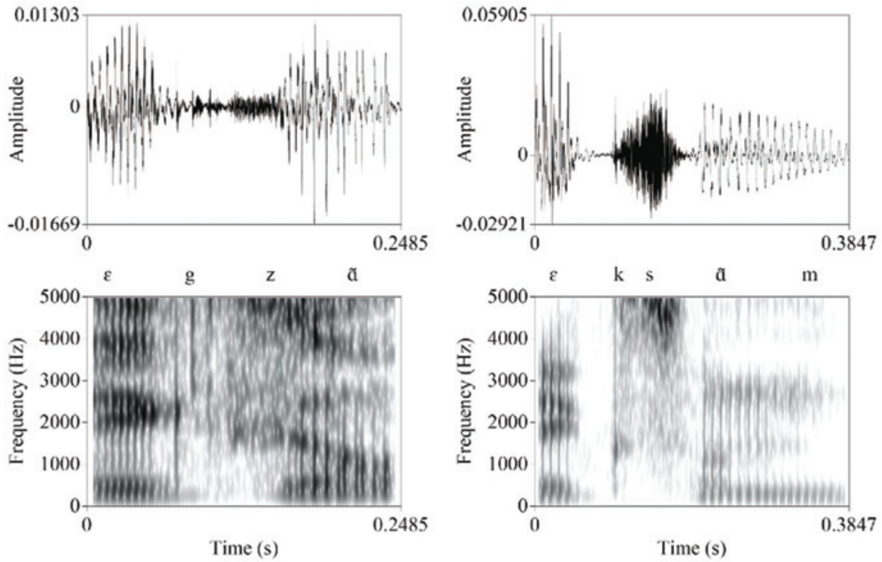

Figure 7: Examples of pronunciations of *exemple* /ɛgzɑ̃plə/ 'example'. In the phrase-final variant on the left, the whole OLS cluster is absent. In the variant on the right, which is followed by *du*, the obstruent has become nasalised.

tokens (seven were pronounced by the same speaker), the liquid and schwa were absent and the obstruent was pronounced as [n] or [m] (e.g.,/ɛgzɑ̃plə/was pronounced as [ɛgzɑ̃m]). The speaker kept the velum lowered, needed for the nasalised vowel, during the realisation of the obstruent, as a result of which the consonant was nasalised. Figure 7 presents two pronunciation variants of the word *example* "example"; one pronounced without the OLS cluster (and thus ending in the nasal vowel) in phrase-final position and one with a nasalised [p], which is followed by *du*. This phenomenon of obstruent nasalisation was also observed by Malécot and Metz (1972) in the context "nasal vowel + stop + word juncture + consonant".

3.2.5 Reduction of phonemes in addition to the OLS cluster

Most of the 45 word tokens without the OLS cluster also lack other phonemes. For instance, *ministre* "minister" is realized as [mis] in 52.9% of the word tokens (in 9 out of 17 tokens, see Figure 8 for an example). In [mis], the whole OLS cluster is missing as well as the phonemes/ni/, and this realisation thus lacks

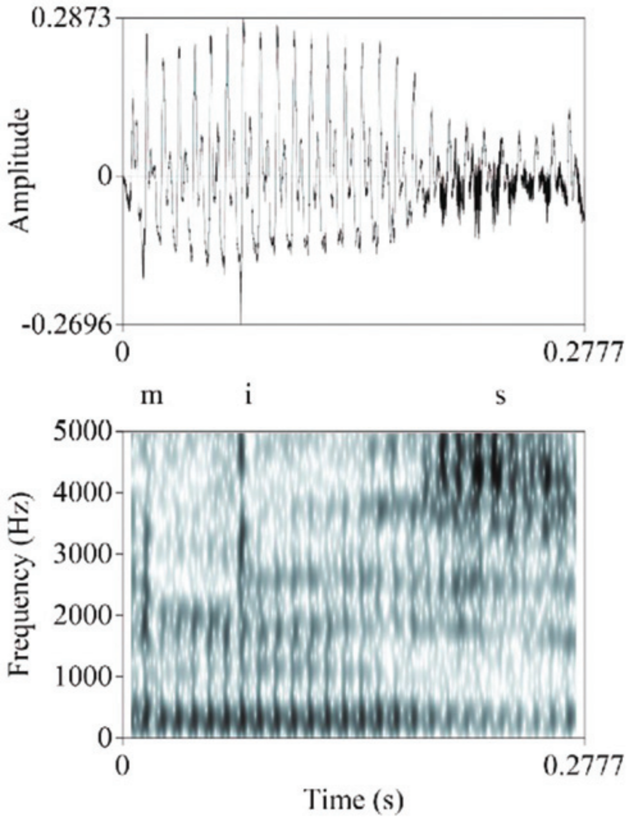

Figure 8: Example of a pronunciation variant of *ministre* /ministʁə/ 'minister', which is followed by *de*, and lacks phonemes in addition to the OLS cluster phonemes.

two complete syllables. The final segment of the token in Figure 8, which is followed by *de*, is relatively long ([s] is 97.97 ms), such that reduction of/tʁə/in *ministre* probably involves lengthening of word-final [s] (see section 2.4.2).

3.2.6 Summary

To summarize, the phonetic analyses show that absent or reduced obstruents and liquids may leave durational and phonetic cues on neighbouring segments. If a stop has a short closure, its burst and following liquid are often lengthened in a compensatory fashion, and if the OLS cluster is completely missing, the preceding phoneme may be lengthened. An absent liquid may leave traces in the form of the voicing of the preceding obstruent. The results further demonstrate that the obstruent can become nasalised after a nasalised vowel. We did not find acoustic traces of segmentally absent schwa.

3.3 Analyses of the duration and absence of each OLS phoneme

This section presents the distributions of the durations of the individual OLS phonemes. In addition, we analyse the predictors of absence and durations of these phonemes. These data will provide further evidence for the categorical versus gradient nature of the processes underlying the phonemes' absence.

3.3.1 The obstruent

Figure 9 shows the distribution of the duration of the obstruent. Absent obstruents are represented as tokens with zero ms and the duration of the obstruent thus ranges between zero ms and 136 ms The distribution shows two peaks (one peak at zero ms, 17.9% of the noun tokens; one peak around 35 ms) with a very shallow dip between them. Because of the shallowness of this dip,

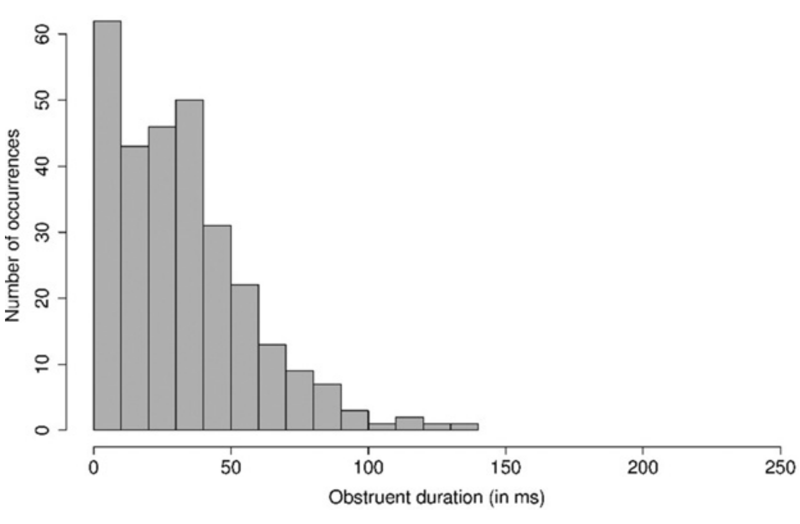

Figure 9: Distribution of the duration of the obstruent (N = 291).

we consider the distribution of the duration of the obstruent rather as unimodal than bimodal.

To determine the predictors of absence of the obstruent, we fitted generalized mixed-effects regression models with the binomial link function, with word and speaker as crossed random variables, and with the following types of potential fixed predictors: 1. two Boolean variables (final position and medial position) representing the phrasal position of the word token, 2. Word frequency based on the NCCFr (log-transformed), 3. The bigram frequencies of the word with the following and with the preceding word (again based on the NCCFr, and log-transformed), 4. Speech rate, quantified as the number of syllables, and thus the number of vowels, realized in the utterance's citation form, divided by the duration of the utterance, 5. The number of syllables in the word, and 6. The nature of the preceding phoneme. Since we observed that a phoneme was more likely to be absent when the following phoneme was also absent, we also incorporated the absence of the liquid as a predictor of obstruent absence. We did not include random slopes because preliminary testing suggested that models including them did not converge. We only retained those predictors in the model that were statistically significant or figured in statistically significant interactions and whose presence resulted in a model with a lower AIC.

For the analysis of the log-transformed duration of the obstruent (excluding the burst phase of the stop), we fitted linear mixed-effects regression models following the same fitting procedure and with the same potential predictors as in the analysis of the obstruent absence. We did not include in our analysis the absent obstruents (52 data points, 17.9%). Finally, we discarded all obstruents with durations that deviated more than two and half times the standard error from the values predicted by the best statistical model and refitted the model.

Table 2 summarizes the final models for obstruent absence and obstruent duration.

The two models have two predictors in common (i.e., liquid absence and phrasal position). If the liquid was absent, the obstruent was more likely to be absent as well and tended to be longer. If the word was in medial position, the obstruent was more often absent and tended to be shorter. The model for obstruent absence also shows that the obstruent was more often absent if the following word was more predictable. Finally, the obstruent was shorter in bisyllabic words than in monosyllabic words. Except for the effect of liquid absence on obstruent duration, these effects are in line with previously reported effects on reduction in general (e.g., Torreira and Ernestus 2009). The longer duration of the obstruent in

Table 2: Summary of the regression models predicting obstruent absence ($N = 291$) and duration ($N = 239$). The intercept represents a word token with a present liquid that is in phrase-final position.

Fixed effects	Absence		Duration	
	ß	*z*	*ß*	*t*
Intercept	−41.55	−3.67***	3.94	22.77
Liquid absent	14.45	3.76***	0.26	3.60***
Medial position	6.11	2.29*	−0.15	−2.08*
Following bigram frequency	3.43	1.99*	-	-
Number of syllables	-	-	−0.28	−2.49*
Random effects		*SD*		*SD*
Word	intercept	26.20	intercept	0.27
Speaker	intercept	11.91	intercept	0.16
			residual	0.46

*Note: *** indicates $p < 0.001$ and * indicates $p < 0.05$*

case the liquid is absent shows that absent liquids may leave durational cues and that “compensatory” lengthening may take place.

3.3.2 The liquid

The distribution of the duration of the liquid is presented in Figure 10. Here again, absent segments were assigned durations of zero ms.

The duration thus ranged from zero ms to 223 ms The distribution shows two peaks (one at zero, 42.9% of the noun tokens; one at around 90 ms) with a deep dip between them.

We analysed the predictors of liquid absence and duration, including the burst of the preceding stops if present, following the same procedures as for obstruent absence and duration. We also tested the same predictors, except for the predictor of liquid absence which was replaced by the predictor of schwa absence. Liquid durations of zero ms (125 data points, 42.9%) were removed for the duration analysis. We also discarded all liquids with durations that deviated more than two and half times the standard error from the values predicted by the best statistical model and refitted the model. Table 3 summarizes the best statistical regression models.

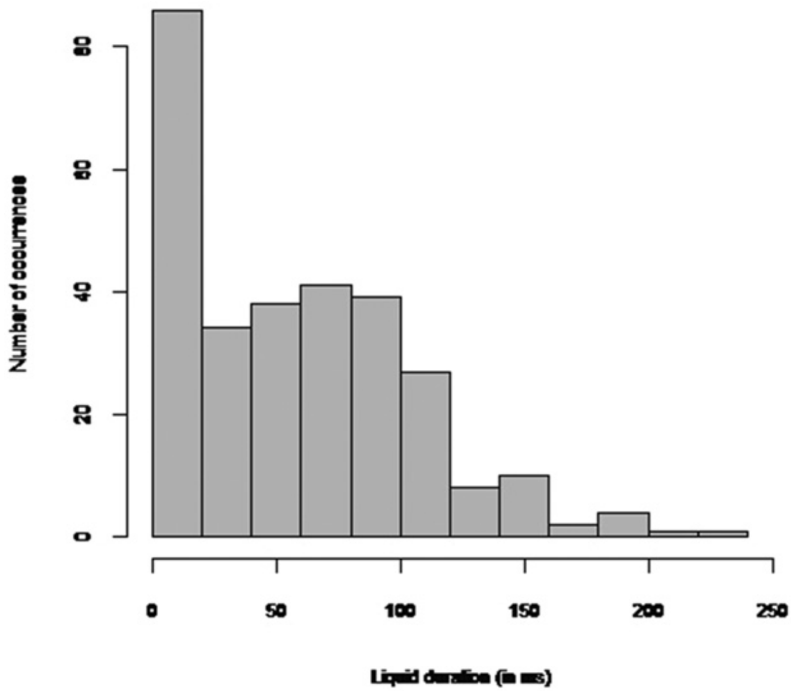

Figure 10: Distribution of the duration of the liquid (N = 291).

Table 3 shows that there is only one variable predicting both liquid absence and liquid duration. If speech rate was higher, the liquid was shorter and more often absent. The liquid was also more likely to be absent if schwa was absent and if the following word was more predictable. The liquid was shorter in phrase-medial position. Similar effects have been found for other reduction patterns (e.g., Keating et al. 2003; Pierrehumbert and Talkin 1992).

3.3.3 The schwa

The distribution of the duration of schwa is presented in Figure 11. Schwa duration ranged from zero ms to 160 ms This figure shows one clear peak at zero ms (79.4% of the data).

Table 3: Summary of the regression models predicting liquid absence ($N = 291$) and duration ($N = 166$). The intercept represents a liquid followed by a schwa for the analysis of the absence of the liquid and a liquid in a word in phrase-final position for the duration analysis.

Fixed effects	Absence		Duration	
	ß	*z*	*ß*	*t*
Intercept	−9.31	−4.51***	5.12	15.85
Speech rate	2.21	2.37*	−0.38	−2.02*
Schwa absent	4.43	4.19***	-	-
Following bigram frequency	0.89	2.65**	-	-
Medial position	-	-	−0.15	−2.47*
Random effects		*SD*		*SD*
Word	intercept	0.39	intercept	0.26
Speaker	intercept	0.59	intercept	0.11
			residual	0.34

*Note: *** indicates $p < 0.001$, ** indicates $p < 0.01$ and * indicates $p < 0.05$*

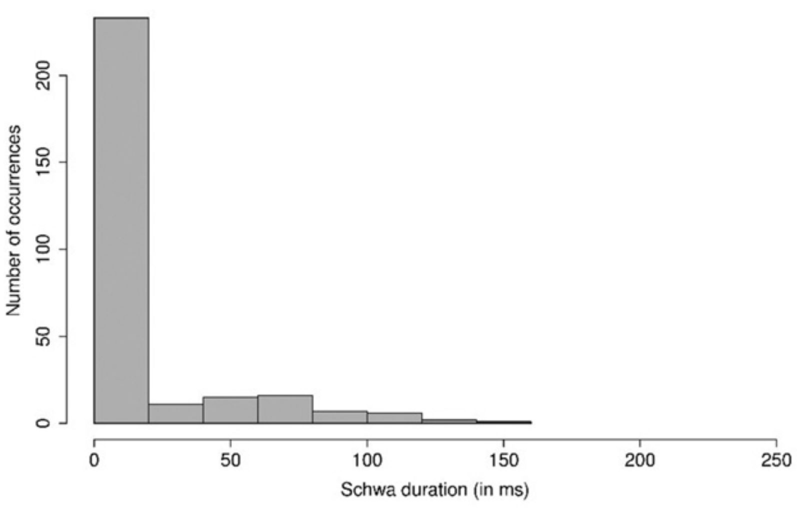

Figure 11: Distribution of the duration of schwa ($N = 291$).

We analysed schwa absence and duration following the same procedure as for obstruent and liquid absence and duration and tested the same potential predictors, except for those of liquid and schwa absence. These latter predictors were replaced by the Boolean predictor indicating whether the following segment was a consonant. Schwa durations of zero ms (231 data points, 79.4%) were removed for the duration analysis. Finally, we discarded all schwas with durations that deviated more than two and half times the standard error from the values predicted by the best statistical model and refitted the model. Probably due to the small number of remaining data points (60), we did not find significant predictors for schwa duration. The predictors for schwa absence are listed in Table 4.

Table 4: Summary of the linear mixed-effects model predicting schwa absence ($N = 291$). The intercept represents a schwa followed by a vowel.

Fixed effects	**Absence**	
	ß	***z***
Intercept	−4.48	−2.19*
Speech rate	3.26	3.02**
Word frequency	0.37	2.38*
Following consonant	−1.34	−3.11**
Random effects		*SD*
Word	intercept	0.00053
Speaker	intercept	1.01

*Note: ** indicates $p < 0.01$ and * indicates $p < 0.05$*

Schwa was significantly more often absent if speech rate was higher and if the word was more frequent. In contrast, schwa was more often present if it was followed by a consonant than by a vowel. The same effects have been found in previous studies (e.g., for schwa in word-final syllable, see Milne 2014; for schwa in word-initial syllable, see Bürki et al. 2011a, Bürki et al. 2010).

4 General discussion

4.1 Segmental variation in OLS clusters

This study investigated reduction in French nouns ending in OLS clusters. In contrast to most previous studies on reduction, our study focused on the reduction of content words, on the reduction of a *sequence* of phonemes, and on the presence versus absence of phonemes as well as phonetic traces of absent sounds. Our analyses were based on 291 noun tokens from the NCCFr (Torreira et al. 2010).

Our data show that few word tokens were pronounced with all segments that could be present. The word *ministre* "minister", for instance, had pronunciation variants ranging from full [ministʁə] to highly reduced [mis]. Reduction thus frequently affects (low frequency) content words. We can distinguish four main pronunciation variants for the OLS cluster at the segmental level. The unreduced form (e.g., *ministre* [ministʁə] "minister") occurs in 18.9% of the tokens. The variant in which schwa is absent (e.g., [ministʁ]) is generally considered as the most frequent variant (e.g., Adda-Decker et al. 1999). In our dataset the most frequent variant of the OLS cluster is the OL variant as well, although it only occurs in 35.7% of cases. Following the variant without schwa, the variant in which both the liquid and schwa are absent (e.g., [minist] for/ ministʁə/) is the most frequent one (27.1%). Strikingly, the variant in which the whole OLS cluster is absent (e.g., [minis]) also occurs quite often (15.5%). Reduction thus often affects sequences of phonemes like LS and OLS.

In addition to these four main categories, we found three categories represented by only a few tokens: LS (e.g., [minisʁə], 1.4%), L (e.g., [minisʁ], 1.0%) and OS (e.g., [ministə], 0.3%). Our finding that the OL (e.g., [ministʁ]), the O (e.g., [minist]) and the X (e.g., [minis]) variants are substantially more frequent than the LS (e.g., [minisʁə]), the L (e.g., [minisʁ]) and the OS (e.g., [ministə]) variants suggests that a phoneme is more likely to be absent if the following phoneme is also absent.

One possible explanation for the observed pattern is that phonemes are more likely to be absent if they are not followed by other phonemes in the word. This might be because final phonemes are likely to be co-articulated with the following word-initial phonemes, which are typically strongly articulated (e.g., Keating et al. 2003). This strong co-articulation may lead to the segmental absence of these final phonemes. Alternatively, the pattern may arise simply because schwas are more likely to be absent than liquids and liquids are more likely to be absent than obstruents (e.g., Adda-Decker et al. 2008; Su and Basset 1998). This hierarchy may be related to the ease with which these phonemes are recovered. Possibly, both tendencies contribute to the emergence of the reduction pattern.

4.2 Residual acoustic cues of absent segments

In 13.9% of the OLS tokens in which the liquid and schwa were absent (and the cluster was thus realized as O), the obstruent was voiced, which shows that the voicing did not always result from regressive voice assimilation. We also observed obstruent voicing before words starting with voiceless consonants. In

French, regressive assimilation is more common than progressive assimilation (e.g., Lodge et al. 1997), and to our knowledge, progressive voice assimilation of a voiceless obstruent to a preceding vowel has not been reported so far. Further, the obstruent is never voiced if the liquid is present. These findings support the idea that obstruent voicing in this context has resulted from the absence of the liquid, at least in some tokens. As such, the obstruent voicing is a signature of this liquid. We assume that the liquid is then co-articulated with the preceding obstruent (as a consequence of the retiming of articulatory gestures).

Segmentally absent phonemes also left durational traces. If the obstruent and/or liquid were/was absent, the preceding phoneme was often longer (e.g., [s] in [mis]). Zimmerer et al. (2011) found similar results for German [t]. Both in French and German, the absence of a phoneme can thus be cued by the lengthening of a neighbouring phoneme.

There are two possible causes for this "compensatory" lengthening. First, the reduced version of a segment (e.g.,/t/) may be indistinguishable from the preceding segment (e.g.,/s/). The reduced segment may then seem to be completely absent while the preceding segment seems to be lengthened. Articulatorily, however, both segments are present and the duration of the preceding segment is independent of the reduction of the target segment. This may be the right account of the lengthening of [s] in German/st/clusters pronounced without [t] observed by Zimmerer et al. (2011), and the extraordinary long duration of [s] in [mis], which is the reduced form of *ministre* "minister" observed in the present study.

A second possible cause for "compensatory" lengthening accompanying segment reduction in French may relate to the rhythmic structure of the language (syllable-timed; e.g., Colantoni and Steele 2011). Speakers may tend to lengthen consonants when the following consonants are absent in order to maintain the syllable timed structure of the phrase. For instance, speakers may tend to lengthen the/t/of [lit]/litʁə/*litres* "liters" after reduction of the liquid following the/t/in order to preserve the duration of the word.

Furthermore, when/k/in the OLS cluster (e.g.,/k/in/spɛktaklə/*spectacle* "show") was absent, the spectrogram could still reveal its phonetic remnants, in the form of a velar pinch (i.e., second and third formants of the preceding vowel come very close to each other). We observed a velar pinch in 62.5% of the tokens with segmentally absent/klə/. This velar pinch provides clear evidence that/k/was not categorically absent and that its absence was due to extreme weakening of the articulatory gestures.

Our results further demonstrate that in 71.4% of the tokens with a nasal vowel, the following stop was nasalised. For instance, the word *exemple*/ ɛgzɑ̃plə/"example" was pronounced as [ɛgzɑ̃m]. This may be unexpected because the common assumption about Parisian French is that, except for prefixed words, nasal consonants do not occur after nasal vowels (e.g., Walker 2001: 64). We believe that the consonant is nasalised as a result of co-articulation: the speaker can keep the velum lowered, a requirement for the articulation of the nasal vowel, as a result of which the following obstruent (e.g.,/p/) is nasalised (resulting in e.g., [m] replacing/p/).

4.3 Categorical versus gradient reduction processes

Obstruent voicing, "compensatory" lengthening, velar pinches, and nasalised obstruents in tokens with nasal vowels suggest that reduction of the obstruent and the liquid in OLS clusters may be gradient and that absence of these phonemes may be the result of extreme co-articulation (in combination with weakening). The phonetic analyses cannot give information about whether the absence of the OLS phonemes can also be the result of categorical reduction processes. If such processes play a role as well, the absence of the OLS phonemes can be complete, without leaving acoustic traces.

To further investigate the nature of the reduction processes underlying the absence of the OLS phonemes, we made histograms of the durations of the three phonemes in the cluster. If the duration distribution shows two clearly distinct peaks, of which one occurs at zero ms, representing the absent phoneme tokens, absence of the phoneme is likely to result from both a categorical process and a gradient shortening process (e.g., due to co-articulation). If, in contrast, the duration distributions show a unimodal distribution, without a clear peak around zero ms, absence of the phoneme only results from extreme shortening (e.g., Torreira and Ernestus 2011; Bürki et al. 2011b, 2007).

The histograms showed no clear bimodal distribution for the duration of the obstruent, but they did for the durations of the liquid and the schwa. The distributions of the durations of the obstruent and the liquid in OLS clusters have never been studied before, such that our results cannot be compared to earlier findings. Our result for schwa differs from the findings on schwa duration by Bürki et al. (2011b), who reported a unimodal, normal distribution for schwa duration. This difference may be due to the position of [ə] in the word: we focused on schwa in word-final position, whereas Bürki and colleagues examined word-medial schwa. Our duration distributions suggest that, in contrast to obstruent reduction, liquid and schwa reduction may also be categorical. However, a note of caution is due here since the shallowness of the dip between the two peaks in the histogram of the obstruent makes this distribution difficult to interpret. It is not completely clear whether the first peak represents a distinct group of its own or not.

We also examined the predictors of phoneme absence and phoneme duration (only for phonemes that were present). Obstruents and liquids were more often absent in phrase-medial position. This finding corresponds to the results from a study by Ernestus and Smith (2018), who reported that Dutch/l/was more often absent in phrase-medial position (53.0%) than at phrase boundary (16.0%). Further, we found that the higher the probability of the following word, the more often obstruents and liquids were absent. This observation is in line with the results of, for instance, Schuppler et al. (2012), who reported that constrictions, bursts and alveolar friction in Dutch/t/are more likely to be absent in word combinations of higher frequencies.

In the duration analyses, phrasal position predicted both obstruent and liquid durations: liquids and obstruents were shorter in phrase-medial position. These findings are in line with previous results which reported shorter segments in phrase-medial position than in phrase-initial position (e.g., Keating et al. 2003; Pierrehumbert and Talkin 1992). Possibly, due to the small number of data points (60), we did not find significant predictors for schwa duration.

If a segment is absent mainly due to extreme shortening (e.g., as a result of co-articulation) and there is hardly any role for categorical reduction processes, its duration and absence should be conditioned by the same variables. Both obstruent absence and duration were predicted by phrasal position: the obstruent was shorter and more often absent in phrase-medial position than in phrase-final position. The absence of the following liquid also affected both the presence and the duration of the obstruent, but this cannot be interpreted as evidence for gradient reduction of the obstruent because when the liquid was absent, the obstruent tended to be either completely absent or relatively long.

In the liquid analyses, only speech rate (one out of four predictors that play a role in either the absence or duration analysis) predicted both liquid absence and duration: if speech rate was higher, the liquid was more often absent and shorter. The overlap of predictors in both the obstruent and liquid analyses is thus not substantial which suggests that the phoneme may be absent as a consequence of reduction processes that do not necessarily lead to sound shortening as well.

The three different methods (phonetic analyses, examination of the distribution of phoneme duration, and the comparison of the predictors of phoneme absence and phoneme duration) do not provide an unequivocal picture of the nature of the reduction processes underlying the absence of the obstruent, the liquid, and the schwa. Based on the phonetic analyses and the distributions of the durations, one may conclude that the reduction process underlying obstruent absence is above all gradient: obstruent absence often leaves phonetic remnants and obstruent duration shows no clear bimodal distribution.

However, the comparison of the predictors of obstruent absence and obstruent duration suggests that obstruent absence and duration are mainly sensitive to different variables and therefore result from different processes, which would imply that the absence of the obstruent does often not result from gradient reduction. This inconsistent pattern of results may be because our dataset consisted of only 291 noun tokens. Possibly a larger dataset shows that similar variables predict both the absence and the duration of the obstruent. We can then conclude that the absence of the obstruent is the extreme result from sound shortening, from overlap in articulatory gestures, or articulatory "undershoot" (Lindblom 1963).

The phonetic analyses suggest that an absent liquid may also leave acoustic traces, for instance, in the form of the voicing of the preceding obstruent. The distribution of liquid duration and the comparison of the predictors of liquid absence and liquid duration suggest that the reduction process underlying the absence of the liquid is often categorical: we saw a clear peak around zero ms in the histogram and no substantial overlap of predictors (one out of four predictors that play a role in either the absence or duration analysis). The absence of the liquid may thus result from both gradient and categorical processes.

The distribution of the duration of schwa shows a clear peak at zero ms, which suggests that the reduction process of schwa is categorical. In line with other positions of schwa in the word (e.g., Bürki et al. 2011a), we assume that in word-final position the absence of schwa may not only result from gradient shortening processes, but also from categorical processes.

4.4 Methodological and theoretical implications

These results raise questions about how to interpret the results from the three methods that we used for investigating the nature of the processes underlying the absence of phonemes. Phonetic analyses can only provide evidence for gradient reduction processes, which nearly always play a role. On the basis of this single method, we cannot determine whether also categorical processes are at play. With respect to distributions of phoneme durations, since there is no clear definition of what counts as a peak, the interpretation of these distributions may be subjective. Finally, the comparison of the predictors of absence and duration of phonemes may not lead to undisputable conclusions because it is not clear how much overlap in predictors is necessary, given the number of data points, to conclude that phoneme absence and phoneme duration are driven by the same processes. Overall, the current data highlight the importance of combining different methods in investigating the nature of processes underlying the absence of phonemes.

The question arises as to how existing speech production models are able to account for our findings. Our results suggest that, if we assume that a word can be lexically stored with more than one pronunciation variant and these variants are stored in the form of strings of phonemes (following, e.g., Bürki and Gaskell 2012; Bürki et al. 2010), all pronunciation variants that are stored for a given word contain the obstruent of the OLS cluster, since the obstruent is likely to be absent only due to gradient processes. The liquid and schwa, in contrast, may also be absent due to categorical processes, and the mental lexicon may therefore contain word pronunciation variants with or without a liquid or schwa. For instance, *ministre* "minister" may have the lexical representations/ministʁ/and/minist/. Alternatively, the liquid and schwa may be categorically absent due to phonological deletion rules (e.g., Levelt et al. 1999).

Finally, some researchers suggest that no word is lexically stored with a final schwa and that if this schwa surfaces, this is due to a categorical schwa insertion rule (e.g., Dell 1985), which is also in line with our data.

Information about phrasal position, speech rate and phonetic context may be incorporated into the lexical representations or into the phonological deletion rules. In addition, the effects of these variables may arise during articulation, as they do for the obstruent. If so, future research should show that these variables especially affect production when the segment has left acoustic traces.

A different type of speech processing model assumes that all tokens of a word are lexically stored with all their fine phonetic detail (in the form of exemplars; e.g., Bybee 1998; Goldinger 1998). The effects of phrasal position, speech rate, and phonetic context may arise from the exact specifications of the exemplars or may arise during articulation.

Our results also raise questions about speech comprehension. The acoustic residues may form cues to the absent sounds, facilitating lexical access. The categorical absence of segments may ask for the use of multiple word pronunciations in the mental lexicon.

4.5 Conclusion

In conclusion, our study has shown that Parisian French word-final OLS clusters are often reduced. We observed that in 80.7% of the word tokens extracted from a corpus of casual speech, at least one phoneme was absent and that in no less than 15.5% the entire cluster was absent. Furthermore, the absence of a phoneme was predominantly determined by the presence or absence of the next phoneme. The OLS phonemes not only showed variation in being present or absent and in their durations but also in their subsegmental traces in neighbouring sounds. Finally, on the basis of the corpus data, we argued that whereas the obstruent is likely to be absent due to gradient processes (extreme shortening and co-articulation), the liquid and the schwa may also be absent due to other (categorical) processes. Future research on a larger corpus is needed to confirm the observed reduction patterns in Parisian French word-final OLS clusters and to further compare the three methods for determining the nature of the processes underlying the reduction patterns. For now, we conclude that our results underline the relevance of corpus-based research in the documenting of pronunciation variation in everyday conversations and of the processes underlying this variation.

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Appendix

Lemmas (number of occurrences)

ancêtre (1), *article* (17), *boucle* (1), *centre* (16), *cercle* (7), *chantre* (1), *chapitre* (3), *chiffre* (3), *coffre* (2), *couple* (16), *couvercle* (1), *diamètre* (2), *disciple* (1), *exemple* (27), *fenêtre* (12), *filtre* (1), *lettre* (30), *litre* (8), *maître* (2), *meurtre* (4), *ministre* (17), *montre* (2), *muscle* (5), *obstacle* (1), *offre* (2), *oncle* (9), *peintre* (1), *peuple* (11), *plâtre* (1), *prêtre* (1), *rencontre* (4), *semestre* (10), *siècle* (10), *souffle* (1), *spectacle* (15), *sucre* (1), *théâtre* (31), *titre* (4), *trimestre* (2), *ventre* (4), *vitre* (4).

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Bionotes

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