Word boundaries and contrast neutralization in the case of enchaînement in French

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Abstract
This paper investigates how the phonetic surface form of segments is influenced by their word and syllable position. Word boundaries in French are often considered to be blurred in running speech by phenomena such as enchaînement, in which word-final consonants are said to be (re-)syllabified across word boundaries with a following word-initial vowel. In this study, VCV sequences containing either an enchaînement sequence, a word-initial, or a word-medial CV syllable are compared to test for preservation of contrast between these different structures. Acoustic comparisons show that enchaînement consonants do not have the surface form of an onset. Consonantal properties, along with differences in the surrounding vowels, contribute to the preservation of contrast between enchaînement sequences and sequences containing an underlying onset. Word-initial and word-medial onsets do not differ reliably, while word boundary cues are found in the acoustics of the surrounding vowels. In addition, a perception experiment shows better monitoring performance for a CV sequence extracted from the enchaînement condition than for an underlying tautosyllabic sequence, suggesting that listeners can use bottom-up information in the processing of enchaînement. Taken together, these results show that enchaînement in French does not imply a neutralization of the acoustic or perceptual contrast with sequences containing an underlying CV syllabic structure.

1. Introduction

Over the last twenty years or so, it has become increasingly evident that the surface phonetic form of a word is conditioned by the prosodic context in which it occurs. A growing number of studies in several languages has shown that variations in the phonetic shape of individual segments, and of sequences of segments, may be governed by higher-level prosodic factors,
Word boundaries and contrast neutralization in the case of enchaînement

such as prosodic prominence and prosodic constituent structure (see Fougeron 1999 for a review, among others). The major insight of these findings has been to focus on above-word effects and to show that phrasal prosodic organization influences the phonetic realization of segments. In the present study we will concentrate on lower level constituents: the word and the syllable, and the long-standing debate on the phonetic marking of their boundaries. This question will be addressed in a case study, in which word and syllable boundaries are said to be misaligned due to an assumed process of (re)syllabification across word boundaries. The phenomenon under investigation is the process of enchaînement in French.

Enchaînement is a sandhi phenomenon, occurring in many languages, by which words in the speech chain are linked or concatenated with one another into larger constituents. As Encrevé (1988:24) pointed out, enchaînement is a general phonetic phenomenon whose interest relies on the fact that it related to a central point of prosodic theories, namely the syllabification of the speech chain. In the process of enchaînement, word final coda consonants are said to be (re)syllabified with following word initial vowels.1 For example, the sentence cette histoire amusante et vrai ‘this-story-funny-and-true’ is said to surface with the following syllabic structure 

\[
\text{:s/1007.} \text{t#} \text{a.my.z\#} \text{e.v/3122/1007},
\]

where (.) and (#) indicate syllable and word boundaries, respectively.

In most phonological theories, the syllabification of the word final consonant with the initial vowel of the following word in the course of enchaînement is taken for granted. This process can be considered as a REsyllabification if one assumes a first syllabification at the lexical level, where the enchaînement consonant is in a coda position, and a later syllabification at the post-lexical level where the enchaînement consonant is resyllabified as the onset of the following syllable. Alternatively, this process can also be considered as a simple syllabification if one assumes that syllabification only occurs at the phrasal level where the enchaînement consonant is directly syllabified as an onset (Levet et al. 1999). In both conceptions, whatever the level at which syllabification occurs, it is usually taken for granted that the process is complete, in the sense that the contrast between resyllabified C#V and underlying CV syllables is neutralized.

The aim of the paper is to determine, first, whether word final enchaînement consonants do surface as onset consonants, and secondly, whether word boundary cues, supposedly blurred by enchaînement, can still be identified. Several arguments based on acoustic analyses and perceptual results will be provided to reject the view that the process of
enchâinement induces a complete neutralization with sequences containing an underlying CV syllabic structure, regardless of whether this CV syllable is word initial or word medial.

The paper is organized as follows: In the first part, I will discuss the notion of word boundaries and the process of enchâinement in French. In sections two and three, I will present experimental results supporting the claim that enchâinement across prosodic words in French does not imply a neutralization of contrast with sequences containing underlying onsets and that enchâinement consonants are acoustically and perceptually distinct from syllable onsets.

2. Word boundaries and enchâinement in French

There is a long tradition in the phonetic and phonological description of French of assuming that word boundaries are blurred in the syllabification of the speech chain. As Grammont (1938:102) noted:

“someone who does not know where words start or end in French would never guess it when listening to someone speaking. […] Usually words are said in groups, in series, without any break, and so tightly linked with one another that it is not rare for a syllable to be formed by the end of one word and the beginning of the other.” [my translation, CF]

This impressionistic feeling may arise from several related factors. Firstly, the phonetic marking of (lexical or prosodic) word boundaries in French may not be as clear as in other languages. Recent studies on the phonetic correlates of prosodic constituent boundaries in French have failed to define unequivocal word boundary cues. While these studies have shown acoustic or articulatory differences between word (often Prosodic Word) boundaries and higher level phrasal constituents boundaries, the distinction between word and syllable boundaries is less striking. For example, when looking at the realization of segments in initial position (i.e., post boundary), Fougeron (1998, 2001) observed that word initial consonants are more similar to syllabic onsets than to Intonational Phrase or Accentual Phrase initial consonants. Out of the 16 acoustic and articulatory comparisons made between the boundaries studied, only 6 exhibited a distinction between word boundaries and (word internal) syllable boundaries. Tabain and Perrier (2005) also found few distinctions between word and syllable boundaries in an acoustic and articulatory comparison of pre-boundary (i.e., final) vowels. However, the pattern they found was
unexpected insofar as it did not follow the prosodic hierarchy: when different, syllable boundaries were found to be stronger than word boundaries. Likewise, Meynadier (2003) did not observe a distinction between word and syllable boundaries when looking at coarticulation patterns between C#C consonants spreading across eight types of prosodic boundaries.

Secondly, the lack of phonetic identity of the word in favor of larger phrasal constituents also arises when considering the accentual system of French. Compared to other Romance languages, the domain of stress in French has changed over the course of its evolution from Latin, from a lexical domain to a phrasal domain (Vaissière 1996). Phrase-internal word boundaries are not marked by accentuation, and the delimitation of the accentual group by a phrase final accent accompanied by an optional initial rhythmic accent also reinforces the impression of cohesion within this phrasal constituent.

Thirdly, the well known tendency of Modern French for a preferred open syllable structure is attested in continuous speech by several external sandhi phenomena, where it is assumed that the syllabification of the speech chain operates across word boundaries. The most famous of these processes is liaison, in which the mute final consonant in some words is realized only when the following word begins with a vowel (e.g., un petit ami [épôtitami] ‘a boy friend’ vs. un petit garçon [épôtigarsɔ̃] ‘a small boy’). While some cases of liaison may occur without enchaînement, as in the political speech studied by Encrevé (1988), in most cases the liaison consonant is said to be (re)syllabified with the following word initial vowel ([pa.tि#a.mi]). Another sandhi involving (re)syllabification across word boundaries is the process of vowel elision occurring in some grammatical words when followed by a vowel initial word (e.g., le chat ‘the cat’ vs l’âne ‘the donkey’, de crier ‘to shout’ vs. d’avoir ‘to have’).³

While liaison and vowel elision processes in French have been extensively described, the process of enchaînement across word boundary has been less systematically studied. Although commonly assumed to be quite frequent in French, Fougeron and Delais’ (2004) corpus-based estimates and observations of running speech have shown that the frequency of enchaînement is actually relatively low. Based on a corpus of read texts and of spontaneous speech totalling 134,841 words produced by 27 speakers, the productivity of the phenomenon was estimated first by looking at the proportion of potential enchaînement contexts (defined as the co-occurrence of a consonant-final word followed by a vowel-initial word)
and then by an examination of the *enchaînement* effectively realized in a subset of the corpus. Results showed that 22% of the words in the corpus had an empty onset and 22% had a final consonant. Out of these final-consonant words, 37% were indeed followed by a vowel-initial word. Expressed as frequency of occurrence, it appears that potential *enchaînement* contexts occurred 8 times every 100 words. Individual examination of the production of 10 of the speakers for the read texts only showed that 60% of the potential contexts were indeed realized with an *enchaînement* (i.e., without pause, glottalization or glottal stop between the two words). When expressed as a proportion of cases over the total number of words in the corpus, the productivity of the phenomenon was found to be relatively low, with only 3 *enchaînements* every 100 words.

The process of *enchaînement* has also been rarely treated in modern phonology (see Encrevé 1988 for a review). Indeed, *enchaînement* is often considered as a late phonetic rule involving the concatenation of words into larger constituents. It does not imply the deletion or insertion of a segment, nor an alternation between two lexical surface forms. Its sole external sandhi effect is in the assumed restructuring of the syllabic affiliation of the isolated lexical forms (assuming that these forms are syllabified). As such this process addresses a central question for both prosodic theories and theories of speech production and perception, namely the syllabification of the speech chain, and is concerned with the questions as to the level at which syllabification is encoded and over which domain the chain is syllabified (lexical or phrasal). As will be discussed in more detail in section 4, the assumed misalignment between word and syllable boundaries created by *enchaînement* also addresses the question of the role of the syllable in lexical segmentation and lexical access. Finally, the assumed (re)syllabification across word boundaries addresses the questions whether and how the syllable plays a role in the prosodic hierarchy and the question of the modelling of the relations between prosodic constituents if one assumes that prosodic constituents have to be strictly layered. Indeed, *enchaînement* occurs across word boundaries but also across higher level constituents. In a study on the prosodic conditioning of *enchaînement*, Fougeron and Delais (2004) examined the occurrence of *enchaînement* in a text read by 6 French speakers. The text was parsed into Accents Phrases based on intonational criteria and into Phonological Phrases based on morpho-syntactic criteria. While most of the *enchaînement* are realized within an Accentual Phrase or a Phonological Phrase, several cases do
occur at the boundary between two Accentual Phrases (36%) or at the boundary between two Phonological Phrases (52%).

3. On the phonetic realization of enchaînement consonants and word boundaries

3.1. Background

Traditionally, (re)syllabification across word boundaries in enchaînement has been considered as a complete phenomenon, neutralizing the difference between sequences with enchaînement and sequences with underlying onset consonants. In his comparison between English, German, Spanish and French, Delattre (1965) claimed that the four languages differ in their “junctural habits” (p. 36). According to him, connected word separation is not distinctive in French and Spanish as compared to the two Germanic languages. Thus, French pairs like du notre vs. d’une autre ‘from ours’ vs. ‘from another’ or les rues sont finies vs. les russes ont fini ‘the roads are finished’ vs. ‘the Russians have finished’, are said not to differ in the same way as comparable English pairs (e.g., an aim vs. a name, cf., Jones 1956). In later work, Delattre (1981) noted no difference in the duration of word final enchaînement consonants /n, l, s/ in comparison to word initial ones. However, in his 1940 paper, Delattre claimed that the distinction between enchaînement consonants vs. syllable/word initial consonants is rarely imperceptible. Indeed, the distinctiveness of enchaînement sequences appeared more clearly when the comparison was made relative to the distinction between liaison consonants and syllable or word initial consonants. Compared to initial consonants, enchaînement consonants were more distinct than liaison consonants. Already in the older descriptions of Passy (1895) or Rousselot (1924), the distinction between purported homophonic sequences was said to vary depending on rate and style of speech, and it was noticed that in certain cases the distinction is noticeable and “The ear is not insensitive to the differences, that translate into accentual, intensity or timber nuances” (Rousselot 1924: 974) [my translation, CF]

Phonetic arguments supporting a preservation of contrast were presented in Durand’s (1936) early physiological work. Looking at
variation in nasal and oral airflow and in lingual articulation, her research yields a very interesting comparison between masculine and feminine forms. While the experimental apparatus and the interpretation of the amplitude of the signals’ oscillations as indicators of muscular tension (and articulatory force) have to be taken with a degree of caution, the interest of her study lies in the fact that she provides some evidence for a physiological difference in the articulation of *enchaînement*, *liaison* and word initial consonants. Compared to *liaison* consonants (*un mauvais état* ‘a bad state’, *un petit orage* ‘a small storm’), *enchaînement* consonants (*une mauvaise épée* ‘a bad sword’, *une petite orange* ‘a small orange’) can retain some cues of their implosive (i.e., syllable final) nature (Durand 1936: 238). While a syllabic break before the *liaison* consonant is assumed from a change in the ‘muscular tension’ curve between the preceding vowel and the consonant (following Grammont 1938), the tension is generally falling gradually during the VC sequence in the case of *enchaînement*, indicating syllabic cohesion. The only cases where she observed a modification in the direction of tension were found in the cases of *enchaînement* consonants before an unstressed vowel.

Differences between *enchaînement* and onset consonants have also been presented in more recent studies. Rialland (1986), Dumay, Content, and Frauenfelder (1999), Gaskell, Spinelli, and Meunier (2002), and Spinelli, McQueen, and Cutler (2003) have observed durational cues differentiating these consonants. They have shown that *enchaînement* consonants are generally shorter than word initial onset consonants and that the vowel preceding *enchaînement* consonants is longer. To our knowledge, the only studies looking at phonetic differences other than duration are the ones of Rialland (1986) and Laeufer (1987) on French /w/. As will be discussed in more detail below, they observed interesting allophonic variations between *enchaînement* /w/ and word initial /s/.

### 3.2. Acoustic experiment: Comparison between *enchaînement* sequences and sequences containing underlying onsets

Assuming that *enchaînement* consonants are indeed (re)syllabified to the onset of the following syllable across word boundaries, and that syllabic affiliation is cued in the phonetic surface form, *enchaînement* consonants should pattern (i.e. should share properties) with underlying onsets.
However, if one considers that lexical boundaries surface in the phonetic output form, it is possible that V.C#V *enchaînement* sequences and underlying V#.CV differ due to their position relative to the word boundary, i.e., to their affiliation to the word preceding or following the boundary.

In the studies presented above, *enchaînement* consonants are often compared with underlying initial consonants without making a distinction between word initial and word medial onset consonants. It is thus unclear whether the durational (or spectral) differences observed are due to word affiliation or syllabic affiliation. Another point to notice in the previous studies is the confusion made between arguments that relate to (re)syllabification per se (i.e., *enchaînement* consonants becoming syllable onsets) and arguments related to contrast neutralization between the sequences created by *enchaînement* and sequences containing underlying onsets. Moreover, in most of these studied either only a few subjects or a few consonants types are observed (except for Dumay, Content, and Frauenfelder 1999).

In the light of these past results, the present acoustic study has the following objectives. First, word initial syllable onsets and word medial syllable onsets are compared in order to test for word boundary cues. Secondly, *enchaînement* consonants are compared to both word initial syllable onsets and word medial syllable onsets in order to determine whether *enchaînement* consonants do share onset properties, and in order to test for an effect of word affiliation difference. Unfortunately, no comparison was possible with word final coda consonants without *enchaînement* since the speakers were unable to produce naturally the VC#V sequences without *enchaînement* (by adding a glottal stop for example), without introducing a stronger prosodic break in the sequence. No comparison was furthermore possible with word medial pre-vocalic coda consonants due to the phonotactic properties of French. Thirdly, the phonetic realization of the whole ‘homophonic’ VCV sequence including the test consonant but also the surrounding vowels is compared in order to test for contrast neutralization between *enchaînement* VC#V sequences and V#CV sequences.
3.2.1. Method

This study is an extension of the work presented in Fougeron et al. (2003). While the material originates from the same recordings, a different set of items was used here.

**Experimental conditions:** A corpus of 41 triplets including a V1CV2 sequence was used. As shown in Table 1, these sequences had identical segmental content, but differed according to the location (before or after the pivot consonant) and the type (syllable or word) of boundary involved in the string. Condition A was created in order to involve an *enchaînement* between two lexical words (Wd)\(^5\) (e.g., *une tante horrible* ‘an awful aunt’). According to traditional description, the pivot consonant C is Wd final but is said to surface as the onset of the following syllable (V\(_1\).C#V\(_2\)). As in condition A, the sequence investigated in condition B straddles a Wd boundary. However, here the boundary occurs after the first vowel (V\(_1\)) in the sequence (e.g., *un temps torride* ‘a torrid weather’). In both surface and underlying form, the pivot consonant is Wd initial and a syllable onset (V\(_1\)#CV\(_2\)). In both conditions A and B, all but one\(^6\) of the triplets were of the forms determiner + adjective + noun (*une petite horreur* ‘a little horror’) or determiner + noun + adjective (*un mec ouvert* ‘a - guy - open minded’) forming a single Phonological Phrase, restructured or not.\(^7\)

Finally, in condition C, the sequence does not straddle a Wd boundary, and a syllabic boundary occurs between V\(_1\) and C. The pivot consonant is thus a Wd medial syllabic onset (V\(_1\).CV\(_2\)). For this condition, non-words were used (see below), as for example *un tantorrite*.

The 41 sequences used are presented in Appendix.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Examples</th>
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<tbody>
<tr>
<td>A</td>
<td><em>Enchaînement</em></td>
</tr>
<tr>
<td>B</td>
<td>Word boundary</td>
</tr>
<tr>
<td>C</td>
<td>Syllable boundary</td>
</tr>
</tbody>
</table>

**Corpus construction and selected speech material:** Two lists of lexical items were extracted from the Brulex database (Content, Mousty, and Radeau 1990) by selecting words beginning (list 1) and ending (list 2) with matching consonants, and for which the initial or final consonant could be
removed to form other French words (e.g., list 1: *couvert* [kuvɛʁ] ‘covert’ > *ouvert* [u 본] ‘open’; list 2: *mec* [mek] ‘guy’ > *mets* [mɛ] ‘dish’). Then, the two lists were matched in order to construct meaningful paired sequences for condition A (VC#V) and B (V#CV), e.g., *un mec ouvert* ‘an open-minded guy’ vs. *un mets couvert* ‘a covered dish’. We were able to construct 91 such paired sequences. For the third condition, it was unfortunately not possible to find enough real French words with the required structure. Therefore, non-words including the same VCV sequence were created (e.g., *un *maicouveur* [mɛkuvœʁ]).

Finally, each sequence was included in a syntactically and semantically plausible carrier sentence controlled maximally for length, sequence position in sentence, and expected prosodic structure. Special care was taken to place the test items in a single accentual phrase to avoid a final accent on the first word in conditions A and B.

These 91 triplets sentences were read in random order by 5 Swiss-French naive speakers (1 repetition each) and recorded in a sound proof booth at the University of Geneva.

For the present study, 41 of the 91 triplets were selected in order to have a relatively homogenous sample for 4 pivot consonants: the stops /t/ (x15 triplets) and /k/ (x10); one fricative /s/ (x7), and /ş/ (x9). In total, 615 tokens were used (41 items x 3 boundary conditions x 5 speakers).

**Acoustic measurements:** All recordings were sampled at 44100 Hz (16 bits quantization), and all measurements were made using Praat software. Segmentation of V₁, C and V₂ was carried out by means of the simultaneous consultation of the waveform display and wideband spectrogram. Several acoustic properties were examined for the pivot consonant and the surrounding vowels:

a. Durational properties of five intervals: preceding vowel (V₁), consonant duration (closure+burst for stops), closure alone, burst alone, and following vowel (V₂)

b. Spectral characteristics of the pivot consonant: Four spectral moments were computed for each consonant on a speech signal filtered below 500Hz to remove energy from the surrounding vowels. A long term FFT (Hanning window) was calculated over the burst for the stops and over the entire consonant duration for /s/ and /ş/. For the bursts, an additional FFT was computed from a 10 ms. Hanning windowed portion of the signal in order to include the first 10 ms. of the burst (explosion included).

Each FFT was treated as a random probability distribution from which the following four moments were calculated (these moments correspond to
automated queries available in Praat):
- The Center of Gravity (CoG) to measure the average frequency height in the spectrum.
- The standard deviation of the distribution to quantify the deviation of the frequencies from the CoG in the spectrum. This corresponds to the square root of the second spectral moment.
- The (normalized) skewness taken as an indicator of the distribution’s asymmetry by comparing the shape of the spectrum below and above the CoG. Normalization is made by dividing the third central moment by the 1.5 power of the second central moment.
- The (normalized) Kurtosis taken as an indicator of the distribution’s peakedness or flatness. Normalization is made by dividing the fourth central moment by the square of the second central moment minus 3.
c. Spectral characteristics of the surrounding vowels: F1, F2, and F3 frequency calculated over the entire duration of the vowel.
d. RMS energy: calculated over the entire duration for the vowels and the consonants /s/ and /s/, and calculated over burst duration for the stops.

3.2.2. Results

Comparative and statistical results are given in Table 2 for measurements showing at least one significant difference between the three conditions. Statistical comparisons are made with repeated measures ANOVAs with the three boundary conditions as within factors, and with subsequent planned comparisons for testing differences between conditions.

a) Durational differences

**Pivot consonant:** Comparison of the whole consonant duration shows a main effect of boundary condition for all consonants, except /s/. Planned comparisons between the conditions show that the total duration of /k/, /t/ and /s/ in the *enchaînement* condition is shorter than in both Wd initial and Wd medial onset conditions, while no difference in duration is found between the latter two.
Table 2. Statistical results of the comparisons between the three conditions A (enchaînement), B (word boundary), and C (syllable boundary): main effect (*=significant at p<.05, (*)=marginally significant at p=.05, ns=non significant), planned comparison and direction of the difference (> = significantly greater than, <=significantly lower than). Only measurements showing at least one significant distinction are presented.

<table>
<thead>
<tr>
<th>Main effects</th>
<th>Planned comparisons</th>
<th>Main effects</th>
<th>Planned comparisons</th>
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<tr>
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<td>Spectral moments</td>
<td>CoG /i/ *</td>
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condition either, but closure alone does show a difference between enchaînement and onset conditions.

Thus, our data confirm the previously observed tendency that enchaînement consonants do not share the durational properties of underlying onsets, but rather are shorter. Moreover, the results show that Wd boundaries are not cued by a lengthening of the Wd initial onset as compared to Wd medial onset.

However, even if these differences are statistically significant, it has to be pointed out that the differences in duration are very small between the three conditions: averaged over all the triplets and all the speakers, the differences (A-B/A-C) are about 5 to 6 ms. for /k/, 10 to 11 ms. for /t/, and 6 to 8 ms. for /s/. Notice that Laeufer (1987) also reported small differences between enchaînement and initial /s/ (18 ms. on average).

Pre-consonantal vowel V₁: Averaged over all consonant types, a significant difference in V₁ duration is observed depending on the conditions. Our triangular comparison shows that for all consonant types V₁ is longer in both condition A (V₁C#V₂) and condition B (V₁#CV₂), than in the word medial condition C. This lengthening of V₁ in conditions A and B may be attributed to Wd final lengthening. Differences between conditions A and B are found only for the consonants /s/ and /k/, with the effect working in opposite directions: condition A is longer than condition B for /s/, but shorter for /k/.

Thus, our results do not replicate the lengthening of V₁ in the case of enchaînement (except for /s/) found in the literature. Many authors have argued that V₁ is longer in enchaînement because it is in a closed final syllable (Rialland 1986; Laeufer 1987; Dumay, Content, and Frauenfelder 1999). However, as shown by O'Shaughnessy (1981) the lengthening of vowels by tautosyllabic coda consonants depends on consonant type: in monosyllabic words, compared to vowels in open syllables (163 ms. in average), vowels in closed syllables are shortened by voiceless stop codas (90 ms.), while they are lengthened by voiced fricative codas (264 ms.) and /s/ codas (207 ms.). In our data, while the results would support the position that enchaînement /k/ belongs to the same syllable as V₁, the absence of lengthening with enchaînement /s/ conflicts with the interpretation that the consonant retains its tautosyllabic effect in condition A. In her study, Laeufer (1987) found lengthening of V₁ before enchaînement /s/ at slow rates for the two speakers and at a normal rate for only one speaker. She takes this as an argument for a partial resyllabification of /s/ in the two cases. I do not fully agree with this
interpretation. Whether the absence of contextual variation in the duration of $V_1$ in the tautosyllabic condition A is a cue to resyllabification is not obvious. Indeed, if we assume that tautosyllabic vowel lengthening is a lexical process, and that /h/ is in coda position at some level of the derivation, then tautosyllabic lengthening would occur independently of a later syllabification across word boundaries. In our data, it may be the case that tautosyllabic lengthening in condition A is equivalent to the word final lengthening that affects $V_1$ in condition B. Therefore, the lack of distinction in the duration of $V_1$ between condition A and B is taken here as an argument in favor of contrast reduction between conditions A and B, and not as an argument for (re)syllabification across word boundaries.

**Post-consonantal vowel** $V_2$: In condition A, $V_2$ is in absolute word initial position; in condition B, it is the nucleus of the word initial syllable; and in condition C it is the nucleus of a word medial syllable. According to boundary strength induced lengthening, one could have expected a lengthening in word initial positions (especially in condition A, and possibly in condition B). The pattern observed is the reverse: $V_2$ duration is generally the longest in condition C, although it was expected to be the shortest. $V_2$ in condition A is never longer than in condition C, it is even shorter for most consonant types or of equal duration for /s/. In condition A, $V_2$ is longer than in condition B with pivot consonants /k/ and /s/, where it is possible that word initial lengthening occurs.

While the lengthening of $V_2$ in condition C remains to be explained (it may be because the items are non-words), neutralization between condition A and B regarding $V_2$ duration appears only for the items containing the consonants /n/ and /t/. For the other items (with /k/ and /s/), the sequences can be differentiated by $V_2$ duration.

**b) RMS Energy differences**

Consonant RMS energy differences when measured as a ratio of the energy of the following vowel did not show any difference between conditions. In contrast, absolute RMS energy comparison showed a significant main effect for the burst of /t/, with word initial /t/ in condition B displaying greater energy than word medial /t/ in condition C. Condition A was not different from either B or C. For the burst of /k/, the main effect of condition was close to being significant ($p<.07$), and planned comparison
showed that the burst in condition A was weaker than in condition B. No differences were found for /s/ and /ʃ/.

c) Spectral differences for pivot consonants

Comparison in terms of spectral moments for /t/, /k/, and /s/: No main effect of boundary condition was found for these three consonants for any of the four spectral measurements. The sole difference appeared in the planned comparisons, with a significant distinction between conditions A and B in the skewness of the first 10 ms of the burst spectra of /t/. The burst of enchaînement /t/ has a more skewed distribution of energy as compared to word initial /t/, with more energy in the lower part of the spectrum. No difference is found between conditions A and C, or B and C.

The case of /ʁ/: /ʁ/ is an interesting consonant in French because it exhibits a certain amount of allophonic variation, and notably position-dependant variation. However, while initial and final allophones of /ʁ/ have been described (Simon 1967; Chafcouloff 1980; Riallant 1986), it is not clear which allophone occurs where, and whether their distribution is conditioned by their word or syllabic position. Final /ʁ/ are generally described as ‘weaker’ variants including, according to the authors, glides, vocalized forms, but also voiceless fricative realizations. According to Laeufer’s (1987) results the allophonic distribution also varies depending on speech rate. A clearer distinction occurs at fast speech rate with initial /ʁ/ being voiced fricatives (46%) or vocalized (27%), and final /ʁ/ being voiceless fricatives (75%). However, at slow or normal speech rate, there is a distributional overlap, with final /ʁ/ being voiceless fricatives, and initial /ʁ/ being either voiced or voiceless fricatives. Since a categorical distinction between the positional allophones does not seem to be straightforward, my choice was to compare the different realization of /ʁ/ by means of a quantitative analysis of their spectral properties rather than by an allophonic categorization.

For the four spectral moments examined, the overall pattern is the same: conditions B and C pattern together, while condition A is distinct. Enchaînement /ʁ/ in condition A have a significantly lower CoG and standard deviation than both initial and medial onset /ʁ/, that is to say a lower concentration of energy in the spectrum and a distribution of this energy over a larger frequency band. Enchaînement /ʁ/ also have higher skewness and kurtosis values than both initial and medial onsets. For all
three conditions, the distributions are positively skewed, but the asymmetry is larger in the case of *enchaînement* /s/, with a greater predominance of energy in the lower frequencies. The difference in kurtosis, on the other hand, indicates that the shape of the spectrum is more peaked in the case of *enchaînement* /s/s. Taken together, these spectral differences show that *enchaînement* /s/s are more sonorous than underlying onsets. Fig. 1 gives an example of the difference in /s/ realization for a speaker showing particularly clear distinctions.

Figure 1. Spectrographic illustration of the difference in /VsV/ realization in condition A (on the left) and B (on the right). Top figure, /ɛ̃sə/ extracted from 'père athée’ (cond. A), and ‘paix ratée’ (cond. B). Bottom figure, /yɛsə/ extracted from ‘mur amolli’ (cond. A), and ‘mue ramollie’ (cond. B).
These results are comparable to Laeufer’s (1987). She compared *enchaînement* /ʃ/s to onset /ʃ/s (either word or syllable initial) and to unlinked /ʃ/s (i.e., not realized with *enchaînement* due to either rate of speech or insertion of a stronger prosodic break) in the productions of two speakers at three speech rates. She found that *enchaînement* /ʃ/s were mostly realized as a voiced fricative (around 65%), a realization close to that of most of the final unlinked /ʃ/s. Notice, however, that there was such a variation in the realization of her initial and final /ʃ/s, that *enchaînement* /ʃ/s appear to overlap greatly with the distribution of both initial and final /ʃ/s.

d) Spectral differences for surrounding vowels

In order to test for spectral variation in the realization of the neighboring vowels, a comparison between the boundary conditions was made according to vowel type, independently of the nature of the consonants. Vowels occurring in at least 15 triplets were selected to allow comparison on a sufficient sample. These vowels were: /y, a, e, ê, i/ for V₁ and /e, a, o, u/ for V₂ (other vowels were discarded).

**V₁ spectral differences:** Condition dependent variations in the formants of V₁ are observed for F₁, F₂, F₃ of /e/, F₂ of /â/ and F₁ of /â/. For /â/, there is no main effect of condition on F₁, but the formant is found to be significantly higher in condition B vs. C. For /â/, F₂ is lower in condition B as compared to condition C, and with a marginal effect, as compared to condition A.

The most interesting differences are found for the mid vowel /ê/. All three formants, F₁, F₂, and F₃, show a main effect of condition. For F₁, there is a three-way distinction: F₁ is higher in condition A, somewhat lower in condition B, and lowest in condition C. For F₂ and F₃, there is only a two-way distinction between the *enchaînement* condition and the two onset conditions: V₁ in condition A has lower F₂ and F₃ values. Notice that French has a specific distribution for mid vowels depending on syllable type: front mid vowels /ê/ and /é/ occur in open syllables, but only /ê/ is allowed in closed syllable position. The present results suggest that the variants of /ê/ in the *enchaînement* condition (e.g., in père, mère, chaire, mec, grec, baisse, fer) are more open and more posterior than the variants of the underlying open syllables (e.g., in paix, mets, chai, grès, baie, fait).
Again, this difference may contribute to the preservation of the contrast between conditions A and B.

**V2 spectral differences:** Condition-dependent variations on V2 are found for the four vowels observed. However, a different trend emerges between condition C (word medial V2) and the other two conditions (strictly word initial V2 in VC#V2, and word initial syllable nucleus in V#CV2). The vowel /o/ in condition C is less open (lower F1) than in condition A, and less posterior (higher F2) than in condition A and B. The vowel /a/ is more central (lower F2) in condition C than in the two other conditions. The vowel /e/ is less open (lower F1) and more posterior (lower F2) in condition C in comparison to condition A. For /e/, it is condition B that stands apart, with a more open vowel (higher F1) than in condition A and C, and a less anterior (lower F2) vowel than in condition A.

These results corroborate the observed pattern found in Meynadier, Fougeron, and Meunier (1999) comparison of sequences comparable to our conditions A and C. While few differences were observed, they followed the same tendency: an increased aperture (F1 of V and EPG contrast between C and V) for word initial vowels (our condition A), for both closed and open vowels. This again may contribute to a preservation of contrast, but here, between condition A and C.

### 3.3. Summary and discussion of acoustic results

Recall that different related hypotheses were tested in this experiment: (a) whether *enchaînement* consonants pattern with underlying onsets; (b) whether there is a neutralization of contrast between *enchaînement* sequences and V#CV/V.CV sequences; and (c) whether support for Wd boundary cues can be found.

Based on the differences found in consonant duration and in the spectral characteristics for the consonant /s/, it appears that *enchaînement* consonants maintain some characteristics that differentiate them from both Wd initial and Wd medial underlying onsets. The lack of comparison with coda consonants (Wd final or medial) without *enchaînement* does not permit us to conclude whether these differences are due to the preservation of Wd final cues and/or coda characteristics. Our results show that *enchaînement* consonants do not pattern as underlying onsets, but we do not know whether this is because (1) they are (re)syllabified as onsets but
maintain some cues of their Wd final position or (2) whether they are not (re)syllabified as onsets.

On the other hand, what clearly emerges from our data is that the contrast between VC#V and V#CV (and V.CV) sequences is preserved in the process of enchaînement across Wd boundaries. Acoustic differences are distributed over the entire VCV sequence, and include both durational and spectral variations on the consonant and on the surrounding vowels.

Regarding boundary cues, it appears that some cues to Wd boundaries can surface in the signal. These cues are not located in the post-boundary consonant, but rather in the surrounding vowels. Except for the skewness of the /t/ burst, no differences are observed between Wd initial consonants (condition B) and Wd medial consonants (condition C). On the contrary, Wd final vowel lengthening, variation in V2 duration, as well as spectral differences in both V1 and V2 are found to distinguish conditions B and C. Moreover, since most of the cues differentiating condition B from C are also found to differentiate condition A from C, these cues associated with the two conditions straddling a Wd boundary can be attributed to differences in Wd affiliation.

However, these conclusions have to be fine-tuned. Indeed, the results are subject to a large variability, depending on the nature of the consonant and the vowel. In a previous analysis of a different set of items, which included 3 more speakers, we have shown that durational effects are also speaker-dependent (Fougeron et al. 2003). Dumay, Content, and Frauenfelder (1999) and Laeufer (1987) also reported variation in their data. This variation was consonant-dependent for the former, and speaker- and rate-dependent for the latter.

4. **On the so-called ‘problem’ of non-alignment between word and syllable boundaries in perception**

4.1. The hypothesized role of the syllable in speech segmentation in French

There are several reasons to predict that enchaînement could affect speech perception if we assume that there is a (re)syllabification of the enchaînement consonant to the onset of the following word and that there is
Word boundaries and contrast neutralization in the case of enchaînement

a neutralization of contrast. Indeed, with a (re)syllabification of the coda consonant to the onset of the following word, enchaînement would create a misalignment between word and syllable boundaries. Therefore, a transitional segmentation ambiguity would occur and it would require the listener to make a choice in segmentation. In addition to a delay in the lexical segmentation procedure, misalignment could also affect the lexical activation process if it impairs or delays the activation of the misaligned word and increases the competition between lexical hypotheses at the misaligned word. For example, in a sentence like chaque petite amie [ʃak.pɔ.ti.ta.mi] ‘each little friend’, an activation of the word tamis ‘sieve’ would compete with the activation of the misaligned word amie.

The potential cost of boundary misalignment relies on the role attributed to the syllable in speech processing. Arguments supporting the contribution of syllabic information to speech processing in French are often cited in reference to the work by Mehler and collaborators (1981). In their famous “palace-palmier” (‘palace - palm tree’) experiment, they showed that syllable monitoring was faster when the target (/pa/ or /pal/) matched the first syllable of the carrier (/pa/ was recognized faster in palace [pa.las] as compared to palmier [pal.mi.e], and /pal/ faster in palmier vs. palace). However, attempts to replicate these results have failed (see Dumay, Frauenfelder, and Content 2002), and the view of the syllable as a classification unit in French has been widely called into question. Nonetheless, syllable-based processing strategies in French have not been entirely abandoned. In a recent proposal by Content, Frauenfelder and collaborators, the syllable is considered as a unit in a segmentation procedure, rather than in a classification procedure. Their Syllable Onset Segmentation Heuristic (SOSH) postulates that syllable onsets constitute alignment points to initiate lexical access (Content, Dumay, and Frauenfelder 2000; Content, Kearns, and Frauenfelder 2001). According to SOSH, if a lexical search is initiated at every syllable onset, any misalignment between a word onset and a likely word boundary defined on syllable onset could have an associated cost.

In the next section, I will review the results of several perception experiments testing the potential cost of boundary misalignment, and present new data supporting the claim that enchaînement does not impair speech processing.
4.2. Perceptual consequences of *enchaînement*

### 4.2.1. Background

In the literature, the effect of *enchaînement* on perception has been much less studied than that of *liaison* (see Spinelli and Meunier (2005) for a review), and different results have been reported. For Dutch, Vroomen and De Gelder (1999) found that the monitoring of a word final phoneme target is slower when it is resyllabified as the onset of the following syllable (*de boot is gezonken*) than when it is not resyllabified (*de boot die gezonken*). This additional cost is attributed to increased processing demands in the case of *enchaînement*, where a lexical search may be initiated at the syllable initial /t/. In French however, most studies have shown that *enchaînement* does not affect perception.

Firstly, the contrast between *enchaînement* sequences and so-called homophonous sequences with underlying onsets appears to be preserved in perception. For example, Yersin-Besson and Grosjean (1996) found in a forced choice recognition task that paired sequences with and without *enchaînement* (*VC#V* vs. *VC#CV*) are not perceived as ambiguous. While the interpretation of these results is not unequivocal, considering the fact that the pairs of words used by the authors (e.g. *chaque ours* vs. *chaque cours*) involve the gemination of a consonant, a lack of ambiguity is also found by Zwanenburg, Ouweneel, and Kevelt (1977). In a forced choice identification task between various sentence pairs containing either a word initial consonant, an *enchaînement* consonant or a *liaison* consonant, the authors also found a preservation of the contrast between *enchaînement* and consonant initial sequences. More interestingly, their data show that the *enchaînement* sequences were better identified than the consonant initial sequences and that the contrast between the two types of sequences was better perceived for the cases of *enchaînement* occurring between two lexical words than the ones realized between a determiner and a word.

Secondly, lexical segmentation and recognition of the assumed misaligned vowel initial word do not appear to be impaired or delayed in *enchaînement* (Matter 1986; Dumay, Content, and Frauenfelder 1999; Gaskell, Spinelli, and Meunier 2002). In a cross modal priming experiment, Gaskell, Spinelli, and Meunier found that recognition of a target word (e.g. *italien* ‘Italian’) was not impaired by its assumed resyllabification due to
Word boundaries and contrast neutralization in the case of enchaînement

Enchaînement (un virtuose italien ‘virtuoso Italian’) or liaison (un généreux italien ‘generous Italian’), compared with an aligned condition (un chapeau italien ‘Italian hat’). In a subsequent fragment monitoring task, they showed that the detection of the initial part of the vowel initial word (e.g., it for italien) was comparable when presented in a delexicalized sequence extracted from the enchaînement condition (e.g., tuose ita for virtuose italien) or from the aligned condition.

Crucially, the results in Dumay, Content, and Frauenfelder (1999) and Dumay, Frauenfelder, and Content (2002) cast serious doubt on the notion of misalignment in the case of enchaînement. While lexical activation is found to be affected by a boundary misalignment in the case of embedded words, this is not the case in enchaînement. As a matter of fact, Dumay, Content, and Frauenfelder (1999) observed that the recognition of a word like roche ‘rock’ is delayed by misalignment when it is embedded in a word like croche ‘eighth note’, but not in a similar sequence [kɾɔʃ] extracted from the enchaînement of magique roche ‘magic rock’ (note that all the cases examined by the authors involve an “enchaînement” between two consonants). However, as shown in (Fougeron, Frauenfelder, and Content 2000), lexical activation can be affected by a misalignment due to the addition of an unpredictable consonant at the beginning of a word. In a phoneme detection paradigm, we observed that the lexical activation of a vowel initial word (e.g., acrobate ‘acrobat’) was present but reduced when the word was preceded by an unpredictable additional consonant (g+ acrobate ‘acrobat’). The misaligned items were produced for the experiment with the additional consonant (as “gacrobate”) and therefore listeners could not rely on possible acoustic cues to the word onset. Interestingly, lexical activation of the vowel initial word was unaffected when the additional consonant was interpretable as a potential French word (l’ as in the elided definite article le ‘the’ in l’acrobate, “lacrobate”). These results suggested that misaligned candidates were not completely disregarded despite misleading syllabic information at word onset, and when the misalignment was created by a consonant that was fully interpretable as a word, the activation was as strong as in an aligned condition.

In summary, it seems that the potential processing cost of enchaînement is not as strong as assumed by segmentation procedures based on syllable boundaries like SOSH. As suggested by the results of Gaskell, Spinelli, and Meunier (2002) and Fougeron, Frauenfelder, and Content (2000), lexical information can be used by listeners to solve segmentation ambiguities if
*Word boundaries and contrast neutralization in the case of enchaînement* 23

*Word boundaries and contrast neutralization in the case of enchaînement* indeed creates a misalignment. Acoustic cues have also been shown to be used by listeners to segment and activate purported misaligned vowel initial words (e.g., Dumay, Content, and Frauenfelder 1999; Gaskell, Spinelli, and Meunier 2002). In the following experiment, I will provide further arguments for the availability of sufficient bottom-up information in the processing of *enchaînement*.

4.2.2. Fragment monitoring experiment.

In the production experiment presented in section 3.2, we observed that acoustic cues are present in the signal to contrast *enchaînement* sequences from sequences with underlying onsets. In the present experiment, the goal is to evaluate whether these cues have perceptual validity.

**Method:**

An auditory fragment detection experiment was run in which participants had to detect a specified CV target sequence in a carrier extracted from the utterances produced in the three boundary conditions used in the acoustic analysis (see section 3.2.1). The CV target corresponded to the pivot consonant (C) and the following vowel (V2). It matched the tautosyllabic Wd initial and Wd internal CV syllable in the Wd boundary (#CV) and syllable boundary (.CV) conditions, respectively. It corresponded to the underlyingly heterosyllabic sequence of the *enchaînement* consonant and the following word initial vowel in the *enchaînement* condition (C#V). In the carrier sequences, the target CV was always embedded in a final CVC syllable, for example /ta/ in [vôta] extracted from *savante amie*, *savant tamis*, *tavantami*. Thus, in none of the conditions did the fragment to detect correspond to a full syllable. Carriers were of different structures: mostly C(G)VCVC and (G)VCVC, and few VCVCVC.

The productions of one of the female speakers recorded for the acoustic analysis were used. A subset of 39 of her 41 triplets were used in the experiment (but only 34 were used in the analysis, see below). They included the four types of pivot consonants /t/ (13 items each), /k/ (10), /s/ (7), /s/ (9), for a total of 12 different CV targets (ka (7), ku (3), ta (7), to (5), te (1), sa (3), si (1), së (1), sy (1), so (1), ka (6), ke (2), kë (1)).
The procedure was designed using DMDX (Forster and Forster 2003) so that the target CV syllable was first presented auditorily to the participants, and exemplified in a (CV)CVC French word (e.g., [ka], comme concave ’[ka], as in concave’; [te], comme hotel ’[te], as in hotel’). Then, the carrier was presented auditorily and participants had to press, as soon as possible, the Yes button if the target was present in the carrier, or the No button if it was absent. Reaction times were measured from the onset of the target consonant.

The same stimuli were presented twice in the experiment (either as “yes” or as “no”). All the conditions were presented to the participants in a pseudo-random order, for a total of 234 trials (39 items x 3 boundary conditions x 2 types of responses (yes/no). Twenty-three French participants were tested at the Laboratory of Phonetics and Phonology, Paris.

Results:

The following analysis includes the results for only 34 of the 39 items since 5 of them had to be eliminated. As shown in Table 3, the overall detection rate of the target sequence is very good under all conditions, with more than 90% hits (94% for condition A, 90% for B, and 92% for C). Correct rejections are also fairly good in all conditions (98% for condition A, 96% for B, and 96% for C). Reaction times (RT) observed are overall quite long, but reasonable considering the fact that the carriers were very short (348 ms. average).

Table 3: Performance and reaction time (in parentheses) for the 23 participants and 34 items for each tested condition.

<table>
<thead>
<tr>
<th>Condition A (enchaînement)</th>
<th>Condition B (Wd initial)</th>
<th>Condition C (syllable initial)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hit</td>
<td>738 (635)</td>
<td>704 (621)</td>
</tr>
<tr>
<td>Miss</td>
<td>44 (838)</td>
<td>78 (724)</td>
</tr>
<tr>
<td>Correct rejection</td>
<td>767 (650)</td>
<td>750 (646)</td>
</tr>
<tr>
<td>False Alarm</td>
<td>15 (809)</td>
<td>32 (820)</td>
</tr>
</tbody>
</table>

Global examination of the results shows that performance tends to be better in condition A as compared to conditions B and C, with more hits and fewer errors (including both misses and false alarm). Reaction times for condition A also tend to be longer.
Repeated measures ANOVAs were run on hits (number and RTs), averaged by items and by participants. Results showed a significant main effect of boundary conditions on performance in the participant analysis ($F(2, 44)=7.01, p=.002$), but not in the item analysis ($F(2,66)=2.57, p=.08$). Subsequent planned comparison showed that the performance in the *enchaînement* condition is significantly better than that in Wd initial condition ($p=.03$ by item, and $p<.01$ by participant), and that of syllable initial condition, but only by participants ($p=.02$). Interestingly, no differences were found between conditions B and C.

Although response time in condition A was on average at least 14 ms. longer than in conditions B and C, no effect of condition was found in the analysis of reaction times.

4.3. Summary and discussion of perceptual results

The aim of this experiment was to evaluate whether listeners can make use of acoustic information found to differentiate the three boundary conditions. Results show that the contrast is preserved perceptually between the *enchaînement* condition and the two underlying onsets conditions, in the sense that the target CV is monitored differently in condition A. However, the pattern observed is somehow unexpected. Indeed, one could have expected that the Wd initial CV in condition B would have been better detected since it corresponded to a word initial syllable, and therefore a strategic unit for lexical activation. This is not the case. Performances for a Wd initial CV are not better than for a Wd medial CV. Moreover, one could have expected the monitoring to be better when the target corresponded to an underlying tautosyllabic CV, an unambiguous prosodic constituent. Again, this is not the case. Rather the CV sequence is better detected when it corresponds to an *enchaînement* consonant followed by a Wd initial vowel. In this case, the CV target is underlingly heterosyllabic, it may be resyllabified but it straddles a Wd boundary. According to the acoustic differences found in the production experiment, it is unclear why performances are better in the *enchaînement* condition. Indeed, *enchaînement* consonants were found to be shorter, which could make them less salient. A closer examination of the acoustic properties of the speaker’s production used, of the potential inter-item differences, and of the correlation between the various acoustic cues and the participant’s performances remain to be done. Nonetheless, these results further support
the studies presented above showing that enchâinement may not be a ‘problem’ for segmentation strategies based on syllable boundaries. Listeners may rely on lexical information, as well as on sufficient bottom-up information to process enchâinement. These acoustic cues are sufficiently salient to signal the difference in syllabic and lexical/prosodic structures between enchâinement C#V and #CV/.CV, and to perceptually preserve the contrast between the sequences.

5. Conclusion

The findings presented here confirm previous results suggesting that the assumed process of (re)syllabification across word boundaries in enchâinement is not complete. That is, it does not imply a neutralization of contrast, neither in production nor in perception, with sequences involving an underlying onset. Our triangular comparison with two kinds of onset has shown that in the process of enchâinement across words, an enchâinement consonant is phonetically different from an onset consonant, whether this onset is Wd medial or Wd initial. Moreover, our fragment monitoring experiment has shown that listeners can make use of these acoustic differences in order to process these sequences in a different way. Along with the observed low productivity of enchâinement in continuous speech, these findings attenuate the so-called problem of boundary misalignment in a segmentation procedure based on syllable boundaries in French.

However, due to a lack of comparison with un-resyllabified Wd final codas, these results do not allow strong conclusion regarding whether enchâinement consonants are indeed (re)syllabified to an onset position. Indeed enchâinement consonants may be partially (re)syllabified but may differ from underlying onsets because they maintain characteristics of their word final affiliation. This has to be tested.

Moreover, in the present study, the only cases of enchâinement considered are the ones occurring across two lexical words. A further comparison with cases of enchâinement occurring between a determiner and a lexical word is needed to obtain a more holistic interpretation of our results and their implication, for both prosodic theories and theories of phonological encoding, regarding the domain of syllabification (e.g., Levelt, Roelofs, and Meyer 1999; Keating and Shattuck-Hufnagel 2002).

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Notes

1. For some authors, enchaînement is also said to occur with consonant-initial words, like in trois petites roues (‘three little wheels’) [tʁwa#.pɛti.tʃru] (Delattre 1940). These cases will not be addressed here.
2. Here and in the following, by ‘underlying’ I mean ‘abstract at some level of representation’.
3. Notice that (re)syllabification in these cases does not concern a final consonant but an initial one after the loss of the syllabic nucleus. This single consonant has been described as being syllabified to the right or to the left, or as remaining extrasyllabic (see Rialland 1986 for a discussion).
4. According to Delattre (1940: 143-144) the use of the term enchaînement in phonetics was introduced by Pernot (1937) for whom an enchaînement is a liaison with a consonant that would be pronounced when the word is produced in isolation, instead of with a consonant that would be mute when the word is produced in isolation. It is interesting to note that this term has been fully adopted in French linguistic descriptions, while various terms are used in English to describe the same phenomenon: linking, concatenation, resyllabification…
5. These words can be considered as Prosodic (or Phonological) Words according to the definition of Nespor and Vogel (1986) or Selkirk (1995), i.e. a lexical head containing a stressable syllable preceded by its determinants, if any.
6. One item in condition A is of the form determiner+noun (chaque allemand ‘each German’)
7. According to a strict definition of the Phonological Phrase, “det+noun+adj” items form two Phonological Phrases, but all cases conformed to the conditions of restructuring two PhP into a restructured PhP (Nespor and Vogel 1986, Post 2000).
8. The remaining of the corpus includes further consonant types, with only few triplets for each.
Word boundaries and contrast neutralization in the case of enchaînement

9. This comparison, not done by the authors, is possible when comparing the 2 groups of sentence made by the authors according to the fact that the second group contain a vowel that may be potentially lengthened by the enchaînement consonant. It is unclear on what ground the authors have made this distinction (the consonants are similar in the two groups and the word containing enchaînement is not accented in either cases), but it appears that all the cases of enchaînement in the second group occur across two lexical words while in the first group, most (10 out of 12) enchaînements occur between a determiner and a word.

10. Lexical activation was tested by comparing reaction time (RT) to item-final target (ex. /t/) in the test conditions (“gacrobatelacrobat”, “acrobate”) with corresponding non-word baseline conditions (“gopribate/lopribate” and “opribate”).

11. The sound file for one item was erroneously presented two times within the same condition and was disregarded from the analysis. Four additional items (3*ta, 1*so) had to be removed from the analysis due to the fact that the target CV syllable presented was very different from the acoustic realization of the CV sequence present in the carrier sequences. Indeed, the amount of coarticulation was such that the /ta/ in /tam/ clearly sounded like [ts], and the /so/ like [sɔ], whatever the condition.

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Appendix

List of the 41 sequences used for the production experiment, according to condition (A : enchaînement, B : word boundary, C : syllable boundary) and consonant type.

<table>
<thead>
<tr>
<th>A : V1.C#V2</th>
<th>B: V1#CV2</th>
<th>C: V1.CV2</th>
</tr>
</thead>
<tbody>
<tr>
<td>/t/ savante amie</td>
<td>savant tamis</td>
<td>tavantami</td>
</tr>
<tr>
<td>savante année</td>
<td>savant tanné</td>
<td>tavantaner</td>
</tr>
<tr>
<td>plante aride</td>
<td>plant tari</td>
<td>plantarite</td>
</tr>
<tr>
<td>tante horrible</td>
<td>temps torride</td>
<td>tantorrite</td>
</tr>
<tr>
<td>plante ombrée</td>
<td>plant tombé</td>
<td>plantomper</td>
</tr>
<tr>
<td>petite amie</td>
<td>petit tamis</td>
<td>vetitami</td>
</tr>
<tr>
<td>conduite aride</td>
<td>conduit tari</td>
<td>quonduitarite</td>
</tr>
<tr>
<td>maudite amie</td>
<td>le maudit tamis</td>
<td>pauditami</td>
</tr>
<tr>
<td>truite achetée</td>
<td>truie tachetée</td>
<td>druittach(e)ter</td>
</tr>
<tr>
<td>petite ermite</td>
<td>petit termite</td>
<td>vetitermide</td>
</tr>
<tr>
<td>maudite horreur</td>
<td>maudit torrent</td>
<td>pauditorrant</td>
</tr>
<tr>
<td>petite horreur</td>
<td>petit torrent</td>
<td>vetitorran</td>
</tr>
<tr>
<td>truite horrible</td>
<td>truie torrent</td>
<td>druittorrite</td>
</tr>
<tr>
<td>truite ombrée</td>
<td>truie tombée</td>
<td>druittomper</td>
</tr>
<tr>
<td>brute horrible</td>
<td>bru torrent</td>
<td>brutorrite</td>
</tr>
</tbody>
</table>

| /k/ grec allemand | grès calmant | graicalmond |
| mec allemand | met calmant | maiqualmont |
| mec ouvert | met couvert | maicouever |
| chaque allemand | chat calmant | chacalmont |
| plaque achetée | plat cacheté | placach(e)per |
| plaque allemande | plat calmant | placalmont |
| plaque ouverte | plat couvert | placouever |
| cric ouvert | cri couvert | cricouever |
| cric allemand | cri calmant | criqualmont |
| brique allemande | brie calmant | briqualmart |

| /R/ chaire ajoutée | chai rajouté | chairajoutu |
| père amené | paix ramenée | pairameneux |
Word boundaries and contrast neutralization in the case of enchaînement

<table>
<thead>
<tr>
<th>mère adoucie</th>
<th>met radouci</th>
<th>mairadousser</th>
</tr>
</thead>
<tbody>
<tr>
<td>père athée</td>
<td>paix ratée</td>
<td>pairater</td>
</tr>
<tr>
<td>fer échauffé</td>
<td>fait réchauffé</td>
<td>faréchover</td>
</tr>
<tr>
<td>armoire achetée</td>
<td>chamois racheté</td>
<td>barmoirach(e)der</td>
</tr>
<tr>
<td>mur amolli</td>
<td>mae ramollie</td>
<td>muramoté</td>
</tr>
<tr>
<td>chevelure emplumée</td>
<td>chevelu remplumé</td>
<td>soveluranplupet</td>
</tr>
<tr>
<td>dure essence</td>
<td>dà récent</td>
<td>duressande</td>
</tr>
</tbody>
</table>

/l/ baisse avouée  baie savourée  pèssavoumé
indécence innée  indécent ciné  andésenciner
résidence indiquée  les résidants syndiqués bésidancindiquo
importance ultime  important sultan  euportensûlème
lisse allée  lit salé  lissaler
lisse olive  lit solide  lissolite
russe abordée  rue sabordée  ruçaborter