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5aSCb1. Acoustic and articulatory evidence for the phonological status of liaison consonants

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French liaison consonants (LC) are a special class of word-final segments whose realization depends on a combination of phonological, lexical, and syntactic factors. Most previous analyses viewed LCs as coda consonants realized only before vowel-initial words. Because of their special status as syntactically and lexically conditioned, an interesting question is whether LCs exhibit typical acoustic and articulatory characteristics of word-final consonants. This paper presents the results of an experimental investigation of LCs in adjective+noun pairings in Quebec French, using electromagnetic articulography to collect kinematic data. Compared to typical coda and onset consonants, liaison consonants were found to exhibit smaller magnitude release gestures, and in some cases LC closure gestures were more similar to those of onsets than codas. Unlike coda consonants, LCs did not induce gestural shortening or laxing (F1 raising) of the preceding vowel. Hence our results indicate that, although LCs have been analyzed as word-final consonants, they exhibit neither typical coda-like or onset-like acoustic and articulatory properties. These results are important because they show that syntactically conditioned lexical phonology can result in non-canonical articulatory patterns, and hence speak to the need for models of production to incorporate both lexical representations and syntactic context as factors.

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1.INTRODUCTION

French liaison consonants (LCs) are a special class of word-final segments whose realization depends on a combination of phonological, lexical, and syntactic factors. LCs typically appears between two words, which we henceforth refer to as Word1 and Word2. When Word2 is vowel-initial, as in example (2), the liaison consonant is realized, but not when Word2 is consonant-initial, as in example (1). However, the examples in (3) to (5) show the interaction between the phonological context and the syntactic and lexical factors. An interesting issue that these examples raise is that of the underlying syllabification of LCs, whether they behave like typical codas, or rather syllabify as the onset of Word2.

(1)	petit jardin	[ptiʒardĩ]	*'small garden'*
(2)	petit ami	[pti**t**ami]	*'boyfriend/small friend'*
(3)	marchand de draps anglais	[dra**z**ãglɛ]	'*merchant of english shee*t'
(4)	marchand de draps anglais	[draãglɛ]	'*english merchant of shee*t'
(5)	bien mieux isolé[i]	[bjɛ̃mjø**n**izɔle]	'*much better insulated*'

Traditional analyses have considered LCs as coda consonant (Schane 1968, Selkirk 1972), affiliated with Word1, but other possibilities (onset syllabification, ambisyllabicity, constructionism) have been brought forward by recent experimental work on acquisition, speech errors and phonetics (Nguyen et al., 2007, Wauquier-Gravelines et Braud, 2005, Dugua, 2006). The goal of this paper is to investigate the syllabic status of LCs in Quebec French. The acoustic and kinematic characteristics of LCs, underlying onsets and codas were analyzed; results show that LCs exhibit predominantly typical characteristics of coda.

2. HYPOTHESIS AND PREDICTIONS

In an important study, Côté (2010) used perceptual data involving phonological processes active at word boundaries in Quebec French and argued that her results supported a constructionist analysis. Two of these processes are vowel laxing in closed final syllables, as seen in (6) and affrication of alveolar stops preceding high front vowels as in (7):

(6)	petite amie	[ptsɪtami]	'girlfriend'
(7)	gros tigre	[grot^{s}ɪg]	'big tiger'

These two phonological processes can be viewed as diagnostic tools for syllabification: if LCs syllabify as coda, we expect them to trigger vowel laxing but not affrication[ii], while an onset syllabification would induce affrication but not laxing.

Two other diagnostic measurements have also been examined: consonant and vowel duration. De-Jean-de-la-Bâtie (1993) established that French coda consonant have a shorter realization time than onset consonant. Therefore, if LCs syllabify as coda, we expect them to have a shorter duration than typical onsets. As for vowels, Nguyen et al. (2007) experimental data shows that vowels in a final syllable closed by a coda are longer than vowels in an open final syllable. If LCs syllabify as codas, we expect the previous vowel to have a longer duration than vowel in open final syllable. Likewise, we investigate kinematic measures such as movement duration, range, and velocity of liaison consonants, to determine whether they are more similar to onsets or codas.

3. METHOD

The experiments were designed to elicit natural speech containing target words of adjective+noun pairing as in (1) and (2) because prenominal adjectives form a small class of words that are in common use in most dialects and that systematically trigger liaison with a following vowel-initial noun. In the first phase, participants were familiarized with simple word/image pairs and were asked to memorize them. Participants were then shown randomized combination of two images, illustrating respectively an adjective and a noun, and asked to produce these target sequences in a carrier sentence such as *Je pense que j'ai vu* ____ *au milieu parc hier* ('I think I saw ___ in the middle of the park yesterday) to avoid repetitive list-like prosody. Images were used in order to avoid the interference of orthography. Trials were balanced between four conditions: intervocalic coda (VC#V), onset (V

#CV), and liaison consonant (VLC?#?V), as well as a hiatus context (V#V).

3.1 Acoustic Experiment

We recorded five native speakers of Québec French between the age of 18 and 23, two male speakers and three females. In a soundproof recording booth, we used E Prime 2.0 Pro (Psychology Software Tools, Pittsburgh, PA) to present the stimuli and collect the output produced by participants.

TABLE 1. Target words with gloss for the acoustic experiment.

Adjectives (fem./masc.)	Nouns	
joli/jolie ('beautiful')	abeille ('bee')	sac ('bag')
petit/petite ('small')	abricot ('apricot')	savon ('soap')
gros/grosse ('big')	assiette ('plate')	tatou ('armadillo')
maudit/maudite ('damned')	avion ('airplane')	tapis ('rug')

Participants each performed 5 blocks of 25 trials where every stimulus combination was presented once in each block in random order , for a total of 125 tokens. Participants took a short break after the third block. We excluded 54 tokens (9% of total) due to misidentification of target words, stuttering or other disruption in the acoustic signal. The first author labeled the remaining 571 tokens in Praat (Boersma & Weenink, 2012), identifying the vowels and the consonant of the target sequences. Onset and offset of voiced (or partially voiced, when possible) vowels were determined respectively by the onset and offset of vibration, as well as the presence of formants in the spectogram. Voiceless vowels were identified as such and the interval correspond to the interval of frication. Closure and release (when applicable) were identified for consonants. The closure was bounded by the offset of the previous vowel and the onset of the release, and the offset of the release was bounded by the onset of the following vowel.

The vowel and consonant duration were extracted from the textgrids, and vowel formants were measured using a robust LPC algorithm (Yao et al., 2010) implemented in Matlab. The first author manually examined the spectograms to identify affrication of the consonant. This examination allowed us to find that affrication of alveolar stop in front of high front vowels happened systematically in all three contexts for all our participants, contra Côté (2010). Moreover, during the segmentation, we observed that the affrication caused the following vowel to devoice either partially or totally in a majority of the cases. Because of this phenomenon, it is not possible to obtain F1 values for /i/.

3.2 Articulatory Experiment

A female native speaker of Montreal French (age 25) and a male speaker of the same dialect (age 24) participated in second experiment, in which articulatory and acoustic data were collected. The design was identical to the first experiment, except that only a subset of the stimuli were used (see Table 2). Articulatory data and synchronized audio were collected using an NDI Wave electromagnetic articulometer (Berry, 2011) and a shotgun microphone positioned approximately 0.75 m from the mouth of the speaker. Reference sensors were placed on the nasion and left/right mastoid processes. Articulator sensors were located in the midsaggital plane on the following: upper lip (UL), lower lip (LL), on the tongue blade approximately 2 cm from the tip (TT), on the body of the tongue approximately 5 cm from the tip (TB), and externally on the jaw (JAW). The speaker performed 21 blocks of 12 trials, where every stimulus combination was presented once in each block in random order. Prior to the acquisition of experimental data, a bite plate was used to measure the orientation of the occlusal plane relative to the reference sensors.

TABLE 2. Target words with gloss for the articulatory experiment.

Adjectives (fem./masc.)	Nouns
joli/jolie ('beautiful')	abeille ('bee')
petit/petite ('small')	abri ('shelter')
gros/grosse ('big')	sabot ('hoof')
maudit/maudite ('damned')	tableau ('blackboard')

The acoustic recordings were hand-labeled in Praat by the first author with the same constraints used for the acoustic experiment.

Articulatory data were processed in Matlab as follows: the reference sensors were used to correct for head movement and the articulator positions were rotated so that the occlusal plane is parallel to the font-back and left-right axes of the coordinate space. Sensor positions were low-pass filtered (reference sensors: 4^{th} order Butterworth, 5 Hz cutoff; articulator sensors: 4^{th} order Butterworth, 15 Hz cutoff). A lip aperture measure (LA) was defined as the euclidean distance between the lips in the midsaggital plane. Kinematic landmarks associated with relevant consonantal articulations in each trial were identified as follows: the point of maximal velocity associated with the release of the target consonant ([s] or [t]) was found in the TT vertical position, using the acoustic segmentation as a guide. Subsequently velocity zeros and extrema associated with the formation and release of the constriction were identified. Gestural onset/target landmarks were located when TT speed rose above/fell below 25% of the maximum associated with constriction formation, and likewise gestural release/offset landmarks were located when TT speed rose above/fell below 25% of the maximum during release. The same procedures were used to identify landmarks associated with the bilabial consonant in the following word, using the LA measure. The velocity associated with each velocity extremum landmark was recorded, as well as movement ranges from onset/offset to maximum vertical position of the TT in the target consonant articulation.

The results reported below are based on an analysis of data from the first speaker, as analysis of the second speaker is in progess.

4. RESULTS

4.1. Acoustic Data

For the three consonantal contexts (coda, LCs, onset), we calculated the following variables: (i) consonant duration, (ii) preceding vowel duration and (iii) vowel F1 value. Then, for each variable, we compared contexts with paired t-test in Matlab.

(i) Consonant Duration

For /t/, the mean value of closure+release of LCs (65 ms) is closer to the mean value for coda (63 ms), while the mean value of onset (80 ms) is significantly higher (for $p<0.05$, see figure 1). For /s/, the mean value of onset (108 ms) is also significantly higher than the mean value of coda and LCs (83 ms, 58 ms), with the addition of the mean value of LCs being also significantly lower than that of coda consonants (see figure 1).

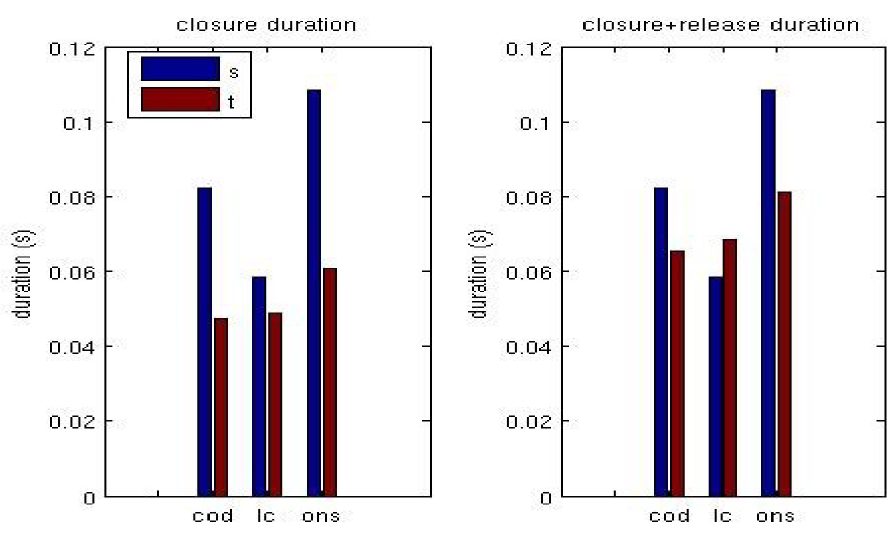

FIGURE 1. Consonant duration by context. The first graph shows results for the portion that was labeled as “closure” only, while the second graph shows results for both the closure a and the release (if applicable).

The significant difference between mean value of coda and LCs might be explained by the voicing of /s/ in coda position. Thus, the data presented in figure 1 seem to indicate that for consonant duration, LCs exhibit a pattern similar to coda consonants.

(ii) Vowel Duration

Figure 2 shows the mean duration of both /i/ and /o/ in all three contexts. While the absolute values of /i/ are shorter than the absolute values of /o/, they both exhibit the same pattern, where LCs and coda mean values (54 ms, 52 ms) are significantly shorter than onset mean value (69 ms) (for $p<0.05$).

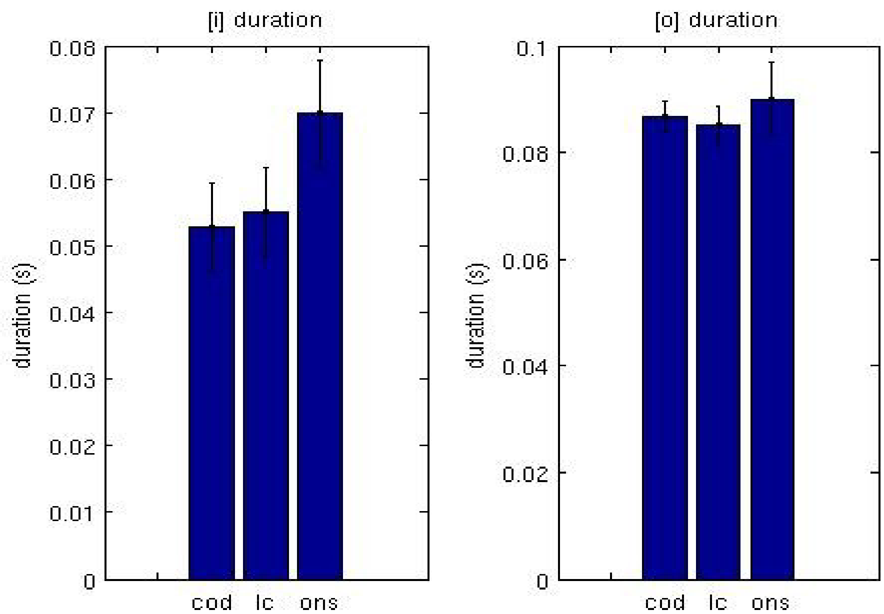

FIGURE 2. Vowel duration by context. The results for /i/ seem to contradict the conclusion reached by De-Jean-de-la-Bâtie (1993). This could be due to the interaction with affrication, which devoiced (partially or totally) the majority of the /i/ tokens. Moreover, the word "petit" has also been problematic throughout the analysis due to its acoustic outcome (see section 4 and 5).

(iii) Vowel F1 Value

While the previous variables seem to indicate a clear coda-like behaviour for LCs, the vowel F1 values presented in figure 3 suggest a different story. For /o/, the mean F1 values for both LCs and onset (369 Hz, 361 Hz) are significantly lower than the mean value of coda (422 Hz) (for $p<0.05$), indicating that LCs, unlike coda, don't induce laxing on the preceding vowel.

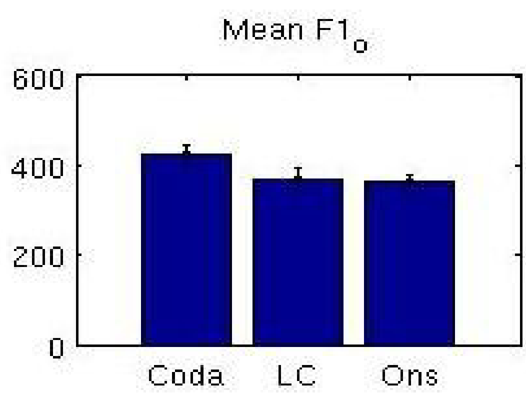

FIGURE 3. Formant mean values for /o/, in Hz. The higher value for coda indicates vowel laxing.

Since we were unable to obtain F1 values for /i/ due to devoicing, we calculated the percentage of devoiced /i/ in all three contexts and both coda and LCs exhibited a significantly higher percentage of devoiced /i/ (87%, 96%) than onset (39%).

To summarize, consonant duration, vowel duration and the percentage of devoiced /i/ seem to indicate a coda-like behaviour, while the F1 values show no laxing on the preceding vowel for LCs, which is a typical onset behaviour. Hence the acoustic data show some ambiguity with regard to whether LCs are syllabified as onsets or codas.

4.2 Kinematic Data

For the three consonantal contexts, the following dependent variables were investigated: the target consonant release duration (time from TT release to TT offset); duration of time from the maximal constriction in the target consonant to the maximum speed of the formation of the bilabial constriction in the following bilabial consonant; the movement range of the release of target consonant; and the maximal velocity associated with that release. For each consonant type and variable, outlier datapoints more than 2.0 standard deviations from the mean were excluded. For each variable, ANOVAs were conducted with the factors WORD (the target word, i.e. gros, maudit, or petit), CONSONANT type (i.e. onset, LCs, or coda), and the interaction of these. Subsequently, post-hoc comparisons were performed using Tukey's HSD with a family-wise $\alpha = 0.05$.

Figure 4 shows that for the release duration and the peak-to-onset duration, LC are more similar to codas than onset exhibiting shorter release durations. There was a main effect of both CONSONANT and WORD on release duration ($F = 7.12$ and 9.02, $p < 0.005$), and also on the timing of the TT maximum and LA onset ($F = 37.77$ and 11, $p < 0.001$). Post-hoc comparisons showed that TT release duration and TT-LA timing in codas and LCs differed significantly from onsets for gros and *maudit*, while the codas and LCs did not differ. For *petit,* these measures were significantly lower in LCs than in both onsets and codas. This lack of significant difference between onset and coda in could be due to the acoustic realization of the word, which is produced as the consonant cluster [ptsi] (with a voiceless [i]) by speakers of the Montreal dialectal area.

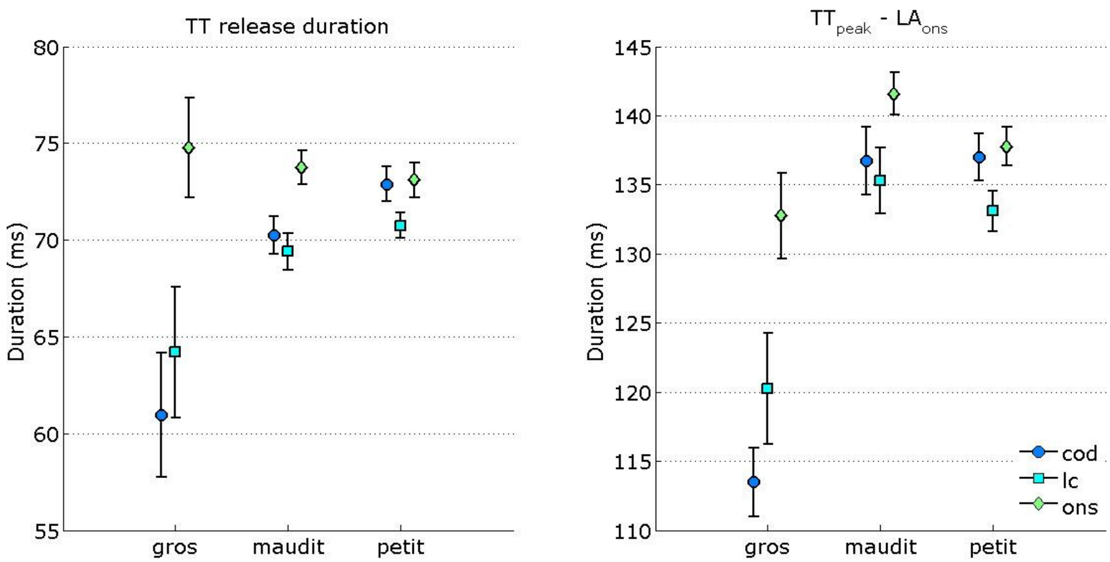

FIGURE 4. Left: duration of release for tongue tip movement. Right: duration from the peak of th tongue tip movement to the onset of the bilabial closure.

The results for range and velocity show similar pattern (see figure 5), where the values for LCs and codas exhibited smaller movement range and maximum speed than onsets. There was a main effect of both CONSONANT and WORD on both the release range ($F = 176.44$ and 102.42, $p < 0.001$), and and on the release maximum speed ($F = 259.81$ and 24.32, $p < 0.001$). Post-hoc comparisons showed that the TT release range differed significantly for all three contexts, while the TT release maximum speed in codas and LCs for *gros* and *petit* differ significantly from onsets, but not between each other. For *maudit,* these measures were significantly lower in LCs than in both onsets and codas.

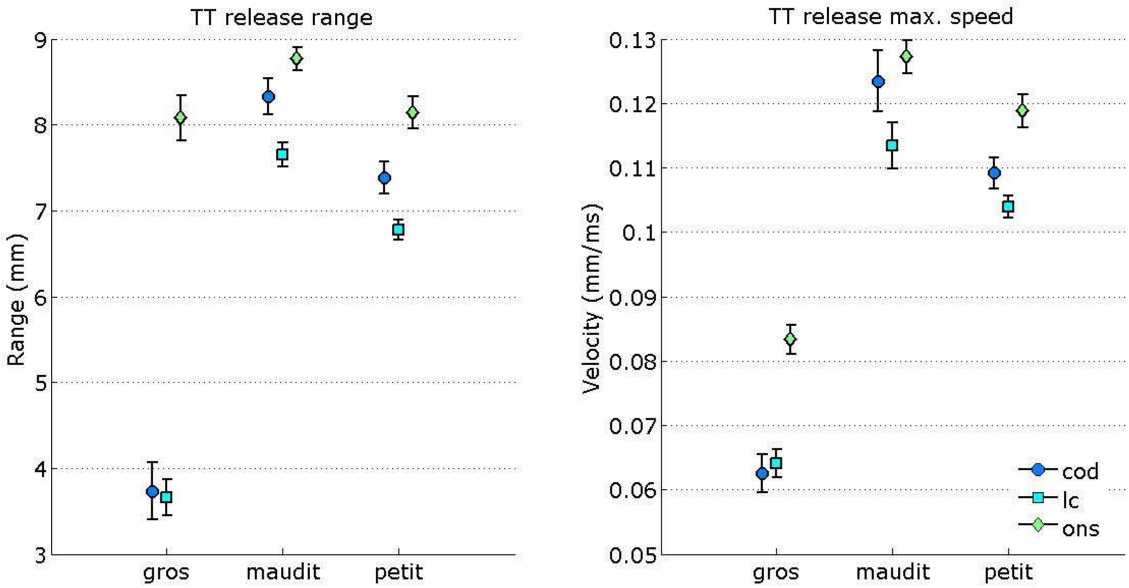

FIGURE 5. Left: release range for the tongue tip. Right: maximal speed of the release for the tongue tip.

To summarize, the general pattern we observed was that LCs are articulatorily more similar to codas than to onsets. This was systematically the case for the word *gros*, while *petit* and *maudit* had more ambiguous results. In *petit*, the LCs articulation was more reduced in release duration, movement magnitude, and maximum speed than either onsets or codas. In *maudit*, the LCs maximal speed in release was significantly lower than both onsets and codas. Overall, we found that across all four variables, the kinematic behaviour of LCs is more similar to that of codas and significantly different from that of onset.

5. DISCUSSION AND CONCLUSION

Our results provide evidence that LCs in prenominal adjectives predominantly display acoustic and articulatory characteristics associated with coda consonants in the same context. The only variable where the results indicate a different behaviour is for vowel laxing in the acoustic data, where vowels preceding LCs do not show traces of laxing, which would indicate an onset syllabification. It is also interesting to note that the relationship between the mean value of duration for /s/ in the acoustic data is inverted in the articulatory data, where the mean value for codas is slightly lower than the mean value for LCs.

It is important to consider the consequences of the observation that the articulatory characteristics of LCs are more in-line with acoustic measures involving duration than measures involving vowel quality. This suggests that the laxing associated with normal codas may not be a suitable diagnostic for syllabification of LCs. One possible interpretation of the observation is that laxing is a lexical process that precedes the syllabification of an LC. In other words, the LC syllabifies as a coda, but does not induce vowel laxing. This is interesting because it demonstrates that, although coda-like phonetically, LCs must be treated differently from normal codas in the phonology of the language.

The results and the methodology presented here add to the growing corpus of empirical data on French phonology. This paper also contain what is, to the best of our knowledge, the first account of the articulatory and kinematic characteristics of consonants in Québec French.

As concluded by Côté (2010), liaison is not homogeneous, and the results presented here contribute to explain only a small fraction of the problem. Future investigation in other contexts where liaison occur, and in different dialectal areas will certainly further our understanding of this complex phenomenon.

REFERENCES

Berry, J. (2011). Accuracy of the NDI Wave Speech Research System. *JSLHR*, 54, pages 1295–1301

Boersma, Paul & Weenink, David (2012). *Praat: doing phonetics by computer* [Computer program]. Version 5.3.39, retrieved 11 november 2012 from http://www.praat.org/

Bybee, J. (2005) La liaison: effets de fréquence et constructions. *Langages* 158 : 24-37.

Côté, M.-H. (2005) Le statut lexical des consonnes de liaison. *Langages* 158: 66-78

Côté, M.-H. (2007) Empty elements in schwa, liaison and h-aspiré: The French Holy Trinity reconsidered. In Jutta M. Hartmann, Veronika Hegedüs & Henk van Riemsdijk, (eds.) *Sounds of silence: Empty elements in syntax and phonology*. Oxford: Elsevier

Côté, M.-H. (2010) Le statut des consonnes de liaison: l'apport de données du français laurentien. In F. Neveu, V. Muni Toke, T. Klingler, J. Durand, L. Mondada & S. Prévost, (eds.) *2ème Congrès Mondial de Linguistique Française*. Paris: Institut de Linguistique Française, 1279-1288.

Davis, J. L. (2000) *French liaison: a case study of the syntax-phonology interface*. Doctoral thesis, University of Indiana, Bloomington.

Dejean-de-la-Bâtie, B. (1993) *Word boundary ambiguity in spoken French*. Doctoral thesis, Monash University.

Desrochers, R. (1994) Les liaisons dangereuses: le statut équivoque des erreurs de liaison. *Linguisticae investigationes* 18 (2): 243-284.

Dugua, C. (2006). *Liaison, segmentation lexicale et schémas syntaxiques entre 2 et 6 ans. Un modèle développemental basé sur l'usage*. Doctoral thesis, Université Stendhal, Grenoble III.

Féry, C. (2003) *Liaison and syllable structure in French*, Ms. Université de Potsdam.

Fougeron, Cécile, Jean-Philippe Goldman & Uli Frauenfelder (2001) Liaison and schwa deletion in French: an effect of lexical f requency and competition? *Proceedings of Eurospeech 2001*, Aalborg, Danemark, 639-642.

Nguyen, N., Wauquier-Gravelines, S., Lancia, L., & Tuller, B. (2007) Detection of liaison consonants in speech processing in French: Experimental data and theoretical implications. In P. Prieto, J. Mascaró & M.J. Solé, (eds.) *Segmental and prosodic issues in Romance phonology*, Amsterdam John Benjamins, 3-23.

Schane, S. A. (1968) *French phonology and morphology*. Cambridge, MA: MIT Press.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime Reference Guide. Pittsburgh: Psychology Software Tools, Inc.*

Selkirk, E.O. (1972) *The phrase phonology of English and French*. Doctoral thesis, MIT.

Spinelli, E. & Meunier, F. (2005) Traitement cognitif de la liaison dans la reconnaissance de la parole enchaînée. *Langages* 158: 79-89.

Wauquier-Gravelines, S. & V. Braud (2005). Proto-déterminant et acquisition de la liaison obligatoire en français. *Langages,* 158, 53-65.

Yao, Y., Tilsen, S., Sprouse, R., & Johnson, K. (2010). Automated Measurement of Vowel Formants in the Buckeye Corpus. *Gengo Kenkyu*, 138, 99-113

[i] Côté (2011)
[ii] Affrication is believed to be a word-internal phenomenon only ; therefore a coda followed by a high front vowel should not affricate.