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Noël Nguyen (1), Sophie Wauquier (2), Leonardo Lancia (1), and Betty Tuller (3)

1 Laboratoire Parole et Langage, Université d'Aix-Marseille & CNRS, Aix en Provence, France
2 Structures formelles du langage, Université de Paris 8 & CNRS, Saint-Denis, France
3 Center for Complex Systems and Brain Sciences, Florida Atlantic University, Boca Raton, USA

in *Segmental and Prosodic Issues in Romance Phonology*, edited by P. Prieto, J. Mascaró & M.J. Solé (John Benjamins, Amsterdam), 2007, pp. 3-23.

Abstract

The goal of the present study is to better understand the mechanisms involved in the processing of liaison consonants by listeners in French. Previous work (Wauquier-Gravelines, 1996) showed that liaison consonants are more difficult to detect than word-initial consonants in a phoneme-detection task. We examined to what extent such differences are attributable to the consonants' phonetic properties, and we also compared the perception of liaison consonants with that of fixed word-final and word-medial consonants, as well as word-initial ones. The results suggest that liaison consonants have a specific perceptual status. Implications for both autosegmental and exemplar-based theories of liaison are discussed.

1 Introduction

French liaison is a well-known phenomenon of external sandhi that refers to the appearance of a consonant at the juncture of two words, when the second word begins with a vowel, e.g. *un* [œ̃] + *enfant* [ɑ̃fɑ̃] → [œ̃nɑ̃fɑ̃] "a child", *petit* [pəti] + *ami* [ami] → [pətitami] "little friend". Liaison consonants are usually *enchaînées*, i.e. realized as syllable-onset consonants, although they can also appear in coda position, compare [pə.ti.ta.mi] (with *enchaînement*) and [pə.tit.a.mi] (without *enchaînement*, Encrevé, 1988). In the following, the two words at the juncture of which liaison consonants appear will be referred to as Word 1 and Word 2, respectively.

Among the many different approaches to French liaison that have been proposed over the last thirty years or so (see Tranel, 1995; Côté, 2005, for reviews), a major bone of contention relates to whether liaison is a phonological or a lexical phenomenon. The phonological approach dates back to early generative studies on French phonology, in which liaison was seen as an exception to a general process of final consonant deletion, referred to as the "French Truncation Rule" by Schane (1968). By contrast, according to another proposal made later in the same general framework (e.g. Klausenburger, 1974, 1977) liaison consonants arose in the course of the derivation owing to an insertion mechanism (views differed as to whether this epenthesis occurred at the end of Word 1 or at the onset of Word 2). More recent treatments of liaison in nonlinear phonology have reconceptualized the deletion/insertion dichotomy, as pointed out by Tranel (1995). Thus, in the autosegmental account proposed by Encrevé (1988) and Encrevé and Scheer (2005), liaison consonants are viewed as floating segments, with respect both to the segmental and syllabic tiers. Such consonants must be associated with both tiers to be phonetically realized, and this association takes place only under certain conditions. In both the linear and nonlinear phonological approaches, liaison is generally portrayed as being subjected to prosodic, morphological, syntactic and stylistic factors.

Lexical approaches to liaison can be divided into two main strands. Suppletive analyses as advocated by Klausenburger (1984) among others, assume that words such as *petit* are associated in the lexicon with two distinct allomorphs, a longer one ending in a liaison consonant (/pətit/) and a shorter one without liaison consonant (/pəti/). In contrast, in exemplar-based models, such as the one recently proposed by Bybee (2001, 2005), liaison consonants are said to take place within specific grammatical constructions, e.g. [NOUN -z- [vowel]-ADJ $]_{\text{Plural}}$, in *enfants intelligents* [ɑ̃fɑ̃zɛ̃teliʒɑ̃] "clever children". Constructions display different degrees of generality/abstractness, and range on a continuum from very abstract (as in the example given above), to fixed, lexicalized phrases like *c'est-à-dire* [setadiʁ] "that is to say". This provides a unified account of both false liaisons, which are attributed to the overgeneralization of a high-frequency construction, as in *quatre enfants* [katʁəzɑ̃fɑ̃] "four children", and word-specific differences in the realization of liaison.

Frequency of use is of central importance, as liaison is assumed to occur more often within a sequence of words characterized by a higher frequency of co-occurrence. This approach is neutral with respect to the issue of whether liaison consonants result from a deletion or insertion process, nor does it make any specific claim as to whether the consonant belongs to Word 1 or 2.

As noted above, liaison consonants when realized are usually *enchaînées*, i.e. syllabified into onset position. This results in a mismatch between word and syllable boundaries. Specifically, the syllable whose onset position the liaison consonant comes to occupy straddles the boundary between Word 1 and Word 2 (e.g. [pə.ti.ta.mi], where the word boundary takes place between [t] and the following [a]). Recent psycholinguistic studies (Wauquier-Gravelines, 1996; Gaskell et al., 2002; Spinelli et al., 2003) have shown that this mismatch does not necessarily make it more difficult for listeners to identify the second word, but may in fact facilitate the recognition of that word with respect to a baseline condition. This raises questions for models of speech perception in which the syllable is viewed as a primary unit of segmentation in lexical access in French (see Content et al., 2001, for a recent discussion in that domain).

A related issue concerns the way in which liaison consonants are processed in speech perception. One may ask which perceptual mechanisms allow a *liaison enchaînée* to be distinguished from word-initial as well as word-final consonants, and to which of the two words the liaison consonant is associated by the listener. More generally, the question arises whether in speech comprehension liaison consonants are processed and represented in a way that is different from fixed consonants. It is this issue which is addressed in the present paper. A series of experiments are reported which together suggest that liaison consonants do have a distinct perceptual status. Implications for current models of liaison in French will be discussed.

2 Empirical evidence for a specific status of liaison consonants in speech perception

Wauquier-Gravelines (1996) examined the speed and accuracy with which listeners can detect the presence of a liaison consonant in the speech chain. Because it has not been published, we present this work here in some detail and in the light of more recent findings. Wauquier-Gravelines compared listeners' responses to liaison consonants and word-initial consonants in a phoneme-detection task. Listeners were presented with a series of sentences and were asked to detect a prespecified phoneme in each sentence. The material contained pairs of sentences that were designed so that the target phoneme appeared as a word-initial consonant in one sentence (e.g. *son navire* [sɔ̃naviʁ] "his ship") and as a liaison consonant (e.g. /n/ in *son avion* [sɔ̃navjɔ̃] "his plane") in the other. The two sentences in each pair were matched with respect to their syntactic, lexical and phonemic make-up. A number of filler sentences were also used. Both the test and filler sentences were recorded by a native speaker of standard French.

Two experiments were conducted. Each experiment was comprised of a training phase and a test phase. The target consonant was /t/ in the first experiment and /n/ in the second one. There were fourteen subjects, all native speakers of standard French, with no known hearing impairment, and naive as to the purpose of the experiment.

The data showed that listeners experienced greater difficulties in detecting the liaison than the word-initial consonant. There were significantly fewer correct responses for the liaison than for the word-initial consonant for both /t/ (liaison: 67.8%, word-initial: 92.8%, $\chi^2 = 9.56, p < 0.01$) and /n/ (liaison: 44.6%, word-initial: 87.5%, $\chi^2 = 21.07, p < 0.01$), although this difference was smaller for /t/ than /n/.

These results suggest that liaison consonants are not processed in the same way as fixed consonants by listeners. There is a potential parallel between this phenomenon and the status liaison consonants have in autosegmental phonology. As indicated above, liaison consonants display both syllabic and skeletal flotation in Encrevé's (1988) autosegmental model. When followed by a word with a null onset (i.e. an onset with no corresponding segmental constituent and no skeletal slot), the liaison consonant is attributed a skeletal slot and, in the unmarked case, is syllabified into onset position. Thus, liaison consonants are not lexically anchored to a timing unit and are in this regard characterized by structural instability. It may be hypothesized that listeners' behaviour in the phoneme-detection experiments is a reflection of this instability. In other words, it would be more difficult for listeners to map a liaison consonant onto a phonemic label because unlike "ordinary" phonemes, i.e. fixed consonants, liaison consonants are underlyingly floating with respect to the skeleton associated with the word to which they belong. The absence of a pre-established link between the liaison consonant and one of the available timing units in the underlying lexical representation would make that consonant harder to detect in an explicit manner.

This phenomenon is reminiscent of Sapir's (1933) observation that speakers of British English are convinced they do not pronounce *sawed* and *soared* in the same way, because *soared* is viewed as underlyingly containing an *r*, even though both words may be phonetically transcribed [sɔːd] (in non-rhotic varieties of BE). In Encrevé's model, the difference between *sawed* and *soared* is attributed to the presence of a floating *r* in the latter but not in the former. Likewise, Wauquier-Gravelines' (1996) findings may suggest that a liaison consonant is perceived by listeners in a way that mirrors its specific phonological status as a floating segment. In other words, syllabic/skeletal flotation may be perceptually and cognitively relevant.

Although differences in the phonological status of liaison and word-initial consonants thus provide an appealing explanation for the observed perceptual patterns, other factors such as the frequency of occurrence of the Word 1-2 sequences, the target's acoustic properties, and the target's position within the carrier word, may have also played a role. We begin with the issue of lexical frequency.

It might be the case that liaison consonants appeared in a context that rendered them less predictable by listeners than word-initial consonants. Recent studies (e.g. Adda-Decker et al., 1999; Fougeron et al., 2001a,b) suggest that the realization of liaison is partially conditioned by a complex interplay between the lexical frequencies of Words 1 and 2. Specifically, Fougeron et al. (2001b) found that the rate of realization of liaison shows both a positive correlation with the frequency of Word 1, and a small, but significant, negative correlation with the frequency of Word 2. Fougeron et al.'s results also revealed that the rate of liaison increases with the frequency of co-occurrence of the two words. In Wauquier-Gravelines' experiments, however, potential lexical frequency effects were fully neutralized for Word 1 since that word was identical for both sentences in each sentence pair. In addition, Fougeron et al. (2001b) point out that because high-frequency words are often short function words, the relationship found between frequency of Word 2 and rate of liaison may actually reflect the fact that liaison is realized less often before short function words than before longer words. Since Wauquier-Gravelines only used nouns and adjectives (most of them di- or trisyllabic) in Word 2 position, it seems unlikely that, in her material, liaison consonants had a lower probability of occurrence than word-initial consonants. Note also that words starting with a vowel are much more numerous in French than consonant-initial words with either of the two target consonants used in the experiments, /t/ or /n/. In such contexts, listeners should have been biased towards identifying the target as a liaison, rather than a word-initial consonant. This again suggests that the lower detection rate obtained for the liaison consonant was not related to the frequencies of occurrence associated with both targets.

Let us now turn to the target consonant's acoustic properties. Differences may arise in that domain between liaison and word-initial consonants, which would make the former less perceptually salient than the latter. Such differences have indeed been found in the vicinity of the consonant in previous work (e.g. Delattre, 1940; Dejean de la Bâtie, 1993; Gaskell et al., 2002; Spinelli et al., 2003). Thus, Dejean de la Bâtie (1993) found that the duration of the closure and that of the following burst are both shorter for liaison /t/ compared with word-initial /t/. In Gaskell et al. (2002), the duration of /t/, /r/ and /z/ also proved to be on average slightly but significantly shorter in liaison (73 ms) than in word-initial position (88 ms; consonant duration was taken as the time interval between the offset of the preceding vowel and the onset of the following vowel). A similar durational difference was found between liaison (64 ms) and word-initial consonants (71 ms) by Spinelli et al. (2003), for /p, r, t, n, g/. Note that the shorter duration for liaison consonants reported in the above studies could be due to actual liaison shortening and/or word-initial lengthening (Fougeron, 2001).

Wauquier-Gravelines carried out a series of acoustic analyses on sentences analogous to those she used as stimuli in the two experiments reported above. For /t/, she found that the closure and burst had a significantly shorter duration in *liaison enchaînée* (mean overall value: 50 ms) than in word-initial position (70 ms), in keeping with previous findings. For /n/, however, the acoustic duration of the consonant was not found to be statistically different in *liaison enchaînée* (58 ms) and word-initial position (61 ms). Thus, it seems that variations in duration in liaison vs word-initial position are both subtle and specific to certain consonants (possibly obstruents) only. Although such data suggest that the observed differences in the listener's responses to the liaison and word-initial consonants are not related to how these two types of consonant are phonetically realized, this issue will be taken up again in the next section.

Yet another factor that may have contributed to making the liaison consonant less easily detectable than the word-initial consonant relates to the position that these consonants occupied in the carrier word. In the phonological approach espoused by Encrevé (1988), among others, the liaison consonant lexically belongs to Word 1 and occurs in final position in that word. Because a greater perceptual weight is attributed to word onsets compared with word offsets in sequential models of word recognition such as Cohort (Marslen-Wilson and Zwitserlood, 1989), it may be speculated that the word-initial consonant was perceptually more prominent than the liaison consonant. Thus, to test the hypothesis that the lower detection rate for the liaison consonant is attributable to syllabic/skeletal flotation, rather than position in the word, it would be necessary to include word-final fixed consonants in the potential targets, and to show that listeners' responses are more accurate for these consonants than for liaison consonants. In Encrevé's model, so-called final fixed consonants are characterized by the fact that the corresponding coda constituent on the syllabic tier is floating with respect to the skeleton. This allows the model to account for the *enchaînement* of final fixed consonants prior to a vowel-initial word. A crucial difference between final fixed and liaison consonants, however, is that only the former is anchored to the skeleton.

Wauquier-Gravelines' material was not designed to undertake systematic comparisons between listeners' responses to liaison and final fixed consonants. These methodological issues were addressed in the experiment described in the following section.

3 Further evidence on the specific perceptual status of liaison consonants

The goal of this experiment was to confirm and extend Wauquier-Gravelines' findings in two directions. First, we examined to what extent differences in the detection rate of liaison consonants vs word-initial consonants are attributable to the phonetic properties of these consonants, by systematically manipulating these properties. Second, the potentially distinctive status of liaison consonants compared with fixed consonants in perception was further explored by inserting fixed word-final and word-medial consonants, as well as word-initial ones, in the material.

3.1 Method

3.1.1 Material

The material was made up of twenty sets of four test sentences. These sentences contained a target consonant which appeared in the vicinity of the boundary between two words. The target consonant was /z/ for twelve of the twenty sets and /n/ for the remaining sets. Within each set, the target consonant was located at the onset of Word 2, at the end of Word 1, in word-medial position, and as a liaison consonant at the juncture between Words 1 and 2. As an example, the position of the target /z/ in each of the four sentences for one of the sentence sets is shown in Table I. The critical words are underlined in the orthographic transcription. A phonemic transcription of these two words is also shown, with the target consonant displayed in bold.

Table I: Position of the target consonant /z/ in each of the four sentences, for one of the twenty sentence sets.

Sentence type	Target position	Example
1	W2-initial	*Il y a <u>des zéros</u>* /de**z**ero/ *partout dans le tableau.*
		"There are zeros everywhere in the table".
2	W1-final	*On a eu <u>seize élèves</u>* /sɛ**z**elɛv/ *qui ont réussi au bac.*
		"Sixteen pupils of ours have passed the baccalaureate exam".
3	Word-medial	*J'ai rapporté <u>du raisin</u>* /dyrɛ**z**ɛ̃/ *du marché ce matin.*
		"I brought some grapes back from the market this morning".
4	Liaison	*J'ai remis <u>des écrous</u>* /de**z**ekru/ *en haut du radiateur.*
		"I put some nuts back on top of the radiator".

In all cases, liaison consonants appeared in an unmarked context which made their prononciation obligatory: determinant + noun (e.g. *des* [z] *écrous* "nuts"), adjective + noun (e.g. *lointain* [n] *ami* "distant friend"), monosyllabic adverb (e.g. *très* [z] *ému* "very touched") or preposition (e.g. *en* [n] *Asie* "in Asia") before another word.

In addition, both Type-1 and Type-4 sentences were locally ambiguous as to the morpho-phonological status of the target consonant, i.e. the first part of the sentence, up to the post-consonantal vowel, was in both cases consistent with the consonant being a W2-initial as well as a liaison consonant. This is true, for example, of the W2-initial [z] in *Il y a des* [z] *zéros* "There are zeros" (where the morpho-syntactic and phonological make-up of the first part of the sentence up to the post-consonantal vowel may allow the listener to interpret [z] as a liaison consonant, until the following word is identified) and, reciprocally, of the liaison [z] in *J'ai remis des* [z] *écrous* "I put some nuts back" (where the first part of the sentence up to the post-consonantal vowel could lead to [z] being temporarily interpreted as the initial consonant of the upcoming word by the listener). Importantly, for most Type-1 sentences, Word 1 contained a liaison consonant whose realization would be obligatory prior to a word-initial vowel. For example, the liaison consonant /z/ associated with the determinant *des* in *des zéros* is obligatorily pronounced when the following word begins with a vowel. [There were only two exceptions to this. In *les délégués zaïrois* "the Zairian delegates" (plural noun + adj., target cons.: word-initial /z/), the realization of the latent liaison consonant /z/ at the end of *délégués* prior to a word-initial vowel is optional. In *un bien naturel* "a natural resource" (sing. noun + adj., target cons.: word-initial /n/), the realization of a liaison /n/ at the end of *bien* before a word-initial vowel is excluded. The corresponding Type-4 sequences are *les avis* "the notices" (det. + noun, liaison /z/) and *bien appris* "well learned" (adv. + past participle, liaison /n/), respectively.] Such constructions allowed us to ensure that the listeners could not predict whether the target consonant was a W2-initial or a liaison consonant from the preceding words in the sentence.

All sentences had about the same number of syllables (mean = 13, s.d. = 1.4) and the rank of the word in which the target consonant appeared was approximately the same across sentences (average rank, from the beginning of the sentence = 4.5 words, s.d. = 1.1). The target-bearing word was as short as possible and contained two syllables on average (s.d. = 0.6) in Type-1 sentences, one syllable (s.d. = 0) in Type-2 sentences, two syllables (s.d. = 0.2) in Type-3 sentences and one syllable (s.d. = 0.2) in Type-4 sentences. The purpose of using such short words was to minimize the possibility for the target consonant to be anticipated by the listener in Type-2, -3 and -4 sentences.

The pre- and post-target vowels were as phonetically similar as possible across the four sentences in each set, differing from each other by at most one distinctive feature (in a standard distinctive-feature system) for most sets. The pre-target vowel itself was preceded by a consonant (e.g. /d/ in *des zéros*) on which two constraints were imposed for Type-1 and Type-4 sentences. First, consonants appearing in that position in the two sentences had to share as many phonetic properties with each other as possible. Second, whenever possible we used consonants characterized by a well-defined acoustic transition with the following vowel, such as voiceless obstruents. These constraints were motivated by the splicing procedure to which Type-1 and Type-4 sentences were later subjected (see below). A further phonetic constraint was that the sounds preceding the target consonant were as different from the target as possible, to avoid any perceptual interference (Stemberger et al., 1985).

In addition, the sentences had similar syntactic structures, and Word 2 was chosen to be as semantically unpredictable as possible from the first part of the sentence (on the basis of the first and second authors' intuitions as native speakers of French).

Finally, we constructed 240 filler sentences (120 without /z/ and 120 without /n/), which were similar to the test sentences with respect to overall length and syntactic structure. Furthermore, part of the words occurring in Word 1 position in Type-1 and Type-4 test sentences also appeared in the filler sentences prior to a word-initial consonant that differed from the target in the test sentences, e.g. *des crêpes* /dekrɛp/ "pancakes". This means that these words were not systematically associated with the presence of the target consonant in the material, and that the listeners were thus prevented from developing a response strategy based on learning such an association over the course of the experiment (thus, *des* was not always followed by /z/, whether as a word-initial or liaison consonant).

3.1.2 Speaker, recording and acoustic labelling

The material was recorded by the first author, whose speech can be characterized as intermediate between Southern and standard French. In particular, this speaker does not pronounce word-final schwas, as is the case in Southern French (see Nguyen and Fagyal, 2007, for further details). The recording took place in a sound-proof room using high-quality recording equipment (sampling frequency = 22050 Hz). The speaker first read the list of test sentences five times, then the filler sentences. Both the test and filler sentences were randomized. The speaker's task was to read the sentences naturally, while maintaining the same rate, rhythm and pitch contour throughout the corpus.

The acoustic data were transferred onto a personal computer for further processing. For each test sentence, markers were placed at the acoustic onset and offset of each segment in each V–target C–V sequence. The location of these acoustic boundaries was determined from both the digital speech waveform and a corresponding wideband spectrogram.

3.1.3 Stimuli and experimental design

The initial set of stimuli consisted of the 80 test sentences and 240 filler sentences. For each of the Type-2 and Type-3 sentences, one repetition out of the five available was selected, which we judged as being articulated fluently, clearly, and at a normal rate. In addition, two different versions of Type-1 and Type-4 sentences were created. In the *identity-spliced* version, the target consonant and preceding vowel originated from another repetition of the same sentence. In the *cross-spliced* version, the target consonant and preceding vowel came from either the Type-1 or Type-4 corresponding sentence, for Type-4 and Type-1 sentences, respectively. To construct the identity- and cross-spliced stimuli, we selected those among the five available repetitions per sentence which allowed the vowel+consonant sequence to be spliced into the carrier sentence with no audible discontinuities across the splicing points. As for Type-2 and Type-3 sentences, fluency, clarity of articulation and rate were also taken into consideration. Although the consonant's duration and that of the preceding vowel did not significantly differ when the consonant was in W2-initial compared with liaison position (as reported in Section 3.2.1 below), variations related to the consonant's position may be shown in the vicinity of that consonant by other acoustic parameters. Cross-splicing allowed us to assess the perceptual relevance of such potential acoustic variations. These were expected to result in a lower target detection rate and/or a longer reaction time in the cross-spliced sentences than the identity-spliced sentences, which we used as a baseline condition.

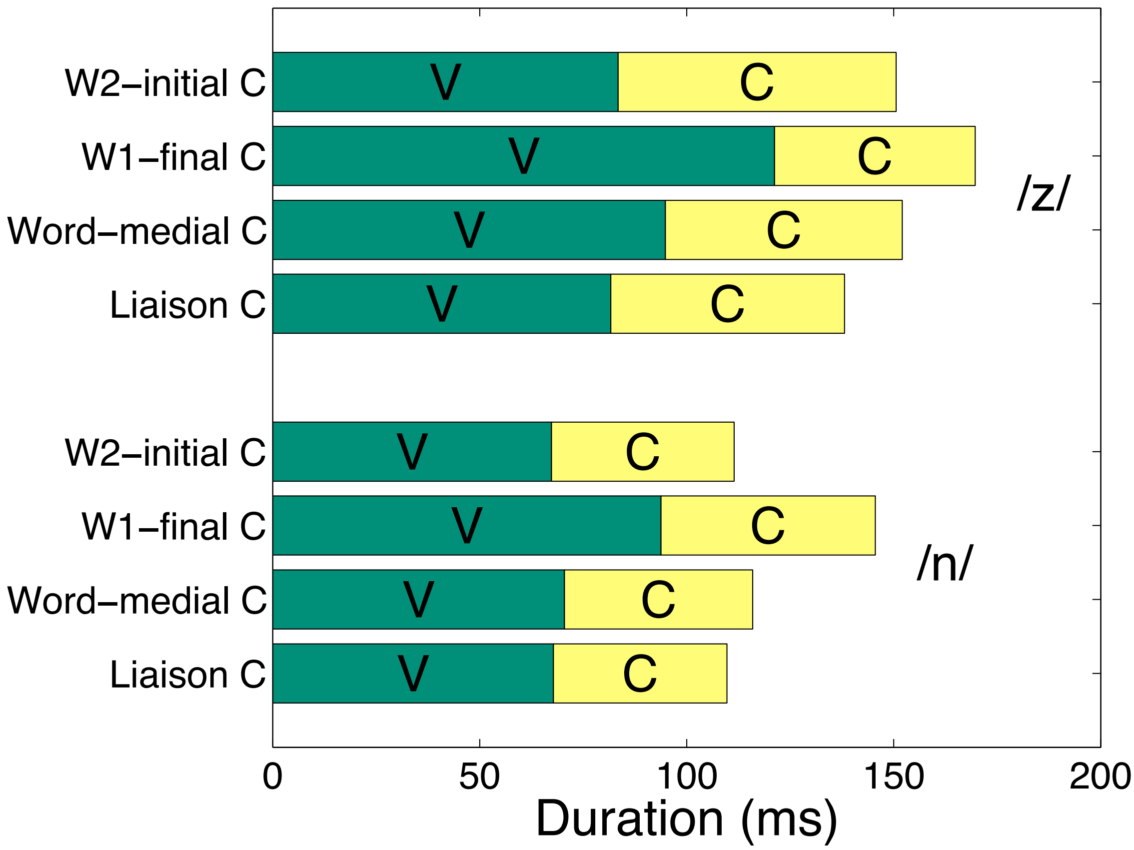
The experimental task was a speeded phoneme-detection task, with two different targets, /n/ and /z/. Thirty-four native speakers of French with no known hearing deficit participated and were partitioned into two main groups. The stimuli were blocked by target, and the order of presentation of the targets was counterbalanced across groups. Test and filler sentences were fully randomized within each block. The two subject groups were further divided into two subgroups. For each of the Type-1 and Type-4 sentences, one subgroup was presented with the identity-spliced version and the other with the cross-spliced version. Which subgroup heard the identity-spliced vs cross-spliced version systematically changed from one sentence to the next. In this way, each subject heard each sentence only once, either the identity-spliced (for half of the sentences) or the cross-spliced version (for the other half). One of the four subgroups contained ten subjects and the others had eight subjects. The stimuli were played over headphones at a comfortable sound level. Subjects had to press a button on a response box, using their dominant hand, if and as soon as they detected the target in the sentence. Reaction time was measured from the acoustic onset of the target phoneme. The test phase was preceded by a short training phase with ten sentences. The experiment lasted about thirty minutes, and each subject received a small fee for her/his participation.

3.2 Results

3.2.1 Durational measurements

In a first attempt to characterize the acoustic properties potentially associated with the target consonant depending on its position and phonological status, we measured the duration of that consonant, along with that of the preceding vowel. Figure 1 shows the average duration for each segment in each of the four types of sentence. Repeated-measure ANOVAs revealed that duration significantly varied as a function of sentence type for /z/ ($F(3,33) = 6.282, p < 0.01$) and the preceding vowel ($F(3,33) = 17.669, p < 0.001$), as well as for /n/ ($F(3,21) = 3.185, p < 0.05$) and the preceding vowel ($F(3,21) = 7.101, p < 0.01$). Scheffé post-hoc tests showed that the duration of /z/ was significantly longer in W2-initial position than in W1-final position ($p < 0.01$). In addition, and for both /z/ and /n/ sentences, the preceding vowel's duration was significantly longer in W1-final than in W2-initial (/z/ sentences: $p < 0.001$, /n/ sentences: $p < 0.01$), word-medial (/z/ sentences: $p < 0.01$, /n/ sentences: $p < 0.05$) and liaison position (/z/ sentences: $p < 0.001$, /n/ sentences: $p < 0.01$). Pairwise comparisons between the mean values associated with the four types of sentence yielded no significant difference for /n/ duration.

Figure 1: Average durations of the target consonant and pre-consonantal vowel as a function of consonant position, for /z/ and /n/.



To summarize, vowels in word-final closed syllables were longer than vowels in other positions and /z/ was longer when it appeared in onset position in word-initial syllables as opposed to coda position in word-final syllables. Importantly, however, the comparison between W2-initial and liaison positions, which formed the main focus of interest in this work, revealed no significant difference in the duration of either the target consonants or the preceding vowel. Note that this is not consistent with the tendency for consonants to be shorter in liaison than in W2-position reported previously (Dejean de la Bâtie, 1993; Gaskell et al., 2002; Spinelli et al., 2003). This may be due, at least in part, to the phonetic make-up of the material used in each study. Dejean de la Bâtie's (1993) analyses focused on /t/; the present work examines /z/ and /n/. The two other studies used a variety of target consonants that included /z/ (Gaskell et al., 2002) and /n/ (Spinelli et al., 2003), but it is unclear to what extent /z/ and /n/ actually contributed to the observed position-dependent differences in duration because the authors only provide mean duration values across all target consonants. A more relevant comparison is with Wauquier-Gravelines (1996), who measured the duration of /n/ in liaison vs W2-initial position, and, as in the present study, found no significant difference between the two.

3.2.2 Perceptual data pre-processing

Data from one subject out of the thirty-four were omitted due to the unusually high error rate (61%); data from two other subjects were omitted because their mean reaction times were more than two standard deviations above the overall mean RT. After these exclusions, the four subgroups of subjects contained seven, eight, nine and seven members. For these thirty-one subjects, the proportion of correct detections ranged from 65% to 93% over both targets, and the mean reaction time ranged from 538 ms to 1396 ms. There was a significant negative correlation between percent correct detection and mean RT per subject ($R^2 = 0.36, t(29) = -4.02, p < 0.001$), i.e. subjects who tended to miss the target more often were also slower to respond when they did detect the target.

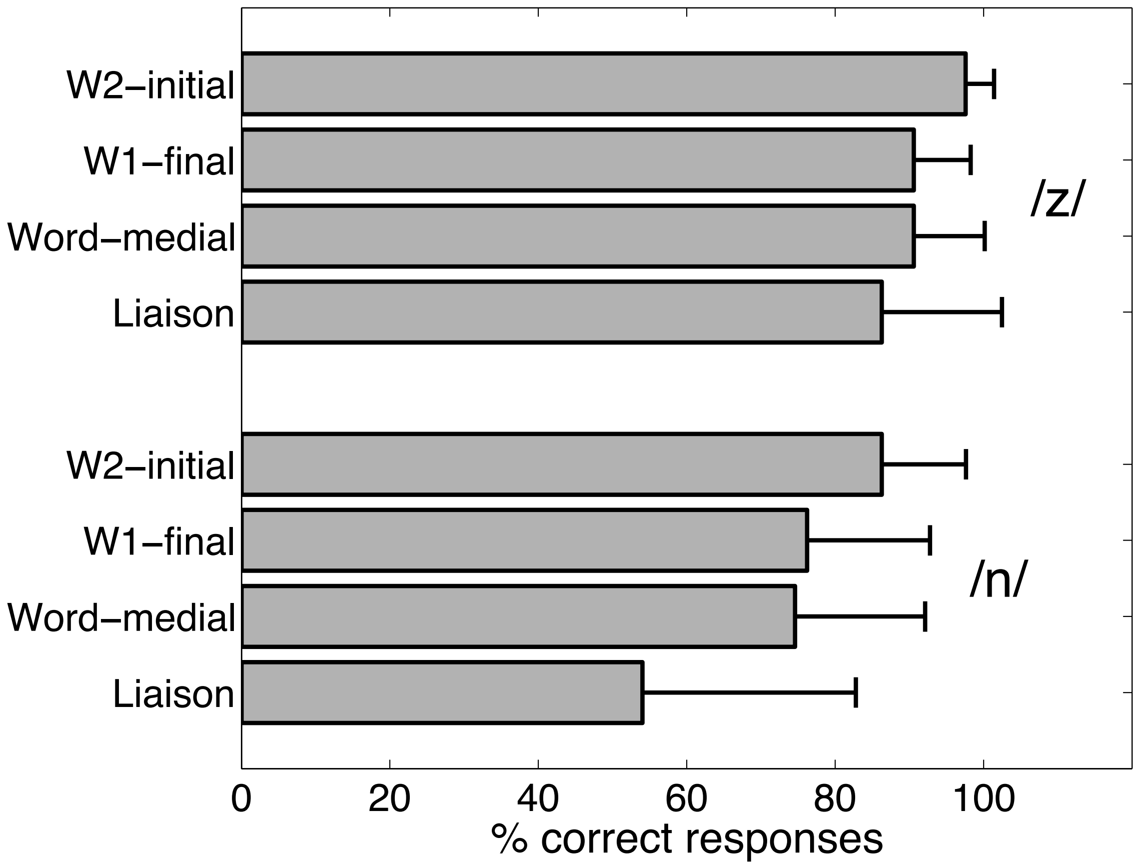
3.2.3 Target detection rates

To assess the effect of cross-splicing on phoneme detection, a by-subject repeated-measures ANOVA was carried out, with target identity, splicing type (identity-spliced vs cross-spliced) and position (W2-initial, liaison) as independent variables and percent correct detection as the dependent variable. All of the independent variables were within-group factors. The experimental design allowed us to put these three independent variables together in a by-subject ANOVA but not in a by-item ANOVA. The analysis was restricted to the W2-initial and liaison positions since cross-splicing was performed for these two positions only. Percent correct detection was submitted to an arcsin transformation prior to being subject to the ANOVA. The percent correct detection was significantly higher for /z/ (92%) than for /n/ (70%; $F(1, 30) = 82.020, p < 0.001$). In addition, the W2-initial position was associated with a more accurate phoneme detection (92%) than the liaison position (70%; $F(1, 30) = 46.851, p < 0.001$). There was a significant interaction between target identity and position ($F(1, 30) = 15.560, p < 0.001$), which reflected the fact that the difference in the detection score between the W2-initial and liaison positions was smaller for /z/ (diff. = +11%) than for /n/ (diff. = +32%). However, the percent correct detection was not significantly different for cross-spliced sentences (80%) and identity-spliced sentences (82%; $F(1, 30) = 0.780, p = 0.384$) and no significant interaction was found between splicing and any of the other independent variables.

This shows that potential acoustic cues associated with consonant position, in the consonant itself and in the preceding vowel, did not have a measurable influence on the accuracy of the listeners' responses. In the analyses reported below, percent correct detection for identity- and cross-spliced sentences were therefore pooled together. Both by-subject and by-item ANOVAs were performed using target identity and position (W2-initial, W1-final, word-medial and liaison) as independent variables.

Average percents of correct detections for the two target consonants in each of the four positions are shown in Figure 2, along with the corresponding standard deviations. Percent correct detection was found to be significantly higher for /z/ (91%) than for /n/ (73%; by-subject repeated-measures ANOVA: $F(1, 30) = 85.060, p < 0.001$; by-item ANOVA: $F(1, 18) = 81.408, p < 0.001$). Variations in percent correct detection as a function of target position were also statistically significant (by-subject ANOVA: $F(3, 90) = 22.970, p < 0.001$; by-item ANOVA: $F(3, 54) = 10.947, p < 0.001$). A significant interaction between target identity and position was found in the by-subject ANOVA ($F(3, 90) = 6.994, p < 0.001$) but not in the by-item ANOVA ($F(3, 54) = 1.334, p < 0.273$).

Figure 2: Average percent correct detection, along with the corresponding standard deviation, in each of the four positions, for each target consonant.



For each target consonant, Scheffé post-hoc comparisons between percent correct detection associated with the four positions were performed. For /z/, percent correct detection was significantly higher in W2-initial vs W1-final position (by-subject analysis, $p < 0.05$), W2-initial vs word-medial position (by-subject analysis, $p < 0.05$), and W2-initial vs liaison position (by-subject analysis: $p < 0.001$; by-item analysis: $p < 0.05$). For /n/, percent correct detection was significantly higher in W2-initial vs liaison position (by-subject analysis: $p < 0.001$; by-item analysis: $p < 0.01$), W1-final vs liaison position (by-subject analysis, $p < 0.001$) and word-medial vs liaison position (by-subject analysis, $p < 0.001$). Other pairwise comparisons between positions for each target were not statistically significant.

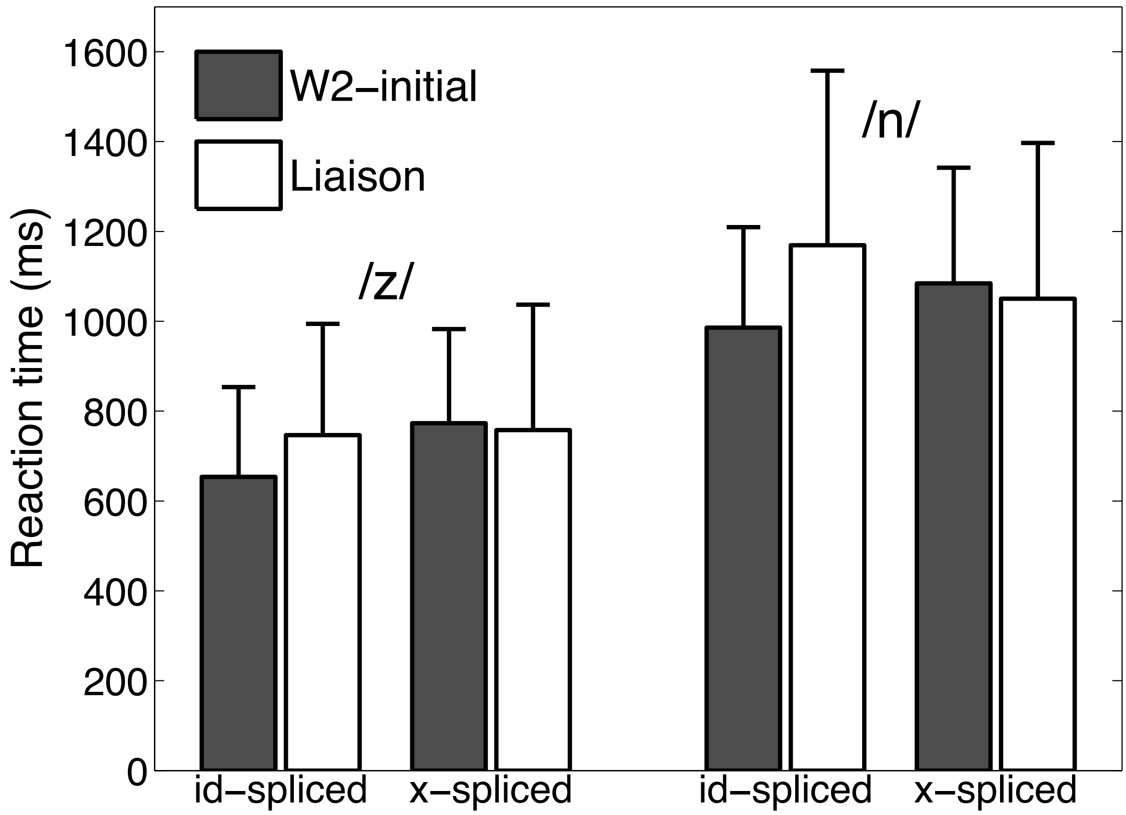
These results replicate Wauquier-Gravelines' (1996) earlier finding that listeners have greater difficulties detecting liaison consonants than W2-initial consonants. Our data show that this tends to be true to a greater extent for /n/ than for /z/. Moreover, they indicate that, in the case of /n/, liaison consonants were more difficult to detect than W1-final consonants. They further reveal that the nasal target is intrinsically more difficult to detect than the fricative.

3.2.4 Target detection reaction times

We now turn to the listeners' reaction times. Figure 3 shows the average RTs associated with correct responses to the identity-spliced and cross-spliced sentences, for each of the two targets, in W2-initial and liaison position. RT partly mirrored the tendencies observed for phoneme detection in that RT was longer for the nasal than for the fricative target, and longer for liaison consonants than W2-initial consonants for the identity-spliced tokens. These trends were confirmed in a by-subject repeated-measures ANOVA (target-identity main effect: $F(1, 22) = 50.580, p < 0.001$; position effect: $F(1, 22) = 4.446, p < 0.05$). However, the observed RT patterns differed from the phoneme detection patterns with respect to splicing. Specifically, whereas splicing did not interact with any of the other factors for percent correct detection, a significant interaction ($F(1, 22) = 6.313, p < 0.05$) between position and splicing was found for RT such that the difference in RT as a function of position in the identity-spliced version disappeared in the cross-spliced version.

Table II allows us to compare the mean RT and corresponding standard deviation for each target across the four positions. For the sake of comparison with Type-2 and Type-3 sentences, the values given for Type-1 and Type-4 sentences were computed from the identity-spliced stimuli only. A by-subject, repeated-measures ANOVA showed that RT was significantly longer for /n/ than for /z/ ($F(1, 26) = 76.429, p < 0.001$), and varied as a function of target position ($F(3, 78) = 12.487, p < 0.001$). In addition, the Target Identity $\times$ Target Position interaction proved significant ($F(3, 78) = 4.110, p < 0.01$), in keeping with the fact that mean RT varied in different directions depending on position for /z/ and /n/. Note, however, that Target Identity was the only variable

Figure 3: Average reaction times associated with correct responses to identity-spliced and cross-spliced sentences, for each target consonant in W2-initial and liaison position. The corresponding standard deviations are also shown.



whose effect on RT was significant in the corresponding by-item ANOVA ($F(1,18) = 140.160, p < 0.001$).

Table II: Mean reaction times (in ms) associated with each of the two target consonants in each of the four positions. The corresponding standard deviation is shown in parentheses.

		Target identity	
Sentence type	Target position	/z/	/n/
1	W2-initial	707 (345)	1040 (425)
2	W1-final	728 (437)	935 (422)
3	Word-medial	714 (434)	954 (442)
4	Liaison	755 (407)	1166 (545)

Scheffé post-hoc tests conducted in conjunction with the by-subject analysis indicated that RT was significantly longer for the liaison target compared with the W2-initial ($p < 0.05$) and word-medial ($p < O.05$) targets for /z/, and with the W1-final ($p < 0.001$) and word-medial

($p < 0.01$) targets for /n/. Other pairwise comparisons between positions for each target did not reach statistical significance.

4 General discussion

To summarize, liaison consonants were found to be more difficult to detect than W2-initial consonants by listeners. Detection scores were lower, and correct responses tended to be slower, for the former than for the latter. Cross-splicing liaison and W2-initial consonants tended to neutralize the difference in reaction times associated with both targets, but had no significant effect on how frequently targets were successfully detected. Proportions of correct responses for W1-final and word-medial targets were halfway between those for W2-initial and liaison targets. Finally, correct responses were both fewer and slower for the nasal than for the fricative target.

The tendency to miss liaison consonants seems to be a robust perceptual phenomenon. In our experiment, it arose even though the position of the target with respect to the beginning of the carrier sentence was roughly the same for all the sentences, which may have made it increasingly easier for listeners to predict that position over the course of the experiment. In addition, failure to detect liaison consonants occurred in spite of the fact that the phoneme detection task should have drawn the listeners' attention to the phonetic level at the expense of higher-level (lexical, in particular) properties of the stimulus.

A main issue in the present experiment was to determine the extent to which differences in detection rate between W2-initial and liaison targets can be accounted for by the targets' acoustic characteristics. Acoustic analysis revealed no significant variation in the duration of the target consonant, nor in that of the preceding vowel, depending on whether the consonant appeared in W2-initial or liaison position. Further analyses will be needed to determine whether position-dependent variations can be found in the vicinity of the consonant along other acoustic dimensions (e.g. rate of transition at the offset of the preceding vowel and/or into the following one, formant pattern of the preceding vowel). What the listeners' responses showed, however, was that potential variations in the target consonant and preceding vowel's acoustic properties, depending on the target's position, had little or no impact on response accuracy.

Failure to detect liaison consonants therefore seems to be attributable to higher-level factors, which may relate to how these consonants are represented as part of the speaker/listener's linguistic knowledge. In the introduction, two main linguistic theories of liaison were presented. In autosegmental theory, the liaison consonant is seen as a highly abstract phonological object whose phonetic realization involves establishing associations between tiers, and is conditioned by a number of syntactic and stylistic constraints. According to exemplar-based theory, liaison is mostly a lexical phenomenon, i.e. it forms one of the elements of frequently co-occurring sequences of morphemes or words, referred to as constructions. Let us consider how failure to detect liaison consonants can be interpreted in the light of each of these theoretical viewpoints.

As already suggested above, it may be the case that the listeners' poorer performance in detecting liaison consonants compared with W2-initial consonants stems from the specific phonological status attributed to liaison consonants in French. In the autosegmental model, liaison consonants differ from fixed consonants in that the former are lexically floating with respect to both the skeletal and syllabic tiers. Most consonants are fixed, i.e. have a pre-established link with one of the available slots in the skeleton, and liaison consonants form a much more specific case. In the phoneme-detection task, it is therefore reasonable to assume that listeners expected the target to be, by default, a fixed consonant. This would explain why they showed a tendency to miss liaison consonants, which do not fall into that general category, more often than W2-initial consonants, and why, when listeners did detect liaisons, it took more time for them to respond.

Another noticeable feature in our perceptual data is how listeners responded to W1-final and word-medial target consonants. The detection rate for these targets was found to be lower than that for the W2-initial target for /z/, on the one hand, and higher than the liaison target detection rate for /n/, on the other hand, in the by-subject analyses. Although these trends were not statistically significant in the corresponding by-item analyses, they nevertheless suggest that W1-final and word-medial consonants may form an intermediate case between W2-initial and liaison consonants, as far as the listener's capacity to detect the presence of the target in the speech chain is concerned. It is particularly interesting to compare the listeners' responses to W1-final consonants and liaisons, because both the W1-final and liaison consonants were systematically *enchaînées* in our material. The tendency for the detection rate to be higher for W1-final consonants than for liaison consonants may indicate that it is not *enchaînement* per se, i.e. the anchoring of the consonant to the onset position of the following vowel-initial word, which makes the liaison consonants more difficult to detect. Rather, failure to detect liaison consonants may be specifically due to flotation with respect to the skeleton, a property attributed to liaison consonants only in Encrevé's model.

Studies by Wauquier-Gravelines (1996), Gaskell et al. (2002), Spinelli et al. (2003), explored the potential impact of liaison and *enchaînement* in spoken word recognition. These studies showed that liaison (Wauquier-Gravelines, 1996; Gaskell et al., 2002; Spinelli et al., 2003) and *enchaînement* (Gaskell et al., 2002) make it easier for listeners to recognize the following word, compared with a control condition. According to Gaskell et al. (2002), the facilitative effect of liaison and *enchaînement* may be caused by lexical knowledge about the offset of the preceding word, combined with sensitivity to the phonological context conditioning the occurrence of liaison and *enchaînement*. In addition, acoustic cues associated with resyllabification may contribute to facilitate the processing of Word 2 in both liaison and *enchaînement* conditions. Quite importantly in the context of the present work, these data show that listeners *are* sensitive to the presence of a liaison consonant in the speech signal, and that this consonant may provide them with early information about the phonological make-up of the upcoming word (which must begin with a null onset for liaison to occur). What our own experimental data suggest is that listeners sometimes fail to identify liaison consonants as phonemic units in an explicit phoneme-detection task. In our view, facilitative effects in word identification, on the one hand, and inhibitory effects in phoneme detection, on the other hand, can both be seen as pointing to the specific status liaison consonants have in French phonology. Because they occur at the juncture between two words, and because their realization and syllabification across that juncture are highly context-dependent, liaison consonants may allow listeners to identify the upcoming word more easily while being difficult to map onto "ordinary" phonemic categories.

We now turn to the exemplar-based approach to liaison as proposed by Bybee (2001, 2005). This approach differs radically from the autosegmental account, most notably because the contexts in which liaison appears are assumed to be encoded in memory as a large set of grammatical constructions with different degrees of abstractness and frequencies of occurrence, as opposed to the parsimonious and uniformly abstract representations used in autosegmental theory. Despite these theoretical differences, failure to detect liaison can also be accounted for by the exemplar-based approach. In this approach, liaisons consonants are deeply entrenched in specific constructions, and the realization of liaison is highly conditioned by the strength of the associations between words within such constructions. According to Bybee (2001), liaison provides evidence "for the existence and nature of storage units beyond the traditional word. The evidence presented so far strongly suggests that frequent fixed phrases are storage and processing units, as are constructions containing grammatical morphemes." It follows that liaison consonants are processed by listeners as being part and parcel of the constructions in which they appear. As a result, listeners may find it difficult to identify them as context-independent phonemic units, as explicitly required in a phoneme-detection task. In the construction [NOUN -z- [vowel]-ADJ $]_{\mathrm{Plural}}$ for example, the liaison consonant /z/ is said to be tightly associated with the other elements of which this construction is composed, and it may be difficult for these elements to be abstracted away by listeners. Thus, in spite of the sharp opposition between the exemplar-based and autosegmental models of liaison—constructions being much closer to surface forms than lexical autosegmental representations—both models would seem to be consistent with the fact that detecting liaison consonants in speech is difficult.

Crucially, however, it seems to us that in the exemplar-based approach, the difficulties experienced by listeners in the phoneme-detection task should not be specific to liaison and should extend to *all* the segments a construction may contain. In other words, W2-initial consonants should be as difficult to process as liaison consonants. More generally, the exemplar-based approach does not seem to lead to the prediction that response accuracy in the phoneme-detection task should differ depending on the position of the target in the construction. The lower detection rates observed for liaison targets compared with W2-initial targets therefore seem to provide better evidence for the autosegmental account than for the exemplar-based account.

One question we have not addressed yet, and which has important implications for autosegmental and exemplar-based approaches, relates to the potential role of the syntactic status of the carrier word in the detection of liaison. From that point of view, an interesting parallel may be drawn between failure to detect liaison consonants and a well-established effect in reading, namely the Missing-Letter Effect (MLE). The MLE refers to the fact that letter detection in connected text is more difficult in frequent function words than in less common words (Healy, 1976, 1994; Koriat and Greenberg, 1994; Greenberg et al., 2004). For example, readers tend to miss the target letter *t* more often in *the* than in *weather*. In Healy's unitization model, the MLE is attributed to the fact that highly common words are associated with whole-word, unitized representations in reading. The fast activation of these representations would prevent lower-level units (e.g. constituent letters) from being fully processed. By contrast, according to Koriat and Greenberg (1994), the MLE reflects the role of function words as cues for sentence structure. Early in text processing, readers focus their attention on function morphemes and use them to establish a structural frame. Subsequently, structural cues recede to the background as attention shifts from structure to content.

In our phoneme-detection experiment, liaison targets generally belonged to high-frequency monosyllabic determiners, while most W2-initial targets belonged to nouns. Thus, we need to determine to what extent failure to detect liaison consonants is attributable to the syntactic status of the carrier word, rather than to the phonological status of the consonant. For the liaison /n/, there was some variation in the carrier word's syntactic category, which may allow us to shed preliminary light on this issue. In addition to including four determiners and one preposition, the eight carrier words also comprised two adjectives and one adverb. We classified these words in two broad categories on the basis of their morphosyntactic properties, namely DET/PREP and ADJ/ADV. A by-subject repeated-measures ANOVA was conducted on the phoneme-detection data with target position (W2-initial, liaison) and syntactic category of the carrier word for liaison (DET/PREP, ADJ/ADV) as independent variables, and percent correct responses as dependent variable. The results showed that percent correct responses was significantly higher for W2-initial targets (86%) than for liaison targets (56%; $F(1, 30) = 38.131, p < 0.001$, arcsin-transformed values) whereas no significant main effect was found for syntactic category. There was, however, a significant interaction between position and syntactic category ($F(1,30) = 6.469, p < 0.05$), which reflected the fact that for the liaison target, the percent of correct responses was lower for DET/PREP (49%) than for ADJ/ADV (62%). In other words, the subjects tended to miss a liaison target more often when this target occurred at the end of a short function word (DET/PREP) compared with an adjective or adverb. There is, therefore, some evidence pointing towards a link between response accuracy and syntactic status of the carrier word for the liaison target, although it must be noted that position-dependent variations in response accuracy remain highly significant.

Such results are at variance with the autosegmental account we have offered for failure to detect liaison, as this account focuses on the phonological properties of the liaison consonant, and assigns no role to the syntactic status and/or frequency of use of the carrier word and its neighbours. By contrast, these results seem to lend support for the exemplar-based model, as they suggest that failure to detect liaison is to some extent dependent upon the strength of the connections between the words at the juncture of which liaison is realized. In the exemplar-based framework, it may be assumed that a determiner+noun sequence such as *son hôtel* "his hotel" will be more likely to form a single processing unit than an adjective+noun sequence such as *un lointain ami* "a distant friend", because of the much higher probability of co-occurrence of the two words in the first sequence than in the second one. As a consequence, the liaison consonant would be more deeply embedded, and therefore more difficult to detect, in a determiner+noun sequence than in an adjective+noun sequence. (Note, in that respect, that liaison is fully obligatory in determiner+noun and preposition+noun sequences, whereas it may not be realized in adjective+noun and adverb+noun sequences.) Response accuracy in liaison detection seems to decrease in carrier word sequences with a higher degree of lexicalisation, as might be predicted by the exemplar-based model.

To conclude, our data indicate that detecting liaison consonants in speech is difficult. These difficulties do not seem to be attributable to acoustic differences these consonants may show with W2-initial consonants, and may reflect the influence of higher-level properties, related to the way in which liaison is represented in the speaker-listener's grammar. Our results are in part consistent with the hypothesis that liaison consonants are characterized by a highly specific phonological status. However, detection accuracy seems to vary to a certain extent depending on the degree of lexicalisation of the carrier word sequence. Future work, extended to non-obligatory liaisons in word sequences with a low probability of co-occurrence, will be conducted with a view to better establish which of the phonological and lexical approaches can best account for how liaison is processed by listeners in French.

Acknowledgements

This work was partly supported by the ACI Systèmes complexes en SHS Research Program (CNRS & French Ministry of Research) and by NSF Grant #0414657. We thank Sharon Peperkamp and Stéphanie Ducrot for drawing our attention to the missing-letter effect. We are also grateful to Robert Espesser for sharing his statistical expertise, and to Pierre Encrevé, Zsuzsanna Fagyal, Cécile Fougeron, Mariapaola D'Imperio, Maria-Josep Solé, Marina Vigário, and three anonymous reviewers for useful comments.

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