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Processing resyllabified words in French

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Abstract

In French, the final [ʁ] of *dernier* is not pronounced in *dernier train* (last train), but is pronounced, in the following syllable, in a liaison environment like *dernier oignon* (last onion). Due to liaison, *dernier oignon* becomes homophonous with *dernier rognon* (last kidney). In four pairs of cross-modal priming experiments, French participants made visual lexical decisions to vowel- or consonant-initial targets (e.g., *oignon*, *rognon*) following both versions of spoken sentences like *C'est le dernier oignon/rognon*. Facilitation was found for both types of target when targets matched the speaker's intended segmentation, but was weaker when they mismatched the intended segmentation. In unambiguous sentences there was facilitation only for targets matching the speaker's intentions. The consonants in the liaison environments were shorter than the word-initial consonants (e.g., [ʁ] in *dernier oignon* vs. *rognon*). Word recognition therefore appears to be influenced by subphonemic cues to the words that speakers intend.

Keywords: Spoken word recognition; Lexical segmentation; French; Liaison

The process of *liaison* in French speech might appear to create a problem for French listeners. When a French speaker says the word *dernier* (last), for example, the final [ʁ] will not be produced if the next word begins with a consonant (e.g., *dernier train*, last train), but will be produced if the next word begins with a vowel (e.g., *dernier oignon*, last onion). Furthermore, when the [ʁ] is produced, it appears in the initial position of the first syllable of the following word. This phenomenon might thus have little effect on the recognition of the first word, since this word is phonologically identical up to its last vowel whether the [ʁ] appears in the following syllable or not. But liaison would appear to make recognition of the second word more difficult, since it makes vowel-initial words seemingly consonant-initial. In the worst case, liaison can generate another word (such as *rognon*, kidney[2]).

How then do French listeners recognize vowel-initial words in liaison environments? We address this question by examining spoken word recognition in sentences which, according to phonological analysis, have the same sequence of phonemes and the same syllabification, and hence are lexically ambiguous (e.g., *C'est le dernier oignon/C'est le dernier rognon;* It's the last onion/kidney). Our findings have important implications for theories of continuous speech recognition. Since it is often assumed that word boundaries tend to coincide with syllable boundaries, syllable onsets have been proposed as locations where word boundaries are more likely to occur (Content, Kearns, & Frauenfelder, 2001a; Content, Meunier, Kearns, & Frauenfelder, 2001b; Cutler & Norris, 1988; Norris, McQueen, Cutler, & Butterfield, 1997; Vroomen & de Gelder, 1997). Although there

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[2] Although they are spelled differently, *oignon* and *ognon* in *rognon* sound the same.

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are different formulations of how syllable onset information is used to constrain lexical access, a simple prediction of all these proposals is that the recognition of candidate words that are misaligned with the beginning of syllables (like *oignon* in *dernier oignon*, syllabified "der.nie.ro.gnon") should be delayed.

There is indeed evidence for misalignment costs in different languages. Vroomen and de Gelder (1997) showed in a cross-modal semantic priming experiment in Dutch that *boos* (angry) is activated in *framboos* (raspberry), but *wijn* (wine) is not activated in *zwijn* (swine). In the latter case, the embedded word *wijn* is misaligned with the beginning of the syllable. These results suggest that embedded words are only strongly activated if their onsets match syllable onsets. With a word-spotting task, again in Dutch, McQueen (1998) showed that detecting a word (e.g., *rok*, skirt) embedded in a nonword was easier when the word was aligned with a syllable onset (e.g., "fim.rok" in which the syllable boundary is imposed by the phonotactic constraint that /mr/ is an illegal consonant cluster in Dutch) than when it was misaligned with the syllable onset (e.g., "fi.drok"). Similarly, Dumay, Frauenfelder, and Content (2002) showed that detecting *lac* (lake in French) is easier in the nonword *zunlac* (syllabified "zun.lac") than in the nonword *zuglac* ("zu.glac"). In English, Weber (2001) showed that detecting *luck* is easier in the nonword *poonluck* ("poon.luck") than in the nonword *marfluck* ("mar.fluck"). These studies all suggest that word recognition (e.g., of the targets *rok*, *lac*, and *luck*) suffers when words are misaligned with the onsets of syllables.

Vroomen and de Gelder (1999) assessed this misalignment cost in continuous speech, in a situation where resyllabification occurred across word boundaries (e.g., *de boo**t** **is** gezonken* in Dutch, syllabified as "de.boo.tis.ge.zon.ken," the boat is sunk). They found with a generalized phoneme-monitoring task that non-resyllabified phonemes (e.g., /t/ in *de boo**t** die gezonken is*) are detected faster than resyllabified phonemes (e.g., /t/ in *de boo**t** is gezonken*). This suggests that non-resyllabified words are easier to recognize than resyllabified words.

If syllable onsets thus constitute good alignment points for segmentation, the processing cost for misaligned words should be striking for languages like French. Such a cost could apply to words that are resyllabified due to the various phonological phenomena that take place in connected French speech: elision, enchainment, and liaison. *Elision* refers to the dropping of phonemes (e.g., *le*, the, and *indien*, Indian, will give rise to *l'indien*, which is syllabified as "lin.dien"). *Enchainment* occurs when a word that ends with a consonant is followed by a word beginning with a vowel. For instance, *chaque avion* (each plane) will be syllabified as "cha.ka.vion." In this case, the final consonant of the first word (e.g., the /k/ of *chaque*) is always pronounced, whether it is resyllabified or not. But in *liaison*, as we have already seen, there are two processes: the surfacing of a latent segment, and resyllabification. A final consonant is realized when the next word begins with a vowel (e.g., *petit avion*, small plane, "pe.ti.ta.vion"). The liaison consonant will not surface and there will be no resyllabification, however, when the next word begins with a consonant (*petit cahier*, small notebook, "pe.ti.ca.hier"; Encrevé, 1988).

Resyllabification might be expected to have a particularly adverse effect on word recognition in French not only because it has a number of different resyllabification processes but also because it has a clear syllabic structure. There is also abundant evidence that syllable boundaries play a role in the segmentation of spoken French (Content et al., 2001a, b; Cutler, McQueen, Norris, & Somejuan, 2001; Cutler, Mehler, Norris, & Segui, 1986; Kolinsky, Morais, & Cluytens, 1995; Mehler, Dommergues, Frauenfelder, & Segui, 1981). Mehler et al. (1981), for example, showed that French listeners were faster to detect BA in *ba.lance* than in *bal.con*, and faster to detect BAL in *bal.con* than in *ba.lance*. That is, listeners were faster to detect target sequences when they matched the syllabification of the target-bearing words. Although the generalizability of this original finding has recently been called into question (Content et al., 2001b), it remains clear that French listeners use syllabic structure in speech segmentation (Content et al., 2001a, b; Dumay et al., 2002).

One might therefore predict that French listeners will have difficulty recognizing words which are misaligned with syllable boundaries, like *oignon* in *dernier oignon*. But French listeners generally do not appear to have problems with word recognition in liaison environments. Recent research has indeed suggested that there are no misalignment costs due to phonological processes like liaison. Gaskell, Spinelli, and Meunier (2002) have shown that resyllabification (due to enchainment and liaison in French) does not inhibit lexical access. They showed in a cross-modal repetition priming study that a visual target word like *italien* was recognized equally fast in a liaison utterance (*un généreux italien*, a generous Italian), an enchainment utterance (*un virtuose italien*, an Italian virtuoso) and a non-resyllabified utterance (*un chapeau italien*, an Italian hat). Furthermore, in a word-detection experiment, participants were asked to detect the targets (e.g., *italien*) embedded in the sentences from the priming study. The fastest responses were observed in the (resyllabified) liaison condition.

How can these results be reconciled with those showing a recognition cost for misaligned words? The most obvious answer to this question, of course, is that liaison is a natural phenemenon and hence that listeners have a means of dealing with it. More specifically, it is reasonable to assume that the speech recognition system may have evolved so that syllabically misaligned words which the speaker intended (like *oignon* in *dernier* *oignon*) can be recognized. Likewise, the system may have evolved so that detection of spuriously embedded words (like *wijn* in *zwijn*; Vroomen & de Gelder, 1997) is very difficult, for the reason that such words are not part of the speaker's message.

What means does the recognition system then have to deal with the effects of liaison? The present study examined this question. We focussed on the recognition of lexically ambiguous phrases like *dernier oignon/dernier rognon*. We considered three sources of information which listeners may use in resolving this kind of ambiguity: acoustic information, lexical information, and contextual information.

The importance of acoustic cues in aiding segmentation has been demonstrated in some off-line studies. For instance, Nakatani and Dukes (1977) showed that listeners can identify the correct segmentations of ambiguous two-word utterances (e.g., *buy zinc/buys ink*). They found that there were acoustic cues for juncture at the beginning of words (and occasionally at the end of words) such as glottal stops, laryngealization and aspiration on voiceless stops. Quené (1992, 1993), with a forced choice task, showed that listeners also exploit durational cues to detect word boundaries in pairs of Dutch words like *diep in/die pin* (deep in/that pin). These cues (duration of the pivotal consonant and the following vowel) were found to vary in natural productions and to affect listeners' judgements. Dumay, Content, and Frauenfelder (1999) have shown that such cues can be used during on-line segmentation.

There is already some evidence that there are acoustic markers of liaison. Dejean de la Bâtie (1993) found that liaison consonants tend to have shorter closure duration and Voice Onset Time (VOT; the time between consonantal release and onset of vocal cord vibration) than non-resyllabified word-initial consonants. Spinelli, Cutler, and McQueen (in press) also found that liaison consonants tend to be shorter than non-resyllabified initial consonants, and showed that manipulation of these acoustic cues affected listeners' segmentation performance. Wauquier-Gravelines (1994) showed that listeners find it harder to detect a liaison phoneme (e.g., /t/ in *grand éléphant*, big elephant, in which *grand* has an underlying /t/ for liaison) than an initial phoneme (e.g., *grand téléphone,* big telephone). Taken together, these results suggest that listeners might be sensitive to subtle acoustic variations associated with liaison. One aim of the present experiments, therefore, was to establish whether there are systematic acoustic differences between the liaison and non-liaison readings of lexically ambiguous utterances.

The second source of information which we examined is that provided by the lexicon. Lexical information can be used to segment continuous speech. In models such as TRACE (McClelland & Elman, 1986) and Shortlist (Norris, 1994; Norris et al., 1997), segmentation is achieved by a process of competition between candidate words. Lexical hypotheses which are consistent with the bottom-up input are activated at any moment in time, regardless of their location in the input.

There is considerable empirical support for this multiple activation process (see Norris et al., 1997, for a review). Of particular relevance here is evidence suggesting that lexical hypotheses are considered even when they span the word boundaries as defined by the speaker's intention (like *rognon* in *dernier oignon*). For example, in a cross-modal semantic priming study, Tabossi, Burani, and Scott (1995) showed that when listeners heard sentences containing sequences like *di amanti* (some lovers), their responses to related visual targets (e.g., *PRECIOZI*, which is semantically related to *diamanti,* diamonds) were facilitated (relative to a control condition). This suggests that the lexical candidate *diamanti* had been activated despite the presence of a word boundary within the sequence *di#amanti*. In a similar vein, Gow and Gordon (1995) showed that matched sequences like *tulips* and *two lips* both facilitated responses to targets related to the longer word (e.g., *FLOWER*), even though there were acoustic cues to the onset of the second word (e.g., *lips*) in the latter sequence.

Competition among candidate words beginning at different points in the input could resolve some of the problems caused by liaison. For example, given the input *petit orage* (little storm), a number of candidates would be activated, including *peu*, *or*, *age*, *tort*, *rage*, *petit*, and *orage*. But only the last two candidates account for the entire input. They would thus win the competition process. Lexically ambiguous phrases like *dernier oignon* still pose a problem, however. How can competition resolve this ambiguity? One possibility is that acoustic cues that might make vowel-initial words plausible candidates in liaison environments might in fact also cause the system to prefer the vowel-initial words over the consonant-initial words. If there is more bottom-up support for *oignon* than for *rognon*, for example, the former could win the competition process.

There are thus three questions to be asked about the acoustics of liaison: (1) Are there clear differences between genuinely word-initial consonants and syllable-initial consonants which have been resyllabified because of liaison? (2) If so, do these differences allow vowel-initial words to be activated in liaison environments, in spite of their misalignment with a syllable boundary? (3) In addition, are these differences sufficient to rule out the consonant-initial word in lexically ambiguous liaison contexts?

In Experiment 1, therefore, we measured the activation of vowel-initial words (like *oignon*) in ambiguous liaison contexts (e.g., *C'est le dernier oignon*), where the speaker intended the vowel-initial word, and hence ought to have produced whatever acoustic markers of liaison there may be. We compared this situation with one in which the speaker produced the matching ambiguous sentences with consonant-initial words (e.g., *C'est le dernier rognon*) and unambiguous sentences with these words (e.g., *C'est un demi rognon*). In Experiment 2, we measured the activation of consonant-initial words (like *rognon*) in these three contexts. If the sequences *dernier oignon* and *dernier rognon* are truly ambiguous, the intended segmentation (*r#oignon* or *#rognon*) in these ambiguous sentences should have no influence on the activation of the two candidates *oignon* and *rognon*. On the other hand, if there are acoustic differences between the two utterances, then vowel-initial and consonant-initial candidates should be differentially activated depending on the intended segmentation.

We predicted that the words which the speaker intended would be activated in the ambiguous (and unambiguous) sentences. In other words, we hypothesized that there would be acoustic information that would allow listeners to retrieve the correct segmentations. Previous research on misaligned words suggested that vowel-initial words embedded in consonant-initial words (e.g., *oignon* in *demi rognon*) would be at best weakly activated. In this case, acoustic information could bias the competition process in favor of the consonant-initial words. In addition, however, lexical information itself would favor the consonant-initial words (e.g., *demi r oignon* leaves the [ʁ] unaccounted for).

The activation of the unintended words in the ambiguous sentences (e.g., *oignon* in *dernier rognon; rognon* in *dernier oignon*) was more difficult to predict. It depends on the degree to which these two types of sentence are acoustically different, and on what effect those cues might have on lexical activation. It was possible that acoustic differences would be strong enough to rule out the unintended candidate words. Alternatively, there could be weak residual activation of these words. This would suggest that while acoustic information can favor the correct word, it does not rule out the wrong one. If so, this would in turn suggest that the resolution of lexically ambiguous phrases like *dernier oignon/dernier rognon* is likely to depend on information from any available sentential, discourse or situational context. In other words, the two readings would need to be passed forward to interpretative processes for resolution on the basis of contextual information.

Experiment 1

In this and all subsequent experiments we used the cross-modal identity priming paradigm. French listeners heard short French sentences. While they were hearing the last word of each sentence, they saw a target letter-string on a computer screen. Their task was to decide whether these letter strings were real French words or not. The critical vowel-initial target words were presented in four priming conditions: an ambiguous liaison condition, in which the target corresponded to the intended segmentation, but in which liaison caused the appearance of the penultimate word's last consonant in the onset of the first syllable of the last word, creating another French word; an ambiguous non-liaison condition, in which the speaker intended the consonant-initial word; an unambiguous condition, in which the consonant-initial candidate appeared after a word which does not trigger liaison; and a baseline condition.

We used a between-subjects design. The listeners in Experiment 1a were presented with the ambiguous liaison, unambiguous and baseline conditions. Those in Experiment 1b were presented with the ambiguous non-liaison condition, and the same unambiguous and baseline conditions (see Table 1). In addition, acoustic measurements were carried out to determine whether systematic acoustic variations were associated with the intention to produce a sentence with liaison versus the intention to produce a sentence without liaison.

Method

Participants

Sixty-one students of the University René Descartes, Paris V, took part in this experiment (30 in Experiment

Table 1
Examples of word and pseudoword targets in their associated priming conditions in Experiment 1

Targets	Ambiguous	Unambiguous	Baseline
Word **oignon** [ɔɲɔ̃]	*Liaison (Experiment 1a)* C'est le dernier oignon [sɛlədɛʁnjeʁɔɲɔ̃] *No liaison (Experiment 1b)* C'est le dernier rognon [sɛlədɛʁnjeʁɔɲɔ̃]	C'est un demi rognon	C'est un ancien nitrate
Pseudoword **asserf** [asɛʁ]	C'est un grand assaut/ [sɛtɛ̃gʁɑ̃taso] C'est un grand tasseau [sɛtɛ̃gʁɑ̃taso]	——	Il est si platré

1a; 31 in Experiment 1b). They were paid for their participation. They were all native speakers of French, had normal or corrected vision and reported no hearing impairment.

Stimuli and design

Twenty seven vowel-initial words were selected from a French database (*Trésor de la Langue Française*, TLF; Imbs, 1971), and served as experimental targets (e.g., *oignon* [ɔɲɔ̃]). The vowel-initial words were selected under the constraint that the realization of these words in liaison contexts gave rise to another word (e.g., *rognon* [ʁɔɲɔ̃] in *dernier oignon* [dɛʁnjeʁɔɲɔ̃]). Four sentences were associated with each target and served as primes. Two of the prime sentences in each set of four were ambiguous minimal pairs. Ambiguous versions with vowel-initial words in liaison contexts were used in Experiment 1a. The versions with consonant-initial words (i.e., no liaison) were used in Experiment 1b. The other two types of prime sentence were used in both sub-experiments. One type contained the consonant-initial words in unambiguous contexts. The final type of primes were unrelated to their targets and hence served as a baseline (see Table 1). Lists of primes and word targets are given in Appendix A.

Twenty-seven pseudowords were also created for presentation as visual targets in both sub-experiments (e.g., *asserf*). Two prime sentences were associated to each of them. One corresponded to an ambiguous condition (*C'est un grand assaut*/*C'est un grand tasseau*, It's a big attack/It's a big bracket, both of which are pronounced [sɛtɛ̃gʁɑ̃taso], because *grand* has an underlying /t/ which appears in liaison environments), and one was unrelated to the target and served as baseline (*Il est si platré*, He is so bandaged up; see Table 1).

The mean target frequency was 177 occurrences per million (frequencies per million, given by TLF). In the ambiguous sets, the average frequency of the penultimate word of the sentence (e.g., *dernier*) was 732 occurrences per million. The mean frequencies of the penultimate words in the unambiguous and baseline sets (e.g., *demi* and *ancien*), were 766 and 596 occurrences per million, respectively. The mean frequency of the last words in the unambiguous set was 25 per million. We tried to match the frequency of the last words in the baseline set (4 per million) to that of the consonant-initial words rather than to that of the vowel-initial words, since the most critical experimental condition was that which measured the activation of vowel-initial words when the speaker intended consonant-initial words.

The two versions of the ambiguous phrases were phonemically identical. One potential concern was that the 15 pairs in which the final vowel of the penultimate word was /e/ (including *dernier oignon*/*dernier rognon*) may not have been phonemically identical. The Closed Syllable Adjustment rule in French (Tranel, 1984) refers to a process in which the vowels/e ə ɛ/neutralize to [ɛ] under some conditions, in particular in word-final closed syllables. It was thus possible that in the liaison contexts, the speaker could have in some sense treated the pivotal consonants as coda consonants rather than onset consonants, and could therefore have neutralized the final vowels of the liaison versions of these 15 items to [ɛ] (e.g., treated the final syllable of *dernier* as if it were closed by the [ʁ]). The difference between the liaison and non-liaison versions could thus have been signalled by a difference in the vowels ([e] in the non-liaison contexts; [ɛ] in the liaison contexts). This concern was unfounded: The speaker produced an [e] in both versions of all 15 of these items. Another possibility was that the speaker could have produced glottal stops before the vowel-initial words in the liaison contexts, thus disambiguating them from the consonant-initial words. There were, however, no glottal stops at the onsets of the vowel-initial words.

In order to reduce the proportion of related pairs to 22%, 108 targets (54 words, 54 pseudowords) were presented in unrelated conditions in both sub-experiments. Thirty-two of them were preceded by a liaison sentence (*C'est un gros éléphant—gachis*; It's a big elephant—waste) and 26 of them were preceded by a "potential liaison sentence" in which the adjective contained a final liaison consonant but the following word began with this consonant (*C'est un brillant tandem—fuseau*; It's a brillant pair—spindle). Overall, there were equal numbers of targets beginning with vowels and consonants in each sub-experiment.

Procedure

The prime sentences were recorded onto Digital Audio Tape (DAT) in a sound-attenuated booth by a female native speaker of French (the first author). The speaker intended to produce vowel-initial words in the ambiguous liaison condition and consonant-initial words in the ambiguous non-liaison condition. Stimuli were down-sampled during transfer to a computer to 16 kHz. Each prime sentence was labeled using the X waves speech editor. The duration from the onset to midway through the final word of each sentence was measured. In addition, in the critical experimental prime sentences (both versions of the ambiguous sentences and the unambiguous sentences), segment durations for the critical pivotal consonants, and for the vowels preceding and following these consonants were measured from waveforms and spectrograms using Xwaves. Vowels were measured from the onset of the second and third formants to the offset of these formants. Consonants were measured from the offset of the preceding vowel to the onset of the following vowel.

The prime sentences were then transferred to the left channel of a DAT. Square wave clicks appeared on the right channel of the DAT and were time-locked with the acoustic onset of the primes, as identified by visual inspection of the waveforms. The clicks were inaudible to the participants and were used to trigger the presentation of the visual targets after a delay, set for each prime to be half way through the last word of the auditory sentence. The visual targets appeared before the offset of the auditory stimuli in order to increase the likelihood of observing priming effects for words that the speaker did not intend (probing at offset could be too late to detect activation of unintended words). Because the words had different syllabic structures, both within conditions (e.g., *osé*, V.CV; *hectare*, VC.CVC; *aliment*, V.CV.CV) and between conditions (e.g., *osé*, V.CV; *posé*, CV.CV; *souscrit*, CVC.CCV), alignment to particular segments could not be used as a criterion to determine target onset location. Durational criteria were therefore used: Targets were presented exactly halfway through the measured duration of each utterance-final word.

In each sub-experiment the stimuli were counterbalanced across three lists. Each participant received all three priming conditions (ambiguous, unambiguous and baseline) but saw each target only once. In Experiment 1a the ambiguous condition involved utterances with liaison; in Experiment 1b it had utterances without liaison. Order of stimulus presentation was pseudo-randomized and target position was kept constant across the lists.

Participants were tested individually in a quiet room. The prime sentence was presented auditorily at a comfortable listening level through headphones. The target was displayed visually in lower case on the center of a computer screen. The participants had been informed that the visual target could be either a word or a pseudoword and their task was to make a lexical decision on the visual target by pressing as quickly and as accurately as possible one of the two response buttons. They were required to press the *yes* button with the forefinger of their preferred hand and the *no* button with the forefinger of their other hand. The computer clock was triggered at the presentation of the target on the screen and stopped when the subject responded. Response latencies and errors were collected. The session lasted approximately 20 min.

Results and discussion

Acoustic analyses

Measurements were conducted on the stimuli from the ambiguous condition in the two intended segmentations, and on the stimuli from the unambiguous condition. The mean segmental durations and SDs for the pivotal consonant (C), the preceding (V_1) and following vowel (V_2) are presented in Table 2.

One-way analyses of variance (ANOVAs) on these data revealed that there was a main effect for the total duration of $V_1 + C + V_2$ ($F(2, 52) = 9.81$, $MSE = 184.84$, $p < .005$). The total duration of $V_1 + C + V_2$ in *dernier oignon* did not differ from the total duration of $V_1 + C + V_2$ in *demi rognon* ($F(1, 26) < 1$) but was shorter than that in *dernier rognon* ($F(1, 26) = 29.96$, $MSE = 104.40$, $p < .001$). Moreover, the total duration of $V_1 + C + V_2$ in *dernier rognon* was longer than that in *demi rognon* ($F(1, 26) = 9.40$, $MSE = 238.63$, $p < .005$).

Table 2
Mean segmental durations (in ms) and standard deviations of the surfacing consonant (C), the preceding (V_1) and the following vowel (V_2) in the experimental sentences

	V_1	C	V_2	Total
Speaker 1 (Experiments 1 and 2)				
Ambiguous vowel-initial (*dernier oignon*)	97	59	90	246
SD	(22)	(23)	(24)	(38)
Ambiguous consonant-initial (*dernier rognon*)	100	71	91	261
SD	(25)	(29)	(29)	(39)
Unambiguous consonant-initial (*demi rognon*)	87	71	91	249
SD	(20)	(24)	(20)	(32)
Ten naive speakers				
Ambiguous vowel-initial (*dernier oignon*)	58	64	83	205
SD	(9)	(5)	(8)	(16)
Ambiguous consonant-initial (*dernier rognon*)	59	71	82	212
SD	(10)	(5)	(7)	(16)
Speaker 2 (Experiments 3 and 4)				
Ambiguous vowel-initial (*dernier oignon*)	73	53	93	219
SD	(18)	(26)	(32)	(51)
Ambiguous consonant-initial (*dernier rognon*)	73	65	88	226
SD	(19)	(26)	(18)	(40)
Unambiguous consonant-initial (*demi rognon*)	82	63	91	237
SD	(30)	(26)	(28)	(44)

There was a significant context effect in the analyses of the duration of V_1 ($F(2,52) = 11.73$, $MSE = 111.42$, $p < .001$). Specific comparisons showed that the duration of V_1 in *dernier oignon* was longer than that in *demi rognon* ($F(1,26) = 10.59$, $MSE = 118.16$, $p < .001$) and shorter than that in *dernier rognon* ($F(1,26) = 4.78$, $MSE = 42.71$, $p < .05$). The duration of V_1 in *dernier rognon* was also longer than that in *demi rognon* ($F(1,26) = 14.23$, $MSE = 173.40$, $p < .001$). There was also a significant context effect in the analyses of the duration of C ($F(2,52) = 14.11$, $MSE = 96.41$, $p < .001$). Specific comparisons showed that the C in *dernier oignon* was shorter than that in *demi rognon* ($F(1,26) = 23.71$, $MSE = 90.81$, $p < .001$) and shorter than that in *dernier rognon* ($F(1,26) = 20.92$, $MSE = 91.77$, $p < .001$). Moreover, there was no significant difference in the duration of C between *dernier rognon* and *demi rognon* ($F(1,26) < 1$). Finally, there was no difference in the duration of V_2 between the three conditions ($F(2,52) < 1$).

In the liaison context we therefore observed a shortening of the liaison consonant (17%) compared to the non-liaison contexts. We also observed a shortening (3%) of the vowel preceding the medial consonant in the liaison context compared to the non-liaison context. In order to test the generalizability of these findings, 10 naive speakers were asked to read aloud the 27 ambiguous pairs of sentences used in Experiment 1. The sentences were mixed with 90 filler sentences. The speakers' productions were recorded onto DAT in a sound-attenuated booth and analyzed by the first author, who was blind to the conditions while performing the analysis. The results are shown in Table 2.

Two-way ANOVAS were performed on the data with intention (vowel-initial, consonant initial) and segment (V_1, C, V_2) entered as main factors. There were effects of intention ($F1(1,9) = 81.00$, $MSE = 1.07$, $p < .001$; $F2(1,26) = 13.22$, $MSE = 19.06$, $p < .001$) and segment ($F1(2,18) = 36.10$, $MSE = 81.13$, $p < .001$; $F2(2,52) = 5.92$, $MSE = 1232.07$, $p < .005$) and an interaction between these two factors ($F1(2,18) = 11.75$, $MSE = 8.07$, $p < .001$; $F2(2,52) = 20.02$, $MSE = 12.70$, $p < .001$). Specific comparisons showed that V1 in liaison contexts was slightly shorter than that in non-liaison contexts; this difference was marginally significant ($F1(1,9) = 4.76$, $MSE = 2.69, p = .055$; $F2(1,26) = 4.17$, $MSE = 12.48$, $p < .05$). There was, however, a significant difference in the duration of the consonant in liaison and non-liaison contexts ($F1(1,9) = 33.14$, $MSE = 7.61$, $p < .001$; $F2(1,26) = 33.40$, $MSE = 20.23$, $p < .001$). The liaison consonant was, on average, 10% shorter than the equivalent consonant in the non-liaison context. There are thus small but robust durational differences between consonants which are syllable-initial because of liaison and those which are actually word initial. Although overall the productions used in Experiment 1 were somewhat slower than those of the naive speakers, they do not appear to be abnormal. Like the naive speakers, the first author tended to signal the presence/absence of liaison in the duration of the pivotal consonants.

Experiment 1a

Reaction times were calculated from onset of visual target presentation to response onset. Those longer than 1200 ms (0.7%) were removed. Errors were also removed (excluding 5.9% of responses). Mean reaction times (RTs), standard deviations (SDs) and error rates for word targets in the three priming conditions are given in Table 3. The results were evaluated using one-way repeated measure ANOVAs with three levels of condition (ambiguous, unambiguous and baseline). *F*-values are reported for analyses with subjects ($F1$) and with items ($F2$) as the repeated measure.

Analyses of RTs revealed a main effect of priming condition ($F1(2,58) = 4.56$, $MSE = 2100.42, p < .01$; $F2(2,52) = 3.22$, $MSE = 2894.73$, $p < .05$). Planned comparisons showed a significant facilitatory effect for the ambiguous condition relative to the baseline condition ($F1(1,29) = 8.47$, $MSE = 2256.14$, $p < .01$; $F2(1,26) = 6.58$, $MSE = 2797.57$, $p < .05$) but no effect for the

Table 3
Mean reaction times (RT, in ms), standard deviations (SD), and percentage of errors to the vowel-initial targets (e.g., oignon) in the three priming conditions in Experiment 1

	Ambiguous (dernier oignon)	Unambiguous (demi rognon)	Baseline (ancien nitrate)
Experiment 1a			
RT	560	580	596
SD	(54)	(81)	(78)
Errors	8.5%	4.4%	4.8%
	(dernier rognon)	(demi rognon)	(ancien nitrate)
Experiment 1b			
RT	572	577	589
SD	(74)	(79)	(74)
Errors	9.6%	5.3%	5.7%

unambiguous condition relative to baseline ($F1(1,29) = 2.01$, $MSE = 1991.63$, ns; $F2(1,26) < 1$). The difference between the ambiguous and the unambiguous condition was not significant ($F1(1,29) = 2.74$, $MSE = 2053.50$, $p < .10$; $F2(1,26) = 2.45$, $MSE = 2671.11$, ns). Analyses conducted on errors revealed no effect of priming condition ($F1(2,58) = 2.59$, $MSE = 58.49$, ns; $F2(2,52) = 2.33$, $MSE = 58.83$, ns). Planned pairwise comparisons among the three conditions showed that none of the pairwise differences in the errors were significant.

Experiment 1b

RTs were again measured from onset of visual target presentation to response onset. Those longer than 1200 ms (0.1%) were again removed. Errors were also removed, excluding 6.9% of responses. Mean RTs, SDs and error rates for word targets in the three priming conditions are presented in Table 3. Analyses of RTs and errors revealed no priming effects (RTs: $F1(2,60) = 1.44$, ns, $F2(2,52) < 1$; Errors: $F1(2,60) = 2.76$, ns, $F2(2,52) = 1.67$, ns).

Combined analyses

We also conducted joint analyses of the RTs from Experiments 1a and 1b. Two-way ANOVAs with priming condition (ambiguous, unambiguous and baseline) and intention condition (consonant intended, vowel intended) were performed. There was a main effect of priming condition ($F1(2,118) = 5.60$, $MSE = 1859.33$, $p < .005$; $F2(2,52) = 4.69$, $MSE = 2304.70$, $p < .05$) but no effect of intention (both Fs < 1). The interaction between priming conditions and intention was not significant (both Fs < 1).

Summary, Experiment 1

As predicted, we obtained evidence of activation of vowel-initial words in the ambiguous condition when the speaker intended them (e.g., *dernier oignon*). There was no clear evidence of activation of vowel-initial words in either of the other conditions, where the speaker intended consonant-initial words (e.g., *dernier rognon* and *demi rognon*). Although in all three cases the target words were misaligned with syllable onsets, we found differential activation of, for example, *oignon* resyllabified in *r#oignon* and *oignon* embedded in *rognon*. The latter case is compatible with the results of Vroomen and de Gelder (1997), who found no activation of *wijn* when it was embedded in *zwijn* and hence misaligned with a syllable onset. In the former case, however, despite resyllabification and misalignment with syllable onset, *oignon* was activated. This result is compatible with the results of Gaskell et al. (2002), who showed that resyllabification due to liaison does not impair recognition of vowel-initial candidates. It thus seems that the tokens of *oignon* coming from the resyllabification of *dernier oignon* and from *dernier rognon* are not fully homophonous and that listeners are able to distinguish between them. Our acoustic analyses indeed showed that there are durational differences between the consonants of consonant-initial words and those which emerge in syllable-initial position because of liaison.

How could the recognition system exploit these acoustic differences? It is possible that these differences could influence the amount of activation of the vowel- and consonant-initial words. Given that the strongest cue to liaison appears to be in the pivotal consonant, this bottom-up activation process could take the form of increasing the support for the consonant-final word (e.g., *dernier*) and/or decreasing the support for the consonant-initial word (e.g., *rognon*). Either way, vowel-initial candidates would become stronger competitors. Another possibility is that the durational cues in a liaison environment are powerful enough to block activation of the unintended word. It is necessary to measure the activation of the consonant-initial words in liaison contexts in order to be able to distinguish between these alternatives. In Experiment 2, therefore, the target words were the consonant-initial words. The experiment was otherwise the same as Experiment 1.

Note, however, that the results of Experiment 1 already suggest that the acoustic cues to liaison are not strong enough to disambiguate pairs like *dernier oignon/dernier rognon* completely. Although there was significant facilitation for vowel-initial words in the ambiguous liaison condition (Experiment 1a) and no significant facilitation in the ambiguous non-liaison condition (Experiment 1b), the interaction across sub-experiments was not significant. Furthermore, although there was no facilitation in the unambiguous condition in either sub-experiment (*demi rognon*), responses in this condition in Experiment 1a were not reliably slower than in the liaison condition (*dernier oignon*). These results suggest two things: first, that in liaison sentences the shorter pivotal consonants do not disambiguate the signal enough to produce reliably stronger activation of vowel-initial words than in situations where these words were not intended, and second, likewise, that the longer pivotal consonants in non-liaison contexts do not necessarily block all activation of vowel-initial words. It thus appears that there is enough acoustic differentiation of liaison and non-liaison utterances to allow syllabically misaligned vowel-initial words to be activated in liaison contexts, but not to remove any lexical ambiguities caused by the liaison process.

Experiment 2

In this experiment we measured the activation of consonant-initial candidates (e.g., *rognon*). The experiment was otherwise identical to Experiment 1, with two sub-experiments which differed only with respect to the speaker's intention in the ambiguous sentences. The sentences in the ambiguous condition in Experiment 2a were those used in Experiment 1b; those in the ambiguous condition in Experiment 2b were those used in Experiment 1a. As the consonant-initial candidate was intended in both the unambiguous condition (*demi rognon*) and in the ambiguous non-liaison condition (*dernier rognon*), we expected to detect activation of *rognon* in both cases (Experiment 2a). The critical condition was the liaison condition (Experiment 2b). If the shorter pivotal consonants strongly mismatch with the consonant-initial words, there should be no activation of these words in this condition. If, however, acoustic cues to liaison are not sufficient to rule out unintended words, we should observe priming for these words in this condition; after all, these words are a perfect phonemic and syllabic match to the input.

Method

Participants

Sixty-one students of the University René Descartes, Paris V, were paid to take part (31 in Experiment 2a; 30 in Experiment 2b). They were all native speakers of French, had normal or corrected vision and reported no hearing impairment. None had participated in the previous experiment.

Stimuli and procedure

Twenty-seven consonant-initial words served as experimental targets. The consonant-initial words were the consonant-initial counterparts of the vowel-initial words used in Experiment 1. The sentence primes were those used in Experiment 1. The mean target frequency was 25 occurrences per million. Fifty-four consonant-initial target fillers were replaced by 54 vowel-initial target fillers in order to keep the same proportion of targets beginning with vowels and consonants. The design and procedure paralleled that of Experiment 1.

Results and discussion

Experiment 2a

As in Experiment 1, RTs were calculated from onset of visual target presentation to response onset. RTs longer than 1200 ms (2.3%) were removed. Errors were also removed, excluding 4.5% of responses. Mean RTs, SDs, and error rates for word targets in the three priming conditions are presented in Table 4.

Analyses of RTs revealed a main effect of priming condition ($F1(2,60) = 18.10$, $MSE = 2301.05$, $p < .001$; $F2(2,52) = 18.94$, $MSE = 2028.29$, $p < .001$). Planned comparisons showed a facilitatory effect for the ambiguous condition relative to the baseline condition ($F1(1,30) = 30.25$, $MSE = 1969.47$, $p < .001$; $F2(1,26) = 38.09$, $MSE = 1476.88$, $p < .001$). Moreover, there was a significant effect of the unambiguous condition relative to baseline ($F1(1,30) = 27.74$, $MSE = 2351.59$, $p < .001$; $F2(1,26) = 21.52$, $MSE = 2739.19$, $p < .001$). The difference between the ambiguous and the unambiguous condition was not significant (both $Fs < 1$). Analyses conducted on errors revealed no effect of priming condition ($F1(2,60) = 2.41$, $MSE = 41.07$, ns; $F2(2,52) = 1.65$, $MSE = 53.86$, ns). As predicted, we observed activation of *rognon* in both the unambiguous and ambiguous conditions. When the speaker intended to pronounce the consonant-initial word in the ambiguous condition, this word's representation was activated.

Experiment 2b

RTs were again measured from onset of visual target presentation to response onset. RTs longer than 1200 ms (0.5%) were again removed. Errors were also removed (excluding 5.5% of responses). Mean RTs, SDs and error rates for word targets in the three priming conditions are given in Table 4.

Analyses of RTs revealed a main effect of priming condition ($F1(2,58) = 21.79$, $MSE = 1717.91$, $p < .001$; $F2(2,52) = 11.16$, $MSE = 2828.47$, $p < .001$). Planned

Table 4
Mean reaction times (RT, in ms), standard deviations (SD), and percentage of errors to the consonant-initial targets (e.g., rognon) in the three priming conditions in Experiment 2

	Ambiguous (dernier rognon)	Unambiguous (demi rognon)	Baseline (ancien nitrate)
Experiment 2a			
RT	586	583	648
SD	(84)	(95)	(82)
Errors	6.4%	2.8%	4.3%
	(dernier oignon)	(demi rognon)	(ancien nitrate)
Experiment 2b			
RT	611	565	634
SD	(98)	(72)	(72)
Errors	6.6%	4.1%	5.6%

comparisons showed a facilitatory effect for the ambiguous condition relative to the baseline condition which was significant only by subjects ($F1(1,29) = 4.06$, $MSE = 2027.13$, $p = .05$; $F2(1,26) = 2.19$, $MSE = 1966.40$, ns). There was a significant facilitatory effect for the unambiguous condition relative to baseline ($F1(1,29) = 47.50$, $MSE = 1522.54$, $p < .001$; $F2(1,26) = 21.06$, $MSE = 2802.05$, $p < .001$). Responses in the ambiguous condition were significantly slower than those in the unambiguous condition ($F1(1,29) = 19.79$, $MSE = 1604.07$, $p < .001$; $F2(1,26) = 8.45$, $MSE = 3716.97$, $p < .01$). Analyses conducted on errors revealed no effect of priming condition ($F1(2,58) < 1$; $F2(2,52) < 1$).

We therefore found evidence of activation of *rognon* in the unambiguous condition (*demi rognon*), replicating the results of Experiment 2a. We also found weak evidence of activation of *rognon* in the ambiguous condition (the effect was only significant by subjects), even though the target did not correspond to the intended segmentation in this condition (e.g., *C'est le dernier oignon*). It seems that whichever segmentation was intended in the ambiguous condition, the consonant-initial candidates were activated. However, because the effect in the ambiguous condition was only significant by subjects, it appears that the activation of *rognon* when the intended word was *oignon* (23 ms priming effect in Experiment 2b) was weaker than when the intended word was the actual target *rognon* (62 ms priming effect in Experiment 2a).

Combined analyses

In order to assess further the effect of the intended segmentation on the activation of consonant-initial candidates, we conducted joint analyses of the RTs from Experiments 2a and 2b. Two-way ANOVAs with priming condition (ambiguous, unambiguous and baseline) and intention condition (consonant intended, vowel intended) were performed. There was a main effect of priming condition ($F1(2,118) = 35.01$, $MSE = 2014.42$, $p < .001$; $F2(2,52) = 31.40$, $MSE = 1916.58$, $p < .001$) but no effect of intention ($F1(1,59) < 1$; $F2(1,26) < 1$). However, the interaction between priming conditions and intention was significant ($F1(2,118) = 4.25$, $MSE = 2014.42$, $p < .05$; $F2(3,52) = 3.34$, $MSE = 2940.19$, $p < .05$).

Thus, the activation of *rognon* was indeed weaker when the intended segmentation favored *oignon* than when it favored *rognon*. This confirms our hypothesis that acoustic cues to word juncture guide listeners' segmentation. However, the activation of *rognon* was not entirely blocked when the intended segmentation favored *oignon*. This suggests that, to a certain extent, lexical hypotheses that cross word boundaries are considered by the recognition system (as also observed by Gow & Gordon, 1995, and by Tabossi et al., 1995).

Summary, Experiments 1 and 2

We have shown that there are small but robust durational differences between phrases involving liaison and phonologically identical phrases (i.e., phrases with the same sequence of phonemes and the same syllabification) with no liaison. We have also shown that listeners are sensitive to the difference between the two readings of these phrases. Specifically, we found evidence of activation of the words the speaker intended (i.e., of the vowel-initial words in liaison contexts and of the consonant-initial words in the matched non-liaison contexts). The acoustic information in liaison environments thus appears to allow listeners to recognize the vowel-initial words speakers intend, even though these words are misaligned with a syllable boundary.

It appears that the durational differences between liaison and non-liaison utterances, however, are not substantial enough to block the activation of unintended words. A sequence like [sɛtɛ̃gʁɑ̃taso] is indeed lexically ambiguous, whatever the speaker's intentions. There was some evidence of activation of consonant-initial words when the speaker intended vowel-initial words (Experiment 2), and of activation of vowel-initial words when the speaker intended consonant-initial words (at least there were no reliable differences between the condition where the speaker intended vowel-initial words and the conditions where she intended consonant-initial words; Experiment 1). Neither of these results was entirely clear, however. In Experiments 3 and 4, therefore, we examined this issue further.

As in Experiments 1 and 2, we examined the activation of both vowel- and consonant-initial words in ambiguous utterances, and we again manipulated the speaker's intentions. There were, however, a number of changes in the design. First, an unambiguous vowel-initial priming condition was added (e.g., *demi oignon*). We could thus compare the activation of vowel-initial words in contexts either with or without liaison.

Second, speaker intention became a within-subject factor. This provided a stronger and more direct test of the effect of speaker intention on lexical activation in ambiguous utterances. In Experiment 3a we measured the activation of vowel-initial words like *oignon* both when the speaker intended those words (e.g., *dernier oignon*) and when the speaker intended the matched consonant-initial words (e.g., *dernier rognon*). We compared activation in these ambiguous utterances with that in unambiguous utterances, where again the speaker intended either vowel- or consonant-initial words (*demi oignon, demi rognon*; Experiment 3b). In Experiments 4a and 4b we measured the activation of the consonant-initial words in the same contexts.

Third, we used the productions of a naive female speaker. Although our acoustic analyses showed similar durational patterns in the productions used in Experiment 1 and those of the set of ten naive speakers, the differences between liaison and non-liaison utterances were larger in the experimental materials than in the naive set. It was thus possible that the first author had exaggerated the natural differences between these two utterance types. The new speaker did not know what the purpose of the experiment was.

Finally, we were able to match the frequency of the final words in the baseline conditions more systematically. In Experiments 1 and 2, the frequency of these words was matched to that of the consonant-initial experimental words. Since we had suspected that the degree of activation of the vowel-initial words when they were unintended would be weaker than that of intended words, we matched the baseline word's frequencies with those of the consonant-initial words. This was appropriate for the unintended vowel-initial words, but not for the unintended consonant-initial words (i.e., the situation where the speaker intended the much more frequent vowel-initial words). In the present design, however, we were able to match the frequency of the last word of the baselines for both types of word. In Experiment 3, where the vowel-initial words were targets, we matched the frequency of the baseline words to that of the consonant-initial experimental words (as in Experiments 1 and 2). But in Experiment 4 we matched the frequency of the baseline words to that of the vowel-initial experimental words (so that we could compare RTs to, e.g., *rognon* in *dernier oignon* with a baseline where the final words were, on average, just as frequent as *oignon*).

Experiment 3

In Experiment 3a, vowel-initial targets were presented in three conditions: an ambiguous condition in which the target corresponded to the intended segmentation; an ambiguous condition in which the target did not correspond to the intended segmentation, and a baseline condition. In Experiment 3b, the same targets were presented following unambiguous sentences in which the targets were again either intended or unintended, and following baseline sentences.

Method

Participants

Sixty-three students of the University René Descartes, Paris V, took part in this experiment for course credit (31 in Experiment 3a, 32 in Experiment 3b). They were native speakers of French, had normal or corrected vision and reported no hearing impairment. None had participated in either of the previous experiments.

Stimuli, design, and procedure

The targets were the same as those of Experiment 1, and were presented in three conditions in each subexperiment: a target-intended condition, a target-unintended condition, and a baseline. In Experiment 3a, the experimental primes were lexically ambiguous (e.g., target intended: *C'est le dernier oignon*; target unintended: *C'est le dernier rognon*). In Experiment 3b, they were unambiguous (e.g., target intended: *C'est un demi oignon*; target unintended: *C'est un demi rognon*). The baseline primes were unrelated to the targets. Their final words had a mean frequency of 25 occurrences per million. This was matched to the frequency of the consonant-initial words (i.e., those in the target-unintended primes, which also occurred on average 25 times per million words). Note that a better matching of these items was achieved here than in Experiments 1 and 2 (where the baseline mean frequency was only 4 per million). In Experiment 3a, the baseline primes contained consonant-final penultimate words which could trigger liaison (e.g., *C'est le premier tumulte*, It's the first tumult); in Experiment 3b these words ended with vowels (e.g., *C'est le vrai tumulte*, It's a real tumult). Moreover, contrary to Experiments 1 and 2, the penultimate words of the two related conditions were re-used in the baseline condition. As a consequence, subjects could not use the information of repeated penultimate words to anticipate a related probe. Full lists of primes and targets are given in Appendix B. Nonword and filler prime-target pairs were the same as in Experiment 1.

The prime sentences were recorded by a female native speaker of French, unaware of the purpose of the experiment, onto DAT in a sound-attenuated booth. The speaker again produced an [e] in both versions of all 15 of the items in which the Closed Syllable Adjustment rule could have generated an [ɛ] in the liaison versions. The two versions of all 27 ambiguous phrases were thus again phonemically identical. There were again no glottal stops before the vowel-initial words. The primes were digitized and measured in the same way as in Experiment 1. All other aspects of design, counterbalancing and procedure were the same as in the previous experiments.

Results and discussion

Acoustic analyses

The durations of the pivotal consonants (C) and the vowels preceding (V_1) and following (V_2) these consonants are given in Table 2. One-way ANOVAs, with three context conditions (ambiguous vowel-initial, ambiguous consonant-initial and unambiguous consonant-initial), revealed that there was no main effect of context for the total duration of $V_1 + C + V_2$ ($F(2, 52) = 2.78$, $MSE = 791.25$, ns). However, there was a significant context effect in the analyses of the duration of the pivotal consonant C ($F(2,52) = 12.34$, $MSE = 94.46$, $p < .001$). The duration of C in *dernier oignon* was shorter than that in *dernier rognon* ($F(1,26) = 22.02$, $MSE = 90.49$, $p < .001$) and shorter than that in *demi rognon* ($F(1,26) = 16.74$, $MSE = 87.36$, $p < .001$). There was no significant difference in the duration of C between *dernier rognon* and *demi rognon* ($F(1,26) < 1$). Finally, there was no difference in the duration of V1 nor of V2 among the 3 conditions ($F(2,52) = 1.70$, $MSE = 462.18$ ns and $F(2,52) < 1$ respectively). We thus again found a shortening of the liaison consonant compared to each non-liaison context (of 16% and 18%, respectively).

Experiment 3a

RTs were again measured from onset of visual target presentation to response onset. Those longer than 1200 ms (1%) were removed. Errors (5.1%) were also removed. Mean RTs, SDs, and error rates for word targets are presented in Table 5. One-way ANOVAs with three levels of condition (target intended, target unintended and baseline) were carried out.

Analyses of RTs revealed no main effect of priming condition ($F1(2,60) = 2.19$, $MSE = 1563.96$, $p = .12$; $F2(2,52) = 2.72$, $MSE = 1801.89$, $p = .07$). However, planned comparisons showed a significant facilitatory effect for the target intended condition relative to the baseline condition ($F1(1,30) = 6.03$, $MSE = 1116.97$, $p < .05$, $F2(1,26) = 4.32$, $MSE = 1934.78$, $p < .05$) and no effect for the target unintended condition relative to baseline ($F1(1,30) = 1.52$, $MSE = 1684.39$, $p = .22$, $F2(1,26) = 2.92$, $MSE = 2101.12$, $p = .09$). The difference between the target intended and the target unintended condition was not significant (both Fs < 1). Analyses conducted on errors revealed no effect of priming condition (both Fs < 1).

We thus found evidence of activation of vowel-initial words like *oignon* when they were intended by the speaker (e.g., in *dernier oignon*), which replicates the results of Experiment 1a. Responses to vowel-initial targets in the unintended condition (e.g., *dernier rognon*) again formed a statistically intermediate case, differing neither from the intended nor from the baseline condition. This suggests that while acoustic cues to word juncture guide listeners' segmentation, they do not entirely block activation of unintended candidate words.

Experiment 3b

RTs longer than 1200 ms (1.4%) were removed. Errors (4.7%) were also removed. Mean RTs, SDs, and error rates are given in Table 5. Analyses of RTs revealed a main effect of priming condition ($F1(2,62) = 21.85$, $MSE = 1914.60$, $p < .001$; $F2(2,52) = 14.24$, $MSE = 2535.63$, $p < .001$). Planned comparisons showed a significant facilitatory effect for the target intended condition relative to the baseline condition ($F1(1,31) = 21.79$, $MSE = 1639.39$, $p < .001$, $F2(1,26) = 19.76$, $MSE = 1771.46$, $p < .001$) and a tendency for inhibition for the target unintended condition relative to baseline ($F1(1,31) = 3.94$, $MSE = 2297.22$, $p = .053$, $F2(1,26) = 1.67$, $MSE = 3230.08$, ns). Responses in the target intended condition were significantly faster than those in the target unintended condition ($F1(1,31) = 44.67$, $MSE = 1807.21$, $p < .001$; $F2(1,26) = 26.07$, $MSE = 2605.34$, $p < .001$).

Analyses conducted on errors also showed an effect of priming condition but only in the subjects analysis ($F1(2,62) = 4.39$, $MSE = 39.88$, $p < .05$; $F2(2,52) = 2.77$, $MSE = 49.58$, $p = .07$). This effect was mainly due to the fact that there were fewer errors in the target intended condition than in the target unintended condition ($F1(1,31) = 8.30$, $MSE = 38.48$, $p < .01$, $F2(1,26) = 7.63$, $MSE = 32.65$, $p < .05$) and the baseline

Table 5
Mean reaction times (RT, in ms), standard deviations (SD), and percentage of errors to the vowel-initial targets (e.g., oignon) in the three priming conditions in Experiment 3

	Target intended (dernier oignon)	Target unintended (dernier rognon)	Baseline (premier tumulte)
Experiment 3a			
RT	542	550	563
SD	(66)	(67)	(58)
Errors	4.9%	3.9%	6.4%
	(demi oignon)	(demi rognon)	(vrai tumulte)
Experiment 3b			
RT	563	634	610
SD	(71)	(86)	(78)
Errors	2.1%	6.5%	5.5%

($F1(1,31) = 5.13$, $MSE = 36.84$, $p < .05$; $F2(1,26) = 2.80$, $MSE = 53.58$, $p = .10$). In unambiguous sentences there was thus clear evidence of activation of the target (e.g., *oignon*) when it was intended (*demi oignon*), and no evidence for activation – even a tendency for inhibition – when it was not intended (*demi rognon*).

It is important to note that the failure to observe evidence of activation of the vowel-initial words in the unambiguous target unintended condition shows that the facilitation observed in other conditions was not due to pure phonological overlap between primes and targets (the number of overlapping phonemes between primes and targets was the same in the target intended and target unintended conditions). This in turn supports our choice of the cross-modal priming task. Although facilitation can be observed when primes and targets share final sounds (Slowiaczek, McQueen, Soltano, & Lynch, 2000), this effect only occurs when both primes and targets are in the auditory modality (Dumay, Benraïss, Barriol, Colin, Radeau, & Bessori, 2001; Radeau, Morais, & Segui, 1995; Spinelli, Segui, & Radeau, 2001). The facilitation observed in the present study thus appears to be due to lexical activation rather than to phonological overlap.

Combined analyses

We conducted joint analyses of the RTs from Experiments 3a and 3b in order to examine whether the pattern of activation in ambiguous conditions differed from that in unambiguous conditions. There was a main effect of priming condition ($F1(2,122) = 16.91$, $MSE = 1742.16$, $p < .001$; $F2(2,52) = 10.05$, $MSE = 2528.83$, $p < .001$), a main effect of ambiguity ($F1(1,61) = 10.24$, $MSE = 11869.87$, $p < .005$; $F2(1,26) = 61.4$, $MSE = 1809.87$, $p < .001$) and a significant interaction between these two factors ($F1(2,122) = 9.07$, $MSE = 1742.16$, $p < .001$; $F2(2,52) = 8.62$, $MSE = 1808.69$, $p < .001$).

The pattern of activation of vowel-initial targets in the ambiguous priming conditions of Experiment 3a was therefore not the same as that in the unambiguous conditions of Experiment 3b. Despite the acoustic cues that could be used to differentiate ambiguous utterances like *dernier oignon* and *dernier rognon,* some ambiguity remained in these utterances. If this conclusion is correct, a similar pattern should be observed for the consonant-initial words. In ambiguous utterances, these words should be activated when they were intended by the speaker and less so when they were not intended. In unambiguous utterances, however, these words should only be activated when the speaker intended them. These predictions were tested in Experiment 4, in which the consonant-initial words served as targets.

Experiment 4

Method

Participants

Sixty students of the University René Descartes, Paris V, took part in this experiment for course credit (30 in each sub-experiment). All subjects were native speakers of French, had normal or corrected vision and reported no hearing impairment. None had participated in any of the previous experiments.

Stimuli, design, and procedure

The targets were the same as those of Experiment 2. The design was the same as that of Experiment 3. Half of the participants heard ambiguous utterances (words in either liaison or non-liaison contexts; Experiment 4a); the other participants heard the same final words but in unambiguous utterances (Experiment 4b). The target unintended primes used in Experiment 3 became the target intended primes in Experiment 4, and the target intended primes became the target unintended primes. The baseline primes, however, were new. The last words of these sentences were now matched in frequency (176 occurrences per million, on average) to the vowel-initial words in the experimental primes (e.g., *oignon*; 177 counts per million, on average). As in Experiment 3, the penultimate words in the baseline primes were either potential liaison words (e.g., *premier*, in *C'est le premier exemple*, It's the first example; Experiment 4a) or not (e.g., *joli*, in *C'est un joli exemple*, It's a cute example; Experiment 4b). Nonword prime-target pairs were the same as in the previous experiment except that 54 consonant-initial target fillers were replaced by 54 vowel-initial target fillers in order to keep the same proportion of targets starting with vowels and consonants. The procedure was the same as in the other experiments.

Results and discussion

Experiment 4a

RTs longer than 1200 ms (3.5%) were removed from the RT analysis, as were errors (5.7%). Summary statistics are given in Table 6. In RTs, there was a main effect of priming condition that was only marginally significant ($F1(2,58) = 2.98$, $MSE = 2137.61$, $p = .057$; $F2(2,52) = 2.55$, $MSE = 2552.94$, $p = .09$). Planned comparisons showed a significant facilitatory effect for the target intended condition relative to the baseline condition ($F1(1,29) = 4.68$, $MSE = 2352.74$, $p < .05$; $F2(1,26) = 4.69$, $MSE = 2585.48$, $p < .05$). The facilitatory effect of the target unintended condition relative to the baseline condition was significant only by subjects ($F1(1,29) = 4.37$, $MSE = 1793.78$, $p < .05$; $F2(1,26) = 2.04$, $MSE = 3234.05$, $p = .16$). The target intended versus target unintended conditions did not differ from each other (both Fs < 1). Analyses conducted on errors revealed no effect of priming conditions (both Fs < 1). As in Experiment 2, there was evidence of activation of consonant-initial words when they were intended by the speaker as well as evidence of weaker activation when they were not intended by the speaker.

Experiment 4b

RTs longer than 1200 ms (1.4%) were removed from the RT analysis, as were errors (8.9%). Summary statistics are again given in Table 6. Analyses of RTs showed a main effect of priming condition ($F1(2, 58) = 7.01$, $MSE = 2426.27$, $p < .005$; $F2(2, 52) = 24.57$, $MSE = 1496.92$, $p < .001$). Planned comparisons showed a significant facilitatory effect for the target intended condition relative to the baseline condition ($F1(1, 29) = 10.35$, $MSE = 1840.57$, $p < .005$; $F2(1, 26) = 24.90$, $MSE = 1478.40$, $p < .001$) and a tendency for inhibition for the target unintended condition relative to baseline that was only significant by items ($F1(1, 29) < 1$; $F2(1, 26) = 4.68$, $MSE = 1049.54$, $p < .04$). Moreover, responses in the target intended condition were faster than those in the target unintended condition ($F1(1, 29) = 11.12$, $MSE = 2754.94$, $p < .005$; $F2(1, 26) = 34.96$, $MSE = 1962.84$, $p < .001$).

Analyses conducted on errors also revealed a main effect of priming condition ($F1(2, 58) = 11.79$, $MSE = 72.18$, $p < .001$; $F2(2, 52) = 7.21$, $MSE = 108.40$, $p < .005$). Specific comparisons showed that there were fewer errors in the target intended condition than in the baseline condition ($F1(1, 29) = 7.65$, $MSE = 44.57$, $p < .01$; $F2(1, 26) = 6.09$, $MSE = 51.42$, $p < .05$) and in the target unintended condition ($F1(1, 29) = 24.66$, $MSE = 68.77$, $p < .001$; $F2(1, 26) = 11.59$, $MSE = 134.33$, $p < .005$). There were also more errors in the target unintended condition than in the baseline condition ($F1(1, 29) = 5.00$, $MSE = 103.20$, $p < .05$; $F2(1, 26) = 3.40$, $MSE = 139.46$, $p = .07$). As in Experiment 3, therefore, we observed that in unambiguous sentences, targets are activated when they are intended but not when they are unintended. Indeed, there was again evidence of inhibition in the target unintended condition. This finding confirms that the facilitatory effects observed in other conditions are due to lexical activation rather than to phonological overlap between the primes and the targets.

Combined analyses

There was a main effect of priming condition ($F1(2, 116) = 7.18$, $MSE = 2281.94$, $p < .001$; $F2(2, 52) = 15.31$, $MSE = 1914.04$, $p < .001$) and no main effect of ambiguity (both $Fs < 1$). However, the interaction between these two factors was significant ($F1(2, 116) = 3.07$, $MSE = 2281.94$, $p < .05$; $F2(2, 52) = 6.55$, $MSE = 2135.83$, $p < .005$). The pattern of activation of consonant-initial targets in the ambiguous priming conditions thus differed from that in the unambiguous priming conditions.

Summary, Experiments 1–4

The results of Experiments 3 and 4 strengthen and clarify those of Experiments 1 and 2. Together, they suggest that in lexically unambiguous utterances the words intended by a speaker are strongly activated in listeners' minds, while unintended words are not, whether they overlap quite considerably with the input (like *rognon* in *demi oignon*) or are embedded in the input but misaligned with a syllable boundary (like *oignon* in *demi rognon*). Reassuringly, speakers thus appear to be able to signal clearly their intentions to listeners. But speakers appear to be less successful in lexically ambiguous utterances. While they can signal the words they intend (like *rognon* in *dernier rognon*, and, critically, misaligned words like *oignon* in liaison environments like *dernier oignon*) they do not appear able to provide listeners with sufficient information to rule out unintended words (like *rognon* in *dernier oignon* and *oignon* in *dernier rognon*). This is shown by the lack of significant differences be-

Table 6
Mean reaction times (RT, in ms), standard deviations (SD), and percentage of errors to the consonant-initial targets (e.g., rognon) in the three priming conditions in Experiment 4

	Target intended (dernier rognon)	Target unintended (dernier oignon)	Baseline (premier exemple)
Experiment 4a			
RT	620	624	647
SD	(79)	(82)	(81)
Errors	5.1%	5.9%	5.9%
	(demi rognon)	(demi oignon)	(joli exemple)
Experiment 4b			
RT	603	648	638
SD	(86)	(94)	(79)
Errors	3.7%	14.3%	8.4%

tween the target intended and target unintended conditions in Experiments 3a and 4a. However, because a trend was systematically observed in the predicted direction (i.e., more priming for intended than for unintended words), we collapsed the two experiments to test this critical comparison.

A joint analysis of the RTs from Experiments 3a and 4a was performed with priming conditions (target intended, target unintended and baseline) and target type (vowel initial, consonant initial) entered as main factors. There was a main effect of priming condition ($F1(2,118) = 5.1$, $MSE = 1845.92$, $p < .005$; $F2(2,52) = 4.79$, $MSE = 2362.55$, $p < .01$), a main effect of target type ($F1(1,59) = 23.30$, $MSE = 11979.56$, $p < .001$; $F2(1,26) = 18.98$, $MSE = 12854.17$, $p < .001$) and no interaction between these two factors (both $Fs < 1$). Specific comparisons showed significant facilitatory effects for the target intended condition relative to baseline ($F1(1,59) = 10.12$, $MSE = 1724.38$, $p < .005$; $F2(1,26) = 8.97$, $MSE = 2263.76$, $p < .01$) as well as a facilitatory effect for the target unintended condition relative to baseline which was significant only by subjects ($F1(1,59) = 5.55$, $MSE = 1738.16$, $p < .05$; $F2(1,26) = 4.03$, $MSE = 3160.37$, $p < .053$ ns). However, the target intended condition did not differ from the target unintended condition (both Fs < 1). These results further confirm that speakers do not provide listeners with cues that are reliable enough to rule out unintended hypotheses, but do provide listeners with information about what their intentions were.

We also addressed a final concern about our results. This was that the findings could have reflected processes specific to the consonant [ʁ], which was used as the pivotal consonant in 15 out of the 27 critical items. This choice was determined by the constraint that the liaison sequences had to be lexically ambiguous. Our results do appear to generalize to other liaison consonants, however. For each of the six sub-experiments which included lexically ambiguous sequences (i.e., all but Experiments 3b and 4b), ANOVAs with an additional factor which categorized the critical consonants as [ʁ] or not [ʁ] were carried out: None of the interactions of this factor with the priming effect was significant.

General discussion

We have examined how lexical ambiguities in liaison contexts in French are processed. In a phrase with liaison like *un petit orage*, the final [t] of *petit* is produced. This consonant is not spoken when the next word begins with a consonant (e.g., *un petit cahier*). Furthermore, in the liaison context, the [t] is resyllabified, such that it appears in the first syllable of *orage* (un.pe.ti.to.rage). This combination of the surfacing of a latent consonant and its resyllabification could make word segmentation and recognition difficult. In particular, vowel-initial words become misaligned with a syllable boundary and may thus be hard to recognize. In some cases, as in this study, liaison can give rise to another word, and thus create a lexically ambiguous sequence (e.g., *C'est le dernier oignon/rognon*); competition between the intended word (e.g., *oignon*) and a competitor word created by the liaison process (*rognon*) may make it even harder to recognize the intended vowel-initial word. We examined the activation of the two competing candidates in ambiguous sentences like this.

We found that, in spite of their misalignment with syllable boundaries, and in spite of the presence of competing consonant-initial words, vowel-initial words are activated in liaison contexts, that is, in contexts where the speaker intended these words. In Experiments 1a and 3a we found priming for vowel-initial targets when they were intended by the speaker. Liaison therefore does not block the activation of intended (vowel-initial) words. There were no significant priming effects for vowel-initial targets, however, in unambiguous sentences where vowel-initial words were not intended by the speaker (Experiments 1a, 1b, and 3b). Although in Experiment 1a the difference between the *dernier oignon* and *demi rognon* conditions was not significant, performance on vowel-initial targets in the *demi rognon* condition in Experiment 3b tended to be poorer than in the baseline condition, and was reliably worse than in the *demi oignon* condition. The failure to find facilitation for unintended embedded words which are misaligned with a syllable boundary is consistent with the findings of Dumay et al. (2002), McQueen (1998), Vroomen and de Gelder (1997), and Weber (2001). This contrasts with the evidence of activation of unintended words which match syllable onsets (Isel & Bacri, 1999; Luce & Cluff, 1998; McQueen, Norris, & Cutler, 1994; Shillcock, 1990). While it is impossible to argue that vowel-initial words are not activated when the speaker intends consonant-initial words in which they are embedded, it is clear that they are not activated to the same extent as when the speaker intends them in liaison contexts. Thus, even though on a syllabic transcription words like *oignon* are equivalently misaligned with a syllable boundary in *dernier oignon* and *demi rognon*, there is a misalignment cost for these words only in the latter case.

We also found no evidence of activation of consonant-initial words when they are not intended by the speaker and mismatch with the input by one consonant (Experiment 4b). This is consistent with the results of a number of studies which have examined the effect of mismatching information on lexical access (Connine, Blasko, & Wang, 1994; Connine, Titone, Deelman, & Blasko, 1997; Frauenfelder, Scholten, & Content, 2001; Marslen-Wilson, Moss, & van Halen, 1996; Soto-Faraco, Sebastián-Gallés, & Cutler, 2001). These studies suggest that while the lexical access system appears to tolerate small degrees of mismatch (e.g., differences of only one acoustic-phonetic feature), it appears to be quite intolerant of large degrees of mismatch. These studies examined a slightly different situation than was tested in Experiment 4b, that is, they looked at the activation of words which are fully segmentally aligned with the input, but mismatch in some way (e.g., the activation of *cabinet* given the input *gabinet*, Connine et al., 1997). Nevertheless, it appears that the same conclusion can be drawn when the mismatch involves segments which are present in lexical representations but not in the input (like the [ʁ] of *rognon*, which is missing from *demi oignon*). Mismatching words like *rognon* in *demi oignon* do not appear to be considered as serious candidates in the lexical competition process.

It came as no surprise that we found priming for both vowel- and consonant-initial words in unambiguous phrases where the speaker intended those words (Experiments 2a, 2b, 3b, and 4b). Likewise, there was robust priming for consonant-initial words in ambiguous phrases where again the speaker intended those words (Experiments 2a and 4a). In all these cases these words matched phonemically with the input perfectly, and were aligned with syllable boundaries. As with the vowel-initial words in lexically ambiguous liaison contexts, there was reassuring evidence that the words the speakers intended were activated as the listeners heard those words.

Unintended words in lexically ambiguous phrases (e.g., *oignon* in *dernier rognon* [Experiments 1b and 3a], and *rognon* in *dernier oignon* [Experiments 2b and 4a]) appear to be weakly activated. In all four experiments, responses were not reliably faster in the target unintended conditions than in the baseline conditions. At the same time, however, responses in the target unintended conditions were not reliably slower than in the matched target intended conditions in Experiments 3a and 4a. Furthermore, although the interactions of priming and lexical ambiguity were significant in Experiments 3 and 4 (suggesting that the patterns of activation of intended and unintended words were not the same in ambiguous and unambiguous phrases), and the interaction of priming with speaker intention was significant in Experiment 2 (suggesting that consonant-initial words like *rognon* were more weakly activated when the speaker intended *dernier oignon* than when she intended *dernier rognon*), the interaction in Experiment 1 of priming with speaker intention was not significant (suggesting that, in contrast to consonant-initial words, vowel-initial words like *oignon* were not more weakly activated when the speaker intended *dernier rognon* than when she intended *dernier oignon*). Unintended words in ambiguous phrases thus seem to be an intermediate case: They appear to be activated, but not as strongly as words the speaker intended.

Our acoustic analyses suggested that there are subtle but reliable durational differences between the two versions of the lexically ambiguous phrases. Measurements of the productions of both speakers used in the experiments and of a further ten speakers showed that when French speakers intend vowel-initial words (and thus that there is liaison), the pivotal consonants tend to be shorter (by between 10% and 18% of total consonant duration, according to our measurements) than when they intend consonant-initial words. It appears that French listeners are sensitive to these durational differences.

Research in English (Fougeron & Keating, 1997; Gow & Gordon, 1995; Oller, 1973) and French (Fougeron, 2001) has shown that word-initial consonants tend to be longer than consonants which are syllable- but not word-initial. It has also been argued that durational differences in word-initial position (along with other acoustic cues) signal the fact that speakers strengthen their articulation of segments at the edges of prosodic domains (Cho & Keating, 2001; Fougeron, 2001; Fougeron & Keating, 1997). French speakers seem to produce a similar type of durational cue to signal the difference between liaison consonants and consonants which are genuinely word initial. It remains possible, however, that listeners may in fact use some other acoustic cue to liaison, one which is correlated with duration. While we have been able to rule out some obvious alternative cues (a difference in the vowels in liaison and non-liaison environments due to the Closed Syllable Adjustment rule; marking of vowel-initial words with glottal stops), further research is required to confirm that consonant duration is indeed the only cue which French listeners use to distinguish between liaison and non-liaison utterances. Nevertheless, it seems reasonable to assume on the basis of the current evidence that, while other cues may be involved, durational differences are at least an important part of this distinction.

The speech-recognition system thus appears to be able to pick up subtle acoustic differences in the speech signal, and to use this information to modulate the activation of competing candidate words. Although these acoustic cues do not appear to be strong enough to rule out the unintended words, they are strong enough to bias the system in favor of the intended words. The acoustic cues to this distinction are subphonemic (given that phonemic transcriptions of *dernier oignon* and *dernier rognon* are identical). Other research has also shown that subphonemic differences can influence processes at the lexical level. Andruski, Blumstein, and Burton (1994), for example, examined the effect of the alteration of VOT on the activation of English words beginning with stop consonants. VOT provides an important cue to the voicing distinction in English stops (e.g., the difference between unvoiced [p] and voiced [b]). Andruski et al. found that words beginning with unvoiced stops were more strongly activated when the input words had normal VOTs than when the VOTs had been shortened. In a similar vein, Marslen-Wilson and Warren (1994; see also Dahan, Magnuson, Tanenhaus, & Hogan, 2001; McQueen, Norris, & Cutler, 1999; Streeter & Nigro, 1979; Whalen, 1984, 1991) demonstrated that lexical and phonemic decisions were slower to words and nonwords which contained mismatching subphonemic information than to words and nonwords which did not contain mismatching information. For example, response latencies were longer to the word ***job***, when the ***jo*** was spliced from a token of *jog* (and thus contained formant transition information consistent with a [ɡ]) than when the ***jo*** was spliced from another token of *job* (and thus had no mismatching information). This again suggests that subphonemic information is passed up to the lexicon.

These earlier studies and the present results suggest that, during spoken word recognition, fine-grained differences in the speech signal influence processing at the lexical level and thus modulate lexical selection. These results thus challenge the view that discrete, categorical decisions about each phoneme in an utterance are made prior to lexical access. They are consistent, however, with models with cascaded processing, in which activation is passed to the lexicon continuously, as information becomes available in the speech signal. Acoustic-phonetic information could cascade to the lexical level directly, or via intermediate phonetic representations, so long as the fine-grained distinctions in the signal were preserved (i.e., were coded via the relative activation levels of those intermediate representations, which in turn would influence lexical activation levels).

The experiments reported here show that there are subphonemic effects during continuous speech recognition (rather than on the recognition of isolated words, as in, e.g., the Andruski et al., 1994, study). They thus suggest that subphonemic information can influence not only the activation of lexical candidates, but also the process by which continuous speech is segmented into words. Other research has led to the same conclusion. Gow and Gordon (1995) found evidence of activation of words in two-word sequences (e.g., of *lips* in *two lips*) but not in matched single-word sequences (e.g., *lips* in *tulips*). They argued that this was because listeners could use subphonemic cues which signalled word onsets. As in the present study, the word-initial consonants (e.g., the [l] in *two lips*) tended to be longer than the non-initial consonants (e.g., the [l] in *tulips*). Recent findings on the recognition of words embedded in the onset of longer words and of those longer words (e.g., *cap* and *captain*; Davis, Marslen-Wilson, & Gaskell, 2002) and on the recognition of words in place assimilation contexts (e.g., where the /t/ in *right berries* may take on a bilabial place of articulation, creating ambiguity with *ripe berries*; Gow, 2002) also suggest that lexical level processes are modulated by subphonemic differences in the speech signal.

We argued in the Introduction that the recognition and segmentation of continuous speech can be achieved by a process of competition between multiple candidate words, as in TRACE (McClelland & Elman, 1986) and Shortlist (Norris, 1994). We see three different ways in which a competition-based model of speech comprehension could use subphonemic information to modulate lexical activation in sequences like *dernier oignon/rognon*. One possibility is that the durational information in the pivotal consonant (and/or other subphonemic information) could be compared directly with stored lexical knowledge, as in an exemplar model with detailed lexical representations (see, e.g., Goldinger, 1998). If subphonemic information were stored in the lexicon, different words could be evaluated at this level of detail against the incoming signal. A relatively short [ʁ] in *dernier oignon*, for example, could provide a better match to *dernier* than to *rognon*, thus biasing the competition process in favor of *oignon*, while a relatively long [ʁ] in *dernier rognon* could provide a better match to *rognon* than to *dernier*, this biasing the competition in the other direction.

A weakness of this account is that it requires that fine-grained acoustic details be stored at the lexical level. It would thus require considerable duplication of knowledge about the acoustics of individual consonants: Each lexical representation of all consonant-final words that can be involved in liaison would need to contain information about the appropriate acoustic form of its latent consonant when it surfaces in a liaison environment, and the representations of all consonant-initial words would need to contain information about the appropriate acoustic form of their initial consonants. This duplication problem is of course not specific to liaison; it applies to all forms of speech input. A traditional response to this problem is to assume that there is a prelexical level of processing which mediates between the speech signal and more abstract lexical representations (as indeed is assumed in both TRACE and Shortlist). The activation of representations at this level of processing could be modulated by acoustic details, and these units in turn could influence lexical activation (in a continuous, cascaded manner) without the acoustic information needing to be coded on each lexical representation.

This, then, is the second way in which an activation-competition model could use subphonemic information to modulate lexical representations. Durational (or other) cues to liaison could bias prelexical representations, hence favoring the activation of the words in either the liaison or no-liaison reading of an ambiguous utterance like [sɛtɛ̃ɡʁɑ̃taso]. Phonemic prelexical representations, however, are unable to code the difference between these two readings, since the strictly phonemic transcriptions of the two utterances are identical. Position-specific segmental representations (e.g., allophones), or representations coding syllabic structure in some other way, are required to capture the difference between the two [ʁ]'s (see, e.g., Sawusch, 1977, for evidence that syllable-initial consonants are not treated by the perceptual system in the same way as syllable-final consonants, even though they have the same phonemic identity). If longer consonants were to activate syllable-initial phones more strongly than shorter consonants, and if shorter consonants were to activate syllable-final phones more strongly than longer consonants, then these differences in prelexical activation could be passed up to the lexicon to favor one of the lexical interpretations of the utterance. A longer [ʁ], for example, could thus provide more support for the *dernier rognon* reading, while a shorter [ʁ] could preferentially activate the *dernier oignon* reading. Note that this account entails the assumption that the initial [ʁ] of *rognon* and the optional [ʁ] at the end of *dernier* are coded for position at the lexical level. The lexical level must be able to distinguish between the two alternative words, and this could not be achieved unless the allophonic difference were also coded at that level of processing.

The third way in which the acoustic differences between liaison and non-liaison utterances could modulate lexical activation is through the operation of a segmentation procedure. On this view, the acoustic information would not be coded in the activation of prelexical segmental representations. Instead, the information would be used to signal the location of likely word boundaries in the signal; these boundaries would then in turn be used to modulate the activation of lexical representations. According to the Possible Word Constraint (PWC; Norris et al., 1997), candidate words which are misaligned with likely word boundaries are penalized (their activation is reduced). A series of studies in a number of different languages (Dutch: McQueen, 1998; McQueen & Cutler, 1998; English: Norris et al., 1997; Norris, McQueen, Cutler, Butterfield, & Kearns, 2001; Japanese: McQueen, Otake, & Cutler, 2001; and Sesotho: Cutler, Demuth, & McQueen, 2002) has suggested that words should be considered to be misaligned when the stretch of speech between the edge of that word and the likely word boundary does not contain a vowel. Norris et al. (1997) also suggested that likely word boundaries could be signalled by metrical, phonotactic, allophonic and acoustic cues.

The PWC account of word recognition in continuous speech thus offers a possible explanation for the present results. At first glance, it might appear that liaison creates a problem for the PWC account. As Norris et al. (1997) pointed out, vowel-initial words like *oignon* should have the PWC penalty applied to them in liaison contexts like *dernier oignon*, because an impossible word, namely the consonant [ʁ], lies between the beginning of *oignon* and the preceding syllable boundary (der.nie.ro.gnon). Norris et al. (1997) therefore suggested that the PWC penalty might not be applied in liaison contexts, if the speech signal signalled liaison in some way. The present results support this suggestion. One way in which the word recognition system could use the durational information in the pivotal consonant in a liaison context would be to mark a likely word boundary after (rather than before) that consonant. This would mean that words like *oignon* would not have a syllable misalignment cost in liaison contexts like *dernier oignon*, but would have that cost (because the PWC would apply) in unambiguous non-liaison environments like *demi rognon*. On this account, *oignon* would also be penalized in ambiguous non-liaison phrases like *dernier rognon*, because the longer pivotal consonant (the [ʁ] of *rognon*) would mark a word boundary before the consonant. This would act to bias recognition in favor of the intended word *rognon*.

We cannot fully distinguish between these three alternative accounts on the basis of the present data. The exact mechanism by which the acoustic cues to liaison help listeners derive speakers' intentions therefore remains to be determined. It will be important to establish whether subphonemic influences on lexical activation can be explained by a single factor, or whether some combination of the above three (or other) mechanisms is required.

Our data suggest that while subphonemic cues are strong enough to allow intended words to dominate the lexical competition process, they are not strong enough to rule out unintended words. As we pointed out in the Introduction, this pattern of data suggests that final resolution of lexically ambiguous phrases in normal language processing may depend on contextual information. The two readings of a phrase like *C'est le dernier oignon/rognon* are therefore likely to be passed to interpretative processes, where sentential or discourse context could be used for disambiguation. Nevertheless, it appears that the subphonemic cues which speakers provide to listeners already bias interpretation in the correct direction.

We have shown that liaison in French does not make the recognition of vowel-initial words problematic for French listeners. In spite of their apparent misalignment with a syllable boundary, and even in contexts where consonant-initial competitor words are created by the liaison process, vowel-initial words are correctly accessed. Listeners appear to be able to succeed in recognizing vowel-initial words in liaison environments because speakers provide them with subtle, subphonemic cues to their intentions. These cues appear to modulate the process of activation and competition among candidate words, thus helping listeners to segment continuous speech.

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Appendix A

Material used in Experiments 1 and 2.

Targets		Primes		
Experiment 1	Experiment 2	Ambiguous	Unambiguous	Baseline
osé	posé	il a beaucoup osé/posé	il a déjà posé	il a vraiment souscrit
heureux	peureux	il est trop heureux/peureux	il est si peureux	il est très tanné
arqués	parqués	ils sont trop arqués/parqués	ils sont si parqués	ils sont très bigots
unis	punis	ils sont trop unis/punis	ils sont si punis	ils sont très huilés
artisan	partisan	il est trop artisan/partisan	il est si partisan	il est peu réducteur
an	rang	c'est le dernier an/rang	c'est le demi rang	c'est le petit pic
oignon	rognon	c'est le dernier oignon/rognon	c'est un demi rognon	c'est un ancien nitrate
homme	rhum	c'est le premier homme/rhum	c'est un vrai rhum	c'est un précieux squale
éveil	réveil	c'est le premier éveil/réveil	c'est un demi réveil	c'est un nouveau coulis
épi	répit	c'est le dernier épi/répit	c'est un mini répit	c'est un ancien module
appel	rappel	c'est le premier appel/rappel	c'est un mini rappel	c'est le second butoir
apport	rapport	c'est le premier apport/rapport	c'est un mini rapport	c'est un nouveau goudron
accord	raccord	c'est un léger accord/raccord	c'est un joli raccord	c'est un ancien brugnon
atelier	râtelier	c'est le premier atelier/râtelier	c'est un joli râtelier	c'est un fameux isoloir
acte	tact	c'est un brillant acte/tact	c'est un joli tact	c'est un petit vol
ami	tamis	c'est un grand ami/tamis	c'est un vrai tamis	c'est un beau solvant
ermite	termite	c'est un grand ermite/termite	c'est un vrai termite	c'est un vieux bruitage
envoi	renvoi	c'est le dernier envoi/renvoi	c'est un demi renvoi	c'est un parfait crachin
osier	rosier	c'est le premier osier/rosier	c'est un joli rosier	c'est un gros crépon
athée	raté	c'est le dernier athée/raté	c'est un vrai raté	c'est un curieux fossile
hectare	nectar	il n'a aucun hectare/nectar	c'est un joli nectar	il n'a aucun pigment
oeuf	neuf	il n'a aucun oeuf/neuf	c'est un joli neuf	il n'a aucun jus
air	nerf	il n'a aucun air/ nerf	c'est un joli nerf	il n'a aucun bus
aliment	ralliement	c'est le dernier aliment/ralliement	c'est un vrai ralliement	c'est un léger coffrage
hommage	gommage	c'est un long hommage/gommage	c'est un vrai gommage	c'est un beau conduit
entier	rentier	c'est le premier entier/rentier	il est aussi rentier	c'est un petit forage
égal	régal	c'est son premier égal/régal	c'est son vrai régal	c'est son doux bandeau

Appendix B

Material used in Experiments 3 and 4.

Targets	Primes			
	Liaison/no liaison (Experiment 3a/4a)	Baseline (Experiment 3a/3b)	Vowel/consonant initial (Experiment 3b/4b)	Baseline (Experiment 4a/4b)
osé/posé	il a beaucoup osé/posé	ils sont trop anxieux/ affreux	il a déjà osé/posé	ils sont si anxieux/affreux
heureux/peureux	il est trop heureux/ peureux	il est trop absorbé/ supérieur	il est si heureux/peureux	il est si absorbé/supérieur
arqués/parqués	ils sont trop arqués/ parqués	ils sont trop honteux/ému	ils sont si arqués/parqués	ils sont si honteux/ému
unis/punis	ils sont trop unis/punis	il est trop actif/fou	ils sont si unis/punis	il est si actif /aussi fou
artisan/partisan	il est trop artisan/partisan	il est trop relatif/hostile	il est si artisan/partisan	il est aussi relatif /si hostile
an/rang	c'est le dernier an/rang	c'est le dernier velours/ moyen	c'est le demi an/rang	c'est un joli velours /le vrai moyen
oignon/rognon	c'est le dernier oignon/ rognon	c'est le premier tumulte/ exemple	c'est un demi oignon/ rognon	c'est le vrai tumulte /un joli exemple
homme/rhum	c'est le premier homme/ rhum	c'est un grand cortège / premier cri	c'est un vrai homme/rhum	c'est un joli cortège/cri
éveil/réveil	c'est le premier éveil/réveil	c'est le premier marquis/ noble	c'est un demi éveil/réveil	c'est le joli marquis /un demi noble

Appendix B (*continued*)

Targets	Primes			
	Liaison/no liaison (Experiment 3a/4a)	Baseline (Experiment 3a/3b)	Vowel/consonant initial (Experiment 3b/4b)	Baseline (Experiment 4a/4b)
épi/répit	c'est le dernier épi/répit	c'est un grand ancêtre /le dernier objet	c'est un mini épi/répit	c'est un vrai ancêtre/objet
appel/rappel	c'est le premier appel/ rappel	c'est le premier message/ travail	c'est un mini appel/rappel	c'est un demi message / vrai travail
apport/rapport	c'est le premier apport/ rapport	c'est un dernier sanglot / long train	c'est un mini apport/ rapport	c'est un demi sanglot/train
accord/raccord	c'est un léger accord/ raccord	c'est un premier concept / leger orgueil	c'est un joli accord/ raccord	c'est un vrai concept/ orgueil
atelier/râtelier	c'est le premier atelier/ râtelier	c'est un grand caillou / dernier morceau	c'est un joli atelier/râtelier	c'est un demi caillou/ morceau
acte/tact	c'est un brillant acte/tact	c'est un grand époux/ silence	c'est un joli acte/tact	c'est un joli époux /vrai silence
ami/tamis	c'est un grand ami/tamis	c'est un léger vertige / grand feu	c'est un vrai ami/tamis	c'est un mini vertige/feu
ermite/termite	c'est un grand ermite/ termite	c'est le dernier océan/ octobre	c'est un vrai ermite/ termite	c'est un mini océan /joli octobre
envoi/renvoi	c'est le dernier envoi/ renvoi	il n'a aucun ongle /c'est un long hiver	c'est un demi envoi/renvoi	c'est un vrai ongle/hiver
osier/rosier	c'est le premier osier/ rosier	c'est un brillant astre/ grand humain	c'est un joli osier/rosier	c'est un joli astre/humain
athée/raté	c'est le dernier athée/raté	c'est le premier insecte/ endroit	c'est un vrai athée/raté	c'est un joli insecte /le vrai endroit
hectare/nectar	il n'a aucun hectare/nectar	c'est un premier accès / grand front	c'est un joli hectare/nectar	c'est un joli accès /mini front
œuf/neuf	il n'a aucun oeuf/neuf	il n'a aucun étang/espace	c'est un joli œuf/neuf	c'est un vrai étang /mini espace
air/nerf	il n'a aucun air/nerf	c'est un léger attrait/écart	c'est un joli air/nerf	c'est un mini attrait/écart
aliment/ralliement	c'est le dernier aliment/ ralliement	c'est le dernier préjugé/ oncle	c'est un vrai aliment/ ralliement	c'est un vrai préjugé /joli oncle
hommage/gommage	c'est un long hommage/ gommage	il a beaucoup conquis/ passé	c'est un vrai hommage/ gommage	il a déjà conquis/passé
entier/rentier	c'est le premier entier/ rentier	c'est un brillant marin/ instant	il est aussi entier/rentier	c'est un vrai marin /demi instant
égal/régal	c'est son premier égal/régal	c'est un long filet/geste	c'est son vrai égal/régal	c'est un joli filet/vrai geste

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