On the production of sandhi phenomena in French: psycholinguistic and acoustic data

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Abstract
This preliminary study addresses two complementary questions about the production of sandhi phenomena in French. First, we investigated whether the encoding of *enchânement* and *liaison enchaînée* involves a processing cost compared to non-resyllabified sequences. This question was answered by analyzing a psycholinguistic production time paradigm. The elicited sequences were then used to address our second question, namely how critical the underlying final consonant of *W1* is with respect to the success of resyllabification. We compared the durational properties of critical sequences containing a word-final coda consonant (*enchânement: V1,C#V2*), an additional consonant (*liaison enchaînée: V1+C#V2*), and a similar onsets consonant (*V1#CV2*). Results on production latencies suggested that the encoding of *liaison enchaînée* involves an additional processing cost compared to the two other boundary conditions. In addition, the acoustic analyses indicated durational differences across the three boundary conditions on *V1* and *V2*. Implications for both, psycholinguistic and phonological models are discussed.

Index Terms: speech production, psycholinguistic, phonology, sandhi.

1. Introduction

Sandhi phenomena can occur in several languages at the boundary of two contiguous words when the first word (*W1*) ends with a consonant and the second word (*W2*) begins with a vowel. Two types of sandhi phenomena can be observed in French. In the case of *enchânement*, the underlying final consonant of *W1* is (re-)syllabified into onset position of *W2* in the surface form (e.g. “sept” /sɛt/ + “ami” /a mi/ -> /sɛ.t.a.mI/ “seven friends”). In the case of *liaison enchaînée*, a consonant appears in the surface form at the juncture of the two words (e.g. “mom” /mɔm/ + “ami” /a mi/ -> /mɔ.ma.mI/ “my friend”). Hence, a misalignment between syllable and word boundaries is created and the onset of *W2* in the surface form does not correspond to the underlying onset of *W2*. If syllables [1] or, at least, syllable onsets [2] trigger lexical access, as suggested by most models of word recognition, this misalignment could delay or prevent the recognition of *W2*. In the sequence /sɛ.t.a.mI/ for example, the activation of the misaligned word /a mi/ (“friend”) should be delayed or prevented by the activation of the word /hamî/ (“sieve”).

However, psycholinguistic studies have reported that *liaison enchaînée* [3, 4, 5] and *enchânement* [4] facilitate the recognition of *W2* instead of preventing it. Moreover, in recent studies using a phoneme detection task [6], the liaison consonants were significantly more difficult to detect than word-initial consonants (see also, [3]). Therefore, one might consider that liaison consonants have a perceptual status that facilitates lexical access on *W2*.

At least two hypotheses can be proposed to integrate these two main results. First, *liaison* and *enchânement* consonants might be acoustically less salient than word-initial consonants. Indeed, *liaison* consonants [7, 8, 4, 5] and *enchânement* consonants [9, 10] have been reported to be shorter than word-initial consonants. Hence, the processing of the misalignment might be facilitated by the presence of subtle acoustic cues that allow the listeners to discriminate resyllabified consonants from word-initial consonants. However, phoneme detection studies established that only liaison consonants perceptually differ from word-initial consonants [6]. Therefore, the effects found in phoneme detection tasks cannot be explained by acoustic differences only. Second, the phonological status of liaison *enchaînée*, *enchânement* and word-initial consonants might differ. As suggested by nonlinear phonology [11, 12], while *enchânement* and word-initial consonants are respectively lexically anchored to *W1* and *W2*, liaison consonants are supposed to be lexically floating segments. Listeners should be sensitive to this structural instability and the early access to the phonological form of the upcoming word might explain facilitation in lexical recognition of *W2*. Moreover, the difficulty to map *liaison* consonants onto a phonological category might explain why liaison consonants are perceptually inhibited. To sum up, since *enchânement* consonants perceptually differ from *liaison* consonants, *enchânement* might be a phonologically intermediate case between a non re-syllabified condition and *liaison enchaînée* [6].

An alternative way to test these hypotheses is to investigate whether sequences involving similar word-initial, *enchânement*, and *liaison enchaînée* consonants are differently encoded by speakers. In the most detailed and quoted psycholinguistic model of language production [13], syllabification is applied to the abstract phonological representation retrieved from the lexicon. This underspecified representation does not contain any information about the syllabic structure of the word and syllables are generated through the application of syllabification rules before indexing syllabic gestural scores, i.e. phonetic syllables. Since no syllabic structure is represented along with the lexical-phonological representation, this kind of model does not predict any additional processing cost for a re-syllabified sequence compared to a non re-syllabified one. Moreover, the model predicts that neither the syllable /ta/ in the sequence /sɛ.t.a.mI/ nor the syllable /na/ in the sequence /mɔ.namI/ differ from any other /ta/ or /na/. However, this assumption is not in line with the acoustic differences.
reported in phonetic studies between non re-syllabified sequences and their re-syllabified counterparts.

In this preliminary study we combined a psycholinguistic paradigm with acoustic analyses. There were two major goals: to investigate whether the encoding of sandhi phenomena involves a processing cost compared to non-resyllabified sequences; and to analyze how critical $V_1C_1V_2$ sequences are phonetically realized across different boundary conditions.

2. Experiment

2.1. Method

2.1.1. Participants

Twenty native French-speaking subjects took part to the study.

2.1.2. Material (Table 1)

90 triplets of (adjective + noun) phrases containing a $V_1C_1V_2$ sequence were constructed by associating 30 masculine nouns with 9 adjectives. Triplets differed according to the underlying status of the consonant.

<table>
<thead>
<tr>
<th>Adjective</th>
<th>Noun</th>
<th>Location of $C$</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>deux</td>
<td>zigzags</td>
<td>Onset of $W_1$</td>
<td>Non re-syllabified</td>
</tr>
<tr>
<td>deux</td>
<td>iguanes</td>
<td>Juncture of $W_1$, $W_2$</td>
<td>liaison enchaînée</td>
</tr>
<tr>
<td>seize</td>
<td>iguanes</td>
<td>End of $W_1$</td>
<td>enchaînement</td>
</tr>
</tbody>
</table>

Six adjectives were selected pair-wise in order to give rise to liaison enchaînée (90 sequences) and enchaînement (90 sequences) on the same consonants ($/l/$: deux (/dœ/ or /dɔ/-zd/), seize (/sɛz/); $/t/$: vingt (/vɛ̃t/ or /vɛ̃-t/), sept (/sɛt/); $/d/$: dènier (/dɛnje/ or /dɛnje/-n/)), super (/syper/). Three adjectives ending with a vowel ( demi, mini, zero) were used as fillers in order to maximize the distance between repeated adjectives or nouns.

2.1.3. Procedure

Participants were tested individually in a quiet room. The experiment was controlled by the software DmDX [14]. Written sequences were presented in the middle of a screen in pseudo-random order for 1500 milliseconds. Participants had to read each sequence as fast as possible as soon as it appeared on the screen. Production latencies (RT: reaction time) were measured with a vocal key and productions were recorded for vocal key check and for further acoustic analyses.

2.2. Results

2.2.1. Behavioral results

Three subjects were excluded from the analysis because of a high error rate in one condition (above 20%). Incorrect responses and outliers (RT that were more than 2 standard deviations away from the mean of each participant) were excluded (5% of the data). Mean production latencies are presented in figure 1. Repeated measures ANOVA were conducted with the boundary condition (enchaînement, liaison enchaînée, non-re-syllabified condition) as within-participants ($F_1$) and within-items ($F_2$) factors and stimulus type (test/control nouns) as within-participants and between-items factors.

Results show that production latencies significantly differed across boundary conditions [$F_1(2, 32)=9.4, p<.001$; $F_2(2, 56)=22.9, p<.0001$] while there was no effect of stimulus type nor interaction between boundary condition and stimulus type (all $F<1$).

Figure 1: Production latencies (RT) for the (adjective + noun) sequences in the different boundary conditions.

Planned comparisons (Fisher test) show that liaison enchaînée differs from both, enchaînement and non re-syllabified conditions (both $p<.01$), while no difference appears between the other two conditions (both $p>.5$).

Since the acoustic analyses presented below were conducted on two consonants only ($/t/ and /l/), RT analyses were carried out separately for those consonants. The effect of the boundary condition was significant for both consonants [respectively for $/t/$: $F_1(2, 32)=12.73$, $p<.001$; $F_2(2, 56)=21.1$, $p<.0001$; and $/l/$: $F_1(2, 32)=3.5$, $p<.05$, $F_2(2, 56)=10.9$, $p<.001$] with no effect of the stimulus type and no interaction between the boundary condition and the stimulus type [all $F<1$].

Similarities between control and test stimuli in the liaison enchaînée condition, may suggest that the observed differences were related to the segmental properties of $W_1$ rather than to the boundary condition. To test this potential bias, RT were collected for the production of the 9 isolated adjectives (16 new participants, 5 repetitions of each adjective among 48 fillers). New analyses were conducted on z-scores transformations relative to the mean production time for the single adjectives in each condition. Results remain unchanged (significant effect of the boundary condition: $F_1(2,32)=17.8$, $p<.0001$; $F_2(2,56)=14.6, p<.0001$) and differences between liaison enchaînée and the two other conditions: both $p<.001$).

2.2.2. Acoustic results

Durational analyses were conducted on the productions of 9 speakers. $V_1C_1V_2$ were excised from the sequences and the duration of the segments $V_1$, $C$ and $V_2$
To sum up, acoustic analysis show that CV₂ is significantly longer in word-initial condition than in sandhi conditions. Moreover, *enchaînement* does not acoustically differ from *liaison enchaînée*.

### 3. Discussion

The aim of this study was twofold. First, by using a psycholinguistic production paradigm, we addressed the question of whether sequences with sandhi phenomena involve an encoding cost relative to non re-syllabified sequences. Second, by analysing the durational properties of the critical sequences, we tested whether acoustic cues can differentiate sequences sharing the same segmental content but differing with respect to the boundary position (before/after C) and to the nature of the sandhi phenomena involved (*enchaînement/liaison enchaînée*).

Results on production latencies are in line with the predictions made by psycholinguistic models of speech production about *enchaînement* [13]. Similar production latencies were found between re-syllabified and non re-syllabified sequences, suggesting that re-syllabified sequences do not involve any additional processing time. Nevertheless, longer production latencies were observed for *liaison* sequences on both, test and control stimuli. Psycholinguistic models of speech production do not explicitly account for the phonological encoding of the floating consonant in *liaison enchaînée*. At least two possible accounts can be hypothesized though. First, two alternative phonological forms (with/without *liaison* consonant) might be stored in the lexicon and the correct one would be indexed according to phonological rules. The longer RT might therefore reflect the retrieval of the appropriate phonological form. Second, a single representation might be stored with a « hidden unit » which would be indexed according to the phonological properties of W₂. The longer RT might therefore reflect the enabling or disabling encoding of this additional segment. Further experiments are needed to disentangle these two possible explanations.

Acoustic analyses confirmed that subtle acoustic cues distinguish sequences sharing the same segmental content but differing according to the boundary location. This study thus provides further evidence that sandhi phenomena do not neutralize the contrast between a sequence which contains a word-final coda consonant (V₁,C#V₂) and a sequence in which the same critical consonant is the onset of the following syllable (V₁#CV₂) in the surface form. In other words, *enchaînement* and *liaison enchaînée* do not involve a complete resyllabification of the speech chain in French. Indeed, V₁ is shorter in both, *enchaînement* and *liaison enchaînée* conditions, than in the non re-syllabified condition.

Discussion

The durational characteristics of the post-consonantal vowel V₂ depended upon both the nature of the consonant [F(1.8)=46.6, p<.001] and the boundary condition [F(2.16)=9, p=.002] without interaction between the two factors [F(2.16)=2, p=.15]. Planned comparisons (Helmert) show that V₂ was significantly longer in the non re-syllabified condition than in the two other boundary conditions (p=.007). Differences between *enchaînement* and *liaison enchaînée* are not significant (p=.3).

To sum up, acoustic analysis show that CV₂ is significantly longer in word-initial condition than in sandhi conditions. Moreover, *enchaînement* does not acoustically differ from *liaison enchaînée*.

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also vary according to the boundary conditions but no differences were found between *enchaînement* and *liaison enchaînée*. In sum, the articulatory patterns required for the production of VC#V sequences differ from those required for the production of their V#CV counter-parts, whatever the nature of the sandhi phenomena involved.

From a phonological standpoint, our results on production latencies challenge an explanation of sandhi phenomena in terms of a simple mechanism of segmental insertion/deletion as suggested by generative phonology (e.g. [15, 16, 17] among others). Since production latencies are longer in *liaison enchaînée* than in the two other boundary conditions, this rather confirms that liaison consonant has a special phonological status of floating segment as suggested by autosegmental phonology [12]. However, autosegmental phonology does not account for the phonetic differences attested between word-initial consonants and liaison consonants. Indeed, these data would be better interpreted in the articulatory phonology framework [18] that suggests that liaison consonants are structurally similar to word-initial consonants but phonetically distinct.

Moreover, taken together, our results partially contradict the predictions made by the psycholinguistic model of speech production cited above [13]. In this model, syllables are generated from the retrieved phonological code through the application of syllabification rules before indexing syllabic phonetic syllables. Thus, the re-syllabified CV₂ sequence addresses the same phonetic syllable as in any other sequence. One possible explanation in line with the model and with the durational differences observed between boundary conditions might be that the CV₂ syllable addressed from a re-syllabified sequence is not a word onset syllable. However, acoustic differences were not only observed on CV₂ but also on V₁ (see also [10]). This suggests that sandhi phenomena do not involve a complete re-syllabification of the speech chain. This interpretation clearly contradicts the prediction made by the psycholinguistic model of speech production [13] arguing that syllable structure is not retrieved along with the phonological code and that syllabification is applied to the retrieved phonological codes before phonetic syllables are indexed.

To sum up, this preliminary study confirms that sandhi phenomena do not neutralize the contrasts between different boundary conditions. This suggests that *enchaînement*, *liaison enchaînée* and non resyllabified sequences are encoded differently by speakers thus providing the listeners with efficient phonological information and fine-grained phonetic cues to avoid missegmentations. Previous results from perceptual studies are thus replicated with a production paradigm that offers the main advantage of testing phonological encoding hypotheses more directly than with perceptual tasks. Further experiments must be carried out with such paradigms not only to refine psycholinguistic models of speech production [13] but also to disentangle between phonological theories that explain sandhi phenomena quite differently [11, 15, 16, 17, 18].

### 4. Acknowledgements

This research was conducted with the support of Swiss National Science Foundation grant no. PP01-118969.

### 5. References

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