COARTICULATORY PATTERNS IN STOP SEQUENCES

M. CHAFCOULOFF *, A. MARCHAL * and T. BENKRANE **

* IPA, URA 261 CNRS, Univ. de Provence, France.
** Univ. Sidi Mohammed Ben Abdellah, Fès, Maroc.

Abstract
An acoustic investigation was undertaken to specify the coarticulatory influence of vowels across consonant clusters. The results show that:
1/ Vowel formants are subject to noticeable variations as a function of the vowel’s quality and consonant’s place of articulation.
2/ Transition frequency onsets and shapes incur important modifications in relation to the consonant’s distinctive articulatory region.
A tentative explanation based on an acoustical-physiological mapping is proposed.

INTRODUCTION
The observation of tongue-to-palate contact patterns in stop sequences /VCCV/ by means of electropalatography [1] has provided information about the following points: consonantal coproduction, vocalic coproduction, double occlusion. As a preliminary investigation had revealed an important overlap between the burst frequency values for /l/ and /k/, an experiment was undertaken to describe the acoustical characteristics of the surrounding vowels and determine which types of coarticulation occur across consonantal clusters.

1. EXPERIMENTAL PROCEDURE
Five native speakers of French (three males and two females) recorded thirty-two natural sentences with the stop clusters /tk/ and /ktl/ at word boundary in symmetric and asymmetric vocalic contexts /i,a,u/. The resulting corpus was read five times by each informant at a normal speaking rate yielding (32 x 5 x 5) 800 tokens. The utterances were digitized and edited with Signaux Speech-Signal Processing Software [2]. The waveform was sampled at 16 KHz using a 12 bit A/D converter. The frequencies of the first three formants were semi-automatically extracted from LPC spectra at the onset, steady-state and offset of each segmented vowel. Moreover, the spectra and amplitude level of the consonantal bursts were measured as well as the relative timing of the articulatory gestures.

II. RESULTS
A. Vowel formants
1. Symmetric context
The effect of the consonantal environment on the vowels second formant is illustrated in Fig 1. The results show that vowel formants are prone to varying changes as a function of both the vowel’s quality and the consonant’s place of articulation.

![Fig 1: Effect of place of articulation of /CV/ on the F2 steady-state of /i,a,u/.](image)

Although a slight change in terms of a downward shift of F2 of /i/ is regularly observed from /k/ to /l/, the differences fail to reach a significance level; conversely in the sequence /tk/, F2 of /a/ is significantly higher close to /k/ and F2 of /u/ is higher close to /l/ in the sequence /ktl/. If we consider the F2 - F1 acoustical distance as a measure of the influence of the consonantal context (Fig.2), this difference proves also to be significant for both vowels and in particular for /a/ characterized by a low F1 in the /tk/ context.

Based on the articulatory data about consonant clusters in French [3], these acoustical differences may be explained if we consider the articulatory...
targets to be reached by the articulators from the consonant to the neighboring vowel and vice-versa.

![Graph showing F2 - F1 acoustic distance measured at vowel steady-state](image)

Fig. 2: F2 - F1 acoustical distance measured at vowel steady-state.

In the /i/ context, there is no systematic shift of F2 indicating that both /k/ and /t/ are palatalized and articulated in a not too distant region.

In the /a/ context, the vowel's configuration is thoroughly different as it is the tongue blade or the bulk of the tongue which is mainly activated during the production of the consonant. Close to /t/, the posterior part of the tongue remains in a low position; thus the vocal tract is rather open and the vowel's F1 (aver. freq.=667 Hz) is significantly higher than in the /k/ context (t=3.207, p<.008). In this latter context, as the occlusion occurs in the posterior part of the tract, the vowel's configuration is markedly closed with a noticeable widening of the pharyngeal passage corresponding to a lower F1 (aver. freq.=471 Hz) and a significantly higher F2 (t=2.813, p<.01). These acoustical data are consistent with those of Vaissière [4] who found a greater acoustical distance F2 - F1 for /a/ close to the velar consonant than close to the coronal consonant.

Lastly, in the back-vowel context /uktu/, there is a significant rise in the second formant of V2 (t=3.463, p<.01). This would suggest a forward displacement of the tongue body related to the front articulation of /t/. We have here a clear-cut case of carryover or left-to-right coarticulation of the consonant over the following vowel.

2. Asymmetric context

The extent to which the quality of a given vowel may influence the formant frequencies of the other vowel(s) was examined in various sequences, i.e. /akti/ vs /iktta/. The following observations were made:

1. From an acoustical point of view, V2 exerts a stronger influence on the preceding vowel than V1 on the following one. In other words, anticipatory coarticulation is stronger than carryover coarticulation.

2. In accordance with the results obtained in the previous section, this influence differs considerably from one vowel to another. In both consonantal clusters, the initial front vowel /i/ remains unaffected by a change in the final /a/ or /u/ vowel. This remark is in agreement with the earlier findings of Stevens and House [5] who showed that some vowel articulations are more stable than others.

3. There are slight but regular variations in the first formant of /a/ as shown by an overall downward shift from /i/ to /u/ (Fig. 3). Although these differences barely reach a significant level, they are nevertheless recurrent across all speakers. These data confirm the relevance of Fant's predictions who demonstrated through simulation, that a modification in the shape of the front resonator by displacement of the tongue body may influence F1 rather than F2, thus inverting the well-established formant-cavity relation [6].

4. Lastly, the effect of anticipatory coarticulation is peculiarly evidenced by the rise of F2 of /u/ as a consequence of the fronting of its articulation in the sequence /uktii/ as opposed to the other contexts, i.e. /uktii/ vs /uktka/, t=4.39, p<.001, and /uktii/ vs /uktuu/, t=2.40, p<.01.

![Graph showing first formant variations of /a/ (V1) as a function of V2](image)

Fig3: First formant variations of /a/ (V1) as a function of V2.

B. Formant transitions

Öhman [7] reported that the F2 transition onset of V1 varied according to the nature of V2 in a VCV utterance. As this influence occurs across a
own data and those of Mrayati et al. (11). As the point of occlusion or constriction is shifted back


ten to the lower compact F1 and F2 frequency onset was observed in our data. It was sometimes found in

declined F2 and F3 onsets (op. cit.) and supports the view that, in addition to the well-known schematized VCV transition patterns presented by Delattre [12], other possible transition patterns predicted by the eight regions model may be actually found in natural speech.

2. No invariant correlates of place of articulation were found in terms of fixed F2 and F3 transition onsets in contradistinction to the locus theory. Conversely, the frequency variations for /I/ and /k/ were quite large and mostly exceeded 500-700 Hz from /I/ to /u/ (Fig.4).

3. The transition slopes of F2 showed little evidence of any invariance. For /I/, they were either positive (/I/), flat (/a/), or negative (/u/) with considerable inter-speaker variability. For /k/ the predicted pattern of clustering F2 and F3 formants suggested by Delattre et al. [9] was not observed in our data. It was sometimes found in the /a/ context, but not in the /I/ (rising F2 and F3 transitions), nor in the /u/ context owing to the well-known low F2 onset (700-1000 Hz). These results from onset frequency measurements are in agreement with recently published data on French [10]. Instead of the F2 and F3 convergence for /k/,

a low compact F1 and F2 frequency onset was often observed across several speakers. Fig.5 shows a close correspondence between the schematized formant transitions drawn from our own data and those of Mrayati et al. [11]. As the point of occlusion or constriction is shifted back along the vocal tract, i.e. from region C to region D, the transition slopes change accordingly as a function of the concerned distinctive region, resulting in a compact F1 and F2 onset of /a/ close to the velar consonant. This finding is consistent with the theoretical considerations of Mrayati et al. (op.cit.) and supports the view that, in addition to the well-known schematized VCV transition patterns presented by Delattre [12], other possible transition patterns predicted by the eight regions model may be actually found in natural speech.

DISCUSSION

The results obtained in this study indicate that V to V coarticulatory effects may extend to the steady part of the vowel(s) across consonantal clusters. Moreover, they show that a vowel-dependent, anticipatory coarticulation prevails in French and seems to be most important for /I/. In that case, it can be assumed that /k/ and /I/ are both palatalized in a stop cluster. For /a/ and /u/, coarticulation effects do not stand out as clearly from the acoustical data as the coronal and posterior part of the tongue cannot act in these phonetic sequences as independent articulators. The articulatory vocalic continuum becomes contradictory with some gestures inherent to the consonant's production. These differences in articulatory gestures and activation pattern of the tongue body should reflect in the relative timing of the various events linked to the production of consonantal clusters. This point will be investigated in a forthcoming study.
REFERENCES


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