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Timing Constraints and Coarticulation: Alveolo-Palatals and Sequences of Alveolar + [j] in Catalan

Daniel Recasens

Haskins Laboratories, New Haven, Conn., USA

Abstract. General articulatory characteristics and V-to-C coarticulatory effects for alveolo-palatals [ɲ], [ʎ] versus sequences [nj], [lj] in Catalan VCV utterances have been measured at the point of maximum alveolar contact and over time by means of dynamic palatography. Data show that the amount of V-to-C coarticulation in tongue dorsum contact varies inversely with the duration of the temporal lag between the periods of alveolar closure and palatal closure. Results support the view that coarticulation is affected by contrasting timing constraints on articulatory activity.

Introduction

Phoneticians have characterized alveolo-palatals [ɲ] and [ʎ] as 'mouillé' or palatalized sounds based on a transitory perceptual effect of a [j] nature caused by the formation of a narrow dorsopalatal channel at the release [*Sweet,* 1877; *Grammont,* 1933; *Jones,* 1956; *von Essen,* 1957]. Moreover, they have argued that [ɲ] and [ʎ] contrast clearly with sequences composed of alveolars [n] and [l] followed by [j], thus, [nj] and [lj]. Such differentiation has been made on the following grounds:

(1) The [j] element is more auditorily salient in sequences than in alveolo-palatals for speakers of languages that contrast the two phonetic categories [*Rousselot,* 1912].

(2) Alveolo-palatals involve more linguopalatal contact than sequences [*Chlumský,* 1931].

The research reported here investigates the articulatory basis for these two differentiation criteria in Catalan in the light of data on articulatory dynamics collected by means of dynamic palatography. The use of dynamic palatography represents an improvement in comparison with the use of static palatography from which those criteria were derived. While dynamic palatography allows tracking changes in linguopalatal contact over time, static palatography allows only one recording of linguopalatal contact to be made at any stage of the total articulatory action. Therefore, it cannot show at what point in time during the release of alveolo-palatals versus sequences the [j] configuration occurs, nor whether alveolo-palatals involve more palatal contact than sequences along all the dynamic stages involved in their articulation or just at a particular moment in time.

First, this study argues that the articulatory differentiation between alveolo-palatals and sequences is brought about primarily by two contrasting timing strategies: while the periods of alveolar closure and palatal closure are produced quasi-simultaneously for alveolo-palatals, a considerable temporal lag occurs between the two periods for sequences. On the other hand, contrasting degrees of linguopalatal contact during alveolar closure and during palatal closure do not help to differentiate invariably between alveolo-palatals and sequences. Support for this hypothesis derives from an understanding of the diachronic process of palatalization that changed Latin clusters composed of alveolar + [j] to alveolo-palatals in Romance languages: the loss of temporal lag between alveolar and palatal closures involved, presumably, an anticipatory raising of tongue body with respect to tongue tip [*Haden*, 1938] with consecutive widening of tongue contact from the alveolar region towards the palatal area [*Bhat*, 1974; *Nandris*, 1952].

A second purpose of this study is to show that the contrasting timing strategies for alveolo-palatals and sequences cause contrasting coarticulatory effects to occur at the period of alveolar closure in VCV utterances. In particular, the following hypothesis was tested: the amount of V-to-C coarticulation in tongue dorsum activity during the period of alveolar closure varies inversely with the duration of the temporal lag between alveolar closure and dorsal closure. The following rationale underlies this hypothesis. Dorsopalatal [j] is, to a large extent, resistant to coarticulatory effects from the surrounding vowels [*Lehiste*, 1964; *Kent and Moll*, 1972; *Chafcouloff*, 1980; *Recasens*, 1984] according to the severity of the constraints imposed upon the tongue dorsum in the constriction gesture required for the production of the consonant. On these grounds, sequences of alveolar + [j] should show smaller coarticulatory effects than alveolo-palatals since the [j] configuration has a more independent status for sequences than for alveolo-palatals.

The present study illustrates how dynamic palatography can be used to analyze the temporal aspects of coarticulation in running speech [see, among other studies which have taken a similar approach, *Wolf* et al., 1976, and *Hardcastle and Clark*, 1981]. The spatial aspects of coarticulation at the moment of maximum linguopalatal contact for alveolo-palatal and alveolar consonants have been investigated in *Recasens* [1984].

Method

The artificial palate used in this study contains 63 electrodes evenly distributed over its surface and allows tracking linguopalatal dynamics over time (1 frame = 15.6 ms). Detailed information about this palatographic system (Rion Electropalatograph Model DP-01) is available in *Shibata* [1968] and *Shibata* et al. [1978].

The electrodes are arranged in five semicircular rows; for purposes of data interpretation, they have been grouped in articulatory regions and sides taking advantage of their equidistant arrangement in parallel curved rows on the artificial palate. As shown in figure 1, the surface of the palate has been divided into four articulatory regions (alveolar, prepalatal, mediopalatal and postpalatal) and two symmetrical sides (right and left) by a midsagittal line traced along the central range of electrodes. This division criterion established in terms of articulatory areas on the palatal surface is based on anatomical grounds (*Catford*, 1977).

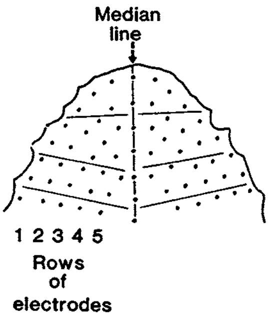

Fig. 1. Electropalate. (With permission from J. Phonet. *12:* 61–73, 1984, copyright by Academic Press Inc., London)

General articulatory characteristics and coarticulatory trends were studied for utterances composed of the vowels [i], [a], [u] arranged in all possible VCV combinations for alveolo-palatals [ɲ], [ʎ] and sequences [nj], [lj]. Sequences *[Vnji], *[Vlji], which would collapse with [Vni], [Vli] since they do not occur in Catalan, were excluded. It was decided to include sequences composed of V + [n, l] + [i] (for V=[i], [a], [u]) since, as for alveolo-palatals and sequences of alveolar + [j], they show a tongue dorsum raising gesture towards the palatal vault after the release of the alveolar closure.

A speaker (the author) of Catalan (a Romance language spoken in Catalonia, Spain) with the artificial palate in place recorded all utterances with [ɲ], [ʎ], [ni] and [li] 10 times, and those with [nj] and [lj] 5 times; repetitions were averaged for data interpretation. They were embedded in a Catalan frame sentence, 'Sap______poc' (He knows______just a little).

Differences in the size of linguopalatal contact and V-to-C coarticulatory effects were analyzed at the point of maximum alveolar contact (PMCA). For alveolo-palatals, PMCA happened to be always the frame in time with the largest amount of on-electrodes at any time in the VCV utterance (PMC). For sequences of alveolar + [j] and sequences of alveolar + [i], two possibilities had to be accounted for:

(1) PMCA coincides with PMC, as for alveolo-palatals.

(2) PMCA precedes PMC. PMC occurs after the release of the alveolar closure. PMCA shows less linguopalatal contact than PMC but still the largest number of on-electrodes during the period of alveolar closure.

Temporal differences in linguopalatal dynamics between the periods of closure at the alveolar region and the palatal region were also analyzed. For this purpose, alveolo-palatals, sequences of alveolar + [j] and sequences of alveolar + [i] were lined up according to the frame that shows maximum linguopalatal contact over the surface of the palate, namely, PMC.

Results

1. Point of Maximum Alveolar Contact

a. Degree of Linguopalatal Contact

Figure 2 shows the linguopalatal configuration at PMCA for alveolo-palatals and sequences of alveolar + [j] in symmetrical environments, except for *[inji] and *[ilji]. Sequences composed of V + [n, l] + [i] are also included for comparison. Tongue contact is represented by the area between the contour lines and the sides of the palate; the area where there is no contact is medial to the contour lines.

To determine the trajectory of each contour line the number of occurrences of linguopalatal contact for each electrode in each row was averaged across repetitions of the same utterance. Contour lines connect averages of contact for electrodes showing less than an average of 100% of occurrences; for this purpose, the distance between two adjacent electrodes in the same row in figures 2 through 7 represents an average of 100% of occurrences across repetitions for the frontmost of the two electrodes. Thus, in figure 2, all repetitions of [anja] show contact for all electrodes in row 1 (100% of occurrences); in row 3 only the four backmost electrodes show 100% of oc-

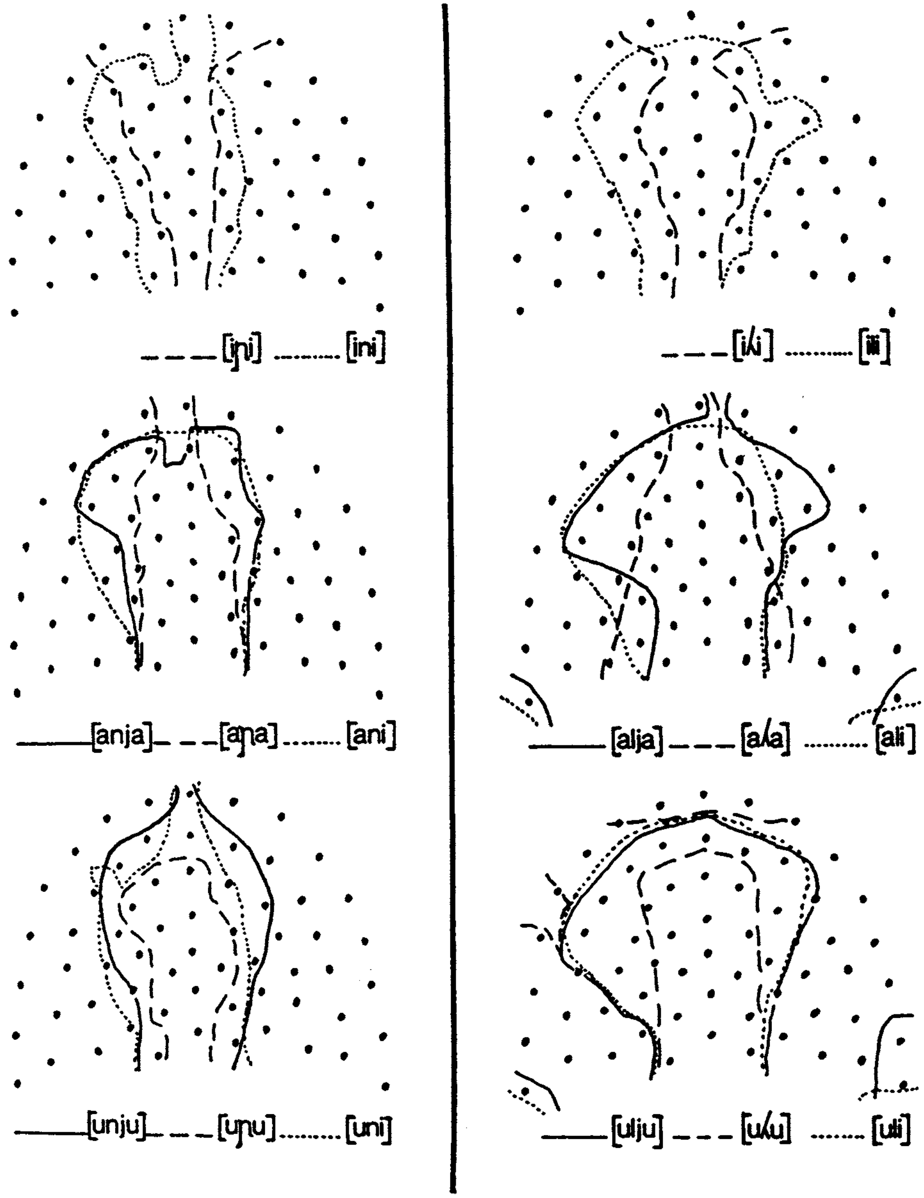

Fig. 2. Linguopalatal patterns at PMCA for alveolo-palatals [ɲ], [ʎ] and sequences [nj], [lj] in symmetrical environments, and for sequences [Vni], [Vli]. They have been plotted simultaneously for comparison.

currences on the right and left sides of the palate while the preceding electrode shows 20% of occurrences (left side of the palate) and 80% of occurrences (right side of the palate); in row 5, no contact was observed for any electrode in any repetition.

It can be observed that sequences of alveolar + [j] and alveolo-palatals show alveolar contact to be more fronted for sequences (using the tongue tip for contact) than for alveolo-palatals (using the tongue blade for contact). Thus, contact occurs only at the periphery of the alveolar region (row 1) for sequences but also in row 2 for alveolopalatals. Behind the alveolar region, a larger central cavity all along the midsagittal line is found for sequences versus alveolo-palatals, except for the postpalatal area where linguopalatal contact can be the same for the two categories (for [anja) versus [aɲa] and for [ulju] versus [uʎu]) or even larger for sequences than for alveolo-palatals (for [alja] versus [aʎa]). Contact for sequences of alveolar + [j] and sequences of alveolar + [i] is highly similar at all articulatory regions: the two show a large alveolo-prepalatal cavity behind the alveolar closure and some narrowing of the constriction towards the rear of the palate due to coarticulation of tongue dorsum activity with the following palatal articulations [j], [i]. Moreover, lateral airflow occurs through postpalatal slits at both sides of the palate for sequences [alja], [ulju], [ali] and [uli], but through a prepalatal slit on the left side for [ʎ] (only for V = [u]). (Since no lateral slits occur for utterances with a lateral consonant in the context [iCi], it is suggested that airflow takes place along a lateral channel between the teeth and the cheeks only.) Figure 2 also shows that the equivalent [ini], [ili] of the nonoccurring sequences *[inji], *[ilji] present, as expected, less contact than [iɲi], [iʎi] all over the palatal surface.

In summary, at PMCA sequences of alveolar + [j] are produced similarly to sequences of alveolar + [i] and present less linguopalatal contact than alveolo-palatals when the whole surface of the palate is taken into consideration. However, this relation does not necessarily hold when each articulatory region is accounted for separately. In particular, the degree of contact at the rear of the palate can be larger, smaller or the same for alveolo-palatals versus sequences.

b. Coarticulatory Activity

Figure 3 shows the linguopalatal configuration at PMCA separately for alveolo-palatals and sequences of alveolar + [j] in symmetrical VCV environments. It allows the analysis of coarticulatory effects from the surrounding vowels upon tongue dorsum activity at PMCA when V1=V2. The nonexistent symmetrical sequences *[inji], *[ilji] have been replaced by [ini], [ili].

For [ɲ], the mediopalatal and postpalatal passage shows maximal narrowing for high vowels [i] and [u], and a larger opening for low vowel [a]; thus, the tongue dorsum appears to be sensitive to tongue lowering (as for [a]), but not to tongue backing (as for [u]) [*Recasens*, 1984]. For [ʎ], differences in size of the mediopalatal and postpalatal passage are found for high front [i] (narrowest) and low [a] (largest), high back [u] falling in between; thus, tongue dorsum placement during the production of [ʎ] appears to be sensitive to degrees of tongue backing as well as tongue lowering in the adjacent vowels [*Recasens*, 1984]. For sequences with [j] and [i], very small effects are found from the surrounding vowels in the degree

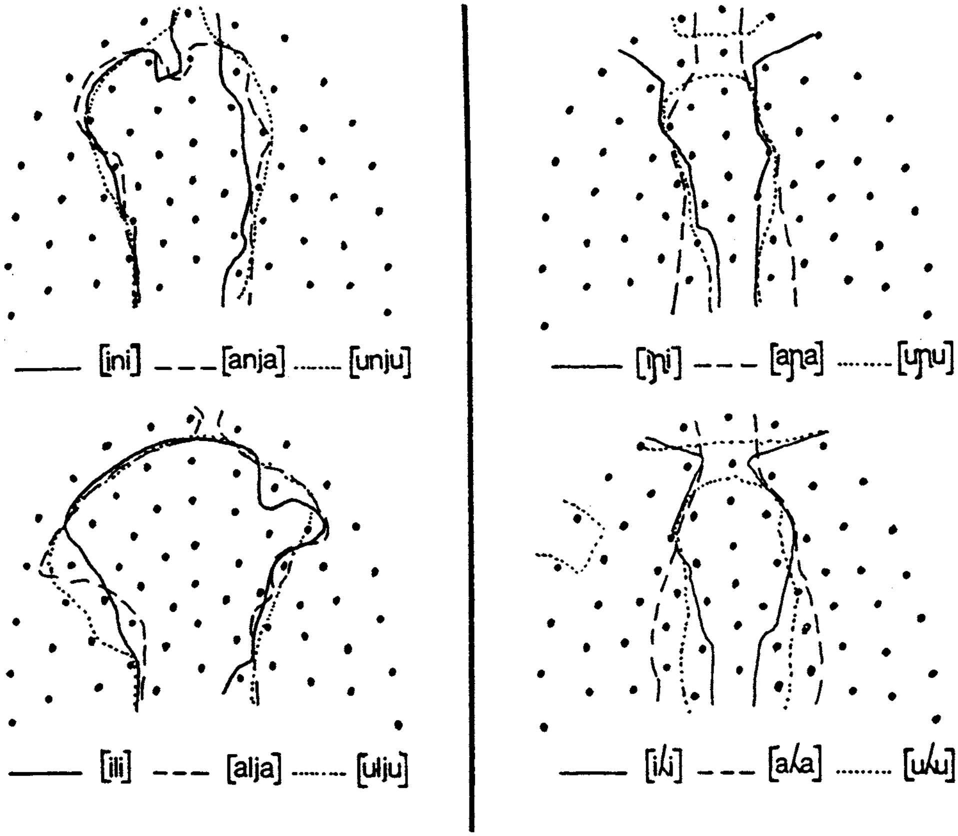

Fig. 3. Coarticulatory effects at PMCA for sequences of alveolar [n, l] + [j, i] (left) and alveolo-palatals [ɲ], [ʎ] (right) in symmetrical environments.

of contact at the mediopalate and postpalate.

Therefore, at PMCA tongue dorsum activity is far more sensitive for alveolo-palatals than for sequences to changes in articulatory configuration caused by the same surrounding vowels. No direct relationship occurs between such coarticulatory effects and differences in degree of contact at the rear of the palate which can be larger, smaller or the same for alveolo-palatals versus sequences of alveolar + [j] (see section 1a).

Figures 4 through 7 show coarticulatory effects at PMCA for alveolo-palatals and sequences in asymmetrical vocalic environments. Anticipatory effects (from V2) and carry-over effects (from V1) in contact size at the rear of the palate are reported below.

Anticipatory effects in degree of mediopalatal and postpalatal contact are very small or nonexistent for the two phonetic categories. In any case, effects for alveolo-palatals are larger than effects for sequences. Thus, as shown in figure 4, contrasting degrees of midsagittal opening are

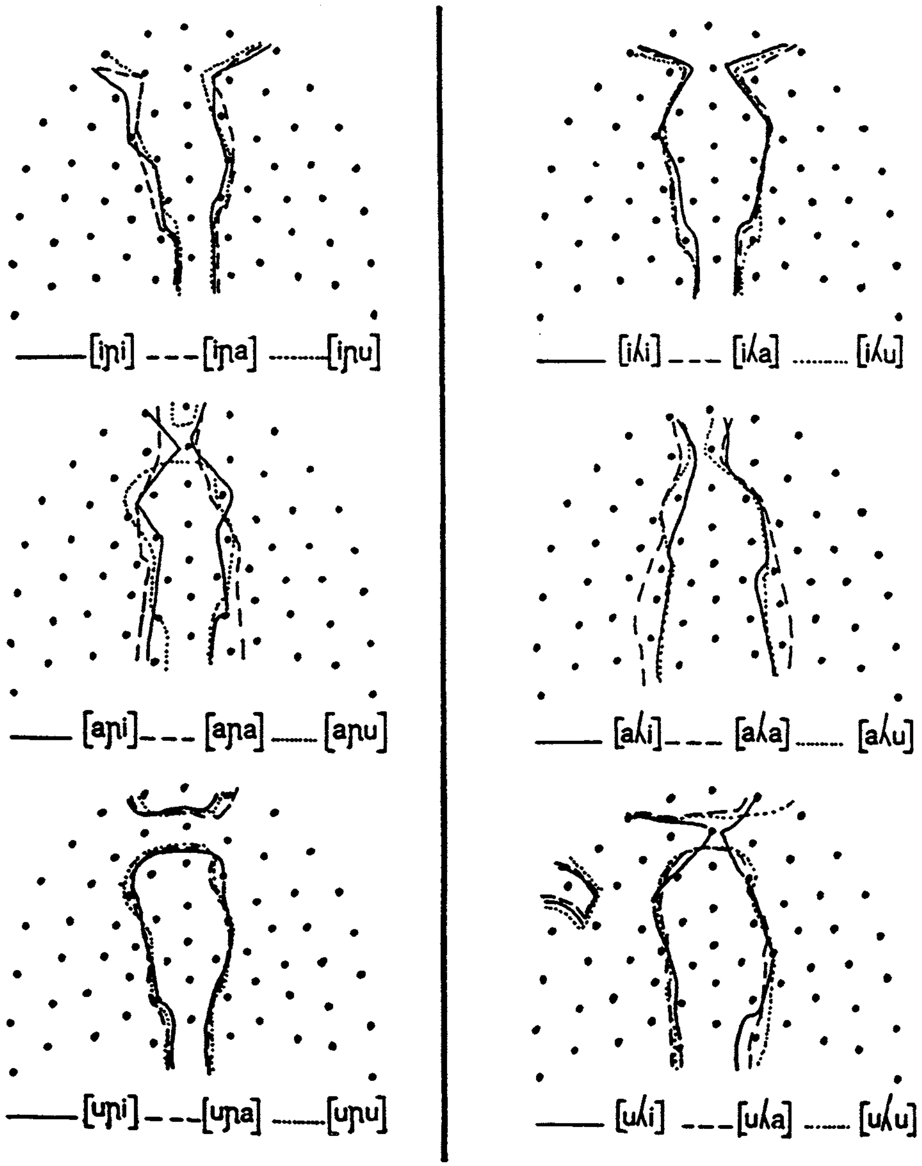

Fig. 4. Anticipatory effects at PMCA for alveolo-palatals [ɲ] (left) and [ʎ] (right).

found for alveolo-palatals for V2 = [a] (larger) versus [i], [u] (smaller) when V1 = [a] (see mid row panels) [*Recasens,* 1984]. According to figure 5, effects for sequences with [j] are very small (mainly for utterances with V1 = [i], [u]) and nonsystematic (mainly for utterances with V1 = [a], for which, contrary to the general expectations,

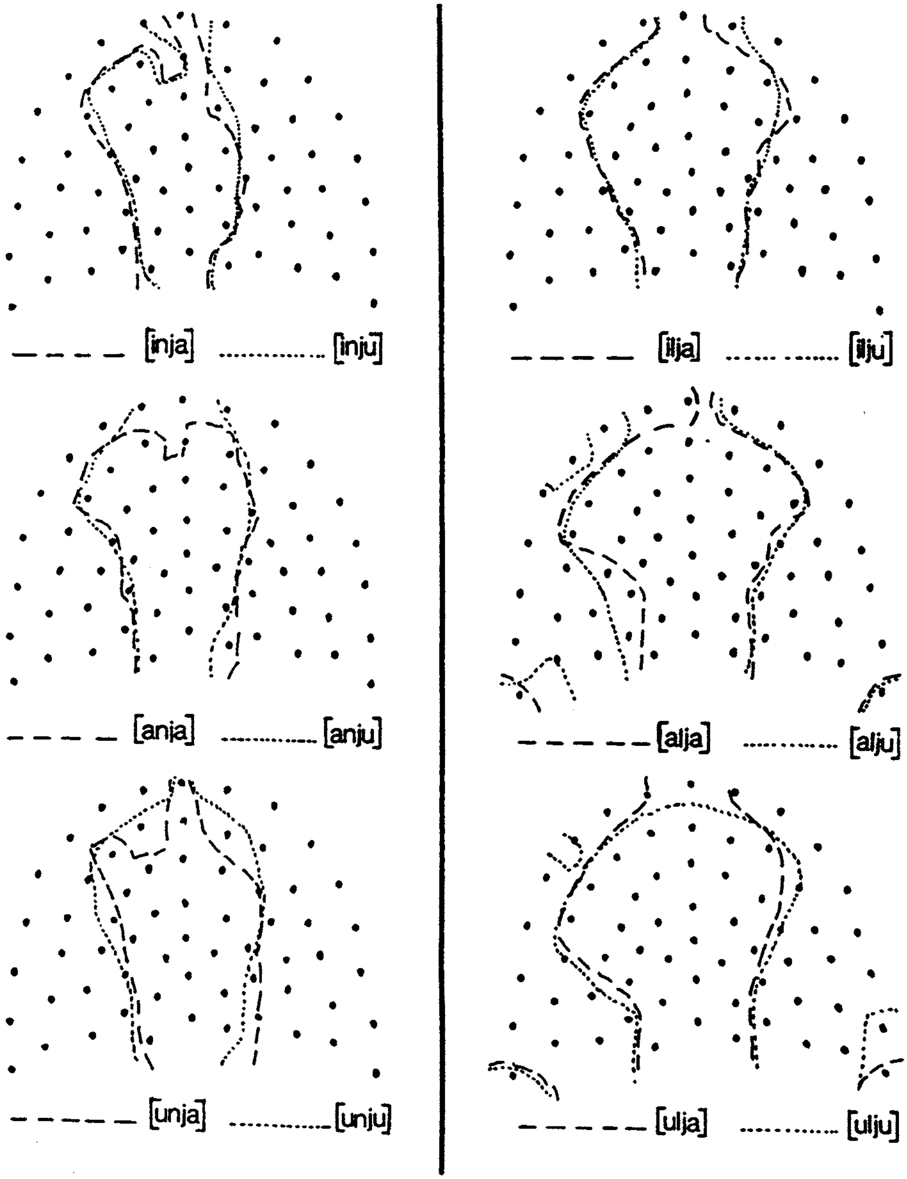

Fig. 5. Anticipatory effects at PMCA for sequences [nj] (left) and [lj] (right).

the midsagittal opening at the palatal region is larger for V2 = [u] versus [a] when C = [lj]).

Carry-over effects in degree of mediopalatal and postpalatal contact are found for alveolo-palatals (fig. 6), more so for [ʎ] than for [ɲ]: for [ɲ] (left column), a preceding low vowel causes less mediopalatal and

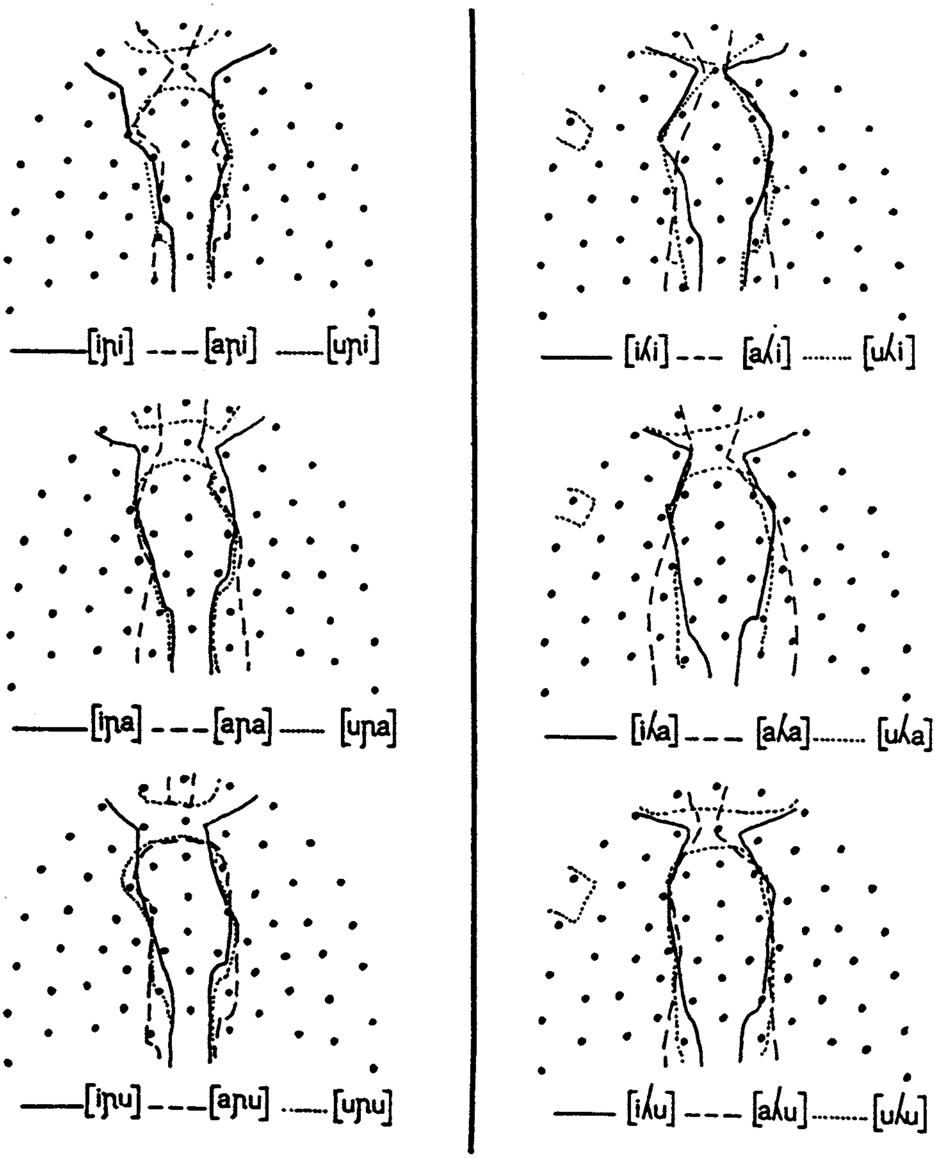

Fig. 6. Carry-over effects at PMCA for alveolo-palatals [ɲ] (left) and [ʎ] (right).

postpalatal contact than a preceding high vowel; for [ʎ] (right column), V1-dependent differences in contact size are found for V1 = [i] (largest contact), [a] (smallest contact) and [u] (in between) [*Recasens,* 1984]. For the two sequence types, namely, alveolar + [j] and alveolar + [i] (fig. 7), carry-over effects in degree of contact at the rear of the

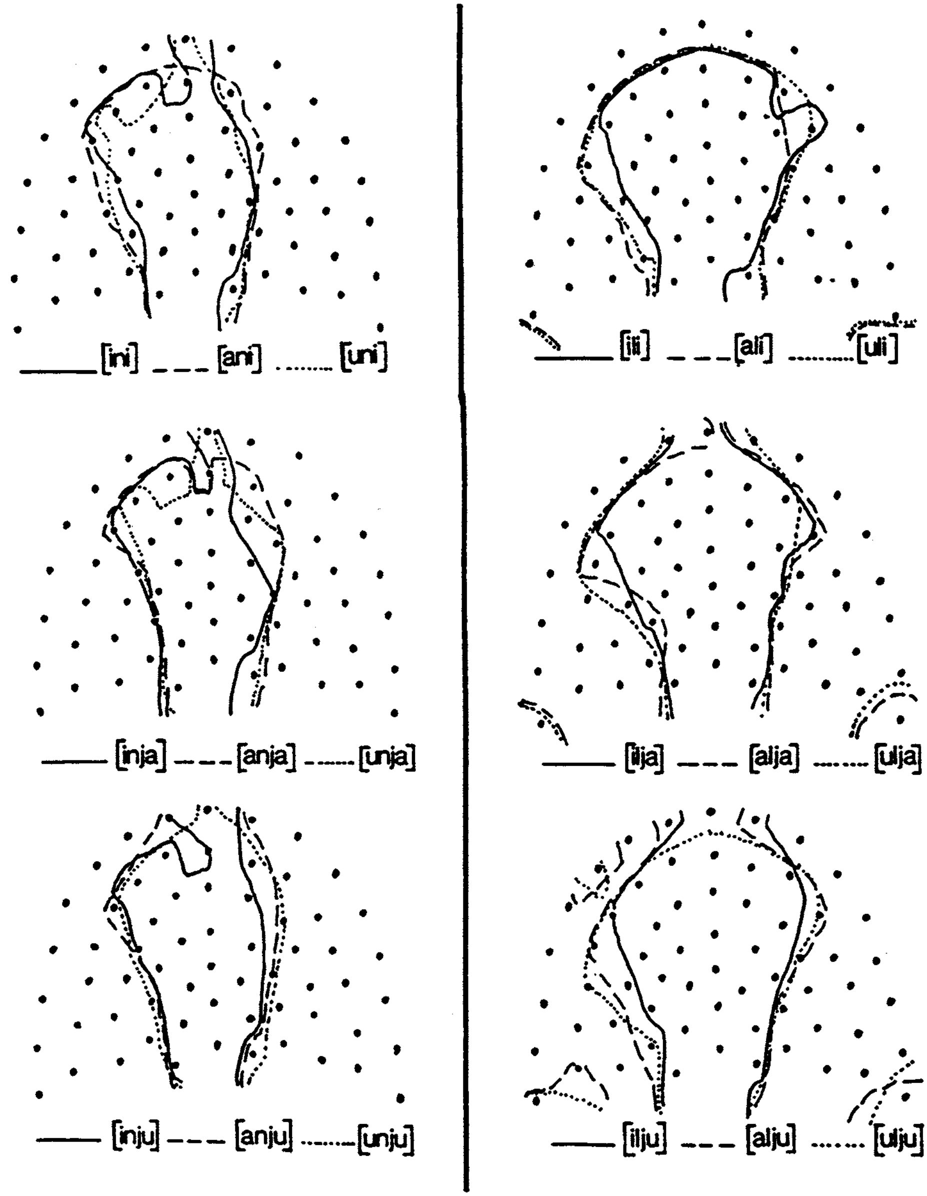

Fig. 7. Carry-over effects at PMCA for sequences [nj], [ni] (left) and [lj], [li] (right).

palate are generally very small, the contact being slightly larger for [i] than for [a], [u].

Therefore, at PMCA alveolo-palatals show larger anticipatory and carry-over effects in degree of contact at the mediopalate and postpalate than sequences of alveolar + [j], which, in their turn, behave similarly to sequences of alveolar + [i]. As for coarticulatory effects in symmetrical vocalic environments, contrasting coarticulatory effects for alveolo-palatals and sequences of alveolar + [j] in asymmetrical vocalic environments are largely independent of differences in degree of contact at the rear of the palate which can be larger, smaller or the same for alveolo-palatals versus sequences (see section 1a).

2. Dynamics

Dynamic palatography allows the analysis of the relative timing of alveolar closure and palatal closure and, thus, the test of the hypothesis that the interval between them should be shorter for alveolo-palatals than for sequences with [j].

Figures 8 and 9 show linguopalatal dy-

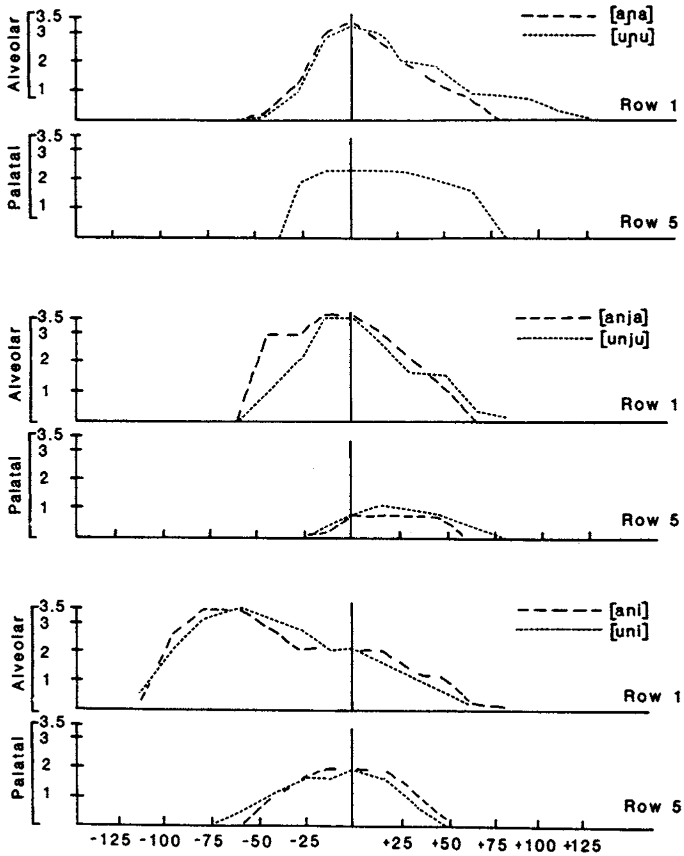

Fig. 8. Linguopalatal patterns over time (ordinate: contact placement; abscissa: time in milliseconds) for [ɲ] (top) and [nj] (middle) in symmetrical environments, and for [Vni] (bottom). The line-up point is at PMC.

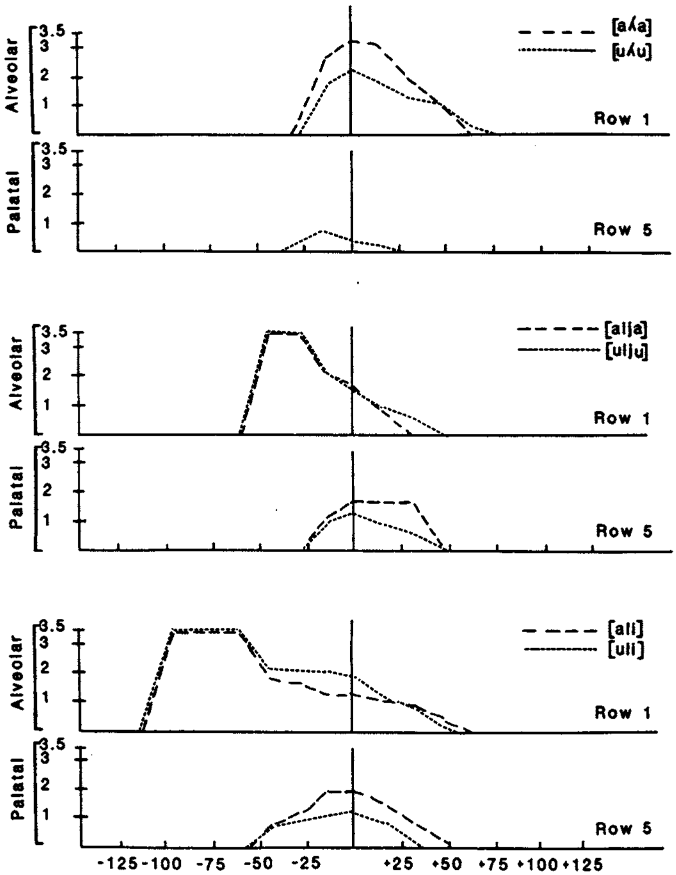

Fig. 9. Linguopalatal patterns over time (ordinate: contact placement; abscissa: time in milliseconds) for [ʎ] (top) and [lj] (middle) in symmetrical environments, and for [Vli] (bottom). The line-up point is at PMC.

namics for alveolo-palatals (uppermost panels) and sequences of alveolar + [j] (mid panels) in symmetrical environments with V= [a], [u]. Linguopalatal dynamics for sequences [Vni] and [Vli] (lowest panels) have also been included for comparison. The line-up point is at PMC. Each panel provides data on contact for the right side of the palate at the periphery of the alveolar region (row 1, fig. 1) versus the central area of the mediopalatal and postpalatal regions (row 5, fig. 1) over time in milliseconds (horizontal axis). Data have been displayed for one side of the palate only since contact on the two sides (right and left) showed a highly symmetrical configuration for all utterances under study. Contact data (vertical axis) are given on an electrode-by-electrode basis starting from the backmost electrode (numbered 1 in the figure) up to the frontmost one (numbered 3.5). Thus, the curve for each time sample represents where the frontmost electrode was located within the pertinent row that showed contact. The electrodes behind this electrode have been found always to show contact in the data under discussion. The frontmost electrode of our artificial palate has been counted as

.5 since it is placed in the midsagittal plane (fig. 1).

For alveolo-palatals, the peak of alveolar contact (row 1) and the peak of palatal contact (row 5) are achieved simultaneously at PMC (as in [uɲu] of fig. 8), or else (as in [uʎu] of fig. 9), the peak of palatal closure can be achieved around 15 ms before the peak of alveolar closure (which is always at PMC). For sequences of alveolar + [j], the onset of maximum alveolar closure can occur between −15 and −45 ms while that of maximum palatal closure is found between 0 and + 15 ms. While alveolo-palatals show no temporal lag between the two peaks, a temporal lag of 15 – 45 ms occurs for sequences ([anja] 15 ms, [unju] 30 ms, [alja] and [ulju] 45 ms). For alveolars followed by [i], the onset of maximum alveolar closure occurs between −60 and −95 ms and that of maximum palatal closure between 0 and −15 ms. Thus, a temporal lag of 60 – 95 ms occurs for sequences with [i] ([ani] and [uni] 60 ms, [ali] 80 ms, and [uli] 95 ms).

Figures 8 and 9 also provide information about the degree of contact at the center of the mediopalate and postpalate associated with the [j] component. The data show that the peak of tongue dorsum activity is larger for sequences with [j] than for alveolo-palatals when laterals and nasals with [a] are taken into account; however, the opposite trend is observed for nasals with [u]. Sequences with [i], on the other hand, show a high peak of tongue dorsum activity in all environments, analogous to or higher than that for alveolo-palatals and sequences with [j].

In summary, while alveolo-palatals show nearly simultaneous peaks of alveolar and palatal contact, sequences show a lag of the palatal contact, which is larger for sequences of alveolar + [i] than for sequences of alveolar + [j]. Moreover, tongue dorsum raising activity at the release as indicated by the peak of palatal contact is greater for sequences with [i] than for sequences with [j], and generally but not always larger for sequences with [j] than for alveolo-palatals.

Discussion and Conclusions

During alveolar closure in alveolo-palatals, two commands are being actualized: tongue-blade occlusion and tongue dorsum raising. As a result of this synergistic activity, a large degree of contact is obtained over the entire surface of the palate. The tip of the tongue is lowered and makes contact with the low incisors as determined by introspection. During alveolar closure in sequences with [j], only one command is actualized: tongue tip occlusion, as indicated by introspection and by the fact that contact at the alveolar region for sequences is generally more fronted than for alveolo-palatals (see section 1a). The tongue dorsum can be said to coarticulate with [j], as shown by a progressive increase in contact towards the rear of the palatal region, analogously to sequences with [i]. The tongue blade shows contact only at the sides of the palate, thus leaving a large central cavity at the front of the palatal region. The degree of contact turns out to be invariably larger for alveolo-palatals than for sequences with [j] when the overall surface of the palate is taken into consideration, but not necessarily with respect to each articulatory region taken separately. Thus, as shown in section 1a, contact at the rear of the palate can be larger, smaller or the same for alveolo-palatals versus sequences.

During palatal closure or approximation, the two consonantal types share an articulatory command for tongue dorsum raising. For alveolo-palatals, this command is actualized together with the command for tongue blade occlusion; for sequences with [j], it is actualized by itself at some temporal lag after alveolar closure. The degree of dorsal contact at the period of palatal closure is generally but not always larger for sequences than for alveolo-palatals. It can be smaller with [u], an articulation that, as for the glide component of the sequences, involves tongue dorsum activity as well.

An interpretation for this set of data supports the hypothesis that presence versus absence of a temporal lag between alveolar closure and palatal closure is a highly systematic characteristic used by the speaker when actualizing alveolo-palatals versus sequences with [j]. Spatial constraints with respect to the degree of linguopalatal contact can be said to act as secondary articulatory traits in the task of differentiation between the two phonetic categories. Thus, the rule of temporal organization, but not differences in degree of linguopalatal contact, helps to differentiate between alveolo-palatals and sequences independent of the quality of the adjacent vowel. On these grounds, the formation of alveolo-palatals in Romance languages from Latin sequences with [j] can be explained as a result of the loss of the temporal lag between alveolar and palatal articulations and, therefore, the acquisition of a new rule of temporal organization that generates the two simultaneously.

Coarticulation data reported in this study can be summarized as follows: Alveolo-palatals show coarticulatory effects at the PMCA in symmetrical and asymmetrical vocalic environments; carry-over effects are larger than anticipatory effects. Coarticulatory effects for sequences with [j] are very small and nonsystematic, analogously to sequences with [i]. These contrasting coarticulatory effects can be explained with reference to the temporal principles involved in the tongue dorsum raising gesture during the production of alveolo-palatals versus sequences. Accordingly, less coarticulation for sequences than for alveolo-palatals indicates that the palatal articulation needs to be less precise when simultaneous with alveolar contact (for alveolo-palatals versus sequences). As a result of this contrasting articulatory mechanism, while the temporally independent [j] component in sequences blocks effects from V1 and V2, the tongue dorsum during the production of alveolo-palatals is freer to coarticulate with the surrounding vowels. Palatographic evidence for differences in articulatory precision in line with differences in coarticulatory activity has been reported in the literature. Thus, *Wolf* et al. [1976] and *McCutcheon* et al. [1980] have shown that different vowels have little effect on the minimum groove width at the alveolar and post-alveolar regions of the palate during the production of [s]; this finding supports the view that the tongue tip positioning has a high degree of precision and consistency for the production of [s] in different contexts [see, also, for cineradiographic evidence, *Subtelny* et al., 1972]. Data reported here show that requirements on articulatory precision of tongue dorsum raising for sequences of alveolar + [j] versus alveolo-palatals are correlated with differences in articulatory timing between different articulatory events (alveolar contact and tongue dorsum raising); thus, precision increases with temporal independence for the [j] component. It is believed that this is a good example of the use of contrasting principles of spatiotemporal coordination during the execution of different articulatory gestures for purposes of phonological differentiation.

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Daniel Recasens,
Haskins Laboratories,
270 Crown Street,
New Haven, CT 06511 (USA)