An Electropalatographic Investigation of Segmental Complexity in Alveolopalatal Consonants

Daniel Recasens,[1] Jordi Fontdevila[2] and Maria Dolors Pallarès[2]

[1] Universitat Autònoma de Barcelona and Institut d'Estudis Catalans

[2] Institut d'Estudis Catalans

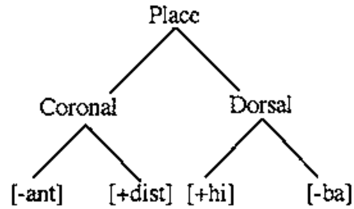
Electropalatographic data on Catalan [ɲ] and [j] indicate the convenience to distinguish at least two articulatory classes of high dorsal consonants (excluding velars), i.e., alveolopalatals and palatals proper. Lingual contact at the medio postpalatal zone is less extensive and more variable for [ɲ] than for [j], which suggests that the tongue dorsum is activated for the latter consonant but not for the former. It is claimed that the presence of a large extent of contact behind the alveolo-prepalatal zone and a [j]-like configuration at closure offset is not indicative of the presence of a dorsal gesture for [ɲ] but results from mechanical effects. This view suggests that alveolopalatals are not complex segments (produced with a tongue blade gesture and a tongue dorsum gesture) but simple segments (produced with the blade and the predorsum at the alveolo-prepalatal zone). Phonetic and phonological processes involving the consonants into consideration can be explained assuming their non-complex status.

1. Introduction

According to Chomsky & Halle (1968), the commonly called palatal articulations [ɲ] (as in Italian *bagno* 'bath'), [ʎ] (as in Italian *battaglia* 'battle'), [c] (Czech *mat'* 'mother'), [ç] (German *ich* 'I') and [j] (English *yes*) are specified for the features [-ant], [-cor] and [+hi]. This feature specification is consistent with the assumption that all these consonants belong to the same articulatory category, and are produced with a dorsopalatal closure or constriction and a neutral tongue blade position (Catford (1977)).

Catalan Working Papers in Linguistics (CatWPL) 3.2 (1994): 71-96
Universitat Autònoma de Barcelona

In Keating's opinion (Keating (1988, 1991)), palatals are complex segments and should be represented with two Articulator Nodes as follows:



The rationale for articulatory complexity in this case is twofold. These productions involve simultaneous activity of two different articulators, namely, the tongue blade (which is responsible for the formation of a primary postalveolo-prepalatal closure or constriction), and the tongue dorsum (which is actively raised as for palatalized consonants). The presence of two simultaneous articulatory gestures would explain why these consonants often show a large degree of linguopalatal contact along the palatal zone.

Several phonologists (Avery and Rice (1989); Lipski, (1989); Lahiri and Evers, (1991)) have also advocated the complex status of [ɲ], [ʎ] and [c] in view of existing phonological processes relating these consonants to alveolars, to the approximant [j], or to sequences of both. Those processes are:

(a) Segmental coalescence. Example: [nj] > [ɲ] (Latin CUNEAM 'kitchen' becomes ['kuɲa] in Spanish).
(b) Segmental decomposition. Example: [ɲ] > [ĭn] (/áɲ##bɔ/ 'good year' is realized [aĭm'bɔ] in Majorcan Catalan).
(c) Segmental reduction. Examples: [ɲ] > [n] (alternation ['an] 'year' - [a'ɲara] 'yearly period' in Alguerese Catalan) and [ɲ] >[ĭ] (Latin IUNIUS 'june' becomes *jui* in Friulian).

Two controversial issues need to be addressed concerning the analysis presented so far, namely, whether all these consonants form a single articulatory class and whether they are complex or simple segments.

First, there are reasons to believe that palatals can be classified at least in two categories: alveolopalatals, with a lamino-predorsal closure or constriction at the back alveolar zone and at the front palatal zone, and palatals proper, with a dorsal closure or constriction along the palatal zone. Stops such as [c] (in Hungarian and Czech) and [ɲ] (in Hungarian, Czech, Catalan and Italian) usually belong to the former category but may belong to the latter (in Ibibio); the approximant [j] appears to be alveolopalatal in some languages (in Czech) but palatal in others (in Catalan and Hungarian) (Recasens (1990); Connell (1992); Keating and Lahiri (1993)).

Second, contrary to Keating's proposal, phoneticians in the Romance languages domain (French: Rousselot (1924-25); Roudet (1910); Spanish: Navarro Tomás (1972); Czech: Straka (1965)) have advocated the view that alveolopalatals [ɲ], [ʎ], [c]... are simple, non-complex segments involving a single lamino-predorsal gesture. Experimental evidence for this can be found in Recasens (1990). In the first place, it is not clear that two contiguous tongue articulators (i.e., tongue blade and tongue dorsum) can act independently in consonantal production. Instead, tongue dorsum raising for alveolopalatals may not be actively controlled but subject to coupling effects: raising the blade and the predorsum for the formation of an alveolo-prepalatal articulation results in a concomitant raising of more posterior tongue dorsum regions. This argument is validated by laminal consonants also exhibiting a higher tongue body position than apicals in line with the former consonantal class involving a larger and more posterior contact surface at the place of articulation than the latter (Dart (1991)). Therefore, the presence of a large dorsopalatal contact area for alveolopalatals is not necessarily indicative of segmental complexity, since the actual tongue region subject to active control may still be quite reduced. In fact, as suggested in section 2.4.1, an increase in overall contact size may result from an increase in the degree of contact pressure at a localized area of the tongue rather than from an extension of or a change in the actual place of articulation.

Consistently with this hypothesis, we have claimed elsewhere (Recasens, Fontdevila and Pallarès, in press) that the phonological processes pointed out above (namely, segmental coalescence, segmental decomposition and segmental reduction) can be accounted for assuming that alveolopalatals are simple, non-complex consonants. In our view, the coalescence process [nj] > [ɲ] originates from spatiotemporal overlap between the apical gesture for [n] and the tongue dorsum gesture for [j] (also Recasens (1984)); its output realization is produced with a single, intermediate lingual region, and may acquire phonemic status as a simple segment. The decomposition process [ɲ] >[in] results presumably from listeners assigning segmental status to the [j]-like acoustic formant transitions associated with the consonantal gesture in prepausal position. The failure to achieve complete closure in reduced realizations of [ɲ] may serve to explain the segmental reduction process [ɲ] > [ĩ].

This paper investigates whether [ɲ] should be treated as a simple or as a complex segment based on lingual contact data. It complements some data on lingual movement trajectories for Catalan [ɲ] recently collected at Haskins Laboratories using the electromagnetic midsagittal articulometry technique (EMMA). In this experiment, the tongue blade and the tongue dorsum were found to achieve and release the closure period highly simultaneously (Recasens and Romero, submitted). Had the consonant been produced with two independent gestures, tongue dorsum maximum displacement would have occurred significantly later than tongue blade maximum displacement. In fact, this was the outcome for a true complex segment analyzed in the same experiment, i.e., the Russian palatalized alveolar consonant [nʲ]. These EMMA data indicate quite convincingly that [ɲ] should not be treated as a complex articulation.

2. Experimental evidence

2.1. General methodology

In order to investigate articulatory complexity in [ɲ], electropalatography (EPG) was used to collect data on lingual contact over time for the symmetrical sequences [VɲV] and [VjV] with vowels /a/ and /u/ and stress on the first syllable. Five Catalan speakers from the Eastern dialect

(DR, JP, JS, JC and DP) repeated those sequences five times each within the Catalan carrier sentence 'Digues ___' ('Say ___'). V2 was realized as [ə] since Catalan /a/ undergoes systematic vowel reduction in unstressed position. The consonant /ɲ/ has phonemic status in the Catalan language, as revealed by minimal pairs such as /'kamə/ *cama* ('leg') - /'kaɲə/ *canya* ('cane') and /'ban/ *ban* ('edict') - /'baɲ/ *bany* ('bath').

The Reading electropalatographic system was used in the recording session (Hardcastle, Jones, Knight, Trudgeon and Calder (1989)). As shown in Figure 1 (above), the artificial palate is equipped with 62 electrodes arranged in eight horizontal rows (R1,..., R8) and four vertical columns on each half of the palatal surface (C1,..., C4). The alveolar zone includes the 4 front rows and the palatal zone includes the 4 back rows; the distance between adjacent rows is much smaller at the former zone than at the latter. The figure also shows the articulatory subdivisions on the tongue surface (on an X-ray configuration; below) and on the palatal surface (both on a palatographic and on an X-ray configuration; above and below, respectively). This EPG system displays one pattern of contact every 5 ms.

The consonantal time span was identified between closure onset and closure offset for [ɲ], and between onset and offset of the maximal constriction at the place of articulation for [j].

2.2. *Articulatory characteristics*

Linguopalatal configurations at the period of maximum contact or constriction (PMC) for [ɲ] and for [j] are shown in Figures 2 and 3 (speakers DR, JP and JC).

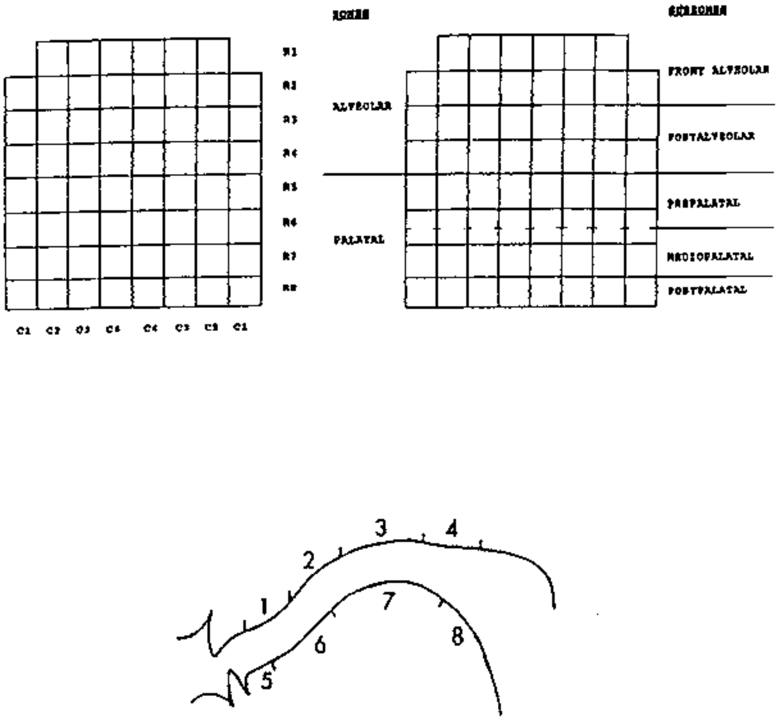


FIGURE 1. (Top left) Distribution of rows R1 through R8 and of columns C1 through C2 on both sides of the electropalate. (Top right) Articulatory zones and subzones on the electropalate. (Bottom) Vocal tract representation with articulatory zones and subzones, and tongue regions: (1) alveolar, (2) prepalatal, (3) mediopalatal, (4) postpalatal, (5) tongue blade, (6) predorsum, (7) mediodorsum, (8) postdorsum.

A comparison between the two consonants reveals that they are produced with different places of articulation. For all speakers, the consonant [ɲ] is articulated with central contact extending along the postalveolar and the prepalatal zone; it is thus alveolopalatal. On the other hand, maximum constriction location for the approximant [j] (and thus its place of articulation) occurs at the medio-postpalatal zone in Catalan; this realization is thus palatal. The presence of a large contact area at the palatal zone for [ɲ] does not allow inferring whether this consonant is simple or complex; as stated in section 1, it could be either associated with an active dorsal gesture or caused by coupling effects. On the other hand, the absence of alveolar contact for [j] is highly consistent with its simple, non-complex status: during the production of this Catalan consonant, the tongue blade is down and does not intervene in the formation of the constriction.

In summary, inspection of the linguopalatal configurations at PMC for the two Catalan consonants under study does not allow drawing any conclusions regarding the complex or simple nature of alveolopalatal [ɲ]. Moreover, it appears that [j] is not an alveolopalatal but a palatal consonant, and a simple, non complex segment. These data are in agreement with the differentiation between alveolopalatals and palatals presented in the Introduction section.

2.3. Testing segmental complexity for [ɲ]

In view of the articulatory characteristics of [j] described in section 2.2, the linguopalatal configuration for this consonant was taken as indicative of an active dorsal gesture. Catalan appears to be a suitable language to study articulatory complexity in alveolopalatals given that [j] is a truly palatal consonant whose medio-postpalatal place of articulation does not overlap the place of articulation for alveolopalatal consonants. Therefore, a comparison between the linguopalatal contact data for [ɲ] and for [j] at the medio-postpalatal zone should provide relevant information about the presence or absence of a dorsal gesture in the former consonant. Given this assumption, the following hypotheses were submitted to experimental analysis:

(a) If [ɲ] is complex and thus produced with two active lingual gestures (dorsal and laminal), the extent of contact at the medio-postpalatal zone could be either the same as that for [j] or larger than that for [j].

The first possibility assumes that there is little coupling between the tongue dorsum and the tongue blade during the production of [ɲ]. Thus, if the articulatory manifestation of the tongue dorsum gesture is barely affected by tongue blade activity, lingual contact at the palatal zone ought to be highly analogous to that for [j]. This outcome is not too plausible, since the raising of the tongue blade and predorsum for the formation of a postalveolo-prepalatal closure should cause some concomitant raising of more posterior togue dorsum regions.

A larger medio-postpalatal contact area for [ɲ] than for [j] implies the existence of strong coupling effects between tongue blade and tongue dorsum. Such effects would cause additional tongue dorsum raising (and thus an increase in palatal contact size) to that required by the dorsal gesture itself. As stated above, this outcome is quite reasonable since it assumes the existence of articulatory coupling effects between adjacent tongue regions.

(b) Less medio-postpalatal contact for [ɲ] than for [j] appears to be a good indicator of the former consonant not involving a dorsal gesture.

The absence of a dorsal gesture means that tongue dorsum raising in this case is exclusively due to coupling and thus, not subject to active control.

It could be argued that [ɲ] may show lesser dorsopalatal contact than [j] while being a complex segment and thus produced with an active dorsal gesture. This would be so if the dorsopalatal constriction for a complex alveolopalatal consonant acted as a secondary articulation, since a secondary dorsal constriction could conceiveably be wider than a primary one. However, coupling effects for alveolopalatals would render this outcome highly implausible: indeed, as indicated in section 2.3.1 (a), the fact that alveolopalatals are produced with the blade at a retracted place of articulation should cause a considerable increase in tongue dorsum raising resulting in a larger dorsopalatal contact size for [ɲ] than for [j].

In order to test the validity of these hypotheses we have taken diferent measures of palatal contact, namely, contact size, central opening width, contact variability and coarticulation.

2.3.1. Dorsopalatal contact size. An initial goal of this study was to test the validity of hypotheses (a) and (b) using dorsopalatal contact data for [ɲ] and [j]: in order for [ɲ] to be characterized as a complex segment, it should be produced with the same amount of medio-postpalatal contact as that for [j] or with more medio-postpalatal contact than that for [j]; otherwise, the finding that medio-postpalatal contact is less for [ɲ] than for [j] should be taken as a good indicator of the former consonant not involving a dorsal gesture. Medio-postpalatal contact was measured at rows 6, 7, and 8 of the artificial palate, separately for [ɲ] and for [j]. This measure reflects possible differences in degree of dorsal contact between the two consonants at the place where Catalan [j] is produced. The analysis was based on the calculation of an index of palatal contact posteriority (CPP), which is described in the Appendix. This index emphasizes the contribution of the very last rows on the palatal surface, thus minimizing possible coupling effects associated with the tongue blade. Analyses were performed at onset and offset of the consonantal period as well as at the point of maximum linguopalatal contact (PMC) in order to test segmental complexity at different temporal points. Statistical analysis was based on non parametric tests (Wilcoxon signed rank tests), which take into account the directionality of the difference between pairs of means; they were preferred to parametric tests (paired t-tests) since these did not provide statistical significance in some cases, probably due to the reduced size of the data population (5 means for each sequence for each speaker).

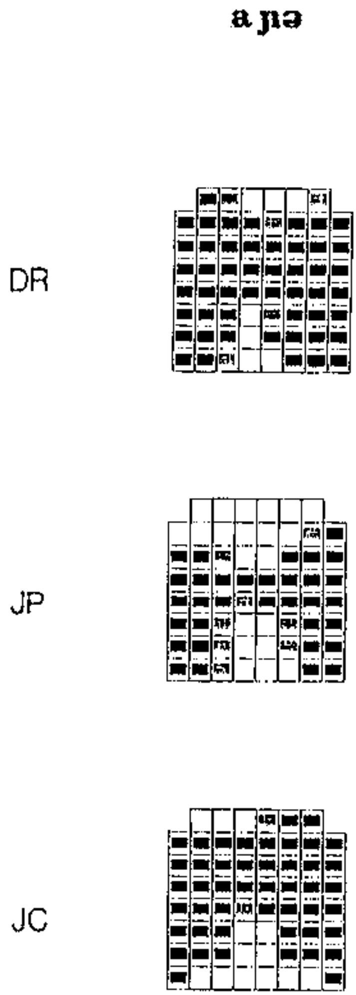


FIGURE 2. Linguopalatal configurations at the point of maximum constriction (PMC) for [ɲ] in the sequence [aɲə] (Catalan speakers DR, JP, and JC). Percentages of electrode activation across repetitions: (black) 80-100%; (dotted) 40-80%; (white) less than 40%.

a j ə

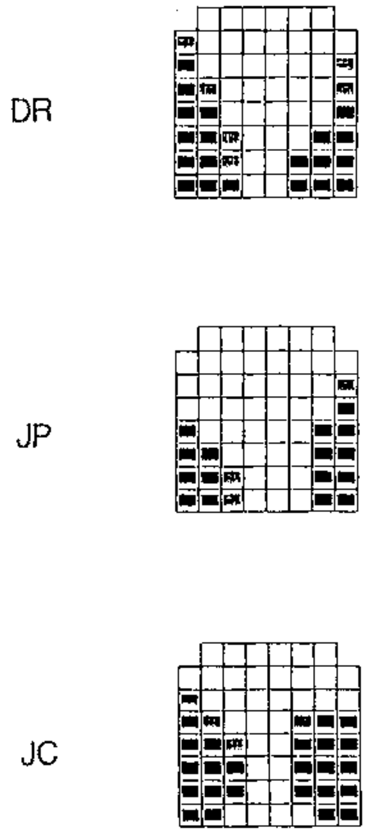


FIGURE 3. Linguopalatal configurations at the point of maximum constriction (PMC) for [j] in the sequence [ajə] (Catalan speakers DR, JP, and JC). Percentages of electrode activation across repetitions: (black) 80-100%; (dotted) 40-80%; (white) less than 40%.

Mean CPP index values for the two consonants are shown in Table I. According to the table, all speakers show a higher CPP index value for palatal [j] than for alveolopalatal [ɲ] at closure onset, at PMC and and at closure offset. Wilcoxon signed-rank tests reveal that the difference between the two consonants at each moment in time is significant at the $p< 0.05$ level. It can thus be ascertained that, in comparison to palatal [j], alveolopalatal [ɲ] is articulated with less dorsal contact at the back palatal zone. This trend is very robust since it occurs for all speakers and at all points in time. Therefore, there are good reasons to suppose that no dorsal gesture is involved during the production of alveolopalatal [ɲ] (hypothesis (b) above) not only at the period of maximum contact but during the entire consonantal period as well.

2.3.2. Central opening width. The hypotheses enunciated in section 2.3.1 were also tested with reference to the area free of contact at the central medio-postpalatal zone (see Figures 2 and 3). The prediction was that, if [ɲ] is a complex segment, central opening width for [ɲ] should be the same as or smaller than for [j]; a larger central opening width for [ɲ] than for [j] would be indicative of the former consonant not being complex.

Possible differences in central opening width between [ɲ] and [j] were investigated at the row showing a constriction maximum for [j], namely, at row 8 for speakers DR, JP and JS and at row 7 for speakers DP and JC. This time the measurement criterion was the number of 'off' electrodes (i.e., electrodes free of contact) at the row of interest. Two points in time were selected for analysis, i.e., PMC and closure offset.

Table II shows the mean number of 'off' electrodes for each speaker and each consonant. Results indicate the presence of a larger central passage for [ɲ] than for [j] for all speakers at PMC and at closure offset. The difference between the two consonants was significant at the $p<.05$ level according to Wilcoxon signed-rank tests. It thus appears that, in comparison to palatal [j], alveolopalatal [ɲ] is articulated with a larger central opening at the back palatal zone. Again this trend is quite robust since it occurs for all speakers at all temporal points.

In summary, significant differences in dorsopalatal contact size (section 2.3.1) and in central passage width (this section) between alveolopalatal [ɲ] and palatal [j] suggest the absence of a [j]-like gesture during the production of [ɲ].

2.3.3. Variability. Contact variability should provide additional evidence for the presence vs absence of segmental complexity in [ɲ]. The principle underlying this assumption is that articulatory variability for a given tongue region depends inversely on its involvement in the formation of a closure or constriction: the activity of a given articulator should be more precise the higher its degree of involvement in the execution of an articulatory gesture. Thus, for example, the degree of tongue dorsum coarticulation varies inversely with the degree of dorsopalatal contact for [ɲ] >[ʎ] >[n] (Recasens (1983); Farnetani (1990)) .It can thus be hypothesized that, if [ɲ] is a complex segment, linguopalatal contact at the medio-postpalatal zone ought to be as variable for [ɲ] as for [j] or less variable for [ɲ] than for [j]; conversely, the finding that [ɲ] is more variable than [j] would suggest that [ɲ] is not complex.

Coefficients of variation (CV) for each speaker across repetitions were obtained using the same data on dorsopalatal contact size and on central opening width reported in sections 2.3.1 and 2.3.2. They are shown in Tables I and II. According to Table I, CV values for CPP are lower for [j] than for [ɲ] at closure onset, at PMC and at closure offset (all speakers, except for JP at closure onset); Table II also reveals higher CV values for central opening width in the case of [ɲ] than in the case of [j] (all speakers except for JS). The fact that dorsopalatal contact is more variable for [ɲ] than for [j] suggests that the tongue dorsum is not actively controlled during the production of the former consonant.

2.3.4. Coarticulation. Additional evidence about variability in tongue dorsum activity at PMC can be obtained from an analysis of coarticulatory effects in CPP for [ɲ] and [j] as a function of adjacent [a] vs [u]. Those vowels differ in degree of contact at the crucial articulatory zone, i.e., at the medio-postpalate, since [a] is a low vowel (less contact) and [u] is high back vowel (more contact). Again, if [ɲ] is a complex segment, coarticulatory effects at the medio-postpalatal zone for [ɲ] should not exceed those for [j]; larger effects for the former consonant than for the latter would be indicative of [ɲ] being a simple segment.

Results indicate a larger vowel-dependent difference in mean CPP values for [ɲ] (0.08) than for [j] (0.04) across speakers. A difference of 0.08 for [ɲ] results from a mean CPP value of 0.80 for [uɲu] (sd=0.12) and of 0.88 for [aɲə] (sd=0.07); a difference of 0.04 for [j] results from a mean CPP value of 0.85 for [ajə] (sd=0.09) and of 0.89 for [uju] (sd=0.05). According to a one-way ANOVA with repeated measures, vowel-dependent differences are significant for [ɲ] ($F(1,4)=13.07$, $p<0.05$) but not for [j]. It thus appears that the back dorsum is more sensitive to coarticulatory effects for alveolopalatal [ɲ] than for the palatal [j], thus suggesting that the former consonant is not complex.

2.4. *Articulatory dynamics for [ɲ]*

Two temporal events should also be related to the issue of articulatory complexity in [ɲ], i.e., the period of contact increase following closure onset and the period of contact decrease preceding closure offset.

2.4.1. Period of contact increase. As shown in Figure 4 (sequence [aɲə]; speakers DR, JP and JC), the consonant [ɲ] undergoes substantial contact changes from closure onset (frame 1) to closure offset (frame 5). Closure midpoint (frame 3) occurs approximately at PMC.

a ɲə

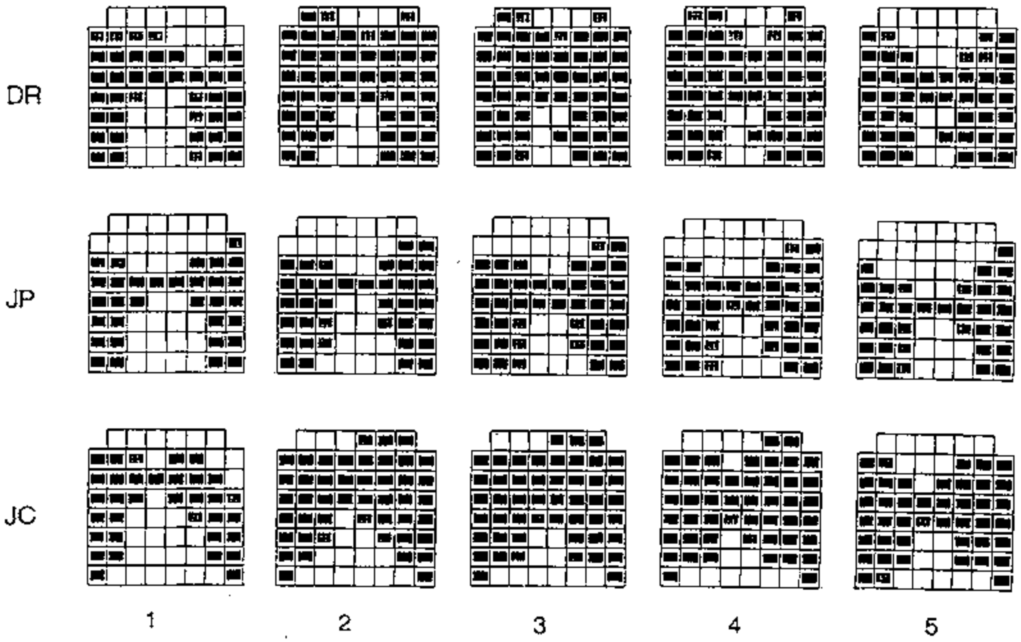


FIGURE 4. Linguopalatal configurations along the closure period for [ɲ] in the sequence [aɲə] (Catalan speakers DR, JP, and JC). (1) Closure onset, (3) closure midpoint, (5) closure offset, (2) and (4) intermediate points. Percentages of electrode activation across repetitions: (black) 80-100%; (dotted) 40-80%; (white) less than 40%.

TABLE I. Contact posteriority index values at the medio-postpalatal zone 9 rows 6, 7 and 8) for [ɲ] and [j] in the sequence [aCə]. The table lists mean values (X) and coefficients of variation (CV) for all Catalan speakers (DR, JP, JS, JC, DP)

		ɲ		j	
		$\bar{X}$	CV	$\bar{X}$	CV
ONSET	DR	0.873	2.82	0.912	2.11
	JP	0.838	2.90	0.881	4.06
	JS	0.816	3.68	0.858	3.11
	JC	0.701	6.87	0.850	2.66
	DP	0.491	46.16	0.649	27.49
	Total	0.744	23.07	0.830	14.67
PMC	DR	0.920	2.25	0.927	1.85
	JP	0.868	6.04	0.884	4.02
	JS	0.831	4.01	0.867	2.91
	JC	0.739	1.09	0.861	0.00
	DP	0.628	24.53	0.702	11.34
	Total	0.797	15.74	0.848	10.24
OFFSET	DR	0.920	2.07	0.927	1.84
	JP	0.867	6.00	0.884	4.02
	JS	0.844	3.31	0.867	2.91
	JC	0.779	5.40	0.850	2.69
	DP	0.570	29.24	0.689	8.79
	Total	0.796	18.20	0.843	10.59

TABLE II. Central opening width in number of "off" electrodes at the medio-postpalatal zone for [ɲ] and [j] in the sequence [aCə]. The table lists mean values (X) and coefficients of variation (CV) for all Catalan speakers (DR, JP, JS, JC, DP)

		ɲ		j	
		$\bar{X}$	CV	$\bar{X}$	CV
PMC	DR	2.60	21.07	2.20	20.33
	JP	3.60	31.67	3.20	26.15
	JS	4.40	12.45	3.60	15.21
	JC	2.40	37.27	2.00	0.00
	DP	4.00	35.36	3.20	26.15
	Total	3.40	25.64	2.84	24.60
OFFSET	DR	2.60	21.07	2.20	20.33
	JP	3.60	31.67	3.20	26.15
	JS	4.20	10.65	3.60	15.21
	JC	2.40	32.27	2.00	0.00
	DP	4.00	35.36	3.20	26.15
	Total	3.36	24.32	2.84	24.60

The figure shows that all speakers start the articulation of [ɲ] (frame 1) with some central contact on rows 3, 4, and/or 5 at the postalveolar and prepalatal zone. It thus appears that the postalveolo-prepalatal place of articulation is already established at closure onset. Evolution towards the closure midpoint (frame 3) involves a contact increase both towards the front alveolar zone and towards the back palatal zone. We suggest that this increase in contact size is not a reflection of the tongue dorsum being activated but results from an increase in lingual pressure at the place of articulation. Thus, while the place of articulation does not undergo significant changes from closure onset to closure midpoint, there is presumably an increase in the force with which the primary articulator presses the palatal surface; such an increase should strengthen the coupling effects between adjacent tongue regions and cause additional contact in front and behind the place of articulation. Evidence for this assumption derives from introspection as well as from data in the literature; indeed, according to Vihman (1967), more dorsopalatal contact for Russian palatalized dentoalveolars than for their Estonian correlates may result from a higher degree of lingual pressure against the palate. Other phoneticians have correlated contact size for [ɲ] and [ʎ] with articulatory effort (Chlumsky (1931); Navarro Tomás (1972)).

It was also hypothesized that the length of time needed to achieve maximum contact at the medio-postpalate would be related to dorsal activation. Indeed, articulations involving active tongue dorsum control should achieve an earlier dorsopalatal contact maximum than articulations not requiring a dorsal gesture. In order to test this hypothesis, the period of contact increase was measured for [ɲ] and for [j] at the medio-postpalate (rows 6, 7 and 8). Duration measurements reveal that this period is quite longer for [ɲ] ($\overline{X}$=35.6, sd=13.2) than for [j] ($\overline{X}$=19.6, sd=12.7) across speakers. Moreover, a significant difference holds for the duration ratio between the entire consonantal period and the period of contact increase at the medio-postpalatal zone (Wilcoxon signed-ranks test, $p<.05$ level of significance); this difference is all the more relevant since the entire consonantal period is not longer for [ɲ] ($\overline{X}$=80.2 ms, sd=16) than for [j] ($\overline{X}$=87.2 ms, sd=19.9). An earlier medio-postpalatal contact maximum for [j] than for [ɲ] may reflect differences in tongue dorsum control between both consonants. The consonant [j] achieves its peak of dorsal activity quite early because it is produced with an active dorsopalatal gesture. On the other hand, the fact that the dorsopalatal contact maximum for [ɲ] occurs quite later means most likely that the tongue dorsum is not subject to active control in this case; it rather appears that this tongue region may be raised as a result of an increase in lingual pressure at the postalveolo-prepalatal place of articulation.

Consistently with the EPG data reported here, EMMA data on [ɲ] for speaker DR (see Introduction section; Recasens and Romero, submitted) indicate that the tongue blade and the tongue dorsum do not achieve the closure midpoint simultaneously. Instead, maximum laminal displacement along the vertical dimension precedes maximum dorsal displacement by 10 ms. This time lag is only slightly longer (by 5 ms) than that obtained for the approximant consonant [j] recorded by the same Catalan speaker, and quite shorter (by 20 ms) than that found for the complex segment [nʲ] recorded by a Russian speaker. A quite shorter time lag for [ɲ] than for [nʲ] is in support of tongue dorsum raising for the former consonant not being caused actively but mechanically.

The data reported in this section suggest that alveolopalatal [ɲ] is produced with a single gesture. It has been argued that an increase in dorsal contact before PMC is not associated with an active gesture but with changes in contact pressure level at the alveolo-prepalatal place of articulation. In comparison to [j], such an increase in lingual pressure at the place of articulation conveys a delay in the achievement of the tongue dorsum contact maximum.

2.4.2. Period of contact decrease. Inspection of the EPG data for [ɲ] reveals the existence of a period of decrease in linguopalatal contact before closure offset. According to Figure 2 (frames 4 and 5), a contact reduction for [ɲ] is found at the alveolar zone but not so (or much less so) at the alveolo-prepalatal place of articulation and at the back palate. It should be mentioned that the release for alveolopalatals proceeds from front to back in other languages besides Catalan (Italian: Farnetani and Recasens, in preparation; Hungarian: Bolla (1980)); see however Pétursson (1974) for Icelandic palatal stops. As previously noticed in the literature, this evolution results into the formation of a [j]-like configuration at closure offset; indeed, several phoneticians have characterized alveolopalatals as 'mouillé' or palatalized sounds based on this transitory 'off-glide', [j]-like perceptual effect at closure release (Grammont (1971); Jones (1956)).

The presence of this [j]-like linguopalatal configuration at the release of [ɲ] could be used to advocate the complex nature of the alveolopalatal consonant; thus, it could be claimed that such a configuration is the articulatory manifestation of a secondary dorsal gesture. This hypothesis is implausible in the light of the data reported in section 2.3: the fact that Catalan [ɲ] is produced with lesser medio-postpalatal contact than Catalan [j] at closure offset suggests that the [j]-like configuration is not associated with an independent dorsal gesture at this point in time. It can be rather interpreted as an automatic consequence of the release for [ɲ] evolving gradually from front to back along the palatal surface. The consonantal release begins at the tongue front either because the tongue dorsum is more massive and moves more slowly than the blade and/or because the blade is the only active articulator and dorsal contact is just the result of coupling.

According to EMMA data on vertical displacement for speaker DR (see Introduction section; Recasens and Romero, submitted), closure release occurs highly simultaneously at the tongue blade and at the tongue dorsum for Catalan [ɲ] and [j]. Indeed, the time lag between the dorsal release and the laminal release is shorter than 10 ms for both consonants. In comparison to Catalan [ɲ] and [j], Russian [nʲ] shows a much longer 30 to 40 ms lag. Consistently with the EPG data, these EMMA data favor the view that the tongue dorsum is not actively controlled during the production of the alveolopalatal consonant [ɲ].

3. Summary

EPG data on Catalan [ɲ] and [j] are in support of the articulatory classification of palatal consonants into alveolopalatals and palatals proper (see Introduction section). Alveolopalatals are articulated at the alveolo-prepalatal zone, as for [ɲ], [ʎ] and [c] in Czech, Hungarian, Catalan and other Romance languages, and [ç] and [j] in languages in which both consonants are fairly front. Palatals are produced at the palatal zone, as for [ɲ] in Ngwo (Ladefoged (1968)) and in Ibibio (Connell (1992)), [c] in Icelandic (Pétursson (1974)), and [ç] and [j] in languages in which both consonantal realizations are articulated further back (e.g., [j] in Catalan and Hungarian). A relevant aspect of this classification is that consonants such as [ɲ] and [j] may behave as alveolopalatals or palatals depending on the language under investigation.

The evidence reported in section 2 suggests that alveolopalatals are simple segments produced with the tongue blade and predorsum at the alveolo-prepalatal zone and do not involve an independent dorsal gesture. An increase in lingual pressure at the place of articulation from closure onset to PMC conveys automatically a contact increase all over the surface of the palate. Therefore, a large contact size in front and behind the alveolo-prepalatal zone is not indicative of the presence of two gestures but results from a high degree of lingual pressure at the place of articulation. Lingual contact at the medio-postpalatal zone is less extensive and more variable for [ɲ] than for [j] which suggests that the tongue dorsum is activated for the latter consonant but not for the former. Closure release for aveolopalatal [ɲ] occurs gradually from front to back, thus leaving automatically a [j]-like configuration at closure offset.

We claim that the term "complex segment" should not be applied to alveolopalatal and palatal consonants but be kept exclusively for double articulations produced with two non contiguous articulatory regions (e.g., the lips and the tongue dorsum in the case of labial-velars, the tongue tip and the tongue dorsum for velarized [ɫ]...). Only one Articulator Node is needed in the phonological representation of alveolopalatals. The rationale underlying this position is that phonological features should not come in contradiction with their phonetic implementation.

Appendix

The CP (contact posteriority) index at the zone including rows 6, 7, and 8 has been calculated on a row by row basis. The value of this index increases as linguopalatal contact becomes more posterior. The following mathematical formula were developed for the calculation of the index values:

$$[\log[[1(R6/8) + 9(R7/8) + 81(R8/8)] + 1]]/[\log (92)].$$

In the ratios within parentheses, the number of activated electrodes on each row (i.e., R6, R7, R8) is divided by the total number of electrodes on the same row or column. Each ratio is multiplied by a row-specific coefficient number. These coefficients have been calculated according to the following principle: the contribution of a given electrode to an index value exceeds the contribution of all electrodes located on the previous front rows. The construction method of the coefficient values is explained below.

A coefficient of 1 has been arbitrarily assigned to the frontmost row R6. It follows from the contact index formula that the maximum CP value for this row when all eight electrodes are activated is 1:

(8 activated electrodes/8 electrodes available) x coefficient value of 1=1.

One 'on' electrode on R7 should contribute more to the CP index value than 1, which is the maximum CP index value for R6, namely,

(1 activated electrode/8 electrodes available) x unknown coefficient value >1.

It follows that the coefficient value for R7 should be higher than 8, namely, (8 x 1) + 1 = 9.

To obtain the coefficient value for R8, one 'on' electrode on this row should contribute more to the CP index value than the previous rows R6 and R7. Since the addition of the maximum CP index value for R6 and R7 is 10, it follows that:

if (1 'on' electrode/8 electrodes available on R8) x coefficient value >10, then the coefficient value for R8=(8 x 10) + 1 = 81.

As shown in the contact index formula, the index values were submitted to a logarithmic transformation in order to compensate for their exponential increase as we proceed from one row to the next. The resulting expressions are divided by the maximum possible value for each contact index so that a range from 0 to 1 is obtained.

The contact index method will be illustrated with a comparison between index values for [ɲ] and for [j] at PMC for speakers DR, JP and JC (see frame 3 in Figures 2 and 3). Linguopalatal configurations for [ɲ] indicate that dorsal contact at the back of the palatal surface decreases in the progression speaker DR > speaker JP > speaker JC; Table I shows indeed a highest CP value for speaker DR (0.920) than for speaker JP (0.868), and a lower value for speaker JC (0.739) than for the two other speakers. Concerning [j], Table II also shows higher index values for DR (0.927) than for JP (0.884), and the lowest value for JC (0.861). Indeed Figure 3 reveals the presence of a narrower constriction on backmost row 8 for speaker DR than for speaker JP; speaker JC, on the other hand, produces [j] with even less contact on row 8 than speaker JP.

• This research was funded by ESPRIT-BRA Project 6975 'Speech Maps' and ESPRIT-BRA Working Group 7098 'Accor' of the European Community. We would like to thank Catherine Browman, Bruce Connell and Joaquín Romero for their remarks.

References

Avery, P., and Rice, K. (1989) 'Segment Structure and Coronal Underspecification', *Phonology* 6, 179-200.

Bolla, K. (1980) 'Magyar Hangalbum', *Hungarian Papers in Phonetics* 6, 1-167.

Catford, J.C. (1977) *Fundamental Problems in Phonetics*, Edinburgh University Press, Edinburgh.

Connell, B. (1992) 'Tongue Contact, Active Articulators, and Coarticulation', in J.J. Ohala, T.M. Nearey, B.L. Derwing, M.M. Hodge and G.E. Wiebe (eds) *ICSLP92 Proceedings* 2, 1075-1078, Priority Printing, Edmonton.

Chlumsky, J. (1931) 'Les sons mouillées et la théorie de l'abbé Rousselot', *Actes du 1er. Congrés de Philologie Slave*, Prague, 541-547.

Chomsky, N. and Halle, M. (1968) *The Sound Pattern of English*, Harper and Row, New York.

Dart, S.N. (1991) 'Articulatory and Acoustic Properties of Apical and Laminal Articulations', *UCLA Working Papers in Phonetics* 79.

Farnetani, E. (1991) 'V-C-V Lingual Coarticulation and its Spatiotemporal Domain', in W.J. Hardcastle and A. Marchal (eds) *Speech Production and Speech Modelling*, 93-130, Kluwer, Dordrecht.

Farnetani, E. and Recasens, D. (in preparation) 'Trajectories of Linguopalatal Contact for Alveolopalatals in Italian and Catalan'.

Grammont, M. (1971) *Traité de phonétique*, Delagrave, Paris, 9th edition.

Hardcastle, W.J., Jones, W., Knight, C., Trudgeon, A. and Calder, G. (1989) 'New Developments in Electropalatography: A State-of-the-Art Report', *Clinical Linguistics and Phonetics* 3, 1-38.

Jones, D. (1956) *An Outline of English Phonetics*, Cambridge University Press, Cambridge, 8th edition.

Keating, P. (1988) 'Palatals as Complex Segments: X-Ray Evidence', *UCLA Working Papers in Phonetics* 69, 77-91.

Keating, P. (1991) 'Coronal Places of Articulation' in C. Paradis and J.F. Prunet (eds) *The Special Status of Coronals* 29-48, Academic Press, San Diego.

Keating, P. and Lahiri, A. (1993) 'Fronted Velars, Palatalized Velars and Palatals', *Phonetica* 50, 73-101.

Ladefoged, P. (1968) *A Phonetic Study of West African Languages*, Cambridge University Press, Cambridge.

Lahiri, A. and Evers, V. (1991) 'Palatalization and Coronality' in C. Paradis and J.F. Prunet (eds) *The Special Status of Coronals* 79-100, Academic Press, San Diego.

Lipski, J.M. (1989) 'Spanish 'Yeísmo' and the Palatal Resonants: Towards a Unified Analysis', *Probus* 1, 211-223.

Navarro Tomás, T. (1972) *Manual de pronunciación española*, Consejo Superior de Investigaciones Científicas, Madrid, 17th edition.

Pétursson, M. (1974) *Les articulations de l'islandais à la lumière de la radiocinématographie*, Klincksieck, Paris.

Recasens, D. (1983) *Coarticulation in VCV Sequences: An Articulatory and Acoustical Study*, Tesi doctoral, The University of Connecticut.

Recasens, D. (1984) 'Timing Constraints and Coarticulation: Alveolopalatals and Sequences of Alveolar + [j] in Catalan', *Phonetica* 41, 125-139.

Recasens, D. (1990) 'The Articulatory Characteristics of Palatal Consonants', *Journal of Phonetics* 18, 267-280.

Recasens, D., Fontdevila, J. and Pallarès, M.D. (in press) 'A Production and Perceptual Account of Palatalization', *Fourth Conference on Laboratory Phonology*, Oxford University (1993).

Recasens, D. and Romero, J. (submitted) 'An EMMA Study of Segmental Complexity in Alveolopalatals and Palatalized Alveolars'.

Roudet, L. (1910) *Éléments de phonétique générale*, Paris.

Rousselot, A.P. (1924-25) *Principes de phonétique expérimentale*, Paris.

Straka, G. (1965) *Les sons et les mots*, C. Klincksieck, Paris.

Vihman, M.M. (1967) 'Palatalization in Russian and Estonian', *Project on Linguistic Analysis Reports*, Phonology Laboratory, University of California at Berkeley, Second Series, 1, V1-V32.

(Daniel Recasens)

Departament de Filologia Catalana

Universitat Autònoma de Barcelona

08193 Bellaterra (Barcelona)

Catalonia (Spain)

E-mail: ilft0@cc.uab.es