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Articulatory, positional and contextual characteristics of palatal consonants: Evidence from Majorcan Catalan

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Abstract

Linguopalatal contact data for Majorcan Catalan reveal that the palatal consonants [c] (oral), [ɲ] (nasal) and [ʎ] (lateral) may exhibit two places of articulation, i.e., alveolopalatal and palatal proper, depending not only on vowel context but on position and speaker as well. In this Catalan dialect, [ɲ] and [ʎ] have phonological status while [c] is an allophone of /k/ and is articulated at a fronter location than front /k/ in languages such as English. Several consonant-dependent differences appear to be of universal validity, i.e., a trend for [ɲ] and [ʎ] to exhibit a more anterior closure location than [c] (perhaps due to manner requirements) or else for [c] and [ɲ] to share a similar place of articulation (presumably for the sake of articulatory economy), and more stability for closures formed at the alveolopalatal zone than at the mediopalate. The three palatal consonants exhibit more overall contact, fronting and duration but also more coarticulation utterance initially than utterance finally (and even intervocalically) thus suggesting that they may blend with the adjacent vowel rather than resisting its influence in the former position while failing to undergo substantial articulatory reduction in the latter.

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1. Introduction

Dentoalveolar and velar palatalization accounts for sound changes involving the formation of palatal consonants produced with a single place of articulation, e.g., in Romance languages, Hungarian and Czech, as well as of complex palatalized consonants implemented through a primary front or back closure or constriction location and a secondary tongue dorsum raising and fronting gesture, e.g., in Slavic languages and Irish. The present paper investigates several articulatory characteristics of the former class of consonants through inspection of linguopalatal contact patterns for the oral stop [c], the nasal stop [ɲ] and the lateral [ʎ] in Majorcan Catalan. Majorcan Catalan is a dialect of the Catalan language spoken in the island of Majorca by about 500,000 speakers. In comparison with other peninsular varieties of Catalan, Majorcan Catalan is endowed with specific phonetic features such as stressed schwa and palatal stop allophones of velar stop phonemes. While the former feature appears to have been part of the Old Catalan vowel system when the Catalans conquered the island back in the XIII century, the latter is probably an autochthonous development. Both linguistic properties are found in other dialectal zones in Romance, e.g., in Northern Italian and in Rhaetoromance.

In Majorcan Catalan, [ɲ] and [ʎ] have phonemic status while [c] is an allophone of /k/ occurring most typically before a front vowel but also before /a/ and /ə/ and word finally, and showing different degrees of palatalization depending on speaker and geographical location (Veny, 1983). Thus, realizations such as [ci] *qui* "who" and [sac] *sac* "sack" correspond to the phonological representations /ki/ and /sak/, respectively.

1.1. Place of articulation

A first research goal is the investigation of the place(s) of articulation for [c], [ɲ] and [ʎ]. The relevance of this research topic derives from earlier reports summarized below showing that closure location for these consonants involves large degrees of tongue contact and, at the same time, is highly variable, i.e., it may extend from the alveolopalatal to the medio-postpalatal zone. All three consonants will be referred to as 'palatal' in this paper unless we need to be more specific about their place of articulation.

In dialectal domains where [c] is a front allophone of /k/, the palatal stop may show large differences in closure fronting. Thus, it may be articulated with a purely palatal closure occurring over the entire palatal zone behind the alveolar ridge or just at the back portion of the hard palate in Romance dialects such as Sicilian, Parisian French and Auvergnat Occitan as well as in Ibibio in Nigeria (Connell, 1991, pp. 360, 368–369; Durand, 1930, pp. 247, 251; Millardet, 1925, pp. 749–750; Rousselot, 1924–25, p. 607). It may also be produced with an alveolopalatal closure and much central contact at the hard palate in the Surmeiran, Surselvan and Lower Engadine dialects of Rhaetoromance (Brunner, 1963, p. 170; Lutta, 1923, p. 40). Palatal and alveolopalatal realizations of [c] may be both available in the same language or dialect (Greek, Romanian, Majorcan Catalan; Barnils, 1933, p. 52; Dukelski, 1960, p. 44; Nicolaidis, 2001, p. 71).

In languages where it has phonemic status, [c] does not seem to require a front place of articulation in order to avoid merging with the velar phoneme /k/. Thus, while being implemented through an alveolopalatal closure in Czech and Slovak (Hála, 1929, pp. 31–35, 1962, pp. 228, 409–410), [c] exhibits a purely palatal closure in Hungarian and Icelandic as well as in Ngwo in

Cameroun (Bolla, 1980, p. 83; Keating & Lahiri, 1993, p. 82; Ladefoged, 1968, p. 52, 2001, p. 147; Pétursson, 1974, pp. 9–13; Scripture, 1902, p. 306). It deserves to be seen whether the need to differentiate two phonemes, i.e., /c/ and /k/, causes [c] to exhibit less variability in place of articulation in these languages than in those where [c] is an allophone of /k/.

What is the relationship between the closure location for [c] and for [ɲ]? In languages and dialects where [c] is absent or is an allophone of /k/, phonemic [ɲ] is typically alveolopalatal and its production often involves a postalveolo–prepalatal closure extending optionally towards the front alveolar zone and mediopalate. This appears to be so for Romance languages where [ɲ] derives from Latin /n:/ or from /n/ before a front vowel or glide, i.e., Catalan (Recasens & Pallarès, 2001, pp. 90–91), Dolomitic Ladin (Tagliavini, 1964, p. 88), French (Dumville, 1912, p. 99; Jones, 1956, p. 172), Gascon (Millardet, 1910, p. 19), Italian (Josselyn, 1900, p. 98; Panconcelli-Calzia, 1911, p. 51; Recasens, Farnetani, Fontdevila, & Pallarès, 1993), Occitan (Maurand, 1974, p. 156; Rousselot, 1892, p. 26, 1912, p. 274, 1924–25, p. 610), Portuguese (Rousselot, 1924–25, p. 610) and Spanish (Fernández, 2000; Josselyn, 1907, p. 131; Navarro Tomás, 1972, p. 132). A more anterior articulation for [ɲ] than for [c] cannot possibly be attributed to the need to avoid confusion between [ɲ] and [ŋ] since the velar nasal is allophonic in these languages and dialects.

Moreover, [c] and [ɲ] may also share the same place of articulation independently of phonological considerations. Thus, the two realizations are typically alveolopalatal in languages with phonemic /c/ and /ɲ/ and allophonic [ŋ] such as Czech and Slovak, exclusively palatal in Ibibio and other African languages where /ɲ/ and /ŋ/ are phonemic and [c] is allophonic, and also purely palatal in dialects with the phoneme /ɲ/ and the allophones [c] and [ŋ] such as Parisian French (Connell, 1991, p. 158; Hála, 1929, p. 33, 1962, pp. 228–229, 412–413; Polland & Hála, 1926, pp. 26–27; Rousselot & Laclotte, 1913, p. 70; Straka, 1965, p. 167).

The palatal lateral [ʎ] differs from [c] and [ɲ] in that it cannot be articulated exclusively at the palatal zone. Palatographic and X-ray data from Romance languages reveal that this consonant exhibits generally an alveolopalatal closure, e.g., in Catalan (Recasens & Pallarès, 2001, pp. 88–89), French (Haden, 1938, p. 86), Italian (Panconcelli-Calzia, 1911, p. 8; Recasens et al., 1993, p. 220), Occitan (Maurand, 1974, p. 162; Rousselot, 1892, p. 25, 1924–25, p. 611), Portuguese (Cagliari, 1977; Rousselot, 1924–25, p. 611) and Spanish (Navarro Tomás, 1972, p. 133). Less often, [ʎ] is produced with a very front closure at the alveolar zone, e.g., in Italian and Spanish (Fernández, 2000, p. 42a, 61a; Josselyn, 1900, p. 98, 1907, p. 127).

In agreement with evidence reported so far, the main prediction regarding place of articulation for palatal consonants is that closure fronting should decrease in the progression [ʎ] > [ɲ] > [c] while overall tongue contact extent should be greater for the two stops than for the lateral. Rather than being associated with their historical source or the phonemic inventory in a particular language, [c], [ɲ] and [ʎ] could be articulated at different places due to aerodynamic requirements: on the one hand, a more retracted closure for [c] than for [ɲ] could ensure that intraoral air pressure level is high enough for the oral stop burst to be perceptually salient; on the other hand, a more anterior place of articulation for [ʎ] than for the two stops helps lowering the tongue predorsum sides and forming lateral channels for the passage of airflow which may also take place behind the back molars. The fact that the place of articulation for the oral stop may also coincide with that for the nasal stop could be associated with articulatory economy, i.e., speakers would tend to assign the same closure location to consonants belonging to the same articulatory class independently of their manner of articulation.

The notion that palatals are unstable articulations follows from the difficulty involved in forming a complete closure at the hard palate. If this is indeed the case, the natural tendency would be for palatal stops derived from velar stops to evolve from mediopalatal articulations formed at the core of the hard palate to alveolopalatal articulations produced at the more stable meeting point between the alveolar zone and the prepalate. This hypothesis is consistent with palatographic data for [c], [ɲ] and [ʎ] showing that dorsopalatal closure for these consonants is often interrupted by areas devoid of contact or by a narrow central channel extending along the median line (Connell, 1991, p. 359).

1.2. Articulatory strengthening and weakening

This paper also investigates differences in articulatory variability for palatals as a function of position and vowel context, i.e., whether consonants articulated with much tongue contact undergo strengthening and reduction as a function of word and utterance position to the same extent as other consonants, and exhibit high degrees of coarticulatory resistance to vowel-dependent effects. For that purpose, [c], [ɲ] and [ʎ] are analyzed in utterance initial and utterance final position ('word/utterance initially' and 'word/utterance finally' in this paper) and in intervocalic position, and in the adjacency of /i/, /a/ and /u/.

1.2.1. Position effects

Strengthening accounts for segmental substitutions involving an increase in contact degree, and applies to long consonants and to consonants occurring in prominent utterance, word, syllable and prosodic positions. Accordingly, word initial or stressed velar stops may become palatal through a gain in tongue contact in front of closure location (Bhat, 1974), and long or word initial dentoalveolars may become alveolopalatal through a gain in back central contact (Catalan [aɲ] *any* "year" derived from Latin ANNU, [ʎum] *llum* "light" from LUCE, Argentinian Spanish [ˈɲuðo] *nudo* "knot" from NODU; Malmberg, 1950, p. 119). On the other hand, weakening through dorsopalatal contact loss may cause palatal consonants to become glides or alveolars in syllable final and intervocalic scenarios favoring articulatory reduction, i.e., [ʎ] > [j] (Modern French; Lausberg, 1966, p. 392) and [ɲ] > [j], [n] (Argentinian Spanish [maˈjana] *mañana* "tomorrow", Catalan from l'Alguer [an] for [aɲ] *any* "year"; Kuen, 1932–34; Malmberg, 1950, p. 119).

Articulatory strengthening and weakening have been related to utterance, word and syllable position in the light of the observation that initial consonants are longer and involve more linguopalatal contact than their final correlates. There also appears to be an utterance-final strengthening effect on coda consonants which may weaken the word-level asymmetry in consonant articulation though dentoalveolars continue to exhibit more tongue contact utterance initially than utterance finally (Keating, Wright, & Zhang, 1999). Both for initial and final consonants, articulatory strengthening and weakening have also been shown to depend on the hierarchical level for domain boundary; indeed, there is some evidence that tongue contact varies in the progression utterance initially > word initially > syllable initially inside the word (Farnetani & Vayra, 1996; Fougeron & Keating, 1997).

Recent findings indicate however that position-dependent differences in contact degree for consonants depend on the specific consonant taken into consideration. Thus, boundary effects may be smaller for dorsovelars than for apicoalveolars (Browman & Goldstein, 1995), and do not apply to fricatives and to palatal affricates which may even be produced with more contact word finally than word initially (Keating et al., 1999). In contrast with stop, nasal and lateral consonants, lingual fricatives and the alveolar trill do not appear to exhibit significant differences in dorsopalatal contact as a function of syllable position in consonant clusters (Recasens, 2004). The obvious conclusion to be drawn from these data is that consonants are strengthened in onset position and weakened in coda position except if specified for high manner and/or place of articulation requirements such as trilling, frication and tongue dorsum involvement in closure formation. Within this framework, the present paper investigates the extent to which palatals resemble other dorsal consonants in blocking position-dependent articulatory effects.

Position-dependent differences in articulatory fronting are analyzed. Data for Catalan clusters reveal indeed that, analogously to differences in dorsopalatal contact degree, alveolar and alveolopalatal consonants are somewhat more retracted syllable finally than syllable initially except for trills and fricatives (Recasens, 2004). Differences in articulatory fronting as a function of position appear to complement the trend for final consonants to fall short of their articulatory targets and thus, to show less overall tongue contact than their initial correlates.

1.2.2. Vowel coarticulation

In addition to segmental duration and tongue contact degree and fronting, segmental strengthening and weakening ought to be related to the degree of coarticulation.

According to coarticulation data in the literature, alveolopalatals are highly resistant to vocalic effects at and behind the place of articulation. Moreover, the degree of coarticulation for those consonants varies inversely with dorsopalatal contact such that, e.g., /ɲ/ shows more dorsopalatal contact and less coarticulation than alveolopalatal /ʎ/ (Recasens, 1984). On the other hand, dorsovelars blend with, i.e., adapt or accommodate closure location to, the following vowel thus becoming postpalatal or medio-postpalatal before front vowels while staying velar before back vowels. The final stop outcome of this blending process may exhibit the same or a close place of articulation to that of the following vowel but also a large closure resulting from the addition of the closure and constriction areas for the two consecutive phonetic segments (Browman & Goldstein, 1990, 1991; Recasens, in press). This blending mechanism is clearly in contrast with contextual coarticulatory variations which would not affect substantially the place of articulation for the consonant and could also occur in front or behind it.

An issue of interest here is whether pure palatal stops and nasals conform to the coarticulation scenario for alveolopalatals or to the blending scenario for velars. Data for pure palatal /ɲ/ in Ibibio indicate that, analogously to velars, palatals exhibit large differences in vowel-dependent closure fronting, i.e., they are produced with dorsal contact all over the palatal zone in the high vowel sequences /iɲi/ and /uɲu/ and just at the postpalate in the low vowel sequence /aɲa/ (Connell, 1992). The alternative prediction is that large degrees of dorsopalatal contact for palatal consonants ought to cause them to become highly resistant to vowel coarticulation independently of their place of articulation.

Alveolopalatals and palatals should also differ regarding the nature of the vowel coarticulatory effects. Alveolopalatals show more dorsopalatal contact with the high vowels /i, u/ than with the low vowel /a/ meaning that closure formation with the blade and predorsum leaves some room for tongue dorsum vertical displacement (Recasens et al., 1993). Pure palatals, on the other hand, could allow more contact for front /i/ than for back /a, u/ or for high /i, u/ than for low back /a/ in line with the blending scenario referred to above.

The present study is also concerned with possible interactions between position and vowel coarticulation. There is some evidence that resistance to tongue coarticulation for word initial consonants depends on the degree to which the tongue body is involved in closure formation for the consonant, i.e., dentals and palatals appear to block anticipatory vowel coarticulatory effects while labials and alveolars allow them to occur (Farnetani, 1995). A comparison between effects in (stronger) initial position and (weaker) final position may yield two opposite outcomes depending on the production mechanisms involved. One possibility is that vowel coarticulation varies inversely with position-dependent differences in linguopalatal contact degree, and thus that initial consonantal realizations are more coarticulation-resistant than their final correlates. The alternative option is for initial consonants to blend easily with the following vowel perhaps in order to render different CV syllables perceptually distinctive from each other in prominent word positions; if so, initial consonants will turn out to be less coarticulation resistant than final consonants. Some support for the second hypothesis derives from impressionistic descriptions stating that /k/ in Majorcan Catalan and Northern Italian dialects is regularly realized as a palatal or as a velar stop depending on whether the following vowel is front or back, respectively, and as a palatal stop in word final position after any vowel (Salvioni, 1901; Veny, 1983).

2. Method

Electropalatographic (EPG) and acoustic data were collected for all combinations of Majorcan Catalan /k/, /ɲ/ and /ʎ/ with /i/, /a/ and /u/ in word/utterance initial (CV), word/utterance final (VC) and intervocalic (VCV) position. In view of the fact that the voiceless velar phoneme may be realized as a voiceless velar or palatal stop (i.e., [k] or [c]) in the Catalan dialect under investigation, we will refer to those two realizations with the symbol /k/ from here onwards.

Twenty-seven CV, VCV and VC sequences were inserted in meaningful words and read seven times each in the sentences listed in Table 1. Five male speakers of Majorcan Catalan of 25–45 years of age (AR, BM, MJ, ND, CA) took part in the recording sessions. In the table, all syllables with the three consonants under analysis bear stress though not primary phrasal stress which falls fixedly on the last sentence stressed word and is thus, available for word/utterance final consonants (sentences 10–18) and for some intervocalic ones (sentences 19–21, 24); moreover, some degree of phrasal stress was also present word/utterance initially on CV syllables with /k/, /ɲ/ and /ʎ/ in sentences 1–9. Overall, we presume that differences in sentence stress must not have had much of an effect on the articulatory implementation of the palatal consonants under analysis. VCV sequences were symmetrical though [a'Ca] had to be replaced by [ə'Ca] since /a/ becomes [ə] in unstressed position in Majorcan Catalan. Intervocalic sequences 19–27 could not be inserted in the same word position due to phonological and semantic restrictions. Word position is not expected to affect the outcoming linguopalatal contact patterns however, considering that speakers were instructed to read all sequences without pausing and that Catalan syllabification rules are essentially the same word medially and across a word boundary. Only for /uku/ the stop has been described as velar word initially and as velar or palatal word finally. In

Table 1
List of sequences in phonetic transcription and orthographic form

Word/utterance initial			
1. /ki/	[ki əribə ˈɾa]	*qui arribarà*	"who will arrive?"
2. /ka/	[kazə ˈkɔmoðə]	*casa còmoda*	"comfortable house"
3. /ku/	[kus ˈfɔrsə]	*cus força*	"he/she sews a lot"
4. /ɲi/	[ɲikɾiz iˈnutil]	*nyicris inútil*	"useless weakling"
5. /ɲa/	[ɲap imˈmɛns]	*nyap immens*	"big mess"
6. /ɲu/	[ɲub vɔl di ˈnus]	*nyuc vol dir nus*	"(the Catalan word) 'nyuc' means knot"
7. /ʎi/	[ʎi ðə sə ˈʒuŋglə]	*lli de la jungla*	"jungle flax"
8. /ʎa/	[ʎat tropiˈkal]	*llac tropical*	"tropical lake"
9. /ʎu/	[ʎujn dəs pəˈɾiʎ]	*lluny del perill*	"far from danger"
Word/utterance final			
10. /ik/	[saviz mol ˈrik]	*l'avi és molt ric*	"grandfather is very rich"
11. /ak/	[umpl ət ˈsak]	*omple el sac*	"fill the bag"
12. /uk/	[ni tɾɛw ət ˈsuk]	*n'hi treu el suc*	"he/she squeezes the juice out of it"
13. /iɲ/	[əsta plə ðənˈʒiɲ]	*és ple d'enginy*	"he is full of wisdom"
14. /aɲ/	[jəribə ŋ ˈgwaɲ]	*hi arriba enguany*	"he/she will arrive this year"
15. /uɲ/	[sabɾəz mol ˈʎuɲ]	*l'arbre és molt lluny*	"the tree is very far away"
16. /iʎ/	[əz um pəˈɾiʎ]	*és un peril*	"it is dangerous"
17. /aʎ/	[um bɔŋ kəˈvaʎ]	*un bon cavall*	"a good horse"
18. /uʎ/	[sajɣo ʒa ˈbuʎ]	*l'aigua ja bull*	"the water is boiling already"
Intervocalic			
19. /iki/	[ən rəpərti ˈkinzə]	*en repartí quinze*	"he/she gave out fifteen items"
20. /aka/	[eʎ noj va ˈkawɾə]	*ell no hi va caure*	"he/she did not realize"
21. /uku/	[tɾɛw ət suˈk ultim]	*treu el suc últim*	"squeeze the last of the juice"
22. /iɲi/	[no li ənˈdiɲis]	*no l'hi endinyis*	"do not give him/her a blow"
23. /aɲa/	[sa bəɲaˈt aɾə]	*s'ha banyat ara*	"he/she has taken a bath now"
24. /uɲu/	[kɔd də puˈɲ util]	*cop de puny útil*	"useful punch"
25. /iʎi/	[um pəɾiʎ inˈtɛrn]	*un perill intern*	"an internal danger"
26. /aʎa/	[wə vəʎaˈt aɾə]	*ho ha vallat ara*	"he/she has fenced it"
27. /uʎu/	[buʎ unz miˈnuts]	*bull uns minuts*	"it boils for some minutes"

view of this potential difference, we decided to select the second option so as to allow for maximal degree of palatalization (see sequence 21 in Table 1).

Linguopalatal contact configurations were gathered with the Reading EPG-3 system every 10 ms using artificial palates equipped with 62 electrodes. Acoustic data were digitized at 10 kHz, filtered at 4.8 kHz, and processed with a Kay CSL analysis system using the same temporal resolution as the EPG data.

Segmentation criteria were as follows. For intervocalic and final consonants, the segmental boundaries for /k/ and /ɲ/ were determined by the onset and offset of full electrode activation at one or more rows of the artificial palate. Segmental landmarks for /ʎ/ were set at the first frame exhibiting full contact at the four central alveolar columns (onset) and at the first frame exhibiting closure release at any of those columns (offset). Segmentation criteria for consonant productions involving no central closure were based on inspection of spectrographic displays. For the intervocalic realizations, segmental boundaries were taken to occur at the edge of the adjacent vowels (for /VkV/) and at onset/offset of the period of formant structure associated with the nasal murmur and with lateral airflow (for /VɲV/ and /VʎV/, respectively). For word/utterance final /ak, uk/, consonant onset occurred at the offset of the preceding vowel and consonant offset at the stop burst which was always present. The closing period for those word/utterance final realizations (also for /ik/) could be held after voicing offset.

Word/utterance initial /k/, /ɲ/ and /ʎ/ before /i, a/ were taken to begin and end at closure onset and offset, respectively. The closure period for the nasal and the lateral often started before voicing onset. In view of the absence of a complete linguopalatal closure for /ku/, consonant onset and offset for this sequence were considered to take place at the first and last frame showing a constriction maximum at row 8. Moreover, a burst was usually apparent at /k/ offset before /u/ on spectrographic displays. Regarding those tokens of /ɲi, ɲa, ka/ exhibiting no EPG closure (speaker AR only), consonant onset was taken to occur at the first frame showing a constriction maximum and consonant offset at the stop burst or at a change in formant structure visible on spectrographic displays.

Closure durations were measured in all positions and vowel context conditions. Linguopalatal configurations for /k/, /ɲ/ and /ʎ/ were gathered at the frame of maximum linguopalatal contact or PMC, i.e., at the frame showing the highest number of on-electrodes over the entire palate surface. Whenever a linguopalatal contact maximum lasted for more than one frame, PMC was taken to occur at the medial frame or at the first of two consecutive frames depending on whether the number of frames exhibiting a maximum contact degree was 3, 5, … or 2, 4, …, respectively. PMC occurred at or close to closure midpoint and linguopalatal contact configurations were highly similar at both temporal points.

It may be claimed that PMC is not a valid line up point since, analogously to velars after back vowels, alveolopalatals and/or palatals could exhibit continuous forward motion during closure (Mooshammer, Hoole, & Kühnert, 1995). The maximum closure configuration was chosen as reference since it appears to correspond to the articulatory target for the consonants under analysis. This criterion is consistent with the existence of two well-defined phases during the closure period, namely, a phase before PMC during which central contact increases simultaneously towards the front alveolar zone and the hard palate for alveolopalatals or just towards the front palate for pure palatals, and another phase after PMC during which the closure area is gradually released from front to back. Based on EPG and tongue movement data for Catalan alveolopalatals and for Hungarian and Icelandic palatals (Bolla, 1981a, p. 38, 1981b, p. 38; Pétursson, 1968–69; Recasens, 2002), we can be confident that the production of those consonants involves no changes in place of articulation but just changes in closure degree.

Another possible problem was the identification of consonant onset for word/utterance initial /k/ before /u/ given that the stop was produced with a closure or constriction at the posterior border of the artificial palate in this case. Indeed, it may be that consonant onset and PMC for this CV sequence were identified too late if closure happened to start behind row 8 and the tongue dorsum moved in a continuous forward loop before reaching the onset of the vowel /u/. This problem was partly coped with by setting consonant onset at the first frame showing a maximum constriction narrowing. No special attention was paid to the fact that speaker ND articulated word/utterance initial /ka/ at row 8 since this speaker assigns this same closure location to /k/ and /ɲ/ in all vowel contexts and positions.

As shown by the EPG contact configurations in Fig. 1, electrodes are arranged in eight rows and in four columns on each half of the artificial palate. The frontmost row 1 just behind the upper teeth is displayed at the top of the EPG graphs and the backmost row 8 just in front of the soft palate appears at the bottom. The palate surface has been subdivided into four articulatory zones for data interpretation, i.e., front alveolar (rows 1, and 2), postalveolar (rows 3, and 4), prepalatal (rows 5, and 6), mediopalatal (7) and postpalatal (8). Electrodes appear in black, grey or white depending on frequency of activation across repetitions, i.e., 80–100% (black), 40–80% (grey) and less than 40% (white).

Linguopalatal contact indices Q and CA, i.e., quotient of overall electrode activation and contact anteriority, respectively, were calculated at PMC for all consonant realizations including those with a complete closure at row 8 only. The index Q was obtained averaging all contacted electrodes by the total amount of 62 electrodes of the artificial palate. The index CA was measured applying the following formula (Fontdevila, Pallarès, & Recasens, 1994):

$$CA = [\log[[1(R_8/8) + 9(R_7/8) + 81(R_6/8) + 729(R_5/8) + 6561(R_4/8) + 59049 (R_3 + 8) + 531441(R_2/8) + 3587227(R_1/6)] + 1]]/[\log(4185098 + 1)].$$

In the ratios within parentheses, the number of contacted electrodes on a given row (i.e., R8, R7, etc.) is divided by the total number of electrodes on that row. Each ratio is multiplied by a coefficient number. These coefficients are chosen so that the activation of all electrodes at and

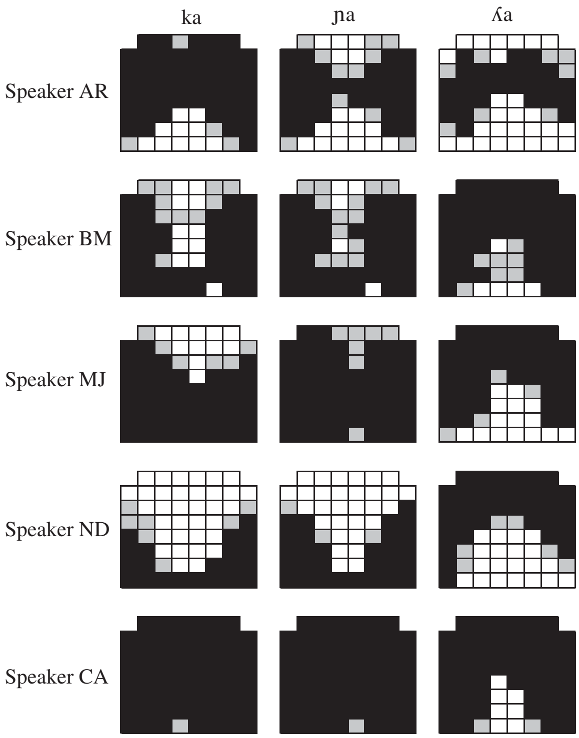

Fig. 1. Linguopalatal contact configurations at PMC for word/utterance initial /k/, /ɲ/ and /ʎ/ before /a/ (all speakers).

behind a specific row always yields a lower index value than the activation of a single electrode at more anterior rows.

In order to investigate those factors causing linguopalatal contact variations to occur, ANOVAs with repeated measures were performed on closure durations and on Q and CA index values with the variable 'speaker' as between-subject factor and the variables 'consonant', 'position' and 'vowel context' as within-subject factors. Conditions for each factor were AR, BM, MJ, ND and CA ('speaker'), /k/, /ɲ/, /ʎ/ ('consonant'), initial, intervocalic, final ('position') and /i/, /a/, /u/ ('vowel context'). The SPSS Windows 11.5 package was used for statistical analysis. Overall, 315 values were entered in each of the three statistical tests, i.e., 3 consonants $\times$ 3 positions $\times$ 3 vowels $\times$ 5 speakers $\times$ 7 repetitions. The level of significance was $p<0.05$. Results reported in Section 3 include main effects for 'consonant', 'position' and 'vowel context', and Bonferroni multiple comparisons between conditions for these three variables, e.g., /k/ vs /ɲ/, /k/ vs /ʎ/ and /ɲ/ vs /ʎ/ across positions and vowel contexts. They also include three-way 'consonant' $\times$ 'position' $\times$ 'vowel context' interactions and the corresponding Bonferroni multiple comparisons, e.g., /k/ vs /ɲ/, /k/ vs /ʎ/ and /ɲ/ vs /ʎ/ in initial position when the contextual vowel is /i/.

3. Results

3.1. Articulation

Figs. 2–4 represent closure location and extent for the consonants /k/, /ɲ/ and /ʎ/ in all positions and vowel contexts over the eight rows of electrodes of the artificial palate for articulatory classification, i.e., over the four front rows at the alveolar zone (above the dotted line) and over the four back rows at the prepalate, mediopalate and postpalate (below the line). Continuous lines indicating closure placement have been assigned to rows showing more than 80% electrode activation even if their two centralmost electrodes did not achieve this contact percentage. No line has been assigned however to those productions which exhibit less than 80% activation at the two central electrodes on row 8 and no central contact at fronter rows, and therefore are articulated behind this row at the velar zone.

Linguopalatal configurations such as those for initial /ka/, /ɲa/ and /ʎa/ in Fig. 1 have been used as reference for the line plotting procedure in Figs. 2–4. Thus, for example, contact patterns for initial /ka/ in Fig. 1 and the corresponding lines in Fig. 2 show that stop closure occurs at the alveolar zone and prepalate for speaker AR (on rows 1–5), at the back palate for speakers BM (rows 7–8) and ND (row 8), over the entire palatal zone for speaker MJ (rows 5–8), and all over the alveolar and palatal zones for speaker CA (rows 1–8).

Data for /k/ in Fig. 2 indicate that this consonant is articulated essentially at the postpalate or medio-postpalate (for speakers ND, and BM and MJ, respectively), or else more anteriorly at the postalveolar or postalveolo–prepalatal zone (speaker AR) or at the alveolopalatal zone (speaker CA). Moreover, the oral stop is produced with much central contact all over the palate surface in the case of the latter speaker. As shown in Fig. 3, the nasal stop /ɲ/ may exhibit the same closure location as /k/, i.e., postpalatal in the case of speaker ND, and postalveolar and optionally prepalatal for speaker AR. However, closure is often fronter for the nasal than for the oral

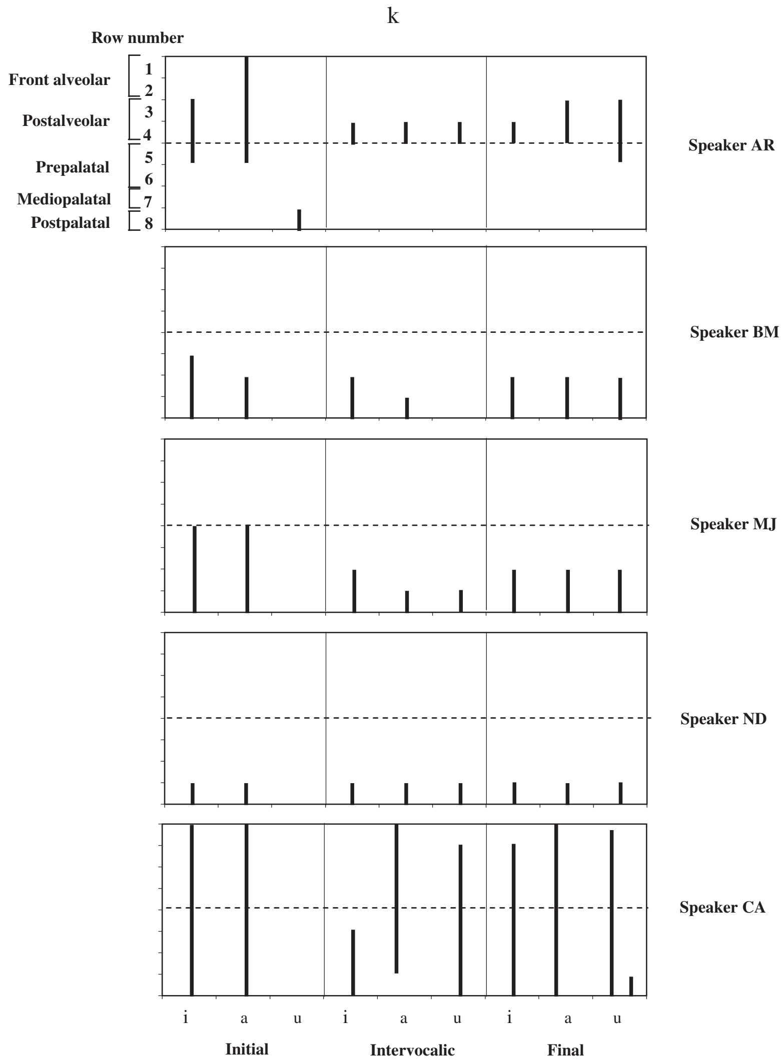

Fig. 2. Closure location for /k/ as a function of position and vowel context for all speakers. The correspondence between rows of electrodes and articulatory zones is given on the abscissa axis. Continuous lines indicate closure placement. Speaker CA shows two closure patterns for /aka, ak, uk/; an empty space to the right of the continuous line in the case of the sequences /aka, ak/ for this speaker indicates that closure occurs behind row 8.

correlate, i.e., alveolopalatal instead of medio-postpalatal in the case of speakers BM and MJ. Regarding speaker CA, while both consonants show a large closure area extending over the alveolar and palatal zones, central contact may be more anterior for /ɲ/ than for /k/ as well.

Linguopalatal contact patterns for /ʎ/ (Fig. 4) differ clearly from those for /k/ and /ɲ/ in that the palatal lateral is always articulated at the alveolar zone and exhibits a fronter place of articulation. The fact that closure location occurs almost systematically at row 1 in all positions and vowel context conditions for speakers BM, MJ, ND and CA suggests that /ʎ/ is dentoalveolar

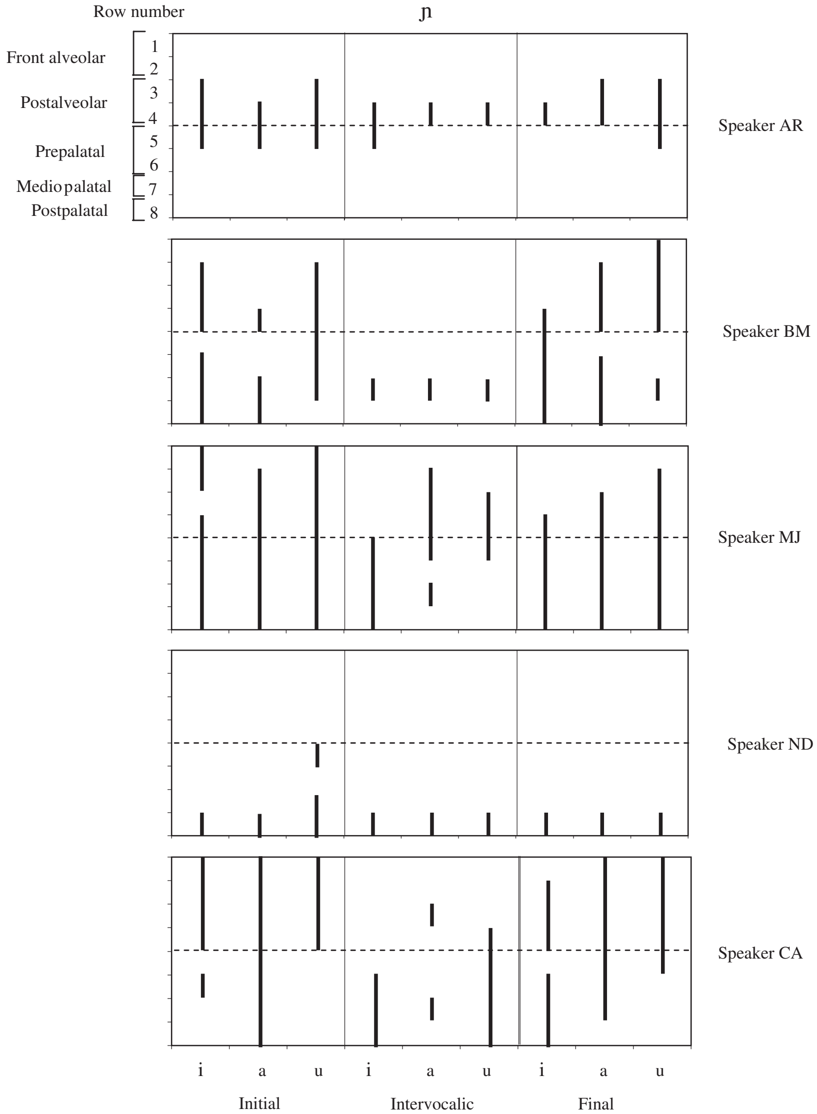

Fig. 3. Closure location for /ɲ/ as a function of position and vowel context for all speakers. See Fig. 2 for details.

rather than alveolar in Majorcan Catalan. Thus, in spite of the fact that row one of the artificial palate does not cover the dental region, dental closure may be inferred from the presence of a complete closure on the frontmost row of electrodes, as in the case of the dental stop /t/ in Spanish and Catalan (Fernández, 2000; Recasens, & Pallarès, 2001). Moreover, the presence of a complete seal at the sides of the prepalate and mediopalate (see Fig. 1) may mean that airflow for /ʎ/ exits through lateral channels located at the postpalate and at the velar zone.

As shown in Fig. 2, the sequences /aka/, /ak/ and /uk/ exhibit more than one contact pattern for speaker CA. Indeed, closure for /uk/ occurs all over the palate surface (4 repetitions) or just at the

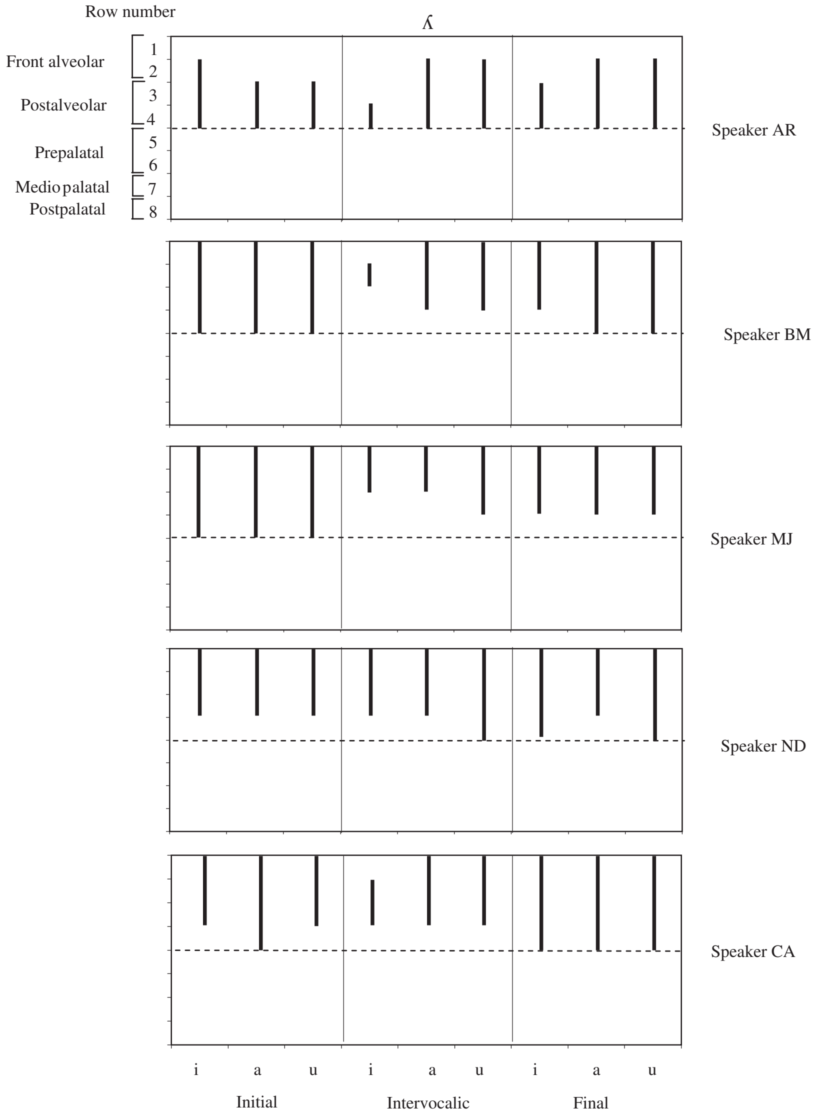

Fig. 4. Closure location for /ʎ/ as a function of position and vowel context for all speakers. See Fig. 2 for details.

postpalate (3 repetitions). On the other hand, closure for /aka/ and /ak/ may be alveolopalatal as indicated by a line extending from row 1 to rows 7–8 (5 repetitions), or velar as implied by the presence of an empty space at the right of this line (2 repetitions). Data in Fig. 3 also reveal the existence of areas devoid of tongue contact at closure location in the case of sequences with [ɲ] for speakers BM (/ɲi, ɲa, aɲ, uɲ/), CA (/ɲi, aɲa, iɲ/), MJ (/ɲi, aɲa/) and ND (/ɲu/). Moreover, though not apparent in Fig. 2, /k/ was found to lack central contact in most repetitions of the sequences /iki/ and /aka/ for speaker AR.

It may be the case that some or all of the closure patterns in Figs. 2 and 3 have been influenced by speaker-dependent palate shape. Thus, highly domed palates may render closure formation at the hard palate especially difficult for some speakers while flat palates cause other speakers to exhibit a great deal of contact all over the alveolar and palatal zones. In order to investigate this issue, maximum height at about rows 7 and 8 was measured for each artificial palate. Measures reveal a larger vertical distance for speaker AR (26 mm) than for speakers CA (19 mm) and BM, MJ and ND (17 mm). Based on these measurements and the contact patterns displayed in Figs. 2 and 3, a highly domed palate for speaker AR could explain why his /k/ and /ɲ/ productions are more anterior than those for the other four speakers under analysis. We can also be confident that a very large contact surface for /k/ for speaker CA is not idiosyncratic since speakers BM, MJ and ND have comparable palate heights and shorter closures at the hard palate; moreover, analogously to speaker CA, speakers BM and MJ are capable of producing alveolopalatal consonant realizations involving a large contact degree (see closure locations for /ɲ/ in Fig. 3). Therefore, the linguopalatal contact configurations for /k/ for speaker CA are not exceptional but consistent with analogous patterns occurring in other Romance dialects (see Section 1).

3.2. Overall contact degree

This section reports results for main effects, significant interactions and multiple comparisons tests for the Q data (see mean Q values for all CV, VCV and VC sequences in Table 2).

ANOVAs on Q index values yielded a main effect of consonant, position and vowel context ($F(2, 58) = 466.55$, $p<0.001$; $F(2, 58) = 175.83$, $p<0.001$; $F(2, 58) = 74.71$, $p<0.001$). Significant differences among conditions conform to the progression /ɲ/ > /ʎ/ > /k/ (consonant), initial > final > intervocalic (position), and /i/ > /a/ > /u/ (vowel context). Mean Q values for each condition are given in Fig. 5 (top graph).

These statistical results are in agreement with the expected linguopalatal contact differences as a function of consonant (at least for /ɲ/ > /ʎ/) and of contextual vowel, and with the notion that articulatory strengthening should yield more tongue contact in word/utterance initial position than in word/utterance final and in intervocalic position. The fact that Q values turned out to be significantly higher word/utterance finally than intervocalically may be due to a trend for dorsal consonants to undergo strengthening and to resist articulatory reduction in the former position and perhaps to weaken in the latter.

ANOVAs also yielded a significant three-way consonant × position × vowel context interaction ($F(8, 232) = 85.51$, $p<0.001$). Table 3 gives results for multiple comparisons tests as a function of 'consonant' (top panel), 'position' (middle panel) and 'vowel context' (bottom panel). Differences in the table correspond to significant effects between variable conditions Thus, for example, the top left cell in the top left panel of the table indicates that /ɲ/ exhibits a significantly higher Q value than /ʎ/ and /k/ in word/utterance initial position while Q differences between /ʎ/ and /k/ were non-significant.

According to statistical results for consonant-dependent interactions in Table 3 (top left panel) and mean values in Table 2, significant Q differences conform to the progression /ɲ/ > /ʎ/ > /k/ in most positional and vowel context conditions. This scenario did not hold for /iCi/ where Q differences varied in the progression /ʎ/ > /ɲ/ > /k/, and applied only in part to /aCa/ and to word /utterance initial /Ci/ and /Ca/ since the pairs /aɲa/-/aʎa/, /ki/-/ʎi/ and /ka/-/ʎa/ did not reach significance. A trend for /i/ to block consonant-dependent differences in dorsopalatal contact is in accordance with the complementary finding that this vowel exerts prominent V-to-C

Table 2
Quotient of linguopalatal contact (Q) and contact anteriority (CA) index values, and durations (in ms) for /k/, /ɲ/ and /ʎ/ as a function of position (word/utterance initial, intervocalic, word/utterance final) and vowel context (/i/, /a/, /u/)

Consonant	Position	Vowel	Q		CA		Duration	
			Mean	sd	Mean	sd	Mean	sd
k	Initial	i	75.95	16.98	0.88	0.11	175.29	55.61
	Initial	a	77.13	19.66	0.88	0.17	159.70	65.74
	Initial	u	27.94	8.15	0.35	0.14	119.41	47.61
	Intervocalic	i	53.92	9.28	0.74	0.10	90.57	25.55
	Intervocalic	a	43.84	21.99	0.54	0.24	52.65	16.93
	Intervocalic	u	55.90	22.61	0.69	0.20	67.71	16.82
	Final	i	62.81	18.34	0.77	0.15	142.35	62.23
	Final	a	59.54	18.02	0.73	0.17	114.59	34.68
	Final	u	57.79	18.35	0.70	0.18	116.76	40.11
ɲ	Initial	i	80.83	15.91	0.92	0.11	177.14	55.44
	Initial	a	79.46	18.53	0.89	0.14	146.36	46.36
	Initial	u	83.82	14.61	0.93	0.10	179.12	63.12
	Intervocalic	i	60.34	9.03	0.77	0.09	127.94	43.26
	Intervocalic	a	65.71	15.14	0.79	0.12	60.00	14.35
	Intervocalic	u	68.89	14.47	0.80	0.10	64.86	12.45
	Final	i	75.19	13.20	0.86	0.08	157.94	45.45
	Final	a	78.43	16.60	0.87	0.12	151.71	21.62
	Final	u	78.08	18.71	0.89	0.16	147.65	36.02
ʎ	Initial	i	77.23	11.76	0.98	0.05	190.29	54.74
	Initial	a	73.48	14.21	0.97	0.06	160.88	38.01
	Initial	u	71.61	15.44	0.96	0.08	158.57	43.60
	Intervocalic	i	69.49	12.25	0.95	0.07	63.14	20.26
	Intervocalic	a	62.95	12.46	0.97	0.06	66.86	12.31
	Intervocalic	u	63.28	16.37	0.95	0.08	65.00	14.41
	Final	i	71.77	12.82	0.97	0.07	167.94	39.14
	Final	a	65.99	9.82	0.98	0.04	186.00	72.85
	Final	u	66.89	13.15	0.98	0.05	160.88	42.38

Data correspond to PMC and have been averaged across speakers. Standard deviations are also given.

coarticulatory effects in tongue dorsum raising and fronting on consonants in general (Recasens, 1984).

As expected, position-dependent differences in linguopalatal contact size for palatal consonants conform to the progression initial > final > intervocalic most of the time (Table 3, middle left panel). There were some exceptions, i.e., Q values for /k/ in the context of /u/ turned out to be higher in intervocalic and final position than in initial position, and Q differences for /ɲa/ vs /aɲ/ and for /iʎi/ vs /iʎ/ failed to reach significance.

Significant vowel-dependent differences in tongue contact size during the consonant were found to hold for /i/ > /a/ > /u/ in specific instances only (Table 3, bottom left panel). Indeed, /k/ shows

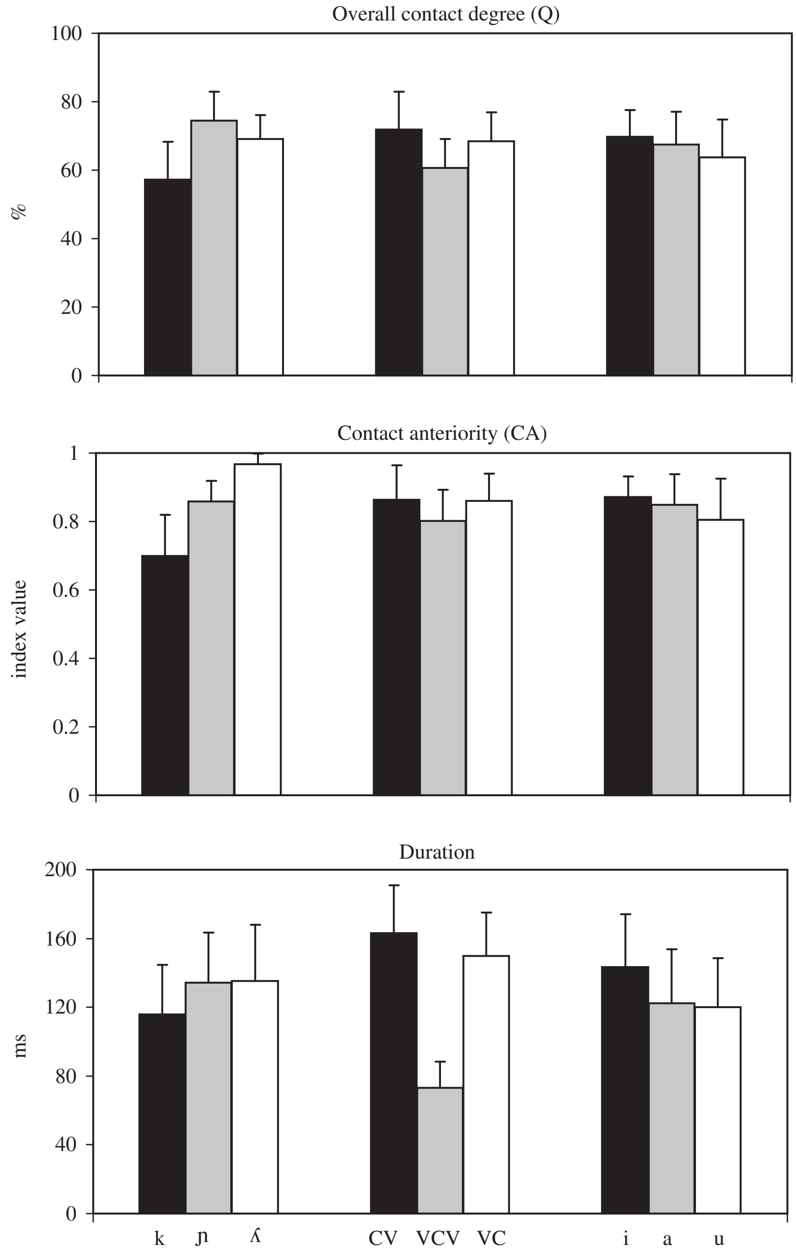

Fig. 5. Mean and standard deviation values for overall contact degree (top), contact anteriority (middle) and duration (bottom) for /k/, /ɲ/ and /ʎ/ as a function of consonant (left), position (middle) and vowel context (right).

some more vowel coarticulation word/utterance initially (for /i/>/u/ and /a/>/u/) than intervocalically (only for /u/>/a/), and no vowel-dependent differences word/utterance finally; on the other hand, /ɲ/ exhibits unexpected vowel-dependent differences in all positions, and /ʎ/ shows differences in vowel fronting for /i/ vs /a/, /u/ but no differences in vowel height as a

Table 3
Consonant-dependent (top), position-dependent (middle) and vowel-dependent (bottom) interactions for Q (quotient of linguopalatal contact index) and CA (contact anteriority index)

	Q			CA		
	Initial (CV)	Intervocalic (CVC)	Final (VC)	Initial (CV)	Intervocalic (CVC)	Final (VC)
i	ɲ > ʎ = k	ʎ > ɲ > k	ɲ > ʎ > k	ʎ > ɲ > k	ʎ > ɲ = k	ʎ > ɲ > k
a	ɲ > ʎ = k	ɲ = ʎ > k	ɲ > ʎ > k	ʎ > ɲ = k	ʎ > ɲ > k	ʎ > ɲ > k
u	ɲ > ʎ > k	ɲ > ʎ > k	ɲ > ʎ > k	ʎ > ɲ > k	ʎ > ɲ > k	ʎ > ɲ > k
	k	ɲ	ʎ	k	ɲ	ʎ
i	CV > VC > VCV	CV > VC > VCV	CV > VC = VCV	CV > VC = VCV	CV > VC > VCV	CV > VC > VCV
a	CV > VC > VCV	CV = VC > VCV	CV > VC > VCV	CV > VC > VCV	CV = VC > VCV	CV = VC = VCV
u	VC = VCV > CV	CV > VC > VCV	CV > VC > VCV	VC = VCV > CV	CV > VC > VCV	VC > CV = VCV
	k	ɲ	ʎ	k	ɲ	ʎ
CV	i = a > u	i = a, u u > a	i > a = u	i = a > u	i = u > a	i = a = u
VCV	i = u > a	a = u > i	i > a = u	i > u > a	i = a = u	a > i = u
VC	i = a = u	a = u > i	i > a = u	i = a i > u a = u	i = a = u	a = u > i

function of back /a/ vs /u/ in all positions. It thus appears that vowel coarticulation may vary inversely with palatality degree rather than with overall tongue contact during the consonant, i.e., in comparison with /ɲ/ and /k/, /ʎ/ exhibits less dorsopalatal contact and more vowel coarticulation at the palatal zone (see also Figs. 2–4). Moreover, vowel coarticulation for /k/ appears to vary positively rather than inversely with overall contact degree when position is taken into consideration, i.e., vowel-dependent effects in Q for this consonant decrease in the progression initial > intervocalic > final. This finding is in support of the hypothesis that consonants involving large degrees of linguopalatal contact blend with the following vowel in initial position and do not undergo articulatory weakening in final position.

3.3. Contact anteriority

ANOVAs yielded a main effect of consonant, position and vowel context on contact anteriority ($F(2,\ 58) = 1362.98$, $p<0.001$; $F(2,\ 58) = 75.48$, $p<0.001$; $F(2,\ 58) = 114.88$, $p<0.001$). Significant differences among consonants, positions and contextual vowels conform to the progression /ʎ/ > /ɲ/ > /k/ , initial, final > intervocalic, and /i/ > /a/ > /u/ (see Fig. 5, middle graph).

These statistical results are in agreement with the expected differences in fronting among the three consonants and the three vowels (see Section 1), but not with the hypothesis that final consonants should undergo more reduction than their initial correlates. It should be noted in this respect however that, though non significantly different, CA values were found to be slightly higher word/utterance initially (0.864) than word/utterance finally (0.860).

The three-way interaction consonant × position × vowel context was also significant (F(8, 232 = 123.14, $p<0.001$). According to the top right panel in Table 3 (see also mean values in Table 2), significant differences in CA conform to the expected trend /ʎ/>/ɲ/>/k/ in most positions and vowel context conditions. Significant differences in contact anteriority failed to occur for /ɲ/ vs /k/ word/utterance initially in the context of /a/ and intervocalically in the context of /i/.

The expected position-dependent differences in contact fronting, i.e., initial>final>intervocalic, turned out to apply to /ɲ/ to a larger extent than to /k/ and /ʎ/ (Table 3, middle right panel). Indeed, CA differences failed to achieve statistical significance for the pairs /ɲa/-/aɲ/, /ik/-/iki/ and /ʎa/-/aʎa/, /ʎa/-/aʎ/ and /aʎa/-/aʎ/, and CA values happened to be unexpectedly higher for /uk, uku/ vs /ku/ and for /uʎ/ vs /ʎu, uʎu/. These findings indicate that /ɲ/ is generally more retracted word/utterance finally than word/utterance initially, and that this is also the case for /k/ next to /i, a/ as opposed to /u/ where the oral stop remains velar in initial position. Failure for the palatal lateral to show the expected position-dependent CA differences in back vowel contexts is related to differences in contact degree at the back closure area rather than to contact fronting since /ʎ/ exhibits a complete closure at row 1 in practically all sequences under analysis (see Fig. 4).

Significant vowel-dependent differences in contact anteriority conforming to the expected progression /i/>/a/>/u/ occurred less often than the expected consonant-dependent and position-dependent effects (see Table 3, low right panel). The oral stop /k/ appears to undergo less coarticulation word/utterance finally (only /i/>/u/) than in the other two positions, and fails to show significantly higher CA values for /i/ vs /a/ word/utterance initially (expected effects occur for /i/>/u/ and /a/>/u/) and for /a/ vs /u/ intervocalically (expected effects occur now for /i/>/a/ and /i/>/u/). On the other hand, the nasal stop exhibits most expected significant differences in initial position only (for /i, u/>/a/), and the palatal lateral shows unconsistent or no vowel-dependent differences in general. In summary, /ɲ/ and /ʎ/ are highly coarticulation resistant presumably in line with the large contact size involved during the production of the former consonant and with the fact that closure location appears to be required to reach the upper teeth for the latter. Vowel coarticulation takes place word/utterance initially rather than word/utterance finally both for the palatal oral stop and the palatal nasal, and /ɲ/ allows more coarticulation in initial vs. intervocalic position as well. Analogously to the Q data, this position-dependent pattern of vowel coarticulation is in support of the hypothesis that palatal consonants blend with the following vowel in word/utterance initial position and do not undergo articulatory reduction word/utterance finally.

3.4. Duration

Statistical analyses yielded significant differences in closure duration for all three factors 'consonant' ($F(2,58) = 38.89$, $p<0.001$), 'position' ($F(2,58) = 694.25$, $p<0.001$) and 'vowel context' ($F(2,58) = 51.35$, $p<0.001$). The closure periods for /ɲ/ and /ʎ/ were found to be significantly longer than those for /k/, positional effects conformed to the progression initial>final>intervocalic, and /i/ caused consonants to be significantly longer than /a/ and /u/ (see Fig. 5, bottom graph). These results are in agreement with position-dependent differences reported for other consonants in the literature and suggest that word/utterance final lengthening

Table 4
Position-dependent interactions for consonant duration

	k	ɲ	ʎ
i	CV > VC > VCV	CV = VC > VCV	CV = VC > VCV
a	CV > VC > VCV	CV = VC > VCV	CV > VC > VCV
u	CV = VC > VCV	CV > VC > VCV	CV = VC > VCV

may be taking place. Differences in closure duration reveal that /i/ contributes to an increase in closure duration, though this finding could be due to the underestimation of /k/ duration for /ku/ due to problems in locating closure onset (see Method section).

There was a significant position × consonant × vowel context interaction in closure duration ($F(8, 232) = 11.5$, $p < 0.001$). As revealed by the statistical results in Table 4 and by closure duration data in Table 2, this was mostly so since consonant closures were always significantly longer at the word edges than in intervocalic position but not so word/utterance initially than word/utterance finally. Indeed, /k/ exhibited longer closures in initial than in final position in the context of /i/ and /a/ but not so in the context of /u/, and closures for /ɲ/ and /ʎ/ were equally long in these two word positions most of the time.

4. Discussion

4.1. Articulation

Data for /k/ and /ɲ/ analyzed in this study reveal the existence of two places of articulation for Majorcan Catalan palatal consonants, i.e., alveolopalatal and palatal proper. Some speakers prefer one place over the other both for the oral stop and for the nasal stop, i.e., palatal in the case of speaker ND and alveolopalatal in the case of speaker AR (though palate shape could account for some contact patterns for the latter speaker). The scenario for the other three speakers is more complex. Tongue contact patterns for speakers BM and MJ reveal that /k/ is palatal while /ɲ/ is alveolopalatal mostly so in word/utterance initial and word/utterance final position. On the other hand, speaker CA shows an alveolopalatal closure for the two consonants which may be somewhat fronter for /ɲ/ than for /k/. The lateral /ʎ/ is dentoalveolar.

As suggested in Section 1, differences in fronting between [ʎ], [c] and [ɲ] cannot be attributed to the size of the phonemic inventory and are presumably conditioned by aerodynamic factors. Thus, a requirement for [ʎ] to be produced with lateral airflow accounts for why the palatal lateral is fronter than the two palatal stops, and differences in air pressure buildup could also explain why [c] may be more posterior than [ɲ].

A relevant finding is that both oral and nasal palatal stops may exhibit the same place of articulation for a given speaker, i.e., palatal for ND, and alveolopalatal for AR and to a large extent CA. This trend could be related to articulatory economy and thus, to the convenience of assigning the same place of articulation to closely related consonants. The fact that /k/ and /ɲ/ show similar articulatory realizations in the case of speakers AR, ND and CA may seem somewhat surprising in view of the fact that the nasal stop derives historically from an alveolar consonant (/n/) while the palatal stop derives from a velar consonant (/k/), and the two consonants are specified for different aerodynamic requirements. Judging from these historical sound sources and the contact patterns for those three speakers, it appears that [ɲ] may have been identified with [c] through closure retraction while [c] may have been equated with [ɲ] through closure fronting. Linguopalatal contact data for [c] and [ɲ] are more in agreement with their velar and alveolar origin in the case of speakers BM and MJ since they both exhibit an alveolopalatal realization for [ɲ] and a palatal realization for [c].

Other findings reported in the present paper are in accordance with the notion that alveolopalatal productions may be viewed as more stable than productions occurring exclusively at the palatal zone in line with the difficulty involved in forming a complete closure at the hard palate. Possible supporting evidence for this hypothesis derives from the observation that closure location for palatal stops originated from front velars may occur not only at the palatal zone but also at the alveolopalatal zone depending on speaker, position and context (see also discussion of [c] in Sicilian, Parisian French, Greek and Romanian in Section 1). Specific speakers, i.e., speaker CA, may alternate palatal and alveolopalatal realizations of the same consonant, and the linguopalatal contact area for [c] has been found to increase frontwards in positions favoring articulatory strengthening (e.g., word/utterance initially). Another relevant finding in support of the unstability of pure palatal stop consonants is the existence of random areas free of contact at the hard palate.

The change of pure palatal realizations of /k/ to alveolopalatal productions may account for the integration of [c] as [tʃ] in Romance, e.g., Italian [ˈtʃento] cento "a hundred" from Latin CENTU (Recasens & Espinosa, 2003). This interpretation runs against the alternative hypothesis that velar softening is not based on articulation but motivated by the perceptual confusion between the burst for front /k/ and the frication component for [tʃ] (Guion, 1998). Gliding and alveolarization processes are also in agreement with the trend for palatal stops to become alveolopalatal through a decrease in dorsopalatal contact degree (see Section 1).

4.2. Positional and vocalic effects

Contact index and closure duration data reported in Section 3 are consistent with position-dependent differences in articulatory strengthening. Indeed, analogously to other consonants, overall contact degree, contact anteriority and duration were often higher word/utterance initially than word/utterance finally, i.e., for /k/ next to /i, a/ (Q, CA, duration), for /ɲ/ next to /i, u/ (Q, CA) and /u/ (duration), and for /ʎ/ next to /i, a/ (Q) and /u/ (Q, duration). The oral stop /k/ fails to show the expected position-dependent differences in dorsopalatal contact and in contact anteriority in the context of /u/ because it is articulated at the velar zone in the sequence /ku/. Two findings appear to be consistent with a trend for final consonants subject to high production demands to undergo some utterance final strengthening: the nasal stop turned out to exhibit the same Q value initially and finally in the context of /a/; all three palatal consonants were longer and more anterior, and involved more tongue contact, in final vs intervocalic position. A complementary possibility with the latter finding is that palatal consonants may undergo articulatory reduction in intervocalic position.

Observed consonant-dependent differences in degree of vowel coarticulation should be interpreted with reference to differences in linguopalatal contact degree among the consonants under investigation. In agreement with data presented in the literature (Recasens, 1984), vocalic coarticulation in dorsopalatal contact size was found to vary inversely with linguopalatal contact degree for /ʎ/>/ɲ/, and the palatal nasal turned out to be highly resistant to V-to-C coarticulatory effects in CA as well. A high degree of resistance in contact fronting for /ʎ/ follows from the fact that this consonant is dentoalveolar in Majorcan Catalan. Moreover, a higher degree of Q and CA coarticulation for /k/ than for /ɲ/ is also in accordance with lower Q and CA index values for the oral stop than for the nasal stop.

Vowel coarticulation has been found to vary positively rather than inversely with position-dependent differences in overall contact and in contact anteriority, i.e., Q and CA were higher initially than finally and lowest intervocalically, while coarticulation turned out to decrease in the progression initial position>intervocalic position>final position. This finding suggests that coarticulatory sensitivity is conditioned by different control mechanisms depending on whether it is associated with segmental production or with position: vowel coarticulation decreases with the manner and place requirements for the consonantal gesture but increases with position-dependent differences in articulatory salience. If so, speakers would aim at enhancing the positional allophones of consonants in strong positions by preserving specific contextual properties, i.e., by implementing initial /k/ through palatalized realizations in front vowel contexts and through back and possible rounded realizations in back rounded vowel contexts. Position-dependent effects are not only associated with /k/ which exhibits large differences in contact anteriority and contact size between the palatal and velar allophones word/utterance initially, but also with /ɲ/ which allows prominent V-to-C effects in contact anteriority at the beginning of the word and the utterance as well. The finding that consonants are more coarticulation resistant word/utterance finally than intervocalically may be attributed to the presence of two adjacent vowels in the latter contextual condition but also to a trend for dorsal consonants to strengthen in utterance final position.

Data reported in this study indicate that two allophones of /k/ are prone to occur word initially rather than syllable initially. Indeed, while all speakers were found to produce a palatal or a velar stop depending on the following vowel in word initial position, this was only so for speaker BM in VCV sequences. Speakers AR, MJ, ND and CA showed the same or a similar postalveolar, alveolopalatal or palatal realization in all VCV contexts. Moreover, the fact that initial /ki/ and /ka/ were produced with a comparable contact configuration ought to be associated with articulatory prominence rather than with the possibility that /ka/ exhibits a large contact degree because /a/ is specially front in Majorcan Catalan. Thus, while the low vowel may be indeed somewhat more anterior and thus produced with some more tongue height in this dialect than in other Catalan dialects (Recasens & Espinosa, submitted), the difference appears to be rather small at least for present-day Majorcan Catalan speakers.

Therefore, it appears that Majorcan Catalan /k/ and /ɲ/ are programmed to be implemented not through a blending mechanism with the following vowel but through a highly resistant alveolopalatal or palatal realization in all vowel contexts and positions, and that this target is generally reached except for initial /ku/ (and before other back rounded vowels according to descriptive data from the literature; see Section 1). This exception could be attributed to two factors, namely, more compatibility between anticipatory lip rounding and closure formation at the velar than at the palatal zone, and the need to render CV syllables perceptually distinctive in prominent word positions. Thus, it may be hypothesized that by rounding velar /k/ in the word/utterance initial syllable /ku/ speakers maximize differences in front cavity length, stop burst frequency and perceptual distance between this allophone and unrounded and more anterior realizations of /k/ in the word/utterance initial syllables /ki/ and /ka/. Both factors are compatible with the realization of /k/ as a palatal stop after /u/ in word final position where anticipatory lip rounding is absent.

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