448

Journal of Phonetics (1984) 12, 61–73

V-to-C coarticulation in Catalan VCV sequences: an articulatory and acoustical study

Daniel Recasens

Department of Linguistics, University of Connecticut, Storrs, Connecticut 06268, U.S.A. and Haskins Laboratories, 270 Crown St, New Haven, Connecticut 06511, U.S.A.

Recieved 17*th October* 1983

Abstract: Electropalatographic and acoustical data on VCV sequences for Catalan consonants involving contrasting degrees of tongue-dorsum contact (dorsopalatal [j], alveolo-palatals [ɲ] and [ʎ], and alveolar [n]) show that the degree of V–to–C coarticulation varies monotonically and inversely with the degree of tongue-dorsum contact and the size of the back cavity behind the place of constriction. Evidence for larger carryover than anticipatory V-to-C effects is also presented. Both findings suggest that, to a large extent, coarticulation on tongue-dorsum contact is regulated by mechanical constraints on articulatory activity.

Introduction

Little progress has been achieved in characterizing the programming of articulatory gestures used by the speaker to actualize phonetic segments in running speech (Harris, 1977). Thus, a large body of experimental evidence supports the view that no one-to-one mapping relationship is to be found between underlying phonemic units and articulatory gestures. Instead, the articulatory manifestations of phonetic segments can be said to coarticulate in running speech in the sense that articulatory gestures are inherently context-sensitive and overlap over time. Therefore, articulatory invariance is to be sought in the process of articulatory dynamics itself. Accordingly, the underlying units that control such a process can best be characterized in terms of dynamic gestures (see Fowler *et al.*, 1980) rather than in terms of static articulatory targets correlated with linguistic units such as phonemes or phonemic features.

A plausible view about how the production process is organized around patterns of articulatory dynamics is that taken by some researchers at Haskins Laboratories. According to Fowler (1980) and Fowler *et al.* (1980), this process is executed by means of coordinative structures, namely, muscle groupings organized functionally to actualize linguistic units in fluent speech. The constraints on articulatory movement allowed by the coordinative structure specify those articulatory dimensions along which context-adjustment may take place. Thus, in the light of this approach, coarticulatory activity ought to be predictable from constraints on articulatory displacement.

To investigate the regularities underlying the process of coarticulation, the effect of surrounding vowels upon tongue-dorsum contact during the production of palatal and alveolar consonants was analyzed in this study. The prediction that the degree of vowel-to-consonant coarticulation varies monotonically and inversely with the degree of tongue-dorsum contact

0095–4470/84/010061+13$03.00/0

was tested. Consistent with Fowler *et al.* (1980), for consonants produced with contrasting degrees of constraint on the tongue dorsum to make dorsopalatal contact, more tongue-dorsum contact ought to produce less coarticulatory activity and less tongue-dorsum contact larger coarticulatory effects.

There is evidence from the literature that coarticulation of tongue-dorsum activity and degree of tongue-dorsum constriction are inversely related. In the articulatory domain, data on alveolar stops for Swedish and English (Öhman, 1966), on English alveolar fricatives (Carney & Moll, 1971), and on German alveolar stops (Butcher & Weiher, 1976) show that, during the production of these consonants, the tongue dorsum coarticulates with the surrounding vocalic environment and produces transconsonantal effects. In the acoustical domain, large effects from surrounding vowels on alveolar [l] are documented in different languages: English (Lehiste, 1964; Bladon & Al-Bamerni, 1976), Italian (Bladon & Carbonaro, 1978), French (Chafcouloff, 1980).

Data for palatal consonants show less coarticulation. Kent & Moll (1972) found no tongue-dorsum effects from the surrounding vowels during closure of English [j] in VCV sequences. Lehiste (1964) for English and Chafcouloff (1980) for French report small F2 effects from V to C in the case of [j]. According to Stevens & House (1964), the spread of F2 values at the boundaries of the vocalic portions of English VCV sequences is smaller for palatals than for consonants articulated further front in the mouth. Analogously, Bladon & Carbonaro (1978) found little or no acoustic evidence of V-to-C coarticulation for the Italian palatal [ʎ] in VCV sequences.

A comparison of coarticulatory trends for both consonantal sets according to data from the literature summarized above shows that V-to-C effects are larger for alveolars than for palatals. Such a difference is associated with contrasting strategies of tongue-dorsum activity as follows: in the case of alveolars, the tongue dorsum is left free to coarticulate with surrounding vowels; for palatals, it appears to be directly involved in the constriction gesture, thus blocking possible coarticulatory effects to a large extent.

To my knowledge the prediction that degree of tongue-dorsum contact and degree of coarticulation can be related monotonically has not been systematically investigated before. In order to test the prediction, V-to-C coarticulatory trends for palatal and alveolar consonants that involve different degrees of tongue-dorsum contact were studied here. Consonants [j], [ɲ], [ʎ], and [n] in Catalan (a Romance language spoken in Catalonia, Spain) have been chosen for this purpose. Contrasting degrees of tongue-dorsum contact are associated with these consonants for [j] > [ɲ] > [ʎ] > [n], both as traditionally described and according to a survey of palatographic recordings from the literature across different Romance languages and contextual conditions (e.g., Rousselot, 1924–1925; Haden, 1938) performed by myself for the present study. Thus, [j] can be characterized as a dorsopalatal approximant, leaving a narrow passage along the palatal median line; [ɲ] and [ʎ] appear to be alveolo-palatal stops produced with large linguopalatal contact over the surface of the palate with the tongue blade and the tongue dorsum (less so than for [j], and more so for [ɲ] than for [ʎ]); [n] is an alveolar consonant produced with tongue-tip occlusion and no contact with the tongue dorsum at the center of the palate.

In summary, it appears that [j], [ɲ], [ʎ], and [n] involve decreasing degrees of tongue-dorsum contact. In a language with alveolars and palatals contrasting in tongue-dorsum contact, [j], [ɲ], [ʎ], and [n] ought to show increasing degrees of V-to-C coarticulation.

Method

Articulatory analysis

Electropalatographic (EPG) data were collected for Catalan consonants [j], [ɲ], [ʎ], and [n] in all possible VCV combinations with V = [i], [a], [u]. The utterances were embedded in a Catalan frame sentence "Sap__poc," 'He knows__just a little.' A single speaker of Catalan (speaker Re, the author), also fluent in Spanish, English, and French, repeated all utterances ten times with the artificial palate in place while the electropalatographic signal and the corresponding acoustic signal were recorded on tape for later analysis.

The artificial palate used in this study contains 63 electrodes evenly distributed over its surface and permits tracking linguopalatal contact patterns over time (1 frame = 15.6 ms). Detailed information about this palatographic system (Rion Electropalatograph Model DP-01) is available in Shibata (1968) and Shibata *et al.* (1978). The electrodes are arranged in five semicircular rows; for purposes of data interpretation, they have been grouped in articulatory regions and sides taking advantage of their equidistant arrangement in parallel curved rows on the artificial palate. As shown in Fig. 1, the surface of the palate has been divided into four articulatory regions (alveolar, prepalatal, mediopalatal, and postpalatal) and into two symmetrical sides (right and left) by a median line traced along the central range of electrodes. This division in terms of areas on the palatal surface is based on anatomical grounds (Catford, 1977).

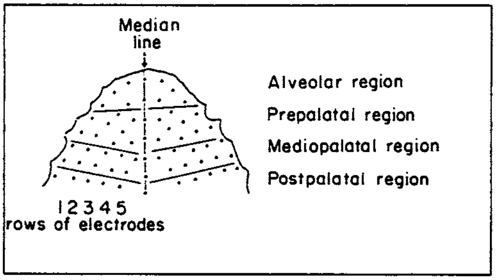

Figure 1 Electropalate.

For each VCV utterance, contact data were tabulated at the frame that presented the highest number of on-electrodes (that is, point of maximum contact or PMC) and averaged across repetitions for interpretation.

Acoustical analysis

Four repetitions of all VCV combinations from this and two other Catalan speakers (Bo and Ca), also fluent in Spanish, were recorded for acoustical analysis. They were digitized at a sampling rate of 10 kHz, after preemphasis and low-pass filtering. An LPC (linear prediction coding) program included in the ILS (Interactive Laboratory System) package was used to measure the frequencies of the three lowest spectral peaks at PMC. To identify PMC on the acoustic wave for speaker Re, EPG data were also digitized at a sampling rate of 20 kHz, with no previous preemphasis or filtering. Labeling procedures were executed using WENDY (Haskins Laboratories Wave Editing and Display system). For speakers Bo and Ca, for whom no EPG data were available, PMC was estimated by visually identifying the F1 frequency minimum in the transition from the first vowel to the consonant. Such a point was found to match PMC satisfactorily for speaker Re. Acoustical data were averaged across repetitions for interpretation.

The prediction that degree of coarticulation varies along with changes in degree of tongue-dorsum contact will be studied according to the following procedure. For each consonant, I will present articulatory and acoustical data at PMC on general production characteristics in symmetrical VCV environments and V-to-C coarticulatory effects in symmetrical and asymmetrical VCV environments. In all cases I will concentrate exclusively on patterns of contact at the rear of the palate (mediopalate and postpalate) that reflect tongue-dorsum activity. In the acoustic domain, only data on F2 frequencies will be presented, given the affiliation between this formant with differences in back cavity size and in degree of palatal constriction for palatal and alveolar consonants (Fant, 1960).

Results

Consonant [j]

In Fig. 2, tongue contact is represented by the area between the contour lines and the sides of the palate; the area where there is no contact is medial to the contour lines. According to the figure, the dorsopalatal approximant [j] is produced with a dorsal constriction along the entire mediopalatal and postpalatal regions except for a narrow passage along the median line, and lowered tongue tip and tongue blade. High F2 values for [j] (1925–2425 Hz, according to Table I) are dependent upon half-wavelength of the combined mouth-pharynx system behind the constriction; the small range of F2 variation (500 Hz) denotes a highly fixed and well-defined back cavity configuration independent of speaker and vocalic environment.

Table I F2 values in Hz for [j], [ɲ], [ʎ], and [n] at PMC in symmetrical environments (speakers Re, Bo, and Ca)

	[iji]	[aja]	[uju]	[iɲi]	[aɲa]	[uɲu]	[iʎi]	[aʎa]	[uʎu]	[ini]	[ana]	[unu]
Re	2350	1925	2200	2350	1775	2150	2275	1600	1900	2210	1570	1075
Bo	2425	2150	2425	2425	2000	2425	2400	2000	1850	2350	1675	1150
Ca	2150	1925	2050	2150	1575	2250	2000	1600	1750	2075	1350	1100

Figure 2 shows coarticulatory effects in symmetrical vocalic environments. They affect the width of the central passage in the mediopalatal and postpalatal areas, with analogous maximal narrowing for high vowels [i] and [u], and more opening for low vowel [a]. As shown in Table I, observed F2 values for [j] vary in direct relationship to the degree of palatal constriction. Thus, they are found to be high for high vowels [i] and [u] (2050 to 2425 Hz) and low for low vowel [a] (1925 to 2150 Hz).

Figure 3 shows coarticulatory effects in asymmetrical vocalic environments. Anticipatory effects from V2 (shown on the left) and carryover effects from V1 (shown on the right) have been measured when the transconsonantal vowel is kept constant. It can be seen that patterns resulting from carryover and anticipatory effects are almost the same as for the symmetrical high-vowel environment: the effect of a high vowel is found to override that of a low vowel systematically, thus causing maximal degree of constriction at the mediopalate an postpalate, independent of coarticulatory direction.

Acoustical data on anticipatory and carryover effects are presented in Table II. F2 values

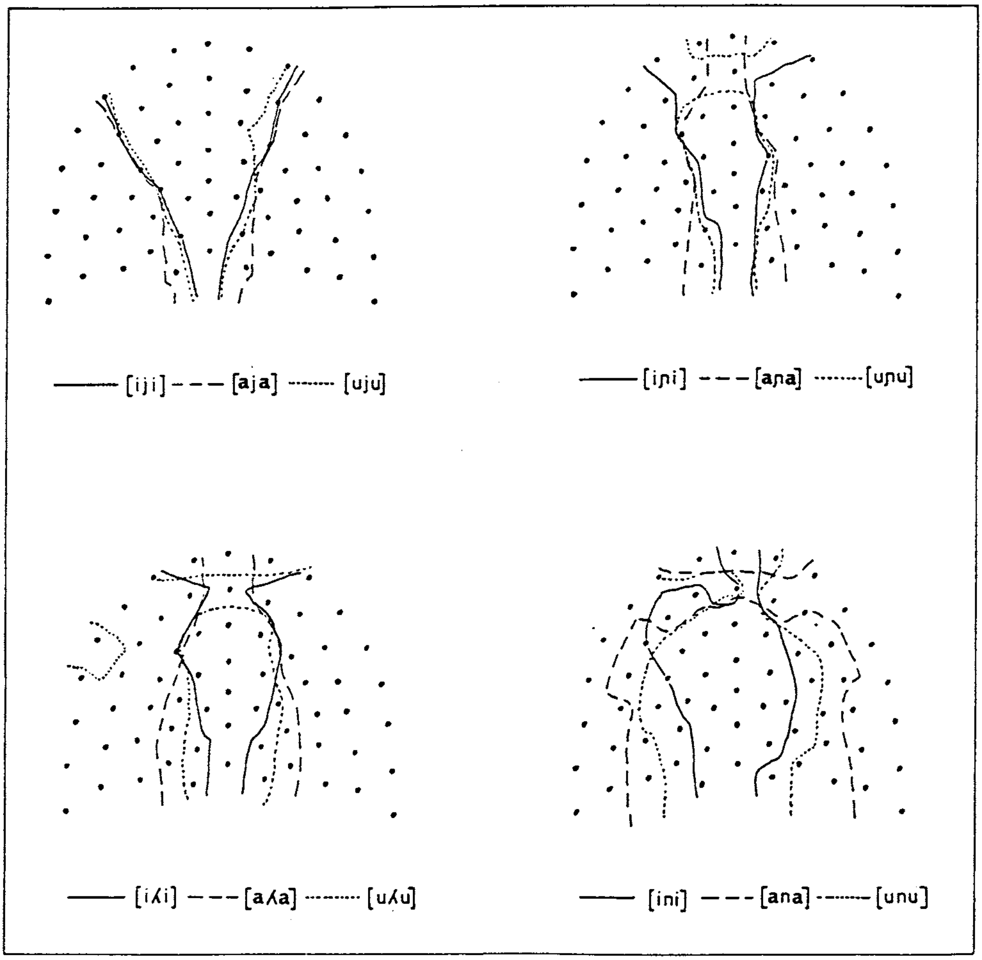

Figure 2 Linguopalatal configuration for [j], [ɲ], [ʎ], and [n] at PMC in symmetrical environments (speaker Re).

have been averaged across VCV contexts for each V2 (anticipatory effects) and V1 (carryover effects) for each speaker. Cross-vocalic ranges have also been included. In contrast to the EPG data, the acoustical data in Table II show larger carryover effects (from V1 = [i], [u] > [a])[1] than anticipatory effects (from V2 = [i] > [u] ⩾ [a]) for all speakers. Thus, the range of F2 values across contrasting V2 is lower (40, 105, and 110 Hz for different speakers) than that across contrasting V1 (100, 210, and 315 Hz for different speakers).

Consonant [ɲ]

The alveolo-palatal nasal [ɲ] is produced with contact all over the surface of the palate with tongue blade and tongue dorsum, except for a narrow passage along the median line (see Fig. 2). At the postpalate, this passage shows equal or less (never more) contact than for [j].

[1] This shorthand notation indicates the ordering of values as a function of vowel environment.

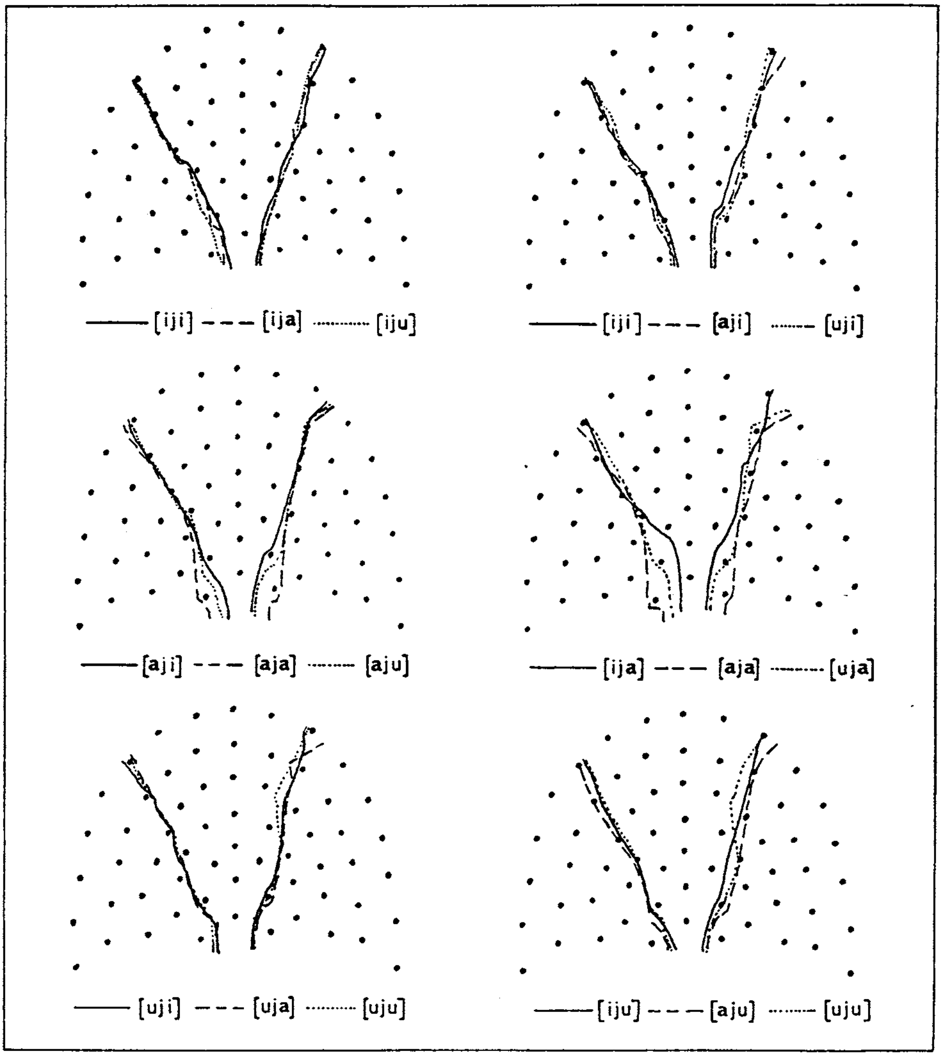

Figure 3 Anticipatory (left) and carryover (right) effects for [j] at PMC (EPG data; speaker Re).

F2 for [ɲ] is pharynx-cavity dependent. As shown in Table I, the range of F2 values for [ɲ] (850 Hz) is larger and the values can be lower (1575–2425 Hz) than for [j]. This is essentially due to the fact that the postpalatal passage can show more variability and can be larger in degree of opening for [ɲ] than for [j].

Coarticulatory trends in symmetrical environments (see Fig. 2) show, just as for [j], maximal narrowing of the passage at the rear of the palate for high vowels [i], [u], and larger opening for low vowel [a]. Differences in degree of postpalatal contact are larger (for [a] vs. [i], [u]) than for [j]. As shown in Table I, F2 values for [ɲ] vary in direct relationship to the degree of palatal contact, as for [j]. Thus, they are found to be high for high vowels [i] and [u] (2150 to 2425 Hz) and low for low vowel [a] (1575 to 2000 Hz). Lower values for [a] with [ɲ] than with [j] accord well with the fact that [aɲa] shows less dorsopalatal contact at the postpalate than [aja].

Table II Anticipatory and carryover effects for [j], [ɲ], [ʎ], and [n] (F2 values in Hz; speakers Re, Bo, and Ca) over all VCV contexts for each V2 (anticipatory effects) and V1 (carryover effects)

	[j]		[ɲ]		[ʎ]		[n]	
	Anticipatory	Carryover	Anticipatory	Carryover	Anticipatory	Carryover	Anticipatory	Carryover
[i]	2240	2300	2185	2300	2005	2190	1655	2230
Re [u]	2135	2225	2115	2210	1885	1935	1595	1075
[a]	2135	1985	2085	1875	1885	1650	1640	1585
Range	105	315	100	425	120	540	60	1155
[i]	2375	2425	2335	2425	2250	2275	1875	2260
Bo [u]	2355	2425	2300	2425	2000	2090	1635	1285
[a]	2335	2215	2285	2065	2140	2050	1765	1735
Range	40	210	50	360	250	225	240	975
[i]	2075	2025	2050	2085	1885	2000	1665	2000
Ca [u]	1990	2085	2015	2065	1835	1800	1485	1215
[a]	1965	1925	1955	1690	1785	1700	1540	1475
Range	110	100	95	395	100	300	180	785

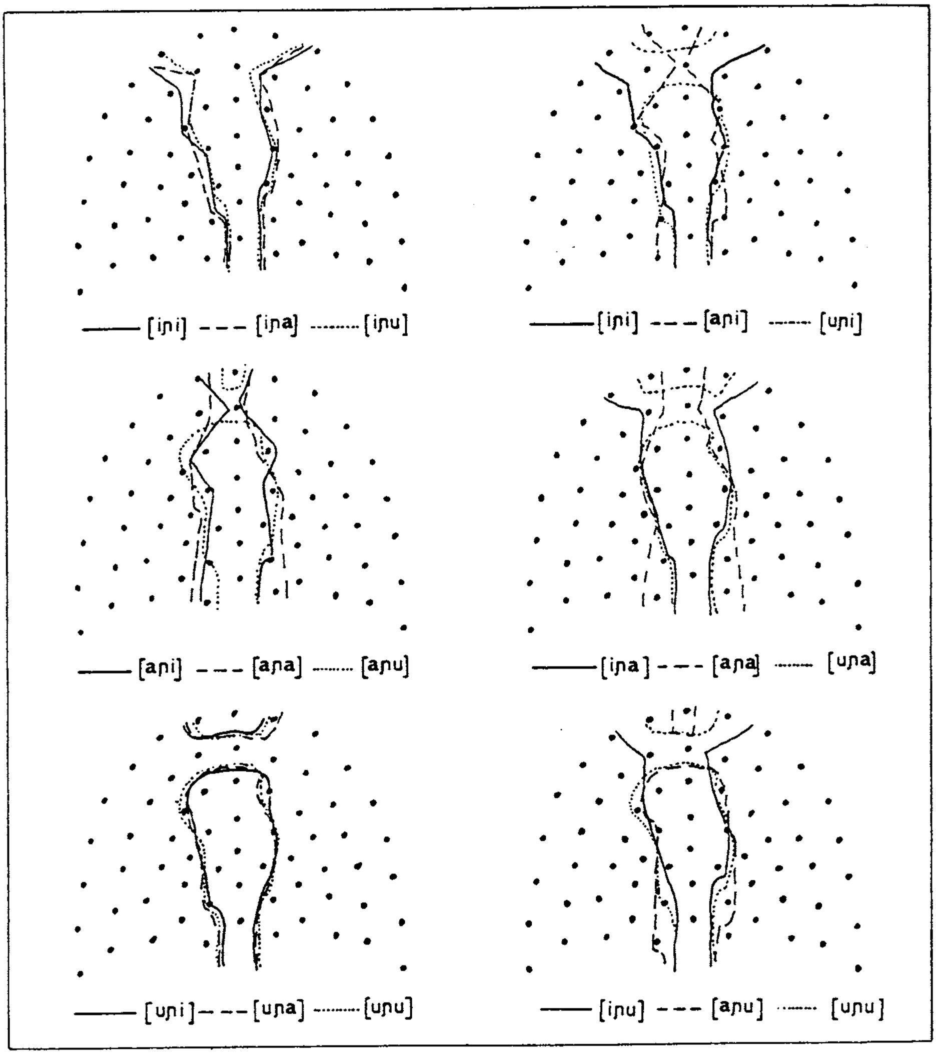

Figure 4 Anticipatory (left) and carryover (right) effects for [ɲ] at PMC (EPG data; speaker Re).

Anticipatory (left) and carryover (right) effects with respect to degree of the constriction at the rear of the palate are shown in Fig. 4. Carryover trends occur systematically, i.e., a preceding low vowel causes a wider passage than a preceding high vowel, independent of V2. Anticipatory trends from V2 are overriden by V1; thus, the passage width is always more open for V1 = [a] than for V1 = [i], [u], independent of V2. Similarly, acoustical data (see Table II) show larger carryover effects (more so than for [j], from V1 = [i] ⩾ [u] > [a]) than anticipatory effects (as for [j], from V2 = [i] > [u] > [a]) for all speakers. The fact that [ɲ] shows similar anticipatory effects and larger carryover effects than [j] at the articulatory and acoustical levels results from the smaller degree of tongue-dorsum contact.

Consonant [ʎ]

The alveolo-palatal [ʎ] is produced with contact all over the palatal surface with tongue blade and tongue dorsum, except for a narrow passage along the median line that is larger than that for [ɲ] (see Fig. 2). Therefore, [ʎ] involves a smaller degree of tongue-dorsum contact than [j] and [ɲ]. As a lateral consonant, [ʎ] is articulated so that the airstream passes out at the sides of the vocal tract. The absence of lateral slits for some utterances and the presence of only a prepalatal slit on the left side of the palate for others, suggests that the airstream passes mainly through a channel formed by the external surface of the teeth and the inner walls of the cheek.

F2 for [ʎ] shows essentially the same cavity affiliation as for [j]. According to Table I, there is a larger range of F2 variation (800 Hz) for [ʎ] than for [j]. The result is consistent with a more variable back cavity configuration. On the other hand, F2 values can be lower (1600–2400 Hz), in accordance with a larger back cavity behind the constriction.

Coarticulatory trends in symmetrical environments (see Fig. 2) show differences in the size of the palatal passage for high front [i] (narrowest) and low back [a] (widest), high back [u] falling in between. This pattern differs from that for [j] and [ɲ], which show no contrast between [i] and [u]. Thus, the tongue-dorsum placement during the production of [ʎ] vs [j], [ɲ] appears to be sensitive to degrees of tongue backing as well as jaw opening in the adjacent vowels. Consistently, contrasting cross-speaker effects on F2 are found according to differences in degree of dorsal contact for [i] (2000–2400 Hz) > [u] (1750–1900 Hz) > [a] (1600–2000 Hz) (see Table I).

According to Fig. 5, carryover effects are larger than anticipatory effects. They are also larger than for [j] and [ɲ] in showing contrasting degrees of contact for V1 = [i] > [u] > [a]; anticipatory effects are small or non-existent and conform always to the degree of mediopalatal and postpalatal opening appropriate for V1. Larger carryover than anticipatory effects are also observed for the articulatory traits that characterize laterality. Thus, a lateral prepalatal slit on the left side of the palate is always found when V1 = [u] and is absent when V1 = [i], [a], while no anticipatory effects are found in this respect.

Acoustical data (see Table II) for F2 frequencies also show larger carryover than anticipatory effects for all speakers. Carryover trends are observed mainly from V1 = [i] > [u] > [a] and anticipatory effects mainly from V2 = [i] > [u], [a]. Ranges of F2 values show that anticipatory effects for [ʎ] are larger than for [j] and [ɲ] (for speakers Re and Bo but not for speaker Ca), and that carryover effects are larger than for [j] and can be larger or smaller than for [ɲ].

Consonant [n]

The consonant [n] is produced with apico-alveolar constriction and complete contact all along the sides of the palate, thus leaving a large central cavity along the median line (see Fig. 2). The cavity is much larger than that for palatal consonants, thus indicating a smaller degree of tongue-dorsum contact. F2 for [n] is dependent upon the pharynx cavity, as for [ɲ]. According to Table I, it is lower (1075–2350 Hz) and shows more variability (1275 Hz) than for [ɲ], thus indicating larger pharynx-cavity size and higher degree of tongue-body adaptability to the vocalic environment.

Coarticulatory effects in symmetrical environments (see Fig. 2) in degree of contact at the rear of the palate are found for [i] > [u] > [a]. The passage becomes narrower towards the postpalate for high [i] and [u] than for low [a]. Cross-vocalic differences in size of the passage are larger than for any alveolo-palatal consonant, thus reflecting higher sensitivity of tongue-dorsum activity to the surrounding vowels. As shown in Table I, large cross-speaker

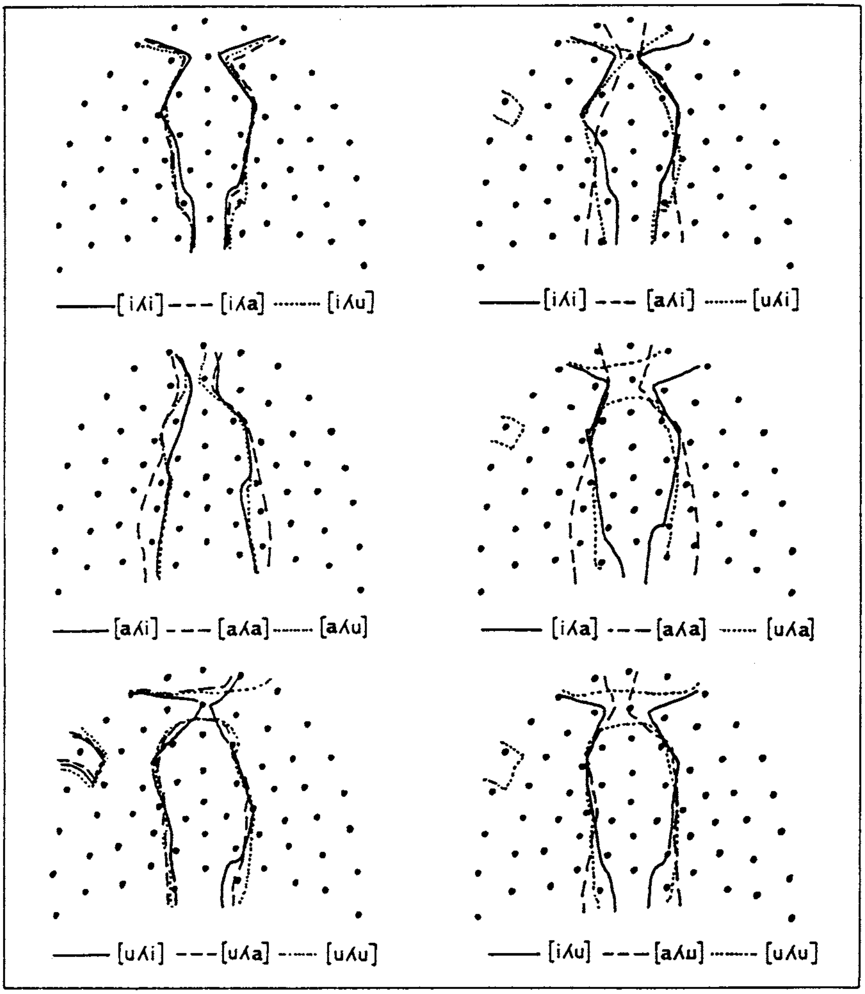

Figure 5 Anticipatory (left) and carryover (right) effects for [ʎ] at PMC (EPG data; speaker Re).

F2 differences are found for [i] (2075–2350 Hz) > [a] (1350–1675 Hz) > [u] (1075–1150 Hz), as a result of important changes in pharynx-cavity size reflected by differences in the size of the passage at the mediopalatal and postpalatal areas. Lower F2 for [u] than for [a] (and not for [a] than for [u], as would be expected from differences in degree of contact at the rear of the palate) may be due to lip rounding effects.

According to Fig. 6, large carryover effects in the opening size of the mediopalatal and postpalatal passage are found when V2 = [a], [u] (from V1 = [a] > [u] > [i]) and very small effects when V2 = [i] (from V1 = [a], [u] > [i]). Anticipatory effects are found when V1 = [a], [u] (from V2 = [a] > [u] > [i]) but not when V1 = [i]. Anticipatory and carryover effects in degree of tongue-dorsum contact are larger for [n] than for any palatal consonant.

Table II shows strong carryover effects upon F2 for all speakers from V1 = [i] > [a] > [u], and much smaller anticipatory effects from V2 = [i] > [a] > [u]. Ranges of F2 values

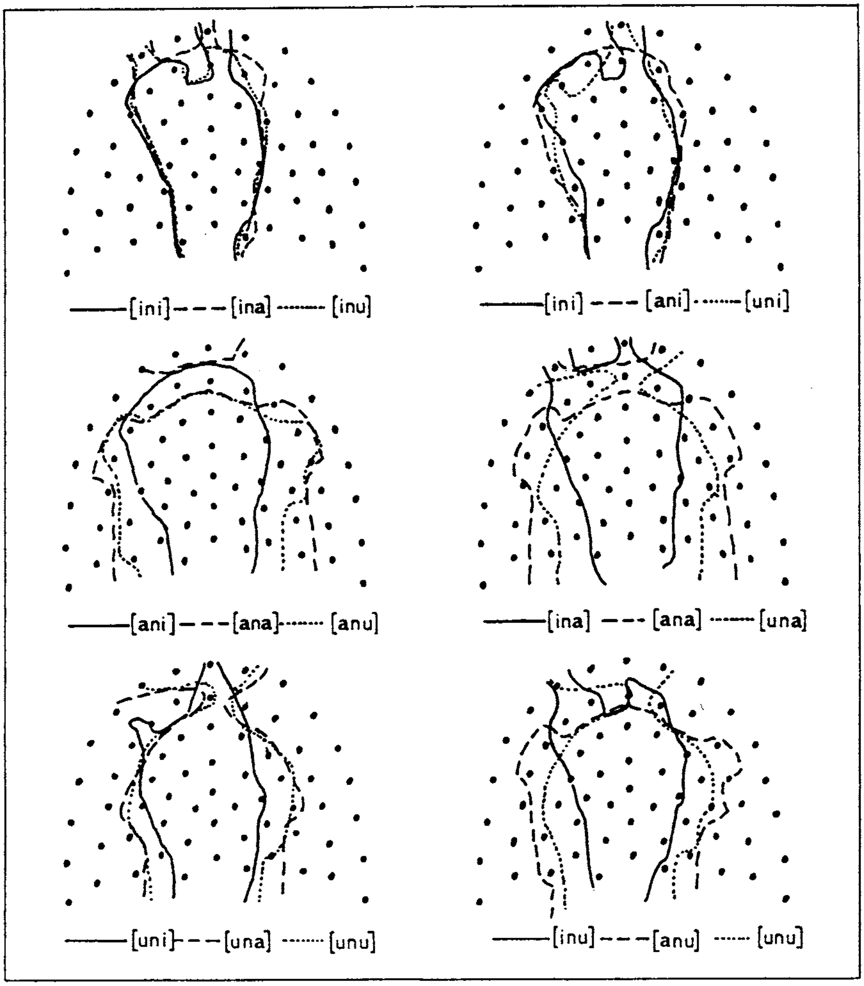

Figure 6 Anticipatory (left) and carryover (right) effects for [n] at PMC (EPG data; speaker Re).

show that carryover effects are always larger for [n] than for palatal consonants, and that anticipatory effects are generally but not always larger.

Summary and conclusions

Palatographic data show that the degree of tongue-dorsum contact, on average, decreases along the series [j], [ɲ], [ʎ], [n]. Coarticulatory effects on tongue-dorsum contact for [j], [ɲ], [ʎ], and [n], measured at PMC, can be summarized as follows:

(1) Dorsopalatal approximant [j]: In symmetrical environments, articulatory and acoustical effects are found from high vs low vowels. In asymmetrical environments, anticipatory and carryover patterns of contact show that the effect of a high vowel always overrides that of a low vowel; in the light of the acoustical data, larger carryover than anticipatory effects are found mainly from high vs low vowels.

(2) Alveolo-palatal nasal [ɲ]: In symmetrical environments, articulatory and acoustical

effects are found from high vs low vowels, more so than for [j]. In asymmetrical environments, articulatory and acoustical data show carryover effects mainly from high vs low vowels and small or non-existent anticipatory effects; overall, [ɲ] shows larger carryover effects than [j] and similar anticipatory effects.

(3) Alveolo-palatal lateral [ʎ]: In symmetrical environments, larger articulatory and acoustical effects than for [j] and [ɲ] are found for high front vs high back vs low back vowels. In the light of articulatory data, contrasting carryover effects occur for those vowels while anticipatory effects are small or non-existent; acoustical data show larger carryover effects for the three vowels than anticipatory effects. Overall, coarticulatory effects in asymmetrical environments are larger than for [j] and [ɲ] in the articulatory and acoustical domains.

(4) Alveolar nasal [n]: In symmetrical environments, articulatory and acoustical effects are found for high front vs high back vs low back vowels, more so than for palatal consonants. In the light of articulatory data, carryover and anticipatory effects can be large or small depending on the quality of the transconsonantal vowel; acoustical data show stronger carryover than anticipatory effects for the three vowels. Overall, coarticulatory effects in asymmetrical environments are larger than for palatal consonants.

It can be concluded that the amount of V-to-C coarticulation is dependent upon the degree of tongue-dorsum contact observed during the production of the consonant. Thus, on the one hand, a defined tongue-dorsum raising gesture towards the palatal area, as for a dorsopalatal consonant such as [j], results in little coarticulatory sensitivity to the surrounding vowels. On the other hand, alveolo-palatals such as [ɲ] and [ʎ], which show a greater degree of opening of the mediopalatal and postpalatal passage and in range of F2 values than [j], coarticulate more freely with the surrounding vocalic environment; moreover, a larger passage for [ʎ] than for [ɲ] results in larger coarticulatory effects. Finally, alveolar [n], produced with less tongue-dorsum contact than alveolo-palatals, shows the largest V-to-C coarticulatory effects of all the consonants studied here.

It is true, then, that the degree of V-to-C coarticulation varies inversely with the degree of tongue-dorsum contact required for the production of the consonant. Moreover, this variation is monotonical: a progressive decrease in degree of tongue-dorsum contact causes coarticulatory activity to vary progressively in similar amounts. Thus, for the different degrees of tongue-dorsum activity for [j] > [ɲ] > [ʎ] > [n], different degrees of coarticulatory activity are obtained for [n] > [ʎ] > [ɲ] > [j].

This systematic dependence of coarticulatory effects on the degree of linguopalatal contact suggests that, to a large extent, coarticulation is regulated by mechanical constraints on articulatory activity. Thus, a large degree of constraint on tongue dorsum results in a large amount of dorsal contact and a small degree of coarticulation; as the degree of constraint decreases, dorsal contact becomes smaller and coarticulatory effects increase. In line with Fowler *et al.* (1980), those may be the invariant relationships underlying the speech production mechanism.

With respect to the issue of directionality of coarticulatory effects, carryover effects have been found to be larger than anticipatory effects independent of speaker and vocalic environment. From the present study, it can be concluded that this finding reflects a language-specific property of how articulatory programming is organized in Catalan. However, evidence for the same trend has been found for English (Bell-Berti & Harris, 1976; Gay, 1974).

I wish to thank the members of my advisory committee, Arthur S. Abramson, Ignatius G. Mattingly, Alvin M. Liberman, and Katherine S. Harris, for their valuable help during all stages of this research. Thomas Baer made very insightful comments on previous versions of the manuscript. The research was supported by NICHD Grant HD 01994 and NINCDS Grant NS-13617 to Haskins Laboratories, and by a fellowship from the government of Catalonia (CIRIT Commission) to the author. An earlier version of this paper was presented at the 104th Meeting of the Acoustical Society of America in Orlando, November, 1982 (*Journal of the Acoustical Society of America*, 1982, 72, S101).

References

Bell-Berti, F. & Harris, K. S. (1976). Some aspects of coarticulation. *Haskins Laboratories Status Report on Speech Research*, SR-45/46, 197–204.

Bladon, R. & Al-Bamerni, A. (1976). Coarticulatory resistance in English /l/. *Journal of Phonetics*, 4, 135–150.

Bladon, R. & Carbonaro, E. (1978). Lateral consonants in Italian. *Journal of Italian Linguistics*, 3, 43–55.

Butcher, A. & Weiher, E. (1976). An electropalatographic investigation of coarticulation in VCV sequences. *Journal of Phonetics*, 4, 59–74.

Carney, P. J. & Moll, K. L. (1971). A cinefluorographic investigation of fricative consonant-vowel coarticulation. *Phonetica*, 23, 193–202.

Catford, J. C. (1977). *Fundamental Problems in Phonetics*. Bloomington: Indiana University Press.

Chafcouloff, M. (1980). Les caractéristiques acoustiques de [j, y, w, l, r] en français. *Travaux de l'Institut de Phonétique d'Aix, Université de Provence*, 7, 7–56.

Fant, G. (1960). *Acoustic Theory of Speech Production*. The Hague: Mouton.

Fowler, C. A. (1980). Coarticulation and theories of extrinsic timing. *Journal of Phonetics*, 8, 113–133.

Fowler, C. A., Rubin, P., Remez, R. E. & Turvey, M. T. (1980). Implications for speech production of a general theory of action. *Language Production*, (B. Butterworth, ed.) pp. 373–420. New York: Academic Press.

Gay, T. (1974). A cinefluorographic study of vowel production. *Journal of Phonetics*, 2, 255–266.

Haden, E. F. (1938). The physiology of French consonant changes. *Language*, 14 supplement, Dissertation no. 26.

Harris, K. S. (1977). The study of articulatory organization: some negative progress. In: *Dynamic Aspects of Speech Production* (Sawashima, M. & Cooper F. S. eds) pp. 71–82. Tokyo: University of Tokyo Press.

Kent, R. & Moll, K. (1972). Cinefluorographic analyses of selected lingual consonants. *Journal of Speech & Hearing Research*, 15, 453–473.

Lehiste, I. (1964). *Acoustical Characteristics of Selected English Consonants*. Research Center in Anthropology, Folklore, & Linguistics, Indiana University, 34.

Öhman, S. E. G. (1966). Coarticulation in VCV utterances: spectrographic measurements. *Journal of the Acoustical Society of America*, 39, 151–168.

Rousselot, A. P. (1924–1925). *Principes de phonétique expérimentale*. Vols I, II. Paris: Didier.

Shibata, S. (1968). A study of dynamic palatography. *Annual Bulletin of the Research Institute of Logopedics and Phoniatrics, University of Tokyo*, 2, 28–36.

Shibata, S., Ino, A., Yamashita, S., Hiki, S., Kiritani, S. & Sawashima, M. (1978). A new portable type unit for electropalatography. *Annual Bulletin of the Research Institute of Logopedics and Phoniatrics, University of Tokyo*, 12, 5–10.

Stevens, K. N. & House, A. S. (1964). Analysis of formant transitions for consonants. *Quaterly Progress Report of the Research Laboratory of Electronics, Massachusetts Institute of Technology*, 73, 165–166.