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Letter to the Editor

The effect of syllable position on consonant reduction (evidence from Catalan consonant clusters)

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Abstract

This paper is an electropalatographic and acoustic investigation of consonant reduction as a function of syllable position in several heterosyllabic consonant clusters of Catalan within the framework of the degree of articulatory constraint (DAC) model of coarticulation. Three contact indices, i.e., alveolar contact anteriority and centrality and dorsopalatal contact quotient, are used for the computation of the linguopalatal contact characteristics for alveolar, alveolopalatal and velar consonants, with care taken to differentiate contextual effects from effects associated with syllable position. Results show that relatively unconstrained stops, nasals and laterals are produced with less front lingual contact and less dorsopalatal contact in syllable final vs. syllable initial position while this is not so for highly constrained fricatives and rhotics. A trend for the palatal fricative vs. the alveolar fricative to exhibit a wider constriction syllable finally vs. syllable initially is also attributed to stricter demands on constriction formation for the latter fricative vs. the former. Overall, these findings are in agreement with the notion that articulatory reduction in syllable final position is conditioned by constraints on consonantal production.

1. Introduction

It is known that consonants are subject to more articulatory reduction syllable finally than syllable initially (Ohala & Kawasaki, 1984). This contrast appears to be implemented through differences in tongue raising and constriction width which is presumably why lenition, gliding, rhotacism, elision and related sound change processes often affect syllable final consonant realizations, e.g., /k/ > [j], [x] and /s/ > [ɹ] in the dialectal Spanish forms [do(j/x)ˈtoɾ],

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[do(ɹ)ˈθjentos] for '*doctor, doscientos*' (Fougeron, 1999; Browman & Goldstein, 1995). Another unattested indicator of consonant reduction as a function of syllable position is tongue retraction, as suggested by segmental replacements affecting syllable final consonants such as /s/ > [ʃ] in Romansh ([ˈveːʃpra] derived from Latin VESPERA, [ˈpaːʃkəs] PASQUA; Lutta, 1923) and Wallon ([baʃ] BASSU; Bruneau, 1913), and perhaps /n/ > [ŋ] in Gascon ([paŋ] PANE; Bec, 1968) and Provençal ([ˈkaːŋte] CANTO; Coustenoble, 1945). Conversely, syllable initial consonants may be reinforced through an increase in duration and constriction degree as shown by the palatalization of word initial alveolars (Catalan [ʎum] LUCE, Leonés [ˈɲuðo] NUDU; Zamora Vicente, 1989).

A goal of this paper is to verify the validity of these articulatory mechanisms of consonant reduction using linguopalatal contact data. A more specific aim of our investigation is to test the hypothesis that the degree of syllable final consonant reduction should be associated with the production requirements involved. If so, unlike less constrained consonantal segments, those consonants imposing a high degree of articulatory constraint (DAC) on a given tongue region should undergo little or no contact loss and/or retraction at that lingual region in syllable final position.

1.1. Degree of articulatory constraint and articulatory characteristics

So far, the notion DAC for consonants has been related to specific articulatory properties, and to data showing that resistance to C-to-C coarticulatory effects at the tongue front and dorsum increases with the articulatory demands imposed on those lingual articulatory regions (see Recasens & Pallarès, 2001). Based on the conclusions drawn from this previous study, the Catalan consonants under analysis in the present investigation (alveolar /n/, dark /l/, /s/, trill /r/; alveolopalatal /ʃ/ and /ʎ/; velar /k/) have been tentatively assigned the DAC values shown in Table 1. The table also provides information about the articulatory characteristics of these consonants, namely, whether they are articulated at a front or back constriction location with the tongue front (at the front alveolar zone or at the back alveolar zone and prepalate, respectively), and whether they exhibit a large or a small constriction width and a high, mid or low tongue dorsum position.

Table 1
Values for degree of articulatory constraint (DAC), front constriction location relative to the alveolar region, front constriction width, and tongue dorsum position for the Catalan consonants under analysis

	Tongue front				Tongue dorsum	
	Constriction location	DAC value	Constriction width	DAC value	Position	DAC value
n	Front	Low			Mid	Low
dark l	Front	Low			Low	Low
s	Back	High	Small	High	Low	High
trill r	Back	High			Low	High
ʃ	Back	High	Large	Low	High	Low
ʎ	Front	Low			High	Low
k	—	Low			High	Low

The rationale for these consonant-dependent differences in DAC specification is as follows. The trill /r/ and the fricatives /s, ʃ/ have been assigned a high DAC value for the tongue front constriction location in line with the demanding requirements involved in the execution of trilling and frication; accordingly, C-to-C coarticulation data reveal that these three consonants (/s, r, ʃ/) block effects of alveolar contact fronting from more anterior and more unconstrained /n, l, ʎ/. Conversely, the tongue front is relatively unconstrained in the case of /n, l, ʎ, k/ either because it does not intervene directly in constriction or closure formation (i.e., in the case of the alveolopalatal /ʎ/ and velar /k/) or as a reflection of the flexibility of the tongue tip articulator (i.e., for the apicals /n, l/); accordingly, the place of articulation for /n, l, ʎ/ is rendered more posterior before back alveolars /s, r, ʃ/ than before other consonants. Moreover, /s/ and /ʃ/ differ in respect of articulatory control on constriction formation probably as a result of the fact that the constriction for apical /s/ is restricted to the central alveolar or postalveolar zone while that for lamino-predorsal /ʃ/ is longer and more retracted (Stevens, 1998); this assumption is consistent with the finding that /s/ is less sensitive to C-to-C coarticulatory effects in constriction degree than /ʃ/. Thus, /s/ is assigned a high DAC value in constriction width (more constrained) and /ʃ/ a low DAC value (unconstrained).

Manner of articulation requirements account for why /s/ and /r/ are also highly constrained at the tongue dorsum and resist coarticulatory effects in tongue dorsum raising exerted by adjacent consonants produced with a higher tongue dorsum position. Consonants of other manners of articulation are specified for a lower degree of constraint. Indeed, a relatively unconstrained tongue dorsum and greater sensitivity to C-to-C tongue dorsum coarticulation is the scenario for consonants not involving this region in constriction formation (/n/), for consonants specified for active tongue dorsum lowering but less strict manner requirements (dark /l/), and for consonants produced with a high tongue dorsum position (/ʃ, ʎ, k/). Consistently, our previous work reports C-to-C effects in tongue dorsum raising and lowering for /n/ (e.g., in the clusters /nʃ/ and /nr/, respectively), in tongue dorsum raising for dark /l/ (e.g., in the cluster /lʃ/), and in tongue dorsum lowering for /ʃ, ʎ, k/ (e.g., before /s, r/ and dark /l/) (Recasens & Pallarès, 2001).

It should be noticed that the DAC values in the table are generally correlated with constriction location and width and with tongue dorsum position. For the tongue front parameter, anterior /n, l, ʎ/ are more unconstrained and thus specified for a lower DAC value than posterior /s, r, ʃ/, and for the constriction width parameter, more constricted /s/ is more constrained than less constricted /ʃ/. As for the tongue dorsum, consonants produced with more or less tongue dorsum raising (/n, ʃ, ʎ, k/) are taken to be less constrained than those involving active tongue dorsum lowering (/s, r/). There are two special cases: velar /k/ which is unconstrained at the tongue front since it is articulated further back in the vocal tract, and dark /l/ which is produced with a low tongue dorsum position and is relatively unconstrained at this lingual articulator.

It should also be stated that the DAC value at the tongue dorsum may vary depending on whether consonants are embedded in clusters or in VCV sequences (Recasens, Pallarès, & Fontdevila, 1997). This is mostly so for alveolopalatals (/ʃ, ʎ/) and velars (/k/) which were assigned a high DAC value in our VCV coarticulation study while being specified for a low DAC in clusters. This contrast is in agreement with the finding that these consonants are less sensitive to tongue dorsum effects exerted by vowels than to those exerted by consonants involving active tongue dorsum lowering (i.e., /s, r/).

1.2. Syllable position

The central hypothesis to be tested in the present paper is based on the assumption that syllable final consonant reduction should contribute to a decrease in DAC, and be implemented with more constriction retraction and width and less tongue dorsum contact. It may be formulated as follows: for the tongue front, the degree of retraction due to syllable finality ought to be greater for less constrained /n, l, ʎ/ than for more constrained /s, r, ʃ/; and for the constriction width, constriction widening due to syllable finality ought to be greater for less constrained /ʃ/ than for more constrained /s/; for the tongue dorsum, the reduction of dorsopalatal contact due to syllable finality ought to be greater for less constrained /n, l, ʃ, ʎ, k/ than for more constrained /s, r/. No substantial articulatory reduction as a function of syllable position is expected to take place for velars at the tongue front since these consonants are articulated with the tongue postdorsum at the palatovelar zone.

Care should be taken however to separate effects associated with syllable position from those associated with the adjacent consonant in the cluster. At the very least, effects exerted by the trill and lingual fricatives on consonants specified for a lower DAC value should be accounted for in light of the fact that they happen to coincide to a large extent with those resulting from articulatory reduction. Indeed, since C-to-V and C-to-C effects exerted by /s, r, ʃ/ are mostly regressive (Recasens, et al., 1997; Recasens & Pallarès, 2001), less alveolar contact fronting and overall less contact degree for unconstrained consonants in C1 vs. C2 position in the adjacency of highly constrained consonants could be attributed to the contextual consonant rather than to syllable location. Consequently, our initial hypothesis should be reformulated as follows:

(a) A more posterior place of articulation for unconstrained front /n, l, ʎ/ in syllable final vs. syllable initial position ought to be associated with syllable position if occurring in the adjacency of /n, l, ʎ, k/ but with the contextual consonant if produced adjacent to highly constrained back /s, r, ʃ/. Differences in alveolar constriction fronting for highly constrained /s, r, ʃ/ and in constriction width for /s, ʃ/ should depend on syllable position in all CC combinations because our previous study showed that these consonants are not influenced significantly by the adjacent consonants in clusters.
(b) Less tongue dorsum height for the unconstrained consonants /n, l, ʃ, ʎ, k/ in syllable final vs. syllable initial position is prone to be associated with syllable position if these consonants occur adjacent to unconstrained consonants but with the contextual consonant in the environment of highly constrained /s, r/. Differences in tongue dorsum height for highly constrained /s, r/ ought to be related to syllable position in all cases.

Changes in tongue fronting and height for consonants in consonant clusters are not restricted to articulatory constraint but may depend on other factors which will be taken into consideration in the present investigation:

(a) gestural incompatibility, when the two consonants in the cluster are highly constrained and specified for conflicting manners of articulation, e.g., a lingual fricative and a trill (Solé, 1999);
(b) tongue repositioning, when the production of the consonantal sequence involves tongue dorsum raising followed by tongue front raising, e.g., in the case of /ʃs/ vs. /sʃ/ (Perkell, Boyce, & Stevens, 1979);

(c) articulatory overshoot in clusters composed of two consecutive palatal consonants in line with the fact that these consonantal articulations exert prominent carryover coarticulatory effects on the following segmental material (Recasens, 1984).

2. Method

Our data sample includes all possible heterosyllabic consonant clusters with the Catalan consonants /n, l, s, r, ʃ, ʎ, k/. The two consonants in the clusters were separated by a word boundary, flanked by the vowel /a/ and produced in sentences composed of two meaningful Catalan words. The presence of a word boundary was needed in order to allow for sequences with an alveolopalatal C1 which are impossible word medially. While articulatory differences between C1 and C2 could be associated with position-in-word effects rather than with position-in-syllable effects, this should be less of a problem than it might appear if we consider that speakers were instructed to read the two word sequences of the reading list as naturally as possible without inserting any break at the word boundaries. Moreover, the fact that the syllabification rules of Catalan are essentially the same word medially and across a word boundary ensures that cluster production may be highly similar in two conditions.

Overall, 30 clusters were analyzed (see Table 2). In the table, phonetic symbols for voiceless stops and fricatives may correspond either to voiced or voiceless realizations depending on the outcome of a regressive voicing assimilation rule applying to stops and fricatives in Catalan (e.g., the phonetic realization for /sn/ is [zn] in this language). The table does not show those clusters which were not recorded because they undergo complete regressive assimilation in the Catalan language (/sr/, /nk/ and /sʃ/ which become [(r)r], [ŋk] and [(ʃ)ʃ]). Other clusters were recorded but had to be excluded from analysis because they were not realized as true biconsonantal sequences (e.g., /ʎʃ/ which was often pronounced [ʎtʃ]).

Three speakers of Eastern Catalan, i.e., DR (the author), JP and JS, recorded the consonant combinations of interest 5, 3 and 3 times, respectively. A small and variable number of repetitions is due to recording time limitations at the University of Reading where those recordings were made back in 1992. Linguopalatal contact and acoustic data were gathered every 5 ms with 62 electrode artificial palates using electropalatography (Reading EPG system; Hardcastle, Jones, Knight, Trudgeon, & Calder, 1989). The acoustic signal was recorded at a 20 kHz sampling rate and processed with a Kay CSL analysis system using the same temporal resolution as the EPG data.

As shown in Fig. 1, electrodes are arranged in eight rows longitudinally (from R1 or most anterior row to R8 or most posterior row) and in eight columns sagitally (from C1 or most lateral column to C4 or most central column, both on the right and left sides of the palate surface). For all speakers, the five front rows of electrodes were assigned to the alveolar zone and the three back rows to the palatal zone since alveolar consonants were articulated at row 5 in some cases.

The temporal boundary between C1 and C2 was determined on the basis of linguopalatal contact and/or acoustic criteria. C1 offset was identified at closure release for /n/ and /ʎ/, and at an alveolar contact opening on the two central columns of electrodes for /l/ and on the four central columns for /r/ which was always produced with a single closure period when occurring in

Table 2
Consonant combinations selected for analysis and Catalan two word sequences of the reading list

/nl/	faran làmines	‘they will draw plates’
/ns/	faran salts	‘they will jump’
/nr/	vendran rams	‘they will sell bouquets’
/nʃ/	portaran xals	‘they will wear shawls’
/nʎ/	faran llàstima	‘they will rouse to pity’
/ln/	un casal nan	‘a very small country house’
/ls/	és un mal salt	‘it is a bad jump’
/lr/	és un mal rastre	‘it is a bad trail’
/lʃ/	és un mal xal	‘it is a bad shawl’
/lʎ/	és un pal llarg	‘it is a long stick’
/lk/	un local car	‘an expensive place’
/sn/	colliràs nards	‘you will pick up spikenards’
/sl/	faràs làmines	‘you will draw plates’
/sʎ/	és un vas llarg	‘it is a long glass’
/rn/	és un bar nan	‘a vey small bar’
/rl/	la mar lata	‘ the broad sea’
/rʃ/	és un bar xava	‘it is a xava bar’
/rʎ/	és un bar llarg	‘it is a long bar’
/rk/	és un bar car	‘it is an expensive bar’
/ʃn/	un calaix nan	‘ a very small drawer’
/ʃl/	un calaix lat	‘a very large drawer’
/ʃr/	un calaix rar	‘a strange drawer’
/ʎn/	un cavall nan	‘a very small horse’
/ʎl/	un cavall las	‘a tired horse ‘
/ʎs/	un cavall sard	‘a Sardinian horse’
/ʎr/	un cavall rar	‘a strange horse’
/ʎk/	un cavall car	‘an expensive horse’
/kl/	és un sac lat	‘a very large sack’
/kr/	un conyac rar	‘a strange cognac’
/kʎ/	és un sac llarg	‘it is a long sack’

C1 position. An acoustic criterion for segmentation was applied to sequences in which C1 was /k/ (given that back velar closures were not usually visible on the linguopalatal contact patterns) or /s/ and /ʃ/ (since fricatives show no central EPG contact). The temporal offset of /k/ was placed at the onset of C2-related formant structure and that of /s/ and /ʃ/ was fixed at the offset of the frication noise. It should also be pointed out that /n, l, ʎ/ did not always achieve complete closure after the two lingual fricatives.

In order to carry out a numerical evaluation of the EPG data, the 62 data points of the linguopalatal contact patterns were transformed into three contact indices, Qp, CAa and CCa, applying the contact index method of EPG data reduction (Fontdevila, Pallarès, & Recasens, 1994).

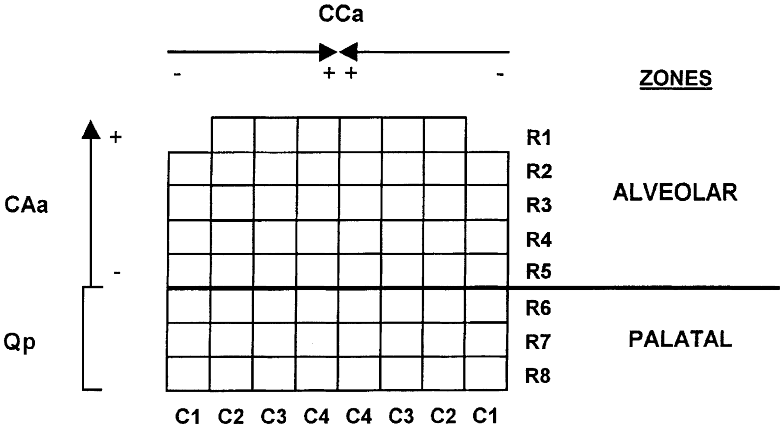

Fig. 1. Subdivision of the artificial palate into rows (R1–R8) and columns (C1–C4 on both sides of the palate). Articulatory zones (alveolar, palatal) and arrows pointing towards maximal contact index values (CAa, CCa) are shown.

(a) Qp, the dorsopalatal contact quotient, was obtained by dividing all contacted electrodes on the three back rows by the total amount of 24 electrodes at the palatal zone, and is thus correlated with the degree of tongue dorsum raising.

(b) CAa, the alveolar contact anteriority index, reflects the degree of alveolar contact fronting (i.e., from the most anterior R1–R5) and is thus strongly correlated with place of articulation. The CAa formula is

$$\begin{aligned}\mathrm{CAa} &= \log[[1(R5/8) + 9(R4/8) + 81(R3/8) + \\ &\quad + 729(R2/8) + 4921(R1/6)] + 1]]/[\log(5741 + 1)]\end{aligned}$$

In the ratios within parentheses, the total number of activated electrodes on a given row (i.e., R5, R4, R3…) 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 behind a given row always yields a lower index value than the activation of a single electrode at more anterior rows.

(c) CCa, the alveolar contact centrality index, reflects channel width such that a high CCa value means narrow constriction width. It was only applied to /s/ and /ʃ/ and provides an estimate of changes in alveolar constriction width. The CCa computation procedure is analogous to that of CAa, and takes into account the electrodes on a given column as well as those on the corresponding symmetrical column on the other half of the alveolar zone:

$$\begin{aligned}\mathrm{CCa} &= [\log[[1(C1/8) + 11(C2/10) + 121(C3/10) \\ &\quad + 1331(C4/10)] + 1]]/[\log(1464 + 1)]\end{aligned}$$

Contact index values were computed at three points in time during C1 and during C2, i.e., at C1 onset, at C1 midpoint (MP1) and at 15 ms before C1 offset (i.e., −15 ms), and at 15 ms after C2 onset (i.e., +15 ms), at C2 midpoint (MP2) and at C2 offset. This computation procedure was carried out for all indices and clusters with two exceptions: CAa for /k/ (since the production of velars involves no central alveolar contact) and for CCa for nonfricatives. In view of the short duration of preconsonantal /r/, contact indices in /rC/ sequences were calculated at −10 ms instead of at −15 ms. Moreover, measurements for C2 = /r/ were made at the first of two alveolar contact periods in line with the fact that /r/ is always realized as a trill after a heterosyllabic consonant in Catalan. Specific phonetic events about 5 or 10 ms long occurring after C1 offset were not considered to be part of C2, i.e., a vocalic period between /r/ and the following consonant, and a stop closure period in some clusters with C2 = /s, ʃ/. In these cases, C2 measures were taken starting at the endpoint of these phonetic events.

Formant frequency measurements were taken on wideband spectrograms using Computerized Speech Lab (CSL) of Kay Elemetrics. F2 and F3 frequencies were estimated at the V1 transitions endpoint and at the V2 transitions starting point for comparison with the EPG data at C1 onset and C2 offset, respectively. When carrying out the articulatory-acoustic comparisons, the expected trend in most cases was for F2 to be positively correlated with Qp and thus with tongue dorsum height and fronting, and for F3 to increase with CAa and thus with a reduction in front cavity size (Fant, 1960, p. 121).

In order to estimate the articulatory and acoustic differences between C1 and C2 in the clusters under analysis, contact index and formant values for a given target consonant at syllable coda position were compared statistically with those for the same consonant at syllable onset position in symmetrical clusters, e.g., for target /n/ in the pairs /nl/-/ln/, /nr/-/rn/ where /l/ and /r/ are the contextual consonants. Statistical comparisons were carried out at C1 midpoint and C2 midpoint, at C1 onset and C2 offset and at −15 ms and +15 ms. It was felt that the two latter comparisons are justified on the grounds that they involve articulatory configurations corresponding to the VC closing and CV opening gestures in the same context condition, i.e., contextual /a/ in the case of the C1 onset/C2 offset pair and a contextual consonant in the case of the −15 ms/+15 ms pair.

Repeated measures ANOVAs were carried out for all possible combinations of constrained and unconstrained consonants except for those involving /s, r, ʃ/ exclusively since the pairs /sr/-/rs/ and /sʃ/-/ʃs/ were not available. As argued in Introduction section, /n, l, ʎ/ were characterized as unconstrained (also /k/ but only as a contextual consonant since velars do not involve active tongue front closure) and /s, r, ʃ/ as constrained for the CAa and F3 data, and /n, l, ʃ, ʎ, k/ as unconstrained and /s, r/ as constrained for the Qp and F2 data. Statistical tests on the CCa data were performed for /s, ʃ/.

3. Results

3.1. CAa (degree of contact fronting), F3

3.1.1. Unconstrained target consonants

Table 3 presents the CAa and F3 data for the unconstrained target consonants at the tongue front /n, l, ʎ/ as a function of unconstrained contextual /n, l, ʎ, k/ and of constrained contextual /s, r, ʃ/ at all temporal points under analysis. C2−C1 differences and the corresponding statistical results are included. A representative sample of these data is displayed in Fig. 2 (top), i.e., CAa differences between the linguopalatal configurations at the midpoint of C2 and C1. Bars in the figure are aligned in the same order as the contextual consonants in Table 3, and are positive if

Table 3
Cross-speaker C2−C1 differences in CAa and F3 for unconstrained target /n, l, ʎ/ as a function of unconstrained contextual consonants (top) and of constrained contextual consonants (bottom)

Target C	Context C	CAa												F3			
		C1 onset/C2 offset				MP1/MP2				−15/+15				C1 onset/C2 offset			
		C2−C1	*F*	df	*p*	C2−C1	*F*	df	*p*	C2−C1	*F*	df	*p*	C2−C1	*F*	df	*p*
n	l	0.28	21.87	1.7	0.002	0.31	18.18	1.7	0.004	0.27	14.16	1.7	0.007	8.00	0.10	1.3	0.776
	ʎ	0.14	6.35	1.8	0.036	0.06	6.52	1.8	0.034	0.03	0.79	1.8	0.400	98.00	9.95	1.7	0.016
l	n	−0.06	3.50	1.7	0.103	−0.15	8.16	1.7	0.024	−0.19	10.67	1.7	0.014	116.00	13.79	1.4	0.021
	ʎ	−0.26	40.46	1.6	0.001	−0.09	404.51	1.6	0.000	−0.01	0.43	1.6	0.535	48.57	1.11	1.5	0.340
	k	0.05	0.53	1.8	0.489	−0.01	0.29	1.8	0.608	0.03	2.05	1.8	0.190	142.22	14.48	1.6	0.009
ʎ	n	0.33	14.77	1.8	0.005	0.11	13.53	1.8	0.006	0.03	0.83	1.8	0.389	6.67	0.00	1.6	0.947
	l	0.20	7.22	1.6	0.036	0.15	8.49	1.6	0.027	0.01	24.39	1.6	0.003	242.86	10.89	1.5	0.021
	k	0.16	5.59	1.8	0.046	0.05	2.17	1.8	0.179	0.11	24.00	1.8	0.001	−142.00	11.37	1.7	0.012
n	s	0.15	10.32	1.7	0.015	0.10	32.55	1.7	0.001	0.08	9.82	1.7	0.017	−43.00	14.46	1.7	0.007
	r	0.24	16.38	1.8	0.004	0.22	7.30	1.8	0.027	0.16	6.01	1.8	0.040	32.50	2.47	1.5	0.177
	ʃ	0.06	2.66	1.8	0.142	0.06	1.57	1.8	0.245	0.06	1.54	1.8	0.250	30.00	4.95	1.5	0.077
l	s	0.19	11.61	1.7	0.011	0.13	15.17	1.7	0.006	0.05	4.08	1.7	0.083	109.09	16.21	1.8	0.004
	r	0.21	80.28	1.8	0.000	0.12	42.96	1.8	0.000	0.07	6.37	1.8	0.036	35.00	1.63	1.6	0.249
	ʃ	0.20	7.60	1.8	0.025	0.06	0.50	1.8	0.498	0.15	15.77	1.8	0.004	52.00	1.63	1.4	0.271
ʎ	s	0.22	12.52	1.4	0.024	0.05	1.27	1.4	0.322	0.08	8.17	1.4	0.046	206.67	9.31	1.4	0.038
	r	0.14	14.23	1.8	0.005	0.13	8.91	1.8	0.017	0.11	6.13	1.8	0.038	228.00	33.65	1.7	0.001

Results for the statistical comparisons are given for all pairs of target and contextual consonants at three temporal points for CAa, and at the CV and VC boundaries for F3.

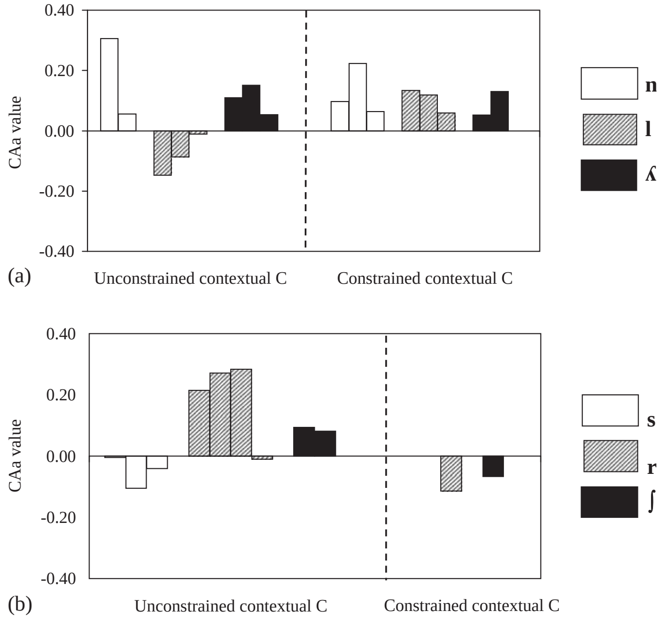

Fig. 2. C2−C1 differences in contact anteriority between the linguopalatal contact configurations at MP1/MP2 for unconstrained target /n, l, ʎ/ (a) and constrained target /s, r, ʃ/ (b) as a function of unconstrained and constrained contextual consonants. Positive bars indicate the existence of a higher CAa at C2 than at C1 position, and negative bars the opposite relationship. See text for details.

contact index values for the linguopalatal contact patterns at C2 position are higher than those at C1 position, and negative if the opposite relationship holds (i.e., the bars with positive differences indicate syllable-final reduction, and the bars with negative differences show the opposite of final reduction).

The table and the top graph in the figure show that C2−C1 differences are positive and statistically significant for the most part not only when adjacent to highly constrained fricatives and trills but also in the environment of unconstrained front consonants. It thus appears that unconstrained consonants at the tongue front are generally more retracted (and have a lower F3) in coda vs. onset syllable position. There is an exception however: while target /n, ʎ/ are indeed more retracted syllable finally than syllable initially in all contextual consonant conditions, this is so for /l/ in the context of constrained consonants but not so in the adjacency of unconstrained consonants. The trend for front consonants to show more anterior realizations in C2 vs. C1 position is illustrated by the EPG patterns for /n/ in the pairs /nl/-/ln/ and /nr/-/rn/ in Fig. 3.

3.1.2. Constrained target consonants

CAa and F3 data for constrained /s, r, ʃ/ as a function of unconstrained contextual /n, l, ʎ, k/ and of those same constrained consonants are presented in Table 4. Fig. 2 (lower panel) plots CAa differences between the linguopalatal configurations at the midpoint of C2 and C1 for the target and contextual consonants of interest.

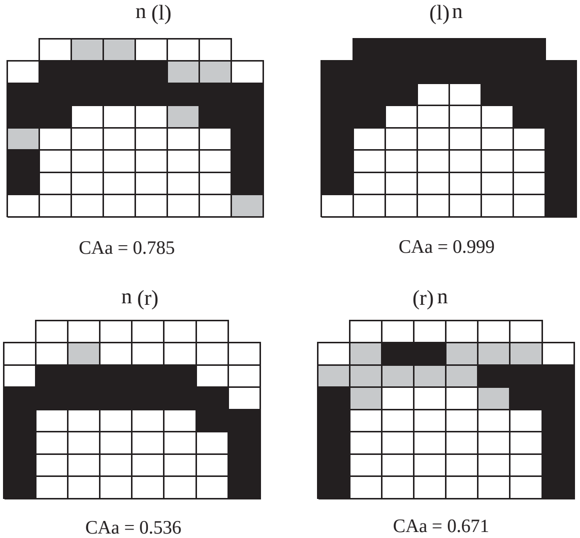

Fig. 3. EPG contact patterns for /n/ in the pairs /nl/-/ln/ and /nr/-/rn/ at MP1 (left) and MP2 (right) (speaker DR). Electrodes are represented in black, grey or white depending on frequency activation (80–100%, 40–80% and 0–40%). CAa values are also given.

As expected, C2–C1 differences for target /s, ʃ/ are non-significant or significant but negative. It thus appears that the two lingual fricatives are not more retracted syllable finally than syllable initially and may even exhibit the opposite trend. On the other hand, the alveolar rhotic /r/ exhibits positive and significant C2−C1 differences in the context of unconstrained contextual consonants (except for /k/) meaning that, unlike the two lingual fricatives, it is more advanced when acting as C2 vs. C1. However, /r/ also exhibits significant negative differences, and, in the context of /ʃ/, is thus more anterior in C1 vs. C2 position. Differences in degree of fronting between /r/ and /ʃ/ as a function of syllable position may be seen in the linguopalatal contact patterns for the pairs /rʎ/-/ʎr/ and /ʃn/-/nʃ/ in Fig. 4.

3.2. Qp (dorsopalatal contact quotient), F2

3.2.1. Unconstrained target consonants

Table 5 gives Qp and F2 data for the unconstrained target consonants at the tongue dorsum /n, l, ʃ, ʎ, k/ as a function of the same unconstrained contextual consonants and of constrained contextual /s, r/. C2−C1 differences for these consonantal sequences are exemplified with data at C1 midpoint (MP1) and at C2 midpoint (MP2) in Fig. 5.

C2−C1 differences in this case are generally positive and significant in all contextual conditions meaning that the target consonants of interest are articulated with more palatal contact in syllable onset position than in syllable coda position. This trend may be exemplified for /ʎ/ in the pair /ʎn/-/nʎ/ (Fig. 6, top).

A closer inspection of the data for the individual target consonants reveals however a considerable number of non-significant C2−C1 differences in Qp. This may be so since the

Table 4
Cross-speaker C2−C1 differences in CAa and F3 for constrained target /s, r, ʃ/ as a function of unconstrained contextual consonants (top) and of constrained contextual consonants (bottom)

Target C	Context C	CAa												F3			
		C1 onset/C2 offset				MP1/MP2				−15/+15				C1 onset/C2 offset			
		C2−C1	*F*	df	*p*	C2−C1	*F*	df	*p*	C2−C1	*F*	df	*p*	C2−C1	*F*	df	*p*
s	n	0.07	0.90	1.7	0.374	0.00	0.04	1.7	0.854	0.01	0.54	1.7	0.488	−245.45	12.25	1.8	0.008
	l	−0.05	1.80	1.7	0.222	−0.11	11.40	1.7	0.012	0.00	0.35	1.7	0.571	86.67	0.04	1.6	0.857
	ʎ	−0.10	7.07	1.4	0.056	−0.04	0.84	1.4	0.411	−0.14	8.93	1.4	0.040	−265.00	62.42	1.2	0.016
r	n	0.20	22.80	1.8	0.001	0.21	36.31	1.8	0.000	0.22	25.34	1.7	0.002	162.50	62.42	1.5	0.016
	l	0.25	16.03	1.8	0.004	0.27	50.15	1.8	0.000	0.26	45.99	1.8	0.000	−40.00	2.48	1.3	0.214
	ʎ	0.19	5.92	1.8	0.041	0.28	9.33	1.8	0.016	0.27	13.10	1.8	0.007	195.56	6.80	1.6	0.040
	k	0.12	1.63	1.4	0.270	−0.01	0.08	1.4	0.795	0.00	0.01	1.4	0.944	25.00	0.42	1.6	0.541
ʃ	n	0.04	1.37	1.8	0.275	0.09	0.86	1.8	0.380	−0.07	6.39	1.8	0.035	86.67	2.76	1.6	0.148
	l	−0.01	0.01	1.8	0.913	0.08	5.21	1.8	0.052	−0.02	0.04	1.8	0.849	6.67	0.12	1.4	0.750
r	ʃ	0.01	0.01	1.5	0.916	−0.11	84.81	1.5	0.000	−0.10	9.92	1.5	0.025	−4.00	1.07	1.7	0.335
ʃ	r	−0.03	0.50	1.5	0.510	−0.07	1.42	1.5	0.287	0.04	1.32	1.5	0.302	10.00	0.00	1.3	0.953

Results for the statistical comparisons are given for all pairs of target and contextual consonants at three temporal points for CAa, and at the CV and VC boundaries for F3.

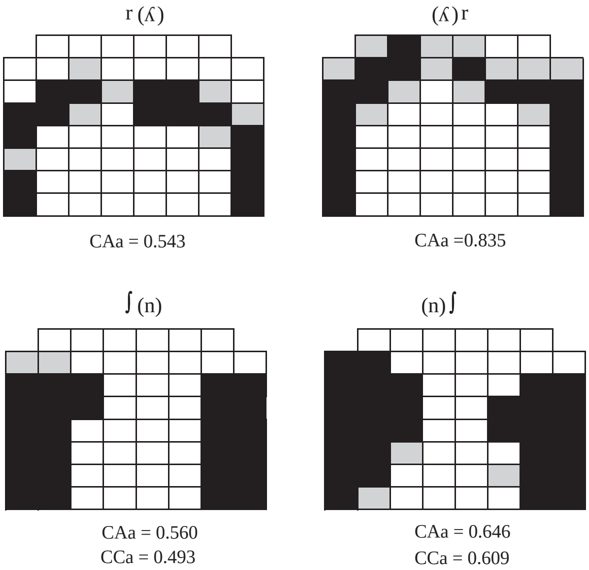

Fig. 4. EPG contact patterns for /r/ in the pair /rʎ/-/ʎr/ and for /ʃ/ in the pair /ʃn/-/nʃ/ at MP1 (left) and MP2 (right) (speaker DR). Electrodes are represented in black, grey or white depending on frequency activation (80–100%, 40–80% and 0–40%). CAa and CCa values are also given.

electropalatographic technique may fail to reflect possible differences in tongue height in the case of consonants produced with little dorsopalatal contact and thus exhibiting low Qp values. Also, while /l, ʃ, ʎ, k/ show more dorsopalatal contact in C2 vs. C1 position most of the time, /n/ exhibits more dorsopalatal contact in C1 vs. C2 position in the adjacency of dorsal consonants (e.g., when the contextual consonant is /ʎ/ in the pair /nʎ/ vs. /ʎn/; see Fig. 6, bottom).

3.2.2. *Constrained target consonants*

C2−C1 differences in Qp and F2 for constrained /s, r/ as a function of unconstrained contextual /n, l, ʃ, ʎ, k/ are shown in Table 6. The table reveals that Qp differences are below 0.05 and thus, absent or negligeable in most cases. Moreover, significant C2−C1 differences in F2 have a negative sign.

3.3. *CCa (fricative constriction width)*

Table 7 gives CCa data for target /s/ and /ʃ/ differing in DAC at constriction location (for /s/ > /ʃ/) as a function of several alveolar and alveolopalatal contextual consonants, i.e., /n, l, ʎ/ in sequences with /s/ and /n, l, r/ in sequences with /ʃ/. The same data are displayed in Fig. 7 at all three temporal points.

A comparison between linguopalatal contact patterns for the two lingual fricatives reveals the presence of positive bars for /ʃ/ most of the time meaning that this consonant is prone to be produced with a wider constriction syllable finally vs. syllable initially (though this position-dependent difference is not always significant and is only available at −15 ms/ + 15 ms when the

Table 5
Cross-speaker C2−C1 differences in Qp and F2 for unconstrained target /n, l, ʃ, ʎ, k/ as a function of unconstrained contextual consonants (top) and of constrained contextual consonants (bottom)

Target C	Context C	Qp												F2			
		C1 onset/C2 offset				MP1/MP2				−15/+15				C1 onset/C2 offset			
		C2−C1	*F*	df	*p*	C2−C1	*F*	df	*p*	C2−C1	*F*	df	*p*	C2−C1	*F*	df	*p*
n	l	0.05	5.91	1.7	0.045	0.05	5.18	1.7	0.057	0.03	3.40	1.7	0.108	−72.50	3.02	1.6	0.133
	ʃ	−0.15	33.21	1.8	0.000	−0.11	28.48	1.8	0.001	−0.09	27.28	1.8	0.001	−196.00	14.10	1.7	0.007
	ʎ	−0.03	1.03	1.8	0.341	−0.02	0.40	1.8	0.544	−0.03	0.77	1.8	0.405	1.82	0.48	1.8	0.508
l	n	0.06	27.85	1.7	0.001	0.10	18.40	1.7	0.004	0.09	15.40	1.7	0.006	−11.43	0.01	1.5	0.939
	ʃ	0.00	0.47	1.8	0.514	−0.06	0.21	1.8	0.661	−0.16	6.95	1.8	0.030	−12.50	0.00	1.6	0.981
	ʎ	0.11	28.13	1.6	0.002	0.10	23.67	1.6	0.003	0.06	2.63	1.6	0.156	110.00	50.73	1.6	0.000
	k	0.03	3.86	1.8	0.085	0.04	3.71	1.8	0.090	−0.02	0.72	1.8	0.421	0.00	0.23	1.8	0.643
ʃ	n	−0.03	20.77	1.8	0.002	−0.06	1.20	1.8	0.305	0.02	0.06	1.8	0.809	45.45	1.39	1.8	0.272
	l	0.02	0.09	1.8	0.771	0.06	2.40	1.8	0.160	0.18	27.49	1.8	0.001	74.29	2.31	1.5	0.189
ʎ	n	0.11	28.62	1.8	0.001	0.11	39.73	1.8	0.000	0.08	32.50	1.8	0.000	69.09	17.09	1.8	0.003
	l	0.10	17.45	1.6	0.006	−0.01	0.02	1.6	0.891	−0.01	0.02	1.6	0.895	110.00	11.87	1.6	0.014
	k	0.13	22.64	1.8	0.001	0.00	0.01	1.8	0.925	−0.06	3.12	1.8	0.115	150.91	42.15	1.8	0.000
k	l	0.16	32.15	1.8	0.000	0.05	0.92	1.8	0.364	0.04	0.89	1.8	0.373	−58.18	5.60	1.8	0.045
	ʎ	0.17	30.35	1.8	0.001	0.05	4.36	1.8	0.070	0.06	6.00	1.8	0.040	−36.36	0.67	1.8	0.435
n	s	0.00	0.18	1.7	0.680	−0.02	3.17	1.7	0.118	0.00	0.14	1.7	0.716	−103.64	45.06	1.8	0.000
	r	0.01	3.25	1.8	0.109	0.01	1.73	1.8	0.225	0.01	1.54	1.8	0.250	−23.64	2.41	1.8	0.159
l	s	0.04	5.37	1.7	0.054	0.06	10.86	1.7	0.013	0.03	0.42	1.7	0.540	14.55	1.59	1.8	0.243
	r	0.09	11.64	1.8	0.009	0.16	80.94	1.8	0.000	0.09	29.14	1.8	0.001	−14.55	1.79	1.8	0.218
ʃ	r	−0.02	1.22	1.5	0.319	0.14	23.81	1.5	0.005	0.16	75.21	1.5	0.000	26.00	0.24	1.7	0.638
ʎ	s	0.06	1.35	1.4	0.310	0.05	2.58	1.4	0.184	0.01	0.13	1.4	0.742	113.33	12.30	1.4	0.025
	r	0.16	27.62	1.8	0.001	0.06	6.25	1.8	0.037	0.08	20.24	1.8	0.002	70.91	17.68	1.8	0.003
k	r	0.24	52.55	1.4	0.002	0.17	15.24	1.4	0.017	0.19	60.79	1.4	0.001	40.00	2.07	1.6	0.201

Results for the statistical comparisons are given for all pairs of target and contextual consonants at three temporal points for Qp, and at the CV and VC boundaries for F2.

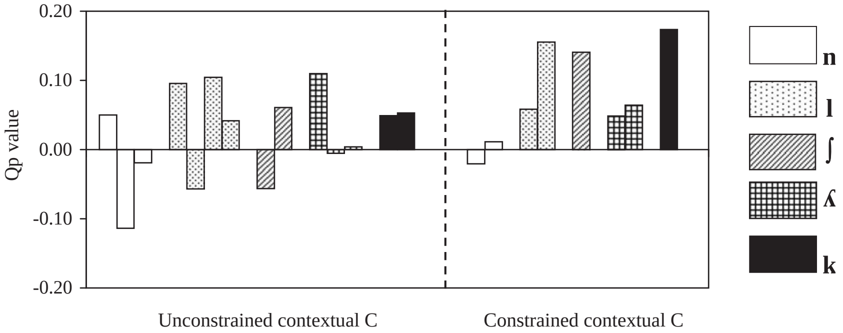

Fig. 5. C2−C1 differences in dorsopalatal contact between the linguopalatal contact configurations at MP1/MP2 for unconstrained target /n, l, ʃ, ʎ, k/ as a function of unconstrained and constrained contextual consonants. Positive bars indicate the existence of a higher Qp at C2 than at C1 position, and negative bars the opposite relationship. See text for details.

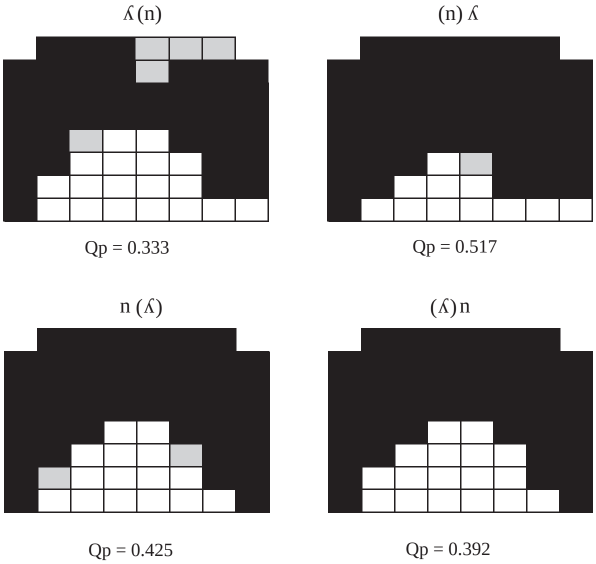

Fig. 6. EPG contact patterns for /ʎ/ in the pair /ʎn/-/nʎ/ and for /n/ in the pair /nʎ/- /ʎn/ at MP1 (left) and MP2 (right) (speaker DR). Electrodes are represented in black, grey or white depending on frequency activation (80–100%, 40–80% and 0–40%). Qp values are also given.

contextual consonant is /r/). This trend is illustrated by the linguopalatal contact patterns for /ʃn/-/nʃ/ in Fig. 4. On the other hand, /s/ shows significant negative bars at C1 onset/C2 offset and MP1/MP2, and significant positive bars at −15 ms/+15 ms for two cluster comparisons. Therefore, /s/ appears to be articulated with a narrower constriction syllable finally than syllable initially but with a wider constriction in the former position vs. the latter as the CC boundary is approached.

Table 6
Cross-speaker C2−C1 differences in Qp and F2 for constrained target /s, r/ as a function of unconstrained contextual consonants

Target C	Context C	Qp												F2			
		C1 onset/C2 offset				MP1/MP2				−15/+15				C1 onset/C2 offset			
		C2−C1	*F*	df	*p*	C2−C1	*F*	df	*p*	C2−C1	*F*	df	*p*	C2−C1	*F*	df	*p*
s	n	−0.03	8.89	1.7	0.020	−0.05	4.33	1.7	0.076	−0.01	0.00	1.7	0.982	−60.00	11.40	1.8	0.010
	l	−0.01	0.76	1.7	0.412	−0.02	2.67	1.7	0.146	−0.03	6.27	1.7	0.041	−80.00	14.82	1.8	0.005
	ʎ	0.00				−0.02	1.80	1.4	0.251	0.01	0.04	1.4	0.859	103.33	6.49	1.4	0.063
r	n	0.01	1.37	1.8	0.275	0.01	1.79	1.8	0.218	0.00				−9.09	6.49	1.8	0.063
	l	0.03	14.80	1.8	0.005	0.01	0.46	1.8	0.516	0.01	0.46	1.8	0.516	−54.55	4.88	1.8	0.058
	ʃ	0.02	1.63	1.5	0.257	0.02	2.14	1.5	0.203	0.01	2.86	1.5	0.152	−150.91	66.86	1.8	0.000
	ʎ	0.01	1.28	1.8	0.290	0.02	9.33	1.8	0.016	0.03	18.48	1.8	0.003	−58.18	5.56	1.8	0.046
	k	0.00	0.00	1.4	1.000	−0.01	0.57	1.4	0.492	0.01	0.06	1.4	0.815	−22.50	0.40	1.6	0.550

Results for the statistical comparisons are given for all pairs of target and contextual consonants at three temporal points for Qp, and at the CV and VC boundaries for F2.

Table 7
Cross-speaker C2−C1 differences in CCa for constrained target /s/ and unconstrained target /ʃ/ as a function of several alveolar and alveolopalatal contextual consonants

Target C	Context C	CCa											
		C1 onset/C2 offset				MP1/MP2				−15/+15			
		C2−C1	*F*	df	*p*	C2−C2	*F*	df	*p*	C2−C3	*F*	df	*p*
s	n	−0.04	17.09	1.7	0.004	−0.12	16.68	1.7	0.005	0.00	0.02	1.7	0.880
	l	−0.19	61.42	1.7	0.000	−0.21	28.44	1.7	0.001	0.22	19.85	1.7	0.003
	ʎ	−0.14	10.26	1.4	0.033	−0.11	9.89	1.4	0.035	0.17	9.90	1.4	0.035
ʃ	n	0.07	0.53	1.8	0.486	0.06	1.42	1.8	0.268	0.06	0.64	1.8	0.447
	l	0.06	1.12	1.8	0.321	0.26	30.95	1.8	0.001	0.30	14.85	1.8	0.005
	r	−0.05	2.36	1.5	0.185	0.00	0.01	1.5	0.922	0.25	31.03	1.5	0.003

Results for the statistical comparisons are given for all pairs of target and contextual consonants at three temporal points

4. Summary and discussion

Data in the Results section show that relatively unconstrained consonants allowing coarticulatory effects in clusters (i.e., /n/, dark /l/, alveolopalatals, velars) are produced with less contact fronting, less dorsopalatal contact and/or a wider fricative constriction in syllable final vs. syllable initial position. Differences in contact fronting and in dorsopalatal contact may be associated with syllable position if occurring in the environment of other unconstrained consonants, but presumably with the contextual consonant if occurring next to highly constrained consonants exerting prominent regressive effects in tongue retraction and lowering. A clear case

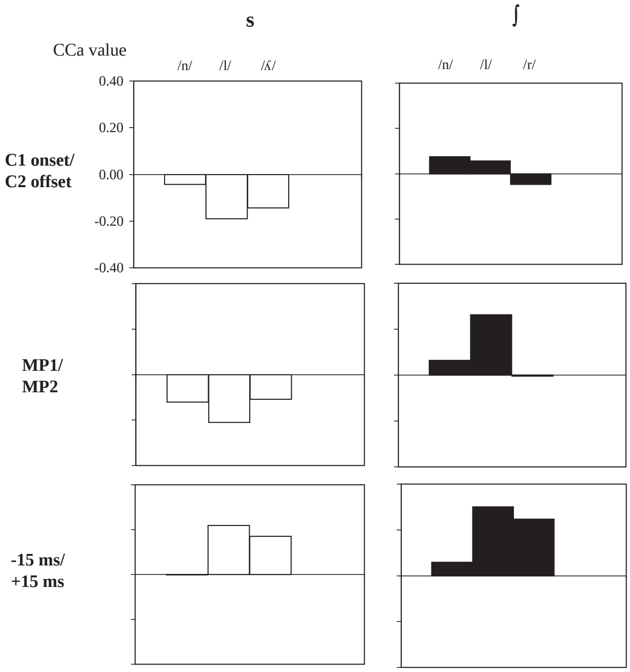

Fig. 7. C2−C1 differences in CCa for constrained target /s/ and unconstrained target /ʃ/ as a function of several contextual consonants (/n/, /l/ and /ʎ/, for /s/, and /n/, /l/, and /r/ for /ʃ/). CCa values are compared at C1 onset/C2 offset, MP1/MP2, and -15 ms/ + 15 ms. Positive bars indicate the existence of a higher contact index value at C2 than at C1 position, and negative bars the opposite relationship. See text for details.

would be that of /l/ which shows lower CAa values syllable initially vs. syllable finally in the context of consonants unconstrained at the tongue front but the opposite trend in the adjacency of highly constrained consonants. On the other hand, highly constrained fricatives do not show consistent articulatory differences as a function of syllable position. While the alveolopalatal fricative /ʃ/ behaves like highly constrained /s, r/ in respect of constriction fronting, it is more akin to unconstrained /n, l, ʎ, k/ in its pattern of dorsopalatal contact. Overall, these findings are in agreement with the notion that articulatory reduction syllable finally (and possibly articulatory strengthening syllable initially) is conditioned by the requirements on consonantal production.

Some apparent exceptions may be associated with special requirements on the production of specific consonants and clusters (see Introduction). The most obvious case is /r/. Thus, while the Qp (and F2) data for this consonant are in agreement with our initial hypothesis in exhibiting no substantial C2-C1 differences, CAa (and F3) values turned out to be higher syllable initially vs. syllable finally in the context of unconstrained front consonants. In principle, this scenario would suggest that this consonant behaves more like other unconstrained consonants (i.e., alveolar nasal, alveolar lateral and alveolopalatals) than like constrained ones (i.e., lingual fricatives). A better interpretation could be sought in the fact that syllable initial rhotics were realized as two-contact trills while syllable final realizations of the consonant were produced with a single contact. It thus appears that the central alveolar contact for a trill is required to be quite front after a front consonant.

Manner requirements may also explain why /l/ and /s/ tend to be more advanced in C1 vs. C2 position when adjacent to unconstrained front consonants (i.e., in the case of target /l/ in the context of /n, ʎ/ and of target /s/ in the context of /l, ʎ/), why C1 = /r/ is more anterior than C2 = /r/ in the adjacency of /ʃ/, and why constriction width for /ʃ/ next to /r/ is not always greater in C1 vs. C2 position. To a large extent, these findings may be attributed to specific manner of articulation requirements, i.e., laterals, fricatives and trills. Thus, a high degree of constriction fronting for /s/ before laterals and for /l/ before unconstrained consonants may be attributed to a trend for laterals to be articulated at a fronter location than non laterals, mostly so if dark in the case of /l/ (Recasens and Espinosa, submitted). Moreover, gestural incompatibility between rhotics and fricatives may account for why the comparison /rʃ/-/ʃr/ did not always yield the expected results.

Regarding the Qp data, less dorsopalatal contact for /n/ in C2 vs. C1 position in the context of dorsal consonants (e.g., in the sequence /ʃn/ as opposed to /nʃ/) could be associated with tongue repositioning. Moreover, the existence of more dorsopalatal contact in C2 vs. C1 position for /ʎ, k/ in clusters composed exclusively of dorsal consonants is attributable to overshoot rather than to syllable position.

Acknowledgements

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