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An EMMA Study of Segmental Complexity in Alveolopalatals and Palatalized Alveolars

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Abstract

The goal of this paper is to test whether the palatal nasal stop /ɲ/, occurring in several Romance languages, Hungarian and Czech, is a two-gesture, complex segment (produced with a tongue front closure and intentional tongue dorsum raising) or else a one-gesture, simple segment (articulated at the alveoloprepalatal zone with a single tongue portion including the lamina and predorsum). In order to investigate this issue, electromagnetic midsagittal articulometer data were collected on apical, laminal and dorsal movement data for Catalan /ɲ/ and Russian palatalized alveolar /n^{j}/ (which is known to be a complex segment); other sound classes of both languages were also recorded, namely, the simple palatal segment /j/ and the two-segmental cluster /nj/. Time lags between position maxima at the tongue front and at the tongue dorsum argue strongly in favor of /ɲ/ being a simple segment: they were found to be considerably shorter for /ɲ/ than for /n^{j}/; moreover, those for /n^{j}/ were significantly longer than those for /j/ in Russian but not so in Catalan. In conjunction with linguopalatal contact data from the literature, it is argued that a longer time lag for /ɲ/ vs. /j/ is representative of an unintentional, transitional event resulting from the alveoloprepalatal closure release for the former consonant occurring at the alveolar zone earlier than at the prepalatal zone.

1. Introduction

Dorsal involvement in the formation of a closure or constriction occurs for the following consonantal categories in languages of the world: alveolopalatals, palatals proper and fronted velars. Alveolopalatals present an alveoloprepalatal place of articulation and are commonly realized with the laminopredorsal section of the tongue, as for /ɲ/ in several Romance languages, Czech or Hungarian [Straka, 1979; Recasens,

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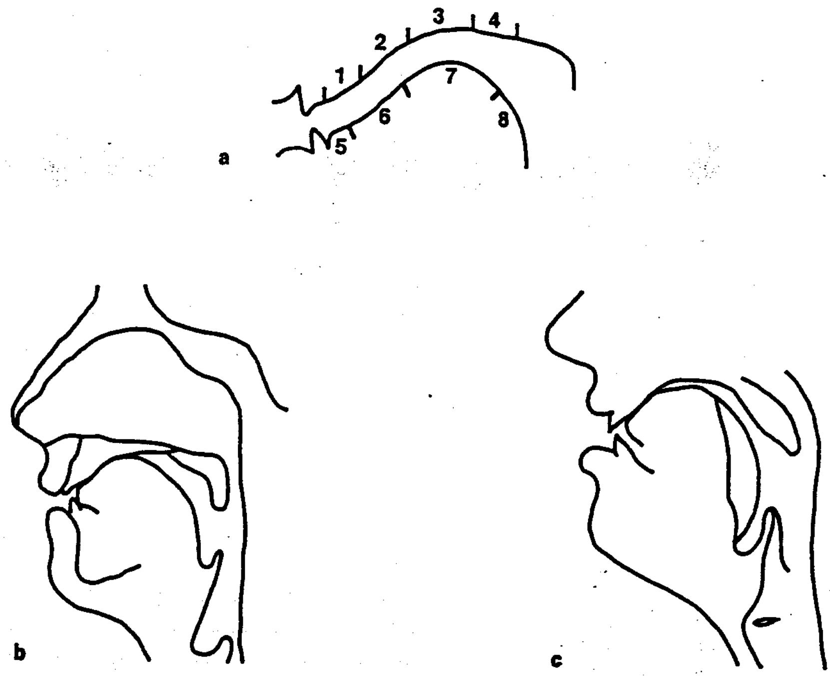

Fig. 1. **a** Articulatory subdivisions on the palatal surface and on the tongue surface [from Recasens, 1990]: 1 = alveolar zone, 2 = prepalatal zone, 3 = mediopalatal zone, 4 = postpalatal zone, 5 = laminal region, 6 = predorsal region, 7 = mediodorsal region, 8 = postdorsal region. **b** Articulatory configuration for Czech /ɲ/ [from Hála, 1962]. **c** Articulatory configuration for Russian /nʲ/ [from Koneczna and Zawadowski, 1956].

1990]. Palatals are articulated somewhere along the palatal zone and may involve either the tongue blade and dorsum (as for /j/ in Czech) or just the tongue dorsum (as for /j/ in Catalan and Hungarian) [Recasens, 1990; Keating and Lahiri, 1993]. Finally, fronted velars (as well as palatalized velars) are typically dorsopostpalatal articulations [Keating and Lahiri, 1993]. Figure 1 exemplifies the two former sound classes and the palatal and lingual areas involved in their production.

The issue of segmental complexity in alveolopalatal consonants has been debated at length in the phonetics and phonology literature. If alveolopalatals are complex segments, then they should be produced with two gestures, i.e., a tongue front gesture and a tongue dorsum gesture. These two lingual regions would thus be independently controlled, i.e., two separate commands would be sent to them by the speaker [see Öhman, 1966, for Russian palatalized consonants]. According to this interpretation, the complex nature of alveolopalatals is consistent with their being articulated with a good deal of palatal contact [Keating, 1988], and with their alternating with the clusters /nj/ and /jn/, the alveolar consonant /n/ or the palatal consonant /j/ in several languages and dialects [Avery and Rice, 1989; Lipski, 1989]. On the contrary, if alveolopalatals are simple segments, they should be produced with a single gesture. Analogously to other simple consonants (dentals, alveolars, velars), active control would be exerted on a single lingual region in this case, i.e., one command would be sent to the primary articulator.

Electropalatographic data on lingual contact in Recasens et al. [1995] is in support of Catalan /ɲ/ being articulated with a single laminopredorsal gesture and no independent involvement of the tongue dorsum:

(a) The consonant shows complete closure at a zone including the postalveolar and prepalatal areas. Lingual contact increases from closure onset to closure midpoint, not only at the palatal zone behind closure location (which might suggest that an independent dorsal gesture is being activated) but also at the alveolar zone in front of closure location. A simultaneous, nonsequential increase in linguopalatal contact throughout the entire surface of the palate is caused presumably, not by the presence of two separate gestures, but by an increase in contact pressure level at the place of alveolopalatal articulation with a lingual region including the lamina and the front part of the tongue dorsum or predorsum. The tongue tip is generally lowered during the production of alveolopalatals.

(b) Coupling effects between the tongue front and the tongue dorsum ought to cause more dorsopalatal contact for alveolopalatal /ɲ/ than for palatal /j/ if the two articulators were involved as separate gestures during the production of the former consonant. This should be so since, while the two consonants require tongue dorsum activation, /ɲ/ (but not /j/) requires active raising of the laminopredorsal region as well. Consequently, tongue dorsum raising should cause more contact if co-occurring with the raising of an immediately adjacent lingual region (for /ɲ/) [see also the argument by Keating, 1988] than otherwise (for /j/). Instead, dorsopalatal contact was found to be less extensive for /ɲ/ than for /j/ in Catalan.

(c) A [j]-like configuration at closure offset and V_2 onset in sequences such as /aɲa/ is not associated with an independent, separately controlled dorsal gesture, but results automatically from the alveoloprepalatal release proceeding fom front to back. This consonantal release does not proceed abruptly but gradually, so that a [j]-like configuration occurs when closure has been released at its frontmost (alveolar) end.

Much of the confusion about the issue of segmental complexity in alveolopalatals arises from the fact that [ɲ] may be the realization of the phoneme /ɲ/ in the languages mentioned above but of the cluster /nj/ or the sequence /ni/ in other languages (English *onion;* Japanese *t˜ony˜u* 'soy milk'). The latter cases suggest that in many instances the alveolopalatal nasal phoneme has originated historically from the blending of a tongue front and a tongue dorsum gesture. Languages in which /ɲ/ has phonemic status may show minimal pairs involving /ɲ/ and /nj/ such as Spanish *huraño* /uráɲo/ 'grump' vs. *uranio* /uránjo/ 'uranium' or Italian *campagna* /kampáɲa/ 'countryside' vs. *Campania* /kampánja/ 'region in Southern Italy'. In addition, /ɲ/ may not be realized as an alveolopalatal consonant but as a palatal consonant with a single dorsopalatal gesture in African languages such as Ngwo and Ibibio [Ladefoged, 1968; Connell, 1992].

A reasonable way of testing segmental complexity in the alveolopalatal consonant /ɲ/ is to compare its articulatory characteristics with those exhibited by consonants which must be characterized as complex on the basis of reliable phonetic and phonological evidence, for example, Russian palatalized alveolar /nʲ/ [Boyanus, 1955; Halle, 1971; Kenstowicz and Kisseberth, 1979]. Russian palatalization is a secondary articulation involving some raising and fronting of the tongue predorsum (anterior section of the tongue body), which is mostly noticeable in palatalized labials and palatalized velars since both the lips and the postdorsum (posterior section of the tongue body) interfere little or not at all with predorsal activity. In comparison to the realization of velars before front vowels in other languages Russian palatalized velars may occur before back vowels and involve greater raising of the lingual surface in front of the postpalatal place of articulation. Traces of the secondary palatal gesture are harder to observe in palatalized dentoalveolar consonants, given the proximity between the primary tongue front articulator and the secondary predorsal articulator during their production. Static palatographic and X-ray configurations from the literature [Koneczna and Zawadowski, 1956; Vihman, 1967] reveal that, in comparison to alveolopalatal /ɲ/, palatalized dentoalveolars may exhibit a more fronted primary constriction location, thus leaving more space for the tongue dorsum to form the secondary constriction. In some cases, however, the lingual configuration for palatalized alveolars (mostly /nʲ/) may be indistinguishable from that of alveolopalatals (i.e., /ɲ/), presumably because blending between the two lingual gestures is at work during the production of the former consonantal class. Figure 1 exemplifies the articulatory configuration of a palatalized alveolar consonant.

Possible differences in articulatory complexity between palatalized /nʲ/ and alveolopalatal /ɲ/ ought to be present in the temporal course of events. The fact that palatalization is manifested at consonantal offset in Russian palatalized dentoalveolars [see Derkach et al., 1970, and Derkach, 1975, for acoustic and perceptual evidence] makes these consonants highly suitable for comparison with Catalan alveolopalatals. Indeed, as pointed out above, /ɲ/ also shows a [j]-like articulatory configuration extending from closure offset to the onset period of the following vowel. This event should be quite short if not actively controlled since it results from the way the consonant is released, i.e., earlier at the lamina than at the predorsum; the consonantal release for /ɲ/ should occur quasi-simultaneously at the tongue front and at the tongue dorsum, though, differently from the simple consonant /j/, the consonant /ɲ/ would still show a short temporal lag between the release at successive lingual regions. If separately controlled (as for Russian /nʲ/), tongue dorsum activity at the offset of Catalan /ɲ/ could be largely independent of tongue front activity, with maximum displacement occurring much later at the tongue dorsum than at the tongue front. Evidence for the two events occurring independently of each other along the time domain accords with the dorsal gesture being implemented as an 'off'-glide in Russian but as an 'on'-glide in Estonian [Sepp, 1987].

In order to test the segmental complexity hypothesis, we will collect tongue front and tongue dorsum movement data for Russian palatalized alveolar /nʲ/ and for Catalan alveolopalatal /ɲ/. Data for /n/, /j/ and the cluster /nj/ in both languages will be presented as well. In the first place, we will characterize the articulatory properties of these sounds (section 3.1). Secondly, measures of interarticulatory timing will be adduced in order to test the simple vs. complex nature of Catalan /ɲ/ (section 3.2).

As mentioned above, the analysis of the palatal consonant /j/ [which is dorsopalatal in Catalan; Recasens et al., 1993] is quite useful to uncover articulatory complexity in both consonants /nʲ/ and /ɲ/. A first prediction is for the different tongue regions to behave analogously for /ɲ/ and /j/ if the former consonant is a simple segment, and thus for apical, laminal and dorsal activity to occur at similar times; if /ɲ/ is complex, a longer temporal lag between tongue dorsum activity and tongue front activity is expected to occur for /ɲ/ than for /j/ meaning that tongue dorsum raising is controlled independently.

Based on previous findings [Recasens, 1984, for some palatographic evidence], other predictions can be made. If Catalan alveolopalatal /ɲ/ is a simple segment, the [j]-like configuration at consonantal offset would be an uncontrolled, transitional event occurring during closure release and thus, ought to be shorter than the dorsal component in the Russian complex consonant /n^j/ (since /^{j}/ in /n^j/ represents an independent gesture of a single phonological segment), and even shorter than the dorsal gesture in the Catalan cluster /nj/ (since /j/ in /nj/ is the realization of a separate phonetic segment). If, on the other hand, Catalan /ɲ/ is complex, the duration of its [j]-like component should be comparable to that of Russian /n^j/ but still shorter than that of Catalan /nj/. Finally, Russian /nj/ ought to show the longest dorsal event of all sound classes presented here, since consonants become palatalized before /j/ in this language, i.e., Russian /nj/ is realized as [n^jj] [Jones and Ward, 1969]; in this case, the tongue dorsum would be involved in the formation of two successive events, namely, the independent gesture at the consonantal release of /n^j/ and the independent segment /j/.

2. Method

Two subjects took part in the experiment: a Catalan speaker from the Barcelona region (the first author of this paper) and a Russian speaker from Saint Petersburg (an advanced student in Slavic literature at Yale University). The Catalan speaker was chosen as a subject because linguopalatal contact data (collected by means of electropalatography) are available in the production of the consonantal classes included in this paper. Each subject was presented with a list of 30 utterances that included symmetrical VCV sequences with the vowels /i/, /a/ and /u/ and several consonants, preceded and followed by the labial stop /p/; stress fell consistently on the second syllable. For the Catalan subject, the target sequences appeared embedded in the carrier phrase *jo guixo* ___ *si vols* ([jɔ ɣiʃu ___ si βɔls] 'I chalk ___ if you want') and for the Russian subject in the phrase Я вижу ___ сейчас ([jə viʒu ___ sítʃas] 'I see ___ right now'). Each subject read the corresponding list 10 times. In this paper, data will be reported for the /aCa/ sequences with the following consonants: /n/, /ɲ/, /nj/ and /j/ for Catalan and /n/, /n^j/, /nj/ ([n^jj]) and /j/ for Russian. Sequences with the vowel /a/ were selected for analysis since, in comparison to high vowels /i/ or /u/, low vowels should not interfere with tongue dorsum raising.

Tongue movement data for the 2 subjects were collected using an electromagnetic midsagittal articulometer (EMMA or magnetometer) [Perkell et al., 1992]. The magnetometer consists of two main parts: (a) a head mount with three magnetic transmitters that generate a magnetic field covering the entire area of articulation of the subject; (b) a set of small transducer coils that can be attached to numerous places in the midsagittal plane of the subject's vocal tract. As the articulators move inside the vocal tract during the speech process, the transducer coils induce a signal that is roughly inversely proportional to the cube of the distance between transmitter and transducer. The output signal results in a set of voltages which can be converted, through software manipulation, to distance.

In the present experiments coils were placed on the following articulatory structures: upper and lower lips; tongue tip (TT); tongue lamina or blade (TL); tongue dorsum or body (TD); lower incisors, as an estimate of jaw movement; bridge of the nose and upper incisors for head movement correction. The tongue receivers were placed in the following order: first, the tongue-dorsum (TD) receiver was placed in the region of the tongue that makes contact with the palate during the pronunciation of [k] in the syllable [ka]; second, the tongue-tip (TT) receiver was placed approximately 5 mm from the very tip of the tongue; third, the tongue-blade (TL) receiver was placed equidistantly between the TD and TT receivers. To the extent that this procedure is replicable, and taking into consideration possible anatomical differences between speakers, this method was used for both subjects.

Also, during the experimental sessions, estimates for the subjects' occlusal plane were obtained as anatomical references to which the data could be rotated, as well as traces of their palates. These were obtained by asking the speakers to trace their own palates by moving their tongue tip, with the receiver attached to it, from the edge of the front teeth backwards along the midsagittal line as far as they could reach.

There were some minor technical problems during the experimental sessions. In the case of the Russian speaker, a malfunction with two of the receiver coils – lower lip and lower incisors – resulted in defective sets of data for those articulatory structures, lower lip and jaw, which were therefore excluded from the analysis. Also, the values for the occlusal plane references fell out of the permissible range of the rotation routine, so that his data could not be rotated to the occlusal plane.

The data were digitized, together with the simultaneous speech signal, using a real-time input system at a sampling rate of 625 Hz for the movement and 10,000 Hz for the speech. Following input, the kinematic data were converted from voltage to distance, calibrated and corrected for head movement and for any possible misalignment of the receiver coils relative to the transmitters. The data were then extracted into separate channels for the X (horizontal) and Y (vertical) dimensions; in addition to the X and Y signals, the extraction procedure generates a signal, R, that includes information on the amount of misalignment correction performed during the extraction process. For each token, a number of synchronized signals were low-pass-filtered and extracted to include only the target pVCVp sequence. In both cases, the palate traces were used as visual aid in the qualitative assessment of the two-dimensional articulatory trajectories, but no quantitative information was gathered from their spatial locations with respect to the spatial movement of the pellets.

In order to identify events in the movement signals, velocity profiles were obtained. Because of the nature of these movement signals – the tongue does not move in a simple horizontal or vertical line during the production of palatal and alveolopalatal consonants – and because of the discrepancy mentioned above between the 2 subjects in terms of data rotation, tangential velocities were derived. Tangential velocity, by virtue of being derived from both X and Y signals, provides a more accurate picture of the characteristics of the movement than separate single first derivatives for the two dimensions.

Next, a software routine was devised that found points of minimum amplitude in the tangential velocity trace of every pair of movement signals. Those points were taken as temporal reference for marking peaks and valleys in the synchronized X and Y movement signals, from which spatial information was derived. The corresponding acoustic signal was also used in the process of identification of those events. Thus, the points of minimum tangential velocity correspond to the points of maximum amplitude in the movement signals, that is, points of maximum position of the articulator during the production of the consonant in the target VCV sequence.

The tangential velocity profiles were also used to obtain measures of interarticulator timing or phasing measures. This was done by measuring the temporal intervals between points of minimum tangential velocity in the signals corresponding to the different articulators during the production of a particular consonant. Thus, phasing measures were obtained for the following pairs of lingual regions: tongue dorsum minus tongue lamina (TD–TL), tongue lamina minus tongue tip (TL–TT) and tongue dorsum minus tongue tip (TD–TT). Figure 2 illustrates how position and phasing measurements were obtained from the tangential velocity signals.

The data were analyzed statistically using separate repeated measures analyses of variance with each of the measurements above as the dependent variable. Also Fisher post-hoc tests were performed in each case in order to test for differences between individual treatments. The analyses were performed with the Statview statistics package for the Macintosh computer.

3. Results

Figure 3 displays movement trajectories over time for the three lingual regions – TT, TL and TD – in a two-dimensional space; each trajectory represents an average of 10 repetitions. Averaging was done by using the maximum amplitude point in the Y signal for every token as a lineup point. Trajectories were then averaged based on a range of 150 ms to the left and to the right of the lineup point.

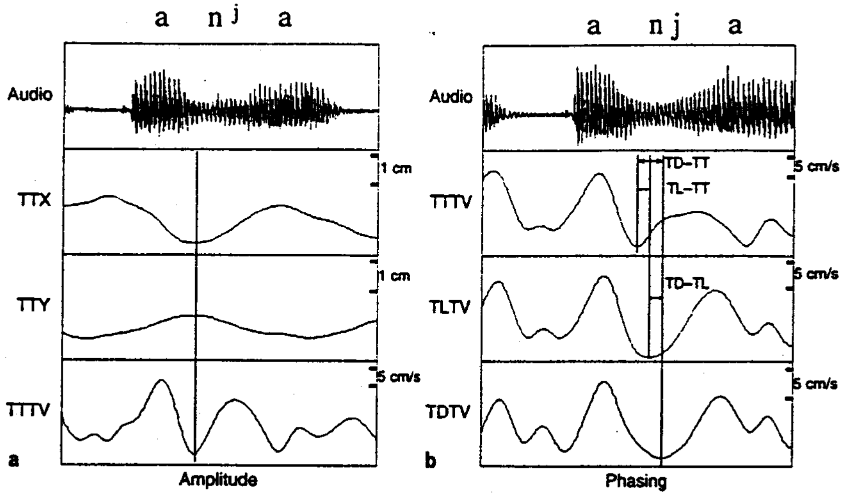

Fig. 2. Display of articulatory events as identified for one representative token of Russian /anʲa/ (**a**) and /aɲa/ (**b**). **a** Point of maximum articulatory position in the TTX and TTY signals as identified from the corresponding minimum in the synchronized tangential velocity signal (TTTV). **b** Phasing events, identified from the tangential velocity signals of TT (TTTV), TL (TLTV) and TD (TDTV).

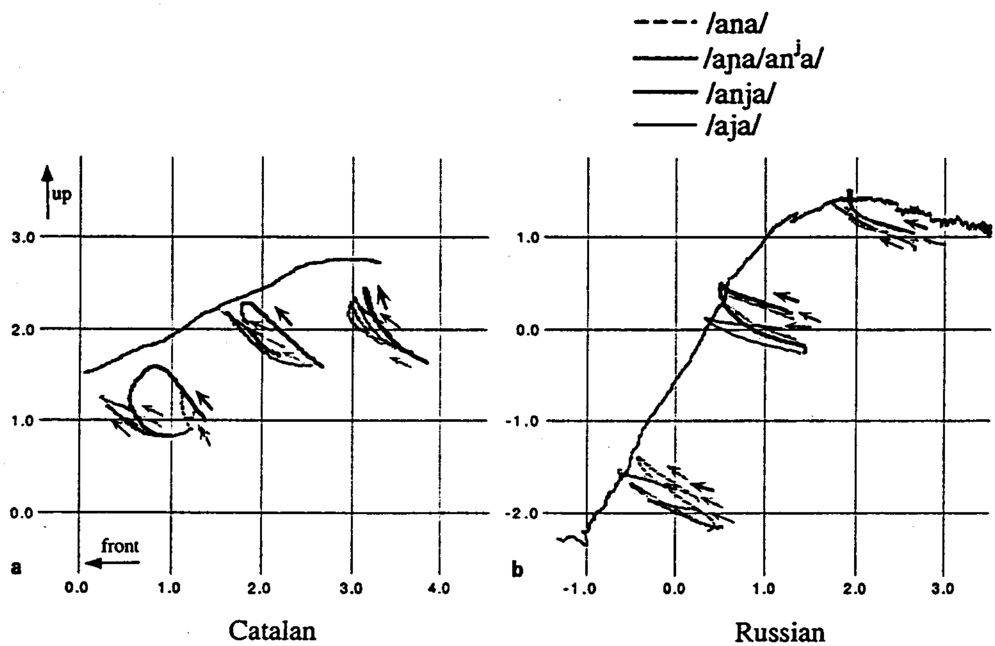

Fig. 3. Two-dimensional representation in X–Y space of TT, TL and TD movement trajectories for the Catalan (**a**) and Russian (**b**) consonants in /aCa/ sequences: each trajectory represents an average of 10 repetitions. The arrows indicate the direction of the movement for each trajectory. The palate traces are provided for help in the spatial appreciation of the movement pattern. The grid divides the space in 1-cm sections.

Table 1. Results of ANOVA analyses (left) and individual means (right) for amplitude measurements (in cm) at the point of maximum articulatory position

Catalan		n	ɲ	nj	j
X	TT $F (3.36) = 144.43, p < 0.01$	2.83	1.92	2.23	1.97
	TL $F (2.27) = 25.921, p < 0.01$		3.28	3.52	3.34
	TD $F (2.27) = 7.662, p < 0.01$		4.76	4.92	4.81
Y	TT $F (3.36) = 65.672, p < 0.01$	0.08	0.01	0.34	–0.09
	TL $F (2.27) = 4.559, p < 0.02$		1.03	1.06	0.97
	TD $F (2.27) = 4.595, p < 0.02$		1.07	1.22	1.14
Russian		**n**	**nʲ**	**nj**	**j**
X	TT $F (3.36) = 80.672, p < 0.01$	–0.4	–0.64	–0.61	–0.28
	TL $F (2.27) = 31.264, p < 0.01$		0.56	0.59	0.39
	TD $F (2.27) = 15.288, p < 0.01$		2.01	2.05	1.84
Y	TT $F (3.36) = 38.432, p < 0.01$	–1.34	–1.5	–1.54	–1.84
	TL $F (2.27) = 74.545, p < 0.01$		0.6	0.65	0.22
	TD $F (2.27) = 35.383, p < 0.01$		1.53	1.73	1.57

Shaded cells indicate missing means (for /n/, which was only analyzed at TT).

3.1 Amplitude

As explained in the previous section, amplitude measurements refer to the points of maximum position in the movement of the lingual regions during the production of the target consonants. Amplitude values of articulatory movement are useful to infer the lingual configuration during consonantal production. In this section, results for amplitude are presented by language. Within each language, the results are compared across lingual regions and across categories, i.e., the different consonants included in the study. Table 1 reports the results of the analyses of variance for the amplitude measurements; these position maxima correspond to the inflection points in the trajectories of figure 3 and can thus be visualized in the figure. Y values in table 1 correspond to vertical movement and vary positively with tongue height (i.e., the larger the Y value, the higher the TT, TL or TD position maximum); X values correspond to hori-

Table 2. Results of individual comparisons (Fisher tests) between types of consonants for amplitude measurements

Catalan	X			Y		
	TT	TL	TD	TT	TL	TD
n–nj	*			*		
n–ɲ	*					
n–j	*			*		
nj–ɲ	*	*	*	*		*
nj–j	*	*		*	*	
ɲ–j				*		

Russian	X			Y		
	TT	TL	TD	TT	TL	TD
n–nj	*			*		
n–n^j	*			*		
n–j	*			*		
nj–n^j						*
nj–j	*	*	*	*	*	*
n^j–j	*	*	*	*	*	

Asterisks indicate significant comparisons. Shaded cells indicate missing comparisons (for /n/, which was only analyzed at TT).

zontal movement and vary inversely with tongue fronting (i.e., the larger the X value, the more retracted the TT, TL or TD position maximum). Table 2 shows results of individual comparisons between the different consonant types.

3.1.1 Catalan

In Catalan, tongue tip height along the Y dimension is directly correlated with apicality in the consonant. Maximal TT values are found for alveolar /nj/ and /n/, with those for /nj/ exceeding significantly those for /n/, presumably because of coupling effects associated with a raised tongue dorsum position during the production of /n/ before /j/ (i.e., anticipatory tongue dorsum raising effects cause the tongue front to raise as well). Minimal TT values along the Y dimension correspond to alveolopalatal /ɲ/ and to palatal /j/ in accordance with the fact that the tongue tip is presumably lowered and does not seem to act as an articulator during the production of these consonants (see 'Introduction' as well). Y values for /ɲ/ are found to exceed those for /j/ significantly, presumably because of coupling effects between the tongue tip and the primary laminopredorsal articulator during the production of the former consonant; these data suggest that laminal activation conveys some apical raising for alveolopalatal /ɲ/ but not so much for dorsal /j/.

Tongue tip amplitude values along the X dimension are in many respects inversely related to those along the Y dimension. Highest values correspond to /n/, both in isolation and in the cluster /nj/, meaning that apical retraction accompanies apical raising for the alveolar nasal stop. Tongue dorsum raising anticipatory effects associated with /j/ convey significantly more apical fronting for /nj/ than for /n/ (fig. 3); electropalatographic data for the same Catalan speaker also show more alveolar closure fronting in the sequence /ini/ than in the sequence /ana/ [Recasens, 1984]. Maximum TT amplitude values along the X dimension correspond to alveolopalatal /ɲ/ and to palatal /j/; these values exceed significantly those for /n/ (and those for /nj/ as well), meaning that the two former consonants are produced with a lower and more fronted tongue tip position than the latter.

Amplitude values at tongue regions located behind the tongue tip (i.e., TL and TD) for /ɲ/ and for /j/ agree with the former consonant being laminopredorsal and the latter being dorsal (though X and Y differences between those two consonantal realizations do not reach significance). TL amplitude values along the Y dimension may be larger for /ɲ/ than for /j/ (/ɲ/ > /j/) while the reverse is usually the case for the TD amplitude values (i.e., /j/ > /ɲ/); in addition, both TL and TD trajectories may achieve a more fronted location along the X dimension for alveolopalatal /ɲ/ than for palatal /j/. TL and TD amplitude values for /nj/ correspond to the /j/ element of the cluster: Y values show that it involves as much laminal raising as /ɲ/, and usually more dorsal raising than intervocalic /j/ and /ɲ/; according to the X values, both lingual regions are placed further back for the /j/ element of the cluster than for intervocalic /j/ and /ɲ/ and this difference is usually significant. No TL and TD data were available for /n/.

More TT, TL and TD fronting for alveolopalatal and palatal consonants than for alveolars may be taken as evidence in favor of the placement of the tongue tip being ruled by the laminodorsal position for /ɲ/ and by the dorsal position for /j/. This observation supports the notion that the tongue front component is not activated separately from the tongue dorsum component for alveolopalatals and, consequently, that these consonants are simple, noncomplex segments.

3.1.2 Russian

In Russian, consonant-dependent relationships in TT amplitude values along the Y dimension are very similar to those found in Catalan. However, /n/ shows significantly more tongue tip height than /nj/, and there is little or no difference between /nj/ and /nʲ/ in this respect: as expected, the lowest TT position corresponds to /j/. As for the horizontal dimension (X), the tongue tip is significantly more retracted for apical /n/ than for laminal /nj/ and /nʲ/ (these two realizations do not differ significantly in X position value), with dorsal /j/ showing the minimum degree of apical retraction. These data accord with /nʲ/ being articulated further back than /n/ in Russian (as for /ɲ/ with respect to /n/ in Catalan), and with /nj/ exhibiting an initial [nʲ] component in the same language. Indeed articulatory descriptions and X-ray configurations mentioned in the literature indicate that Russian /nʲ/ is produced with a primary laminopostalveolar articulation often extending into the prepalatal zone [Jones and Ward, 1969].

Analogously to Catalan /ɲ/ vs. /j/, tongue laminal (TL) height along the Y dimension is significantly more salient for [nʲ] (both as realization of /nʲ/ and as first element of the cluster /nj/) than for /j/. Tongue dorsum (TD) height, on the other hand, usually decreases in the progression /nj/ > /j/ > /nʲ/ (analogously to Catalan /nj/ > /j/ > /ɲ/): dorsal /j/ exceeds nonsignificantly laminal /nʲ/, and the dorsopalatal element [j] of the cluster /nj/ ([nʲ]) exhibits significantly more dorsal raising than /j/. Concerning the X dimension, /j/ has been found to occupy a significantly more anterior TL and TD posi-

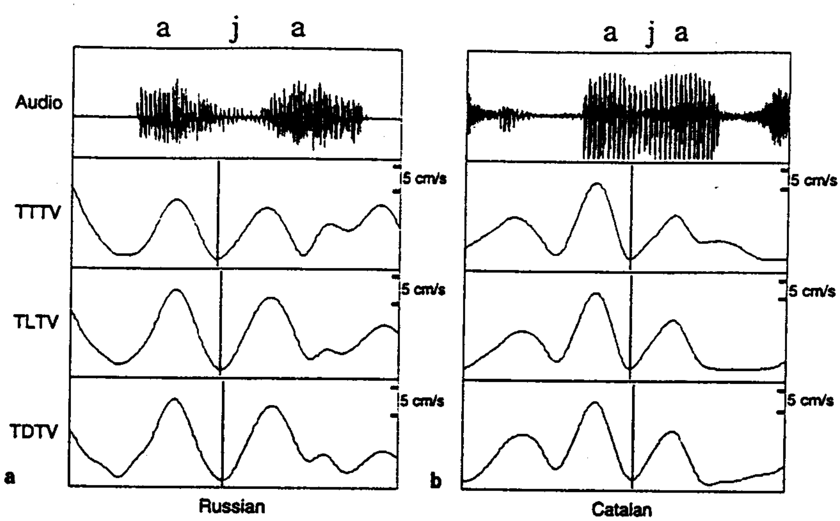

Fig. 4. Example of interarticulatory phasing for Russian (**a**) and Catalan (**b**) /j/ tokens. Each graph shows the audio signals with synchronized tangential velocity signals for the three tongue regions: tongue tip (TTTV), tongue lamina (TLTV) and tongue dorsum (TDTV). The vertical bars in the velocity signals indicate points of minimum velocity. Both graphs display a 500-ms span in the temporal scale.

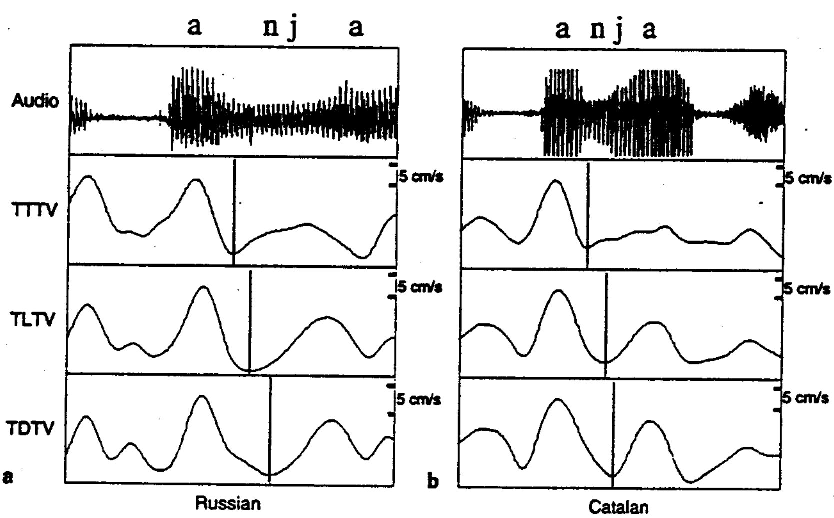

Fig. 5. Example of interarticulatory phasing for Russian (**a**) and Catalan (**b**) /nj/ tokens. Each graph shows the audio signals with synchronized tangential velocity signals for the three tongue regions: tongue tip (TTTV), tongue lamina (TLTV) and tongue dorsum (TDTV). The vertical bars in the velocity signals indicate points of minimum velocity. Both graphs display a 500-ms span in the temporal scale.

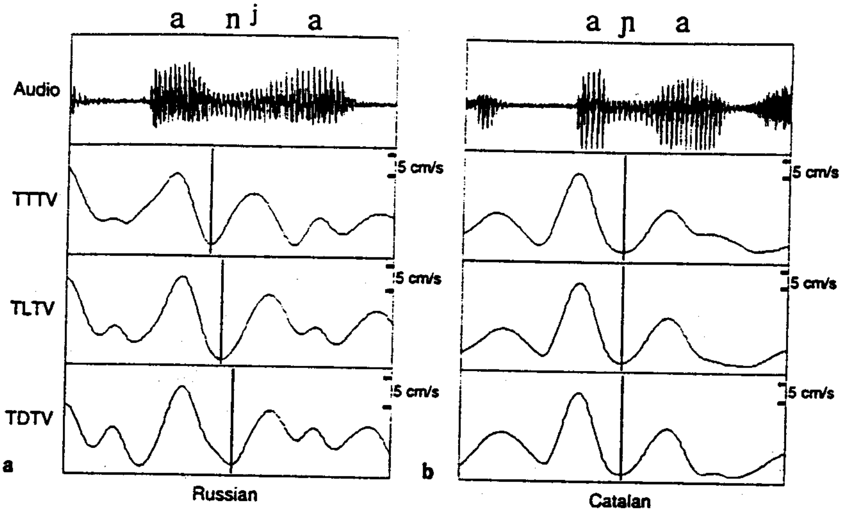

Fig. 6. Example of interarticulatory phasing for Russian /nʲ/ (**a**) and Catalan /ɲ/ (**b**) tokens. Each graph shows the audio signals with synchronized tangential velocity signals for the three tongue regions: tongue tip (TTTV), tongue lamina (TLTV) and tongue dorsum (TDTV). The vertical bars in the velocity signals indicate points of minimum velocity. Both graphs display a 500-ms span in the temporal scale.

the former case (independent /j/ gesture for the complex consonant /nʲ/ and following segmental unit /j/ of the cluster /nj/).

The complex nature of the /nj/ cluster in both Russian and Catalan is illustrated in figure 5, where both languages show clear time lags between the three regions of the tongue. Also, as shown in table 4, all comparisons between the phasing values of /nj/ and /j/ are significant in both languages at all three lingual points.

3.2.3 Alveolopalatal /ɲ/ and Palatalized Alveolar /nʲ/

Data in table 3 show that all lags are much shorter in Catalan /ɲ/ than in Russian /nʲ/. Concerning the TD-TL difference, it could be concluded that the activity of the two lingual regions is far more dissociated in /nʲ/ than in /ɲ/. This finding is consistent with the notion that an increase in tongue dorsum raising during the closure period (see 'Introduction' section) is associated with a separate gesture for /nʲ/ and with an increase in lingual pressure level at the place of articulation for /ɲ/. Language-dependent TL–TT lag differences can be taken as evidence for a higher coherence level between the activity of the tongue lamina and the tongue tip in Catalan than in Russian. This finding accords with electropalatographic data for Catalan showing that the referred increase in lingual pressure conveys a contact increase not only at the palatal zone but in front of the place of articulation as well. Longer TL–TT lag values for Russian vs. Catalan are consistent with the primary tongue front constriction being released before the secondary tongue dorsum constriction is formed, and suggest that /nʲ/ is produced with a more anterior articulation than /ɲ/ (see 'Introduction').

The finding that position maxima for TL and for TD are delayed in Russian vs. Catalan also accords with the tongue front and the tongue rear regions being released simultaneously for Catalan /ɲ/ but sequentially for Russian /nʲ/. This is the expected behavior for a simple (/ɲ/) vs. complex (/nʲ/) segment and accords with the observation in the 'Introduction' that closure release for Catalan /ɲ/ does not occur abruptly but proceeds from the alveolar zone towards the prepalatal zone.

It is important to underline that the observed time lag differences between Catalan and Russian cannot possibly be due to language-dependent differences in speech rate exclusively; they represent a genuine difference between the nature of the two types of consonants. Thus, the phasing differences between the two languages are much larger for the /ɲ/–/nʲ/ pair than for the other two sets of consonants, i.e. /j/ and the cluster /nj/, as shown in table 3. Table 3 also shows longer time lags for the cluster /nj/ in Catalan and Russian than for /ɲ/–/nʲ/, which is in accordance with the bisegmental nature of the cluster and the monosegmental nature of simple /ɲ/ and complex /nʲ/. These differences are significant, except for TD–TL in Catalan, even though the same trend is observed here as well.

More importantly, comparisons of mean phasing durations by consonant type in table 4 show a different scenario in Catalan vs. Russian. While /ɲ/ and /j/ do not differ significantly for any of the three time lags in Catalan, /nʲ/ and /j/ do so for all of them in Russian. Given that /j/ is a simple segment in both languages, this finding accords with the simple nature of /ɲ/ and the complex nature of /nʲ/, and is consistent with the observation that the three lingual regions act as a whole during the production of the Catalan /ɲ/ but not so for Russian /nʲ/.

4. Discussion and Conclusions

The EMMA data reported in this study suggest that there is a difference in articulatory complexity between palatalized alveolar /nʲ/ (Russian) and alveolopalatal /ɲ/ (Catalan). Both TL–TT and TD–TL lag values are considerably longer for /nʲ/ than for /ɲ/, meaning that the activity of the two articulators, i.e., tongue front and tongue dorsum, are more temporally dissociated for the palatalized alveolar than for the alveolopalatal consonant. In many respects, Russian /nʲ/ behaves like /nj/ but with a shorter TL–TT lag, since the cluster is produced with a more anterior and independent tongue tip component. TD–TL and TL–TT lags for both /nʲ/ and /nj/ are longer than for other consonantal classes. This supports the existence of two independent and consecutive lingual gestures.

On the other hand, the articulatory behavior of the three lingual regions for Catalan /ɲ/ is highly homogeneous and does not differ significantly from that for /j/ (which is a one-gesture, simple segment in both languages, as confirmed by the presence of short interarticulatory phasing values); the opposite finding has been reported for Russian /nʲ/, i.e., there is an important time lag between the activity of the tongue back and that of the tongue front, which differs significantly from that measured for the simple segment /j/. This comparison of time lags between /j/ and /ɲ/–/nʲ/ is strong evidence in support of the simple nature of /ɲ/ and the complex nature of /nʲ/. In agreement with this observation, amplitude and phasing data reported in this paper reveal that Russian /nʲ/ is more fronted than Catalan /ɲ/. This finding supports the notion that tongue front and tongue dorsum must be placed as far apart as possible (as for /nʲ/ vs. /ɲ/) in order to be simultaneously activated for the production of a two-gesture, complex consonant.

The phasing values obtained in these experiments agree with the electropalatographic data showing an increase in palatal contact as full closure is being achieved, for both /nʲ/ and /ɲ/. This contact increase results from an increase in lingual pressure level at the alveoloprepalatal place of articulation for /ɲ/, and from the activation of a secondary dorsal gesture for /nʲ/. The [j]-like articulatory configuration for /ɲ/ does not result from the activation of an independent dorsal gesture, but is associated with a gradual release proceeding posteriorly from the alveolar to the palatal zone; short positive lag values are in agreement with the transitional nature of the alveolopalatal release.

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