Velar movements in French: An articulatory and acoustical analysis of coarticulation

Solange Rossato, Pierre Badin and Florence Bouaouni
Institut de la Communication Parlée, CNRS – Université Stendhal – INPG, Grenoble, France
E-mail: rossato@icp.inpg.fr, badin@icp.inpg.fr

ABSTRACT

This study deals with the effects of spatial and contextual coarticulation on the velar position in vowels and consonants, and on the associated acoustic outputs. We present first an articulatory analysis of velar movements for consonants and vowels recorded for a French male subject uttering a corpus of VCV sequences. The velum in nasal consonants appears to be surprisingly high in comparison with nasal vowels. Moreover, a clear overlap between the ranges of velum height for oral vowels and nasal consonants was found. A strong carryover effect was observed for vowels at the articulatory level, though this did not systematically result in significant effects on the acoustic spectral peaks. Anticipatory velar movements were never observed.

1 INTRODUCTION

Nasal sounds are produced by a lowering of the velum, which results in the coupling of the nasal fossa and various paranasal sinuses with the oral tract. The nasality feature corresponding to this articulatory movement exists in most language (over 96% of the world languages). In French, nasality plays an important phonological role, both for consonants and vowels: consonants [b] and [m] differ by the closed / open status of the velum, as well as vowels [ɔ] and [ɔ̃] differ (mainly) by the velum position. These relatively simple velar movements have complex acoustic consequences, related to the apparition of a complex set of poles and zeros in the acoustic transfer function of the vocal tract [1]. Observations of velopharyngeal setting ([3], [4]) have shown that coarticulation influences velar position. *Spatial coarticulation* is related to the constraints imposed by the position of other articulators (pharynx, jaw and tongue) that are connected to the velum via the palatoglossus and the palato-pharyngeal muscles. Clumeck's study [3] on six languages shows that vowel height (that is tongue elevation) influences velar height. *Contextual coarticulation* that plays also an important role in velopharyngeal position is related to the question whether the velar position during consonant depends on vocalic context, and whether anticipation or carryover occurs for the realisation of nasal consonants. This paper presents an analysis of articulatory and acoustic data gathered on a French subject in order to bring some light to these questions.

2 ARTICULATORY AND ACOUSTIC DATA

The corpus used to observe the variations of the velar positions during consonants and vowels was constituted of a single occurrence of all the symmetric [#VCV#] sequences where C is one of the French consonant [p t k b d g f s ʃ v z ʒ ʁ l m n], and V one of the French oral or nasal vowels [a ɛ e i y u o ø ɔ œ ɑ̃ ɛ̃ ɔ̃ œ̃]. A complementary corpus, constituted of series of sequences [pVCVp] repeated five times, the consonant C being restricted to [p b m t d n], was used to compare more precisely nasal stops, voiced and voiceless oral stops having the same place of articulation, labial or dental. One single male French subject has been recorded so far.

Articulatory movements and speech sound have been recorded synchronously. One of the coils of an electromagnetic midsagittal articulograph (EMA) was attached to the velum at about half way between the junction of the hard palate and of the velum and the extremity of the uvula of the subject, in the most mobile region of the velum, so as to provide an estimation of the velum movements (see Figure 1). The vertical displacement of the coil is called hereafter *velum height* (note that the origin of the coordinates is arbitrary, the X horizontal axis being nearly aligned with the occlusal plane). The articulatory movements were sampled at 500 Hz, while the speech signal was sampled at 20 kHz. The articulatory analysis concerned both coordinates of the velum coil, sampled at the centres of vocalic and consonantal segments that had been manually labelled.

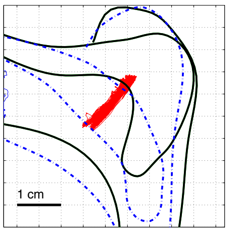

Figure 1: Velum coil trajectories for all VCVs superposed on vocal tract contours ([t[a]], [n[a]]) for the same subject (zoom on velum region).

The acoustical analysis was performed for the vowels only. The formants were estimated from a steady portion in the middle of the oral vowels. Formants values were automatically computed, based on traditional LPC analysis, and gross errors were manually corrected. In order to include nasal vowels in the acoustic analysis, we estimated also the two first peaks of the auditory spectra [1], using an 8th order PLP analysis [2].

ISBN 1-876346-48-5 © 2003 UAB

3 ARTICULATORY ANALYSIS

The articulatory data have been submitted to a series of analyses aiming at assessing various coarticulatory influences. The statistical tests used in this study were based on the variance analysis ANOVA with a significance level $p < 0.01$ by default.

3.1 NASAL AND ORAL SEGMENTS

We first analysed the overall distribution of velum position. The maximum overall range of velum height is about 1.05 cm, from 9.8 cm for the very low position attained for nasal vowels up to 10.85 cm observed for oral stops. Figure 2 displays velum height histograms for the four categories of oral and nasal vowels and consonants. The oral and nasal vowels are clearly separated: the oral vowels are produced with a velum height between 10.4 cm and 10.8 cm (mean 10.66 cm), whereas the nasal vowels are realised with a velum height between 9.8 cm and 10.2 cm (mean 9.96 cm). Most of the oral consonants are produced with a velum height about 10.7 cm. A striking observation is that the velum height range of the nasal consonants is rather wide (Figure 2): if most nasal consonants are produced with a velum height around 10.5 cm, their global range spans from 9.9 to 10.65 cm, which overlaps the oral vowels and consonants distributions. Note also that velum is clearly higher in nasal consonants than in nasal vowels.

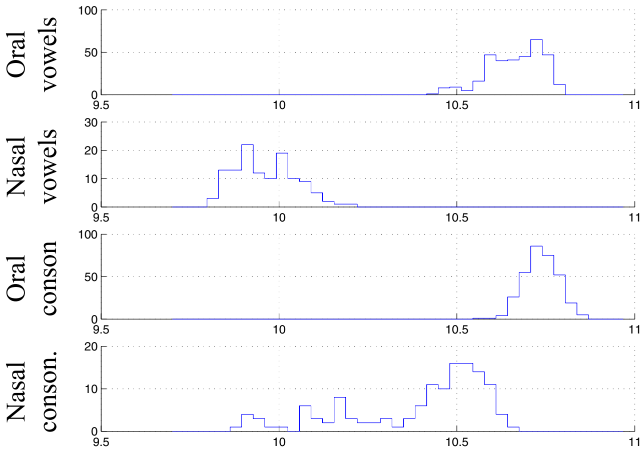

Figure 2: Distributions of velar height for all classes.

The data show that the same velum height can be used to produce an oral vowel and a nasal consonant. We can reasonably suppose that the low oral vowels are produced with a slightly opened velopharyngeal port, as also found by Clumeck [4]. More surprisingly, some of the oral consonants appear to be produced with the same velum height than nasal consonants (cf. the slight overlap between oral and nasal consonants). This raises the question whether the velopharyngeal port is open or closed for these oral consonants. One could also wonder if velum height is a unique and reliable indicator of velopharyngeal port opening. Further studies are thus needed to clarify this and to determine if a additional parameter should be added to velum height to explain different velopharyngeal port sizes for a given velum height. Nasal airflow recordings on the same subject for the same corpus are under way to check if nasal airflow is present or not for the oral phonemes produced with a low velum.

3.2 CONSONANTS: VOICING, MANNER AND PLACE

Another spatial coarticulation effect was then studied, i.e. the influence of voicing, manner and place of articulation on the position of the velum in consonants. Our data revealed that the voicing feature has no significant influence on velum position for consonants, either oral stops or fricatives. Velum height for stops was found significantly higher (by 0.08 cm) than that of fricatives.

The horizontal position of the velum coil of oral consonants was also analysed. Significant differences were observed between labial, dental and velar stops: dental consonants are realised with a velum more advanced (by 0.07 cm) and a little higher than bilabial ones; velars are realised with still a more advanced position (by another 0.05 cm). A similar – though less marked – phenomenon was observed for fricatives and nasals. This phenomenon can be explained by the fact that, due to the apicodental contact, the tongue in dentals must be in a more advanced position, constraint that is likely transmitted via the palatoglossus muscle to the velum, and would result in a more advanced position. For velar stops, the velopalatal contact constitutes an even stronger constraint inducing a total shift of about 0.12 cm.

3.3 CONSONANTS: VOWEL INFLUENCE

The vocalic context was found to influence the velar position, and the vowels could be classified in three groups: the high vowels [i y u], the mid and low vowels [e ø o ɛ œ ɔ a], and the nasal vowels [ɛ̃ œ̃ ɔ̃ ɑ̃]. For each class – stops, fricatives or nasals – the velum positions for the consonant in the three vocalic contexts were significantly different. Figure 3 shows the velar positions grouped according to the context high vowels, mid-low vowels or nasal vowels for oral and nasal stops in the pVCVp sequences.

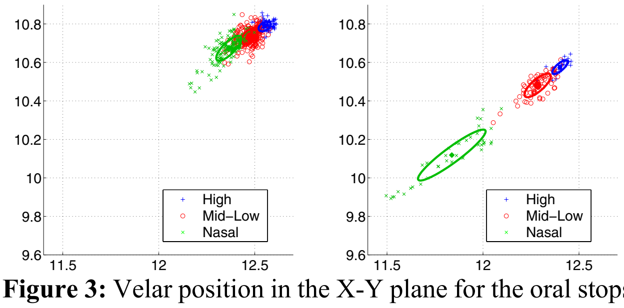

Figure 3: Velar position in the X-Y plane for the oral stops [p t b d] (left), and for the nasal stops [m n] (right).

3.4 VOWEL QUALITY

In previous studies on vowel production (cf. e.g. [3], [4]), it has been reported that the velum is not always closed during oral vowels, and thus slightly lowered. Furthermore, a tendency for the velum to be more open for low vowels than for high ones has been widely noticed (cf. e.g. [4] for a review). This tendency was verified in our data. For the statistical analysis, the ten oral vowels were grouped by vowel aperture: high vowels [i y u], mid vowels [e ø o ɛ œ ɔ], and the low vowel [a], as illustrated in Figure 4. The differences in velar height between these classes were all significant. As expected, velum height is related to vowel height.

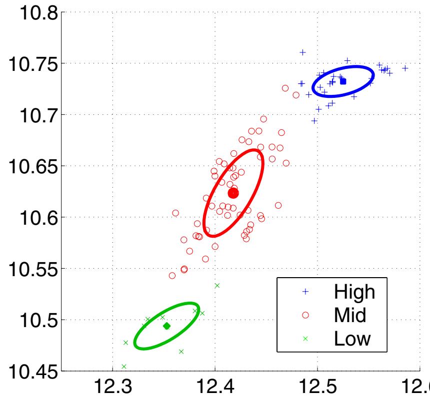

Figure 4: Velar coil positions in the X-Y plane for oral vowels in symmetrical context pVp: high vowels (+),all mid vowels grouped (o), and the low vowel (×).

The velum height during the nasal vowels differs according to vowel quality. In our data, the velum height is significantly higher for [ɔ̃], not significantly different for [œ̃] and [ɑ̃] and significantly lower for [ɛ̃]. Figure 5 shows the velar coil position for each nasal vowel in the symmetrical context pV_np. The higher velar position for [ɔ̃] is also observed in Delvaux' MRI study [5] and in Amelot's fiberscopic study [6] on French nasal vowels. Delvaux found intermediate velar heights for [ɛ̃] and [œ̃] and a lower velar position for [ɑ̃], while Amelot et al. found for [ɑ̃] a velar height close to the nasal vowel [ɔ̃], [ɛ̃] being the vowel produced with the lowest velar position.

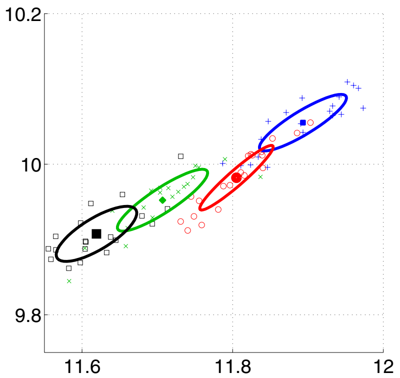

Figure 5: Velar positions for nasal vowels in symmetrical context pV_np: [ɔ̃] (+), [ɑ̃](o), [œ̃] (×), and [ɛ̃] (□).

3.5 VOWELS: CONSONANTAL INFLUENCE

In this section, we compare the velar positions during the vowel preceding or following a nasal versus an oral consonant in pVCVp sequences.

Anticipation: In our data, the velum height during the vowels preceding a nasal consonant is not lower than when preceding an oral stop. There is no trace of any anticipatory velar movement in the middle of the previous vowel. In fact, oppositely to what we expected, the velum is a little higher (depending on the vowel, by 0.02 cm to 0.09 cm) when the following consonant is nasal than when it is oral (this difference is significant for all the oral vowels except for [e]: p=0.014). Note that, for the nasal vowels, no significant differences were observed.

Carryover: All the oral vowels show significant differences in velum height depending on the nasality of the preceding consonant. The velum in the vowel is lower when the following consonant is oral than when it is nasal (difference of 0.15 ± 0.03 cm, averaged over all vowel qualities). Figure 6 shows the velum position for all the oral vowels in both conditions. Our data reveal a clear and consistent carryover. For nasal vowels, the same phenomenon can be observed, though with less amplitude (0.09 ± 0.02 cm, averaged over the four nasal vowels).

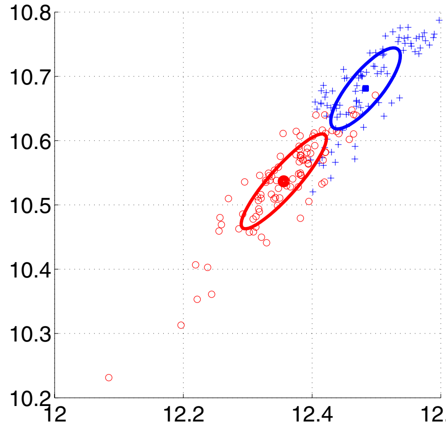

Figure 6: Velar coil positions in the X-Y plane for oral vowels *following* an oral stop (+) or a nasal stop (o).

4 ACOUSTICAL ANALYSIS

Acoustical analyses have been performed on the pVCVp sequences in order to determine if the coarticulation effects on vowels observed in the articulatory analysis were sufficient to produce significant effects on the acoustic output of the vocal tract. Either formants F1 and F2, or peaks P1 and P2, were considered in a variance analysis.

4.1 FORMANT ANALYSIS

Anticipation: For each vowel, we compared formant values in both oral and nasal stop contexts. Our analysis shows no significant difference. The small difference observed in the velar position between oral and nasal contexts induces no significant difference on formant values.

Carryover: An ANOVA has been carried out on the vowels following an oral or a nasal consonant. Results depend on vowel quality. For the vowels [e ɛ œ ɔ a], the difference of F1 between oral and nasal contexts is significant, while it is not for the vowels [i y u ø o] (cf. Table 1). When the difference is significant, that is for mid-low vowels, [a] and [e], F1 is higher in the nasal context than in the oral one. An ANOVA applied to F2 did not reveal any significant difference between oral and nasal contexts, except for [y] and [e]; for both vowels, F2 tends to be higher in the nasal context.

ISBN 1-876346-48-5 © 2003 UAB

4.2 AUDITORY SPECTRA

Anticipation: As expected, the analysis of the first two peaks of the auditory spectra did not reveal any anticipatory effects, as for the formants.

Carryover: The analysis of carryover effects showed that P1 for vowels [e ɛ ɔ a] is significantly higher in nasal context than in oral context, while P1 is lower for vowel [y]. For vowel [œ], P1 is higher in nasal context, though with a significance level of only 0.012. Note that the nasal vowels do not show any significant carryover.

Both analyses show the importance of the low frequencies: F1 and P1 explain most of the significant acoustical effects observed, while F2 and P2 do not undergo any significant effects. For vowels [e ɛ œ ɔ a], F1 and P1 are higher in nasal context. Vowel [y] shows a different pattern: P1 is lower and F2 is higher. These observations are not consistent with results of previous studies ([7], [8]) that have reported a lower F1 for low vowels and a higher F1 for high vowels, claiming that nasality tends to centralise vowels. However, Delvaux et al. [5] have also found a tendency for F1 to be higher for vowels [ɛ œ ɔ] for some subjects.

	F1 (Hz)		P1 (Hz)	
	oral	nasal	oral	nasal
i	229	232	321	321
y	224	224	**331**	**319**
u	219	219	344	331
e	**350**	**410**	**386**	**415**
ø	332	319	408	419
o	351	367	391	398
ɛ	**548**	**591**	**632**	**711**
œ	**476**	**547**	510	570
ɔ	**465**	**533**	**488**	**536**
a	**685**	**717**	**772**	**808**

Table 1: Mean F1 and P1 values for the French oral vowels following an oral consonant or a nasal one. Significant differences are marked in bold characters.

5 DISCUSSION AND CONCLUSION

This study brings evidence that the velar position during vowels and consonants depends not only on the nasal feature but is also largely influenced by spatial and contextual coarticulation effects. Spatial coarticulation is very likely a consequence of biomechanical constraints. We have observed that velar horizontal position is clearly related to tongue place of articulation. As well, velum height is highly related to tongue height. Contextual coarticulation may be related to articulatory coordination, i.e. actively controlled, within the limits imposed by mechanical constraints. The fact that carryover effects are much more important than anticipation effects supports the idea that these movements are controlled. It is worthy of note that there exists a velum height range (10.4 – 10.65 cm, cf. Figure 2) in which both oral vowels and nasal consonants are produced: the precise control of velum would not be necessary to produce sequences such as [mama]. This would explain the fact that children can produce such sequences at an age where they are not supposed to be able to control coordination between velum and jaw movements [9].

We have observed that the significant carryover effect found for the vowels at the articulatory level is not always reflected in the acoustic domain. The absence of significant acoustic changes could be explained, for the nasal vowels, by the fact that a small change in velar position would not change very much the velopharyngeal port size, as it is already large. For the high oral vowels, the first hypothesis was that the velum is lower, but not enough to open the velopharyngeal port. However, the vowel [y] has also shown significant changes that no movement other than that of the velum could explain: we verified that the jaw and tongue coils showed no significant differences between the nasal and oral contexts. This would imply that the velopharyngeal port would be open for the high vowel [y], despite the fact that the velum height reaches 10.59 cm. Note that this velum position is higher than those for all the other vowels. This would suppose that the carryover effects would induce an open velopharyngeal port for all the oral vowels, unless an additional parameter such as velum horizontal position would be envisaged to control the velopharyngeal port size, in addition to the main velum height parameter. Further experiments are on the way in order to find answers to these questions: aerodynamic measurements, MRI-based articulatory model of the velum.

REFERENCES

[1] Maeda S., “Acoustics of vowel nasalisation and articulatory shifts in French nasal vowels,” in *Nasals, Nasalisation and the Velum*, pp. 147–167, Academic Press, 1993.

[2] Hermansky H., “Perceptual linear predictive (PLP) analysis of speech,” *JASA.*, vol. 87, pp. 147–167, 1990.

[3] Ushijima T. and Sawashima M., “Fiberscopic observation of velar movements during speech,” *Annual Bull.*, No 6, RILP, Tokyo, pp. 25–38, 1972.

[4] Clumeck H., “Patterns of soft palate movements in six languages,” *J. Phonetics*, vol. 4, pp. 337–351, 1976.

[5] Delvaux et al., “Propriétés acoustiques et articulatoires des voyelles nasales du français,” *XXIV*^èmes^ *Journées d’Etude sur la Parole*, pp. 357–360, 2002.

[6] Amelot et al., “Nasalité en français spontané : mesures aérodynamiques et fibroscopiques, études préliminaires,” *XXIV*^èmes^ *Journées d’Etude sur la Parole*, pp. 361–364, 2002.

[7] Wright J.T., “The behavior of nasalized vowels in the perceptual space,” in *Experimental Phonology*, pp. 45–67, Academic Press, 1986.

[8] Beddor P.S. and Hawkins S., “The influence of spectral prominence on perceived vowel quality,” *JASA*, vol. 87, pp. 2684–2704, 1990.

[9] Lalevée, C. and Vilain, A., “Development of speech frame control: a longitudinal study of the oral/nasal control.,” *ICPhS 2003*, these proceedings, 2003.