Velar movements for the feature [±nasal] for two French speakers

Angelique Amelot, Solange Rossato

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Angélique Amelot, Solange Rossato
Institut de la Communication Parlée
Université Stendhal - 1180, Avenue Centrale, BP 25, 38040 GRENOBLE CEDEX 9
Tél. +33 (0)4 76 82 43 37

angelique.amelot@icp.inpg.fr, solange.rossato@icp.inpg.fr

Abstract. *This study deals with the velar movements involved in (i) the realisation of the phonemic [±nasal] contrast on vowels and (ii) contextual nasalization. We measure velar positions with an electromagnetic articulatograph (EMA) for two French speakers. Our results confirm that (i) nasal vowels are produced with a lower velum height than nasal consonants; (ii) velum height targets for nasal and oral segments can overlap, especially sequences of nasal consonant and contextually nasalized oral vowels or /l/ and /ʁ/ consonants (iii) contextually nasalization in French is rather a carryover of the lowering of the velum than an anticipation of this movement.*

1. Introduction

The nasality feature is widely spread in the world's languages. 96.5% of the 451 languages from UPSID database (UCLA Phonological Segment Inventory Database (Maddieson, 1981) (Vallée, 1994) (Boë *et al.*, 2002) use this feature in their consonantal system. It is also the most frequent secondary dimension used in vocalic systems (22.4% of UPSID languages), on a par with the dimension of length. This binary feature [±nasal] is produced by the lowering of the velum, which connects the nasal passage to the oral tract. For nasal vowels, the acoustic consequences are quite complex; they depend not only on velum position but also on the articulatory configuration of the vocal tract, as shown by simulation studies (House and Stevens, 1956; Fujimura and Lindqvist, 1971; Feng, 1986; Maeda, 1993). Maeda (1993) synthesized a continuum from an oral vowel to a nasal one by an articulatory model and perceptual tests showed that a small opening of the velopharyngeal port (on the order of 0.4 cm^2) was sufficient to perceive a nasalized [i], whereas [a] was still perceived as oral, a coupling greater than 1.6 cm^2 being necessary to perceive nasalization on an [a].

Different velar positions have been observed during the production of oral vowels. Clumeck (1976) used photodetection of velar activity on several subjects across six languages and clearly established a link between the height of the oral vowels and the velum position: /a/ is produced with a lower velum than other oral vowels. The electromyographic data recorded by Iwashita (1965) for Japanese vowels showed that velum position was correlated with lingual position. The correlation between vowel height and velar position may depend on the activity of the palatoglossus (Moll, 1962), following the hypothesis according to which this muscle could serve a palate-lowering function when the activity of the levator muscle is suppressed. However, Bell-Berti and Hirose (1973) find differences in the pattern of palatoglossus activity, measured by electromyography, in vowel-nasal and nasal-vowel combinations: the palatoglossus function for velum lowering may exist for speakers of some languages, but this function does not occur for all speakers and all languages. Therefore, the palatoglossus activity is not sufficient to explain the relationship between the lowering of the velum and the height of the vowel. No biomechanical link can explain the fact that low vowels are produced with a low velum height. It has been noticed that the velar position observed in low vowels could even be so low as to imply an open velopharyngeal port. For example, Durand (1953 p.34), on the basis of radiographic data on French, observed that /a/ in oral context (“il l’a” [il:a]) was produced with a velum 10 mm distant from the back pharyngeal wall. Very importantly, such a slightly open velopharyngeal port may not be sufficient to induce a nasal percept (Maeda, 1993). The opening and closing phases of the velopharyngeal port involved in the production of nasal consonants also tend to nasalize the adjacent vowels. The degree of coarticulated nasality is language-specific (Clumeck, 1976; Cohn, 1990). Clumeck (1976) reported a strong variation across languages in the timing of anticipatory velopharyngeal port opening in vowels preceding a nasal consonant; this variation was not closely related to distinctiveness of vowel nasalization. Some phonemes did not allow the spreading of the nasality feature. Benguerel *et al.* (1975), on the basis of fiberscopic data on French, observed that the plosive consonants involve more contextual constraints and less spreading of nasalization. They only allow a slight velopharyngeal port opening of less than 0.1 cm^2 (Warren *et al.*, 1993), therefore the nasal vowel can be produced partly as an oral vowel.

Between partly oralized nasal vowels and partly nasalized oral vowels, how the phonological contrast can be maintained on an articulatory level? What are the specific targets for oral and nasal segments and how sensitive are these targets to contextual variations? To investigate the intrinsic height of the velum for oral/nasal phonemic contrast either on consonants or on vowels and its variations due to neighboring phonemes, we measured the velar movements in VCV sequences for all phonemes in French. The contrast between nasalized oral vowel and nasal vowel is analyzed more precisely through a specially designed part of the corpus.

2. Articulatory measurements

2.1. Corpus

The first part of the corpus is made up of /#VCV#/ sequences, in order to measure velar position for each French consonant (/p t k b d g f s ʃ v z ʒ ʁ l m n/), whatever the vocalic context: the five oral vowels /i e a o u/ and all French nasal vowels (/ɛ̃ œ̃ ɑ̃ ɔ̃/). A single repetition of the 160 sequences was recorded. These sequences also allow for the analysis of velar position during oral and nasal vowels whatever the consonantal left or right context. The second part of the corpus focuses on the effect of contextual nasalization on oral vowels in French as compared to nasal vowels with sequences like /C_nV/, /VC_n/ and /C_nVC_n/. C_n is the nasal consonant /n/, as the alveolar occlusion is clearly visible on the apex coil of EMA. V is one of the French vowels /i y u e o ɛ œ ɔ ɛ̃ œ̃ ɔ̃ ɑ̃/. These sequences were embedded in a carrier sentence: “Vous dites ___ trois fois”; ‘You say ___ three times’. The other parts of the corpus are made up of /CV$_n$C/ sequences, words with nasal plus oral consonant clusters, and sentences, which are still under analysis.

2.2. Instrumentation

The articulatory movements were recorded with an electromagnetic midsagittal articulograph (EMA Carstens AG100). Six coils were attached with the medical glue used by dentists. A Cyanoveneer glue was used for the skin and mucous membrane, and a CG Fuji 1 glue for the tongue.

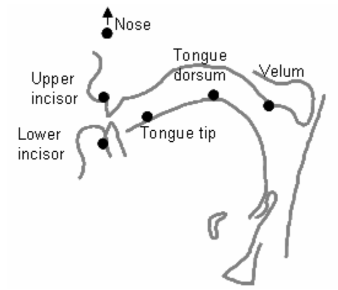

Figure 1. Position of the six coils fixed on the articulators.

Twos coils are used as references on two fixed points: one coil on the gum between the two incisors and the other one on the upper part of the nose, where the skin is least influenced by facial movements. Both coils are useful to estimate the movement of the helmet in relation to the head's subject, allowing, if necessary, for a correction of those movements. The coil fixed between the lower incisors indicates the jaw movements; two coils, respectively on the tongue tip and tongue dorsum, supply partial information on tongue movements. This study focuses on the velum coil fixed about half-way between the junction with the hard palate and the extremity of the uvula. Two French female speakers (S1 and S2) without known vocal pathology or upper respiratory infections at the time of the study were recorded. Speaker S1 is native of France and S2 is native of Belgium. As S1 only has three nasal vowels (/ɑ̃ ɛ̃ ɔ̃/) in her phonemic inventory, the corpus was modified accordingly.

The coil trajectories are sampled at 500 Hz, and filtered with a low-pass filter that cuts off frequencies above 20 Hz in order to remove noise. The velum is a relatively slow articulator which takes approximately 200-300 ms to make a complete cycle from a closed velopharyngeal port to an open one and back to a closed port (acoustic measurements on /imi/ and /ama/, (Stevens, 1998 p.43)). Thus, the filtering does not alter velar movements. The trajectories of the coils are indicated in midsagittal plan by two coordinates given in centimetres. The velum height is the vertical position of the velar coil, i.e. the Y coordinate. The audio signal was recorded simultaneously with the microphone of the Carsten device and sampled at 44100 Hz. All the transitions and the middle of phonemes are labeled as shown in figure 2. Labels are established from the acoustic signal and the sonogram.

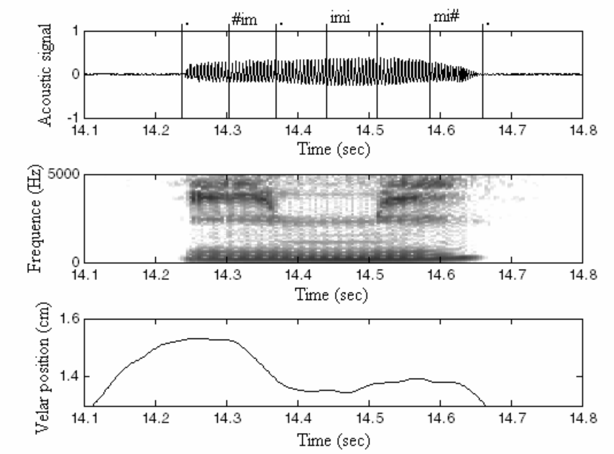

Figure 2. Acoustic signal with labels, sonogram and velum height for /imi/ sequence produced by S2.

3. Results

The statistical tests used in this study were based on the variance analysis ANOVA with a significance level $p<0.001$ by default.

3.1. Velum height for oral and nasal segments

Figure 3 presents the velum height distribution for four classes: oral consonants (OC; n=118 for S1; n=141 for S2), oral vowels (OV, n=160 for S1; n=191 for S2), nasal consonants (NC; n=18 for S1; n=20 for S2) and nasal vowels (NV; n=114 for S1; n=129 for S2). The velum height is the Y coordinate of the velum coil at the middle of the segment, extracted for each phoneme of VCV sequences.

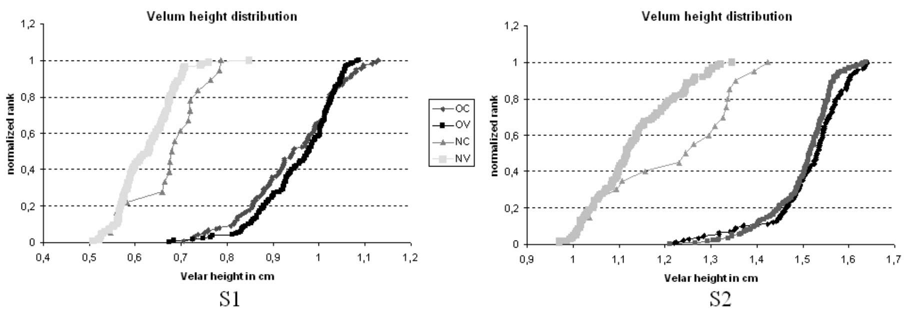

Figure 3. Normalized rank of velum height measured for each class (Left: S1 and right: S2).

Both oral vowels and consonants are produced with a similar range of velum height, no significant differences appear (S1: $F(1,276)=2.131$, $p=0.1455$; S2: $F(1,330)=1.358$, $p=0.2447$). Nasal phonemes are produced with the lowest velum height for both subjects; they are clearly different from oral phonemes, with a significant difference for the oral/nasal phonemic contrast (S1: $F(1,408)=1310.851$, $p<0.001$; S2: $F(1,479)=1824.096$, $p<0.001$). Nevertheless, there is some overlap between oral and nasal segments. Some oral segments are produced with an open velopharyngeal port: this concerns some oral vowels following or preceding a nasal consonant, and productions of the oral consonants /l/ or /ʁ/ in nasal vowel contexts. A similar velum height is measured during the production of nasal consonants between oral vowels, and of some tokens of nasal vowels following plosives and liquids for S2. Whilst no significant difference has been observed between oral consonants and vowels, there is a significant difference between nasal vowels and nasal consonants (S1: $F(1,130)=11.495$, $p=0.009$; S2: $F(1,147)=13.442$, $p=0.003$). Nasal vowels are produced with a lower velum height than nasal consonants. The lowest velum positions for nasal consonants are reached in nasal vowel context. Nasal consonants show a clearly bimodal distribution. The figure 4 presents the mean value and standard deviation of the velum height in the four classes.

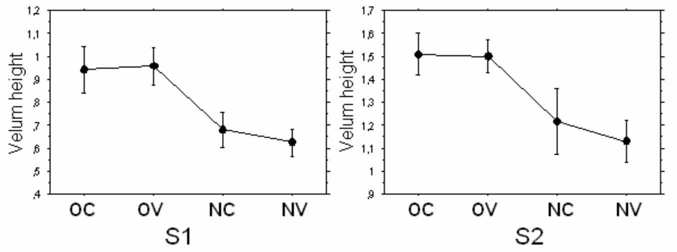

Figure 4. Mean value and standard deviation for oral consonants, oral vowels, nasal consonants and nasal vowels for the two speakers.

3.2. Velum height and vowel height

The velum height for the five vowels [i u e o a] is presented in figure 5. The number of items for S1 is /i/=31, /u/=30, /e/=33, /o/=34 and /a/=32; for S2, the numbers are: /i/=64, /u/=32, /e/=32, /o/=32 and /a/=31. We observe that the vowel produced with the lowest velum is the same for the two speakers: [a] is realized with a lower velum than /e i u o/ (S1: mean(/a/)=0.87 cm, mean deviation=0.053, mean(/iueo/)=0.978 cm, mean deviation=0.054; S2: mean(/a/=1.42 cm, mean deviation=0.063, mean(/iueo/)=0.978 cm, mean deviation=0.042). We find a significant difference for /a/ compared to /e i u o/ (S1: F(1,158)=59.631, p<0.001; S2: F(1,189)=60.647, p<0.001).

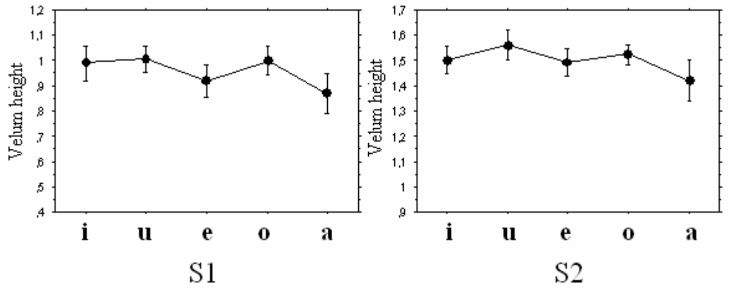

Figure 5. The velar position of the oral vowels for the two speakers.

In order to observe the link between vowel height and velum height, we grouped vowels into three groups: the two high vowels /i u/, the two mid vowels /e o/, and the low vowel /a/. The results show a significant difference depending on vowel height for S1 (F(1,157)=35.772, p<0.001), and no significant difference between mid and high vowels for S2 (F(1,158)=1.751, p=0.1876). Our results do not show consistent patterns of correlation between vowel height and velum height.

3.3. The velum height for the consonants

Figure 6 shows velum height for all consonants. We group the consonants into six classes: unvoiced stops (n=24 for S1; n=30 for S2), voiced stops (n=23 for S1; n=30 for S2), unvoiced fricatives (n=24 for S1; n=30 for S2), voiced fricatives (n=30 for S1; n=31 for S2), /l/ and /ʁ/ (n=17 for S1; n=20 for S2) and nasal consonants (n=18 for S1; n=20 for S2). As for oral vowels, we observed a speaker-specific behavior. Nasal consonants are clearly produced with the lowest velum position. For the two speakers, some productions of /l/ or /ʁ/ can be produced with a velum height equivalent to that of the nasal consonants, whereas this is not the case for any of the other oral consonants.

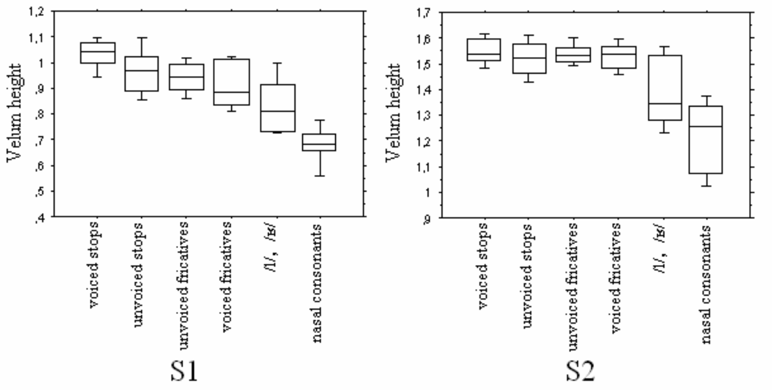

Figure 6. Mean and standard deviation for the intrinsic height of the velum for the consonants for the two speakers.

For S1, paired tests reveal that all the pairs are significantly different except unvoiced fricatives which show no significant difference with voiced fricatives and unvoiced stops ($F(1,52)=2.575$, $p=0.1146$, $F(1,46)=1.274$, $p=0.2648$). For S2, there is a significant difference between nasal consonants and the others (S2: $F(1,159)=163.168$, $p<0.001$ for each group compared with the nasal consonants), and no significant differences are found between fricatives and plosives.

3.4. Contextual nasalization

The velum height of contextually nasalized oral vowels (as compared to nasal ones) is obtained from the analysis of the second part of the corpus, measuring the position of the velum at the middle of each vowel for the three sequences /C_nV/, /VC_n/ and /C_nVC_n/ where C_n=/n/ (S1: n=44; S2: n=44). Sequences /C_nV/ offer evidence of carry-over of nasalisation, /VC_n/ of anticipation, and symmetrical sequences /C_nVC_n/ quite predictably involve the greatest amount of contextual nasalisation on oral vowels. Figure 7 shows the results depending on those positions. The oral/nasal contrast for vowels is always maintained (S1: $F(1,42)=37.97$, $p<0.001$; S2: $F(1,42)=219.184$, $p<0.001$), nasalization of the vowel due to the context never reaches the target of the nasal vowels. The velum position is higher for oral vowels followed by the nasal consonant /VC_n/ than for oral vowels preceded by the nasal consonant /C_nV/, indicating that there is more carryover than anticipation. No significant difference appears between vowels preceded by the nasal consonant and vowels surrounded by the nasal consonant (S1: $F(1,27)=0.211$, $p=0.6493$; S2: $F(1,27)=0.388$, $p=0.5387$). It is interesting to note that for S1's nasal vowels, velum height is higher in the context /C_nVC_n/ than in the other contexts, indicating that the symmetrical nasal consonant context tends to raise the velum during the nasal vowels.

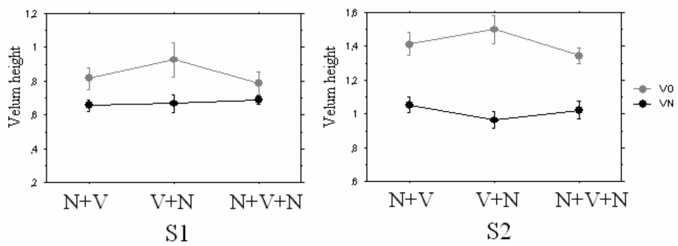

Figure 7. Velum height depending on oral and nasal vowels followed, preceded or surrounded by the nasal consonant /n/ for the two speakers.

4. Discussion

Targets for nasal and oral segments are clearly separated, even though some overlap is observed. Nasal vowels show the lowest velum positions, nasal consonants reaching similar values only in nasal vowel context. Those results confirm a preliminary EMA recording on a single male French speaker (Rossato *et al.*, 2003). The overlap between nasal and oral segments is mainly observed for contextually nasalized oral vowels. Results on the contextual nasalization on oral vowels reveal that velum height during the vowel is more affected by the preceding nasal consonant (or by a symmetrical nasal context) than by the following one, though without reaching the target of nasal vowels, hereby maintaining an articulatory difference between nasal vowel and nasalized ones. Several studies show that nasalization processes are language-specific. Our data on French yield some evidence in favor of a greater amount of carry-over than of anticipation. Some of the oral consonants /l/ and /ʁ/ are produced with a slightly lowered velum position in nasal vowel context, suggesting that they are produced with an open velopharyngeal port. This has been observed for both subjects.

Acknowledgments

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