AN INVESTIGATION OF SAGITTAL VELAR MOVEMENT AND ITS CORRELATION WITH LIP, TONGUE AND JAW MOVEMENT

Alan A. Wrench
Queen Margaret University College, Edinburgh, UK.

ABSTRACT

This paper examines the correlation between velar movement and the movement of other articulators in the midsagittal plane. A physiological model is proposed, which, while being based on common knowledge, is more extensive than has been used explicitly to explain observed movements of the velum. The model is used to guide the measurements taken from raw articulatory data provided by Electromagnetic Articulograph (EMA). The midsagittal velar movement is then examined for four different sentences by separate speakers and attempts are made to explain the patterns by reference to the model. The data was taken from a database of between 220 and 460 phonetically balanced sentences per speaker. This type of dataset allow general patterns of behavior to be uncovered. One such observation made and discussed in this paper is velum lowering before oral velar stops.

1. INTRODUCTION

There have been many studies examining the movement of the velum in the fields of phonetics, phonology and pathology. A general phonetic viewpoint on velar movement can be summarised as:

"The position of the velum is not specified simply in a binary manner (open versus closed port) but in a continuous one with intermediate positions between maximally open (low) and maximally closed (high) being dependent on phonetic identity."[1]

Physiological studies by Moll[2], Lubker[3], Bell-Berti[4] and Kent [5] amongst others have tried to establish the part that muscles which are directly attached to the velum play in its movement.

1.1. Physiological studies of muscle activity and their relation to velar movement

The palatoglossus (PG) muscle extends from the anterior velum via the anterior faucial pillars to insert into the side of the root of the tongue. The functional potential of this muscle is to lower the anterior velum and/or to raise and retract the root of the tongue (as well as narrowing the distance between the left and right faucial pillars). There has been a debate as to the degree to which the PG acts to lower the velum and the Levator Veli Palatini (LP) acts to raise it.

Lubker[3] suggests for four modes of PG activity

1. raising the tongue (tense LP)
2. narrowing the faucial isthmus (Tense LP and stiff tongue root)
3. lowering the velum (relaxed LP)
4. opposing forward and down tongue motion (tense LP)

It has often been inferred that velar position is linearly correlated with electromyographic activity in the levator and that the palatoglossus activity is primarily related to tongue root retraction [3]. However Kuen et al [5] found that levels of levator activity were not directly related to velar position. They go on to suggest that Lubker's use of large suction cup electrodes leaves open the possibility that "Lubker's high correlations between velar position and electomyographic activity may reflect an unknown composite of muscle activity other than activity from only levator."

Kuen[5] and Fritzell[6] agree that "superior constrictor, palatoglossus and palatopharyngeus might play a more important role in some subjects, reducing the influence of the levator and its correlation with velar displacement", suggesting a trading relation between the three muscles: palatoglossus, palatopharyngeus and levator veli palatini.

Later research by Dixit, Bell-Berti and Harris[7] "unambiguously supports …active velar lowering [by the palatoglossus] for the production of front nasal vowels whereas in the case of central and back vowels, nasal and nonnasal , the palatoglossus appears to be primarily involved in moving the tongue body."

By extending the model of velar lowering to include the influence of the extrinsic tongue muscles, it should help to explain the observed muscle activity.

2. PHYSIOLOGICAL MODEL

The position of the base of the palatoglossus at the tongue root is determined by the other extrinsic tongue muscles: styloglossus (SG), posterior genioglossus (GG) and hyoglossus (HG). Extending the model further, the position of the genioglossus and possibly the hyoglossus (through the mylohyoid muscle) is dependent on the position of the jaw. The hyoglossus also depends on the position of the hyoid which is considered in the model presented here to be stable, but which may be influenced by pitch. The velum biasing network is shown in figure 1.

With reference to figure 1, the velar height will be dependent on four primary factors:

a) The amount of contraction of the velum raising muscles, (for the purpose of this paper referred to collectively as LP)
b) The amount of contraction of the PG
c) The position of the tongue root
d) The stiffness of the tongue root independent of the PG i.e. whether it is being held high or low

The tongue root will be lowered if

i) the hyoglossus contracts
ii) the jaw drops with the posterior GG in tension
iii) the posterior GG contracts

The tongue root will be raised if:

i) the SG contracts more than the GG
ii) the PG contracts more than the HG and the LP is not

relaxed.

The model now assigns the continuum of LP (and other velum raising muscles) into four categories.

1. High level of contraction sufficient to close the velar port
2. High level of contraction insufficient to close the velar port
3. Intermediate contraction (the default condition for speech).
4. Relaxed

2.1. General predictions

When the LP is relaxed a modest downward force is sufficient to lower the velum. For /n/, this force is most likely due to a low front tongue root position combined with a modest tension in the PG. For /m/ the tongue position is unspecified and the downward force is likely to vary with context. For /ŋ/ the PG contracts to provide velar tongue contact and, even against a moderate root stiffness, this should bring the velum down.

Contracting the tongue raising muscles to seal the velar port requires extra effort which is only employed when necessary for physical production i.e. oral stops with burst release or for phonological contrast.

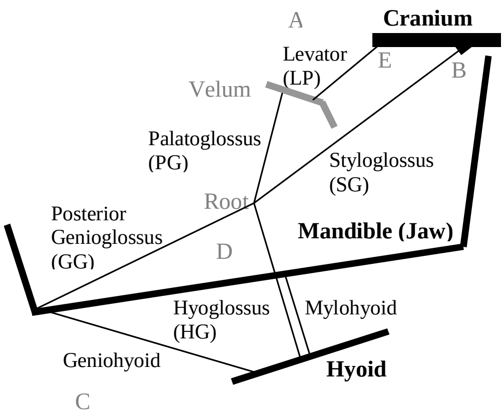

Figure 1. Extrinsic articulatory muscles which have the potential to influence tongue root position. A B C D E show points from which EMA sensor distances were calculated.

3. DATA AND PROCEDURE

A large multispeaker multichannel articulatory database was used for this study. The dataset contains a wide variety of phonetic contexts with a number of articulatory channels which allow a broad range of articulatory behaviour and interarticulation coordination to be observed. For this study the articulatory behaviour of four speakers of English from different dialectical regions of Britain was observed. They were recorded with Electromagnetic Articulograph (EMA) using 7 sensors. These were placed on the vermillian border of upper and lower lips, anterior tongue (1cm from tip and referred to as tip/blade), mid tongue (~3-4cm from tip), posterior tongue (~5-7cm from tip and referred to as dorsum), velum (~1-2cm from the edge of the hard palate). Acoustic, Laryngograph and Electropalatograph (62 contacts) were simultaneously recorded. The read texts consisted of up to 460 TIMIT sentences (modified to improve coverage of phone contexts encountered in British English). The subject details are shown in table 1.

Subject	sex	dialect	TIMIT sentences
maaw0	male	east central Scotland	1-438
mjms0	male	west central Scotland	1-448
flae0	female	southwest England	1-330
ffeg0	female	southern England	1-460

Table 1. Subject details

Speaker mjms0 has velum movement recorded by means of a sensor attached to a flexible plastic paddle anchored to the posterior inferior surface of an artificial electropalatographic palate and resting against the velum. The other three subjects had the coil glued directly to the velum with cyanoacrylate glue. All other EMA sensors were also attached with cyanoacrylate.

The sensor is small and light and unlikely to significantly influence velar movement. However, it is possible that tongue contact, particularly in velar looping gestures, may result in small excursions which would not occur if the sensor were absent.

The tongue root position cannot be accurately recorded using a coil placed on the tongues surface. The surface of the tongue nearest the root is influenced not only by the extrinsic muscles but also by the intrinsic transverse and longitudinal muscles which raise the surface position relative to the root when they contract. However, it is probably fair to assume that gross surface patterns reflect underlying root movement.

Movement of the tongue root was measured in two directions corresponding to the alignment of the PG and SG muscles. Movement due to the PG was estimated by calculating the distance between the tongue dorsum sensor and a fixed point (A in figure 1). Movement of the tongue root due to the SG was estimated by calculating the distance between the tongue dorsum sensor and another fixed point (B in figure 1). Similarly, jaw movement, tongue tip movement and velum movement are represented by distances between sensors and points C, D and E respectively. Lip movement is represented by the distance between the two lip sensors.

Using MATLAB, each articulatory trace is displayed so that the peaks correspond to constriction of the vocal tract i.e. tongue raising, velum raising, lip closure. In some instances this required negation of the distance values as can be seen from the y-axis tick mark labels.

Figures 2 shows four sentences (broad transcriptions shown below)

"Chocolate and roses never fail as a romantic gift"
tʃɔklət ən rəʊzəz nɛvə feɪl əz ə rəʊmantɪk gɪft
"Catastrophic economic cutbacks neglect the poor"
katəstrɔfɪk ɛkənɔmɪk kʌʔbaks nəglɛkt ðə pʉə
"Addition and subtraction are learned skills"
ədɪʃn̩: n səbtrakʃən ə lɛrnd skɪls
"Beg that guard for one gallon of petrol"
bɛg ðat gard fər wʌŋ galən əf pɛtrəl

Vertical lines have been drawn through selected minima and peaks in the velar trajectories. The following ascii - IPA translation is required to interpret the figure labelling.

/e/ - ɛ /aw/ - ɔ /uh/ - ʌ /ng/ - ŋ

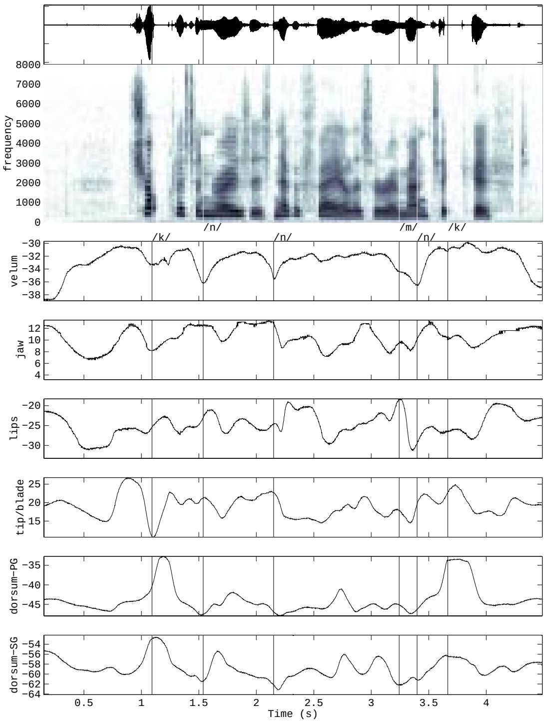

Figure 2a. Speaker ffeg0 "Chocolate and roses never fail as a romantic gift" tʃɔklət ən rəʊzəz nɛvə feɪl əz ə rəʊmantɪk gɪft

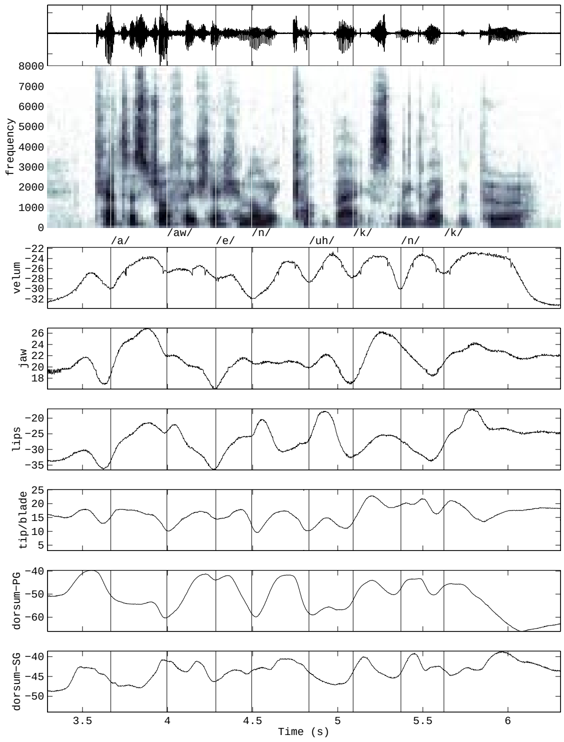

Figure 2b. Speaker mjms0 "Catastrophic economic cutbacks neglect the poor" katəstrɔfɪx ɛxnːɔmɪk kʌʔbaks nŋglɛkt ðə pʉə

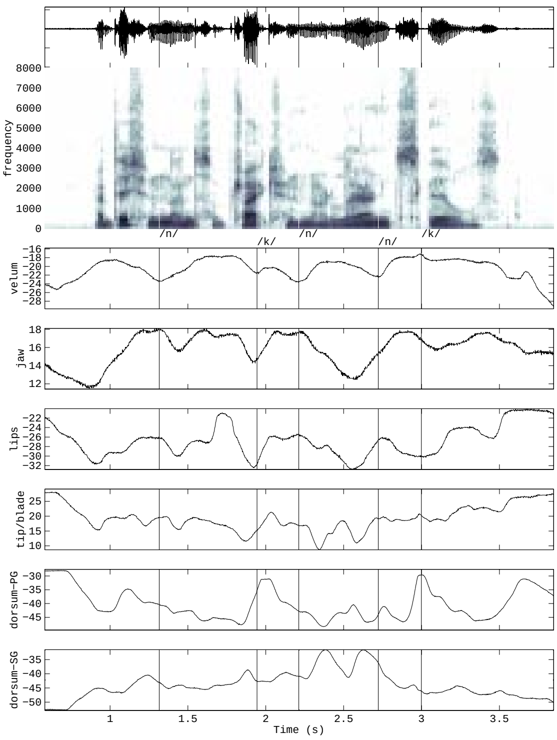

Figure 2c. Speaker maaw0 "Addition and subtraction are learned skills" ədɪʃn̩ː n səbtrakʃən ə lɛrnd skɪls

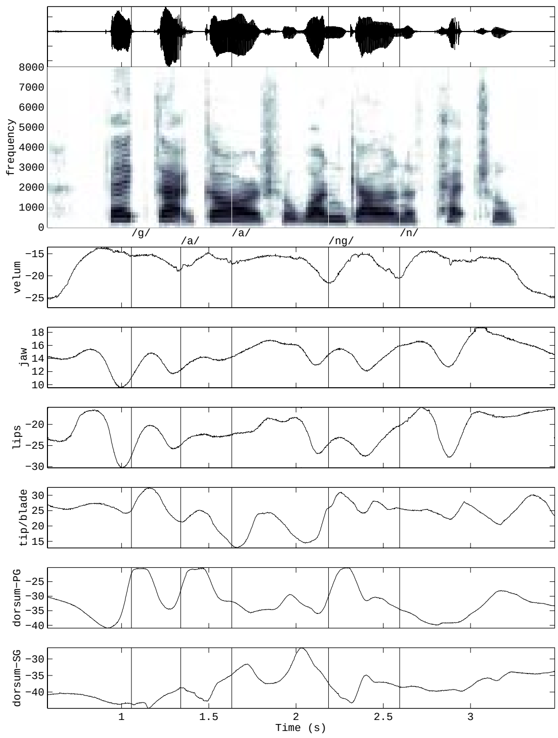

Figure 2d. Speaker flae0 "Beg that guard for one gallon of petrol" bɛg ðat gard fər wʌŋ galən əf pɛtrəl

4. DISCUSSION

4.1. Nasal stops

In general /n/ is characterised by static low front tongue dorsum position or a dynamic which is trying to achieve this:

1. A static low front tongue position, indicated by low or slightly rising dorsum-PG and low or falling dorsum-SG traces is caused by the HG and GG pulling the tongue dorsum forward and the PG pulling up. Since the PG is at full stretch, even if it is relaxed the force may be sufficient to bring the velum low.

If the tongue dorsum is not already in a low front position, the HG and GG muscles will act to bring it to this condition. All instances of /n/ in figure 2 show the dorsum-SG either low or falling indicating this dynamic. The dorsum-PG trace can be either falling (indicating HG contraction) or rising (indicating PG contraction) both of which will pull down the velum.

/ŋ/ requires the PG to contract strongly to raise the tongue dorsum thus providing the necessary force even if the HG and GG relax or the SG contracts. The single instance of /ŋ/ shows the dorsum-SG trace falling indicating GG contraction and dorsum-PG trace rising indicating PG contraction.

/m/ has no tongue specification and so the degree of velar lowering is variable. The two instances of /m/ show higher velar positions than the neighbouring /n/.

4.2. Oral stops

Evidence for active velar raising for closure of the velar port is present in the traces but has to be interpreted with caution since it is difficult to tell what height constitutes closure. However, examining the instances of oral stops, it is clear that velar raising is insufficient for closure in many cases. This is particularly true for oral velar stops /k/ and /g/ which fail to reach their phonemic target in several instances. For example in "economic" the /k/ is realised as a velar fricative. Even in instances where the broad phonetic transcription labels the segment as a velar stop there is evidence to suggest that stop release may be achieved by strategies other than velar raising. For instance glottal stopping in "chocolate" where the dorsum-PG trace falls before stop release and the use of the tongue dorsum to stop both oral and velar ports simultaneously in "subtraction" where the dorsum-PG trace raises with the same pattern as the velar trace.

One common contextual reason for this is the presence of a low front vowel. This necessitates a strong PG contraction to raise the tongue dorsum and consequently places a high downward force on the velum. A modest contraction of the LP is not then sufficient (as it would be in a high back vowel context) to close the velar port.

4.3. Fricatives

As with stops, fricative strength can be compromised by a low front vowel context. The lower velar position will result in weaker frication if not compensated for by higher rate of airflow.

4.4. Vowels

For non nasal vowels which do not require a phonological contrast with nasal equivalent the LP is assumed to be in the default intermediate tension state. In this case low front tongue dorsum position will stretch the PG maximally and provide a significant downward force on the velum pulling it down. Low-mid front vowels and low back vowels will have a similar but lesser effect. The effect will decrease from low front to high back vowel position. Examples of velar minima being reached in the vowels /a/ /ɛ/ /ɔ/ and /ʌ/ can be seen in the data.

Any consonant surrounded by a low front context and a moderate or relaxed LP specification will be likely to exhibit a lower velar position than in other contexts.

4.5. Jaw movement

Jaw lowering will act to stretch the GG and hence bring the tongue dorsum low and forward. This action will accentuate the lowering of the velum. This often occurs as part of low front vowel articulation.

4.6. Lip movement

According to the model and from observation, lip movement has no direct effect on the movement of the velum.

5. CONCLUSION

The model provides a framework for interpreting the observed sagittal velar movement. The model compliments Lubker's suggestion for four modes of PG activity. The model also allows for Lubker's 'gate pull' model as one possible velum lowering strategy. Observations support Bell-Berti's contention that this mechanism is most consistently adopted for the velar nasal cannot be confirmed but is supported by the data presented here.

The contention that velar lowering in vowels is due to an intrinsic level [8] rather than nasal context is only partly supported. It would appear that vowels have a graded susceptibility to velar lowering but nasal contexts or oral velar contexts provide conditions where the velum is likely to be pulled lower.

ACKNOWLEDGMENTS

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