

The role of the palate in tongue kinematics: an experimental assessment in VC sequences from EPG and EMMA data

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Abstract

The effect of palatal contact on tongue tip kinematics was investigated using simultaneous EMMA and EPG recordings. The material consisted of VC sequences, where C is a voiced or voiceless alveolar stop. The kinematic characteristics were studied by analyzing parameters of the velocity profile and the deceleration peaks of the closing gesture.

No evidence could be found for a potential influence of lateral contacts. Central contacts, associated with the beginning of the consonantal closure, are strongly correlated in time with the velocity drop. It supports the hypothesis that for achieving a consonantal closure tongue tip kinematics is not controlled by a specific target on the palate, and that its deceleration phase is mostly influenced by the collision with the palate.

1. Introduction

A classical and fruitful approach to study speech motor control consists in studying kinematic patterns of vocal tract articulators and to observe to which extent they can be correlated with the linguistic inputs or/and with speaking conditions (see e.g. [1], [2], [3]). However, speech movements are not always true images of the control since physical factors such as air pressure in the vocal tract [4], contacts with the palate, and the biomechanics of the articulators ([5], [6]) are also likely to contribute to the kinematic output.

The role of the palate on tongue shaping and positioning was already assessed in the literature. Fujimura and Kakita [7] and Perkell [8] suggested that palatal contacts would act in combination with a “saturation effect” of the posterior genioglossus to simplify the control of the lingual articulation for vowel [i]. Stone [9] emphasized that some tongue shapes, such as the ones observed in some alveolar articulations, could not be reached in a free standing position, and are due to the fact that the tongue pushes against the palate. The same author [10] also showed evidence that speakers would use palatal contacts to stabilize tongue positioning, to coordinate tongue and jaw movements and to control the varying airflow and pressures in the vocal tract. Hoole and Kühnert [11] studied the contextual and token-to-token variability in German vowels and concluded that a distinction should be made between palatal and non-palatal vowels due to influences of the palatal contact. Perkell *et al.* [12], studying

the articulatory-to-acoustic motor equivalence for [u] in American English observed variable speaker dependent trading relations between lips and tongue. They found that these motor equivalence strategies were consistent with the shape of the coronal contour of the palate.

All these studies contributed to demonstrate the role of the palate in tongue positioning and they suggest that, similarly, it can influence the kinematic characteristics of tongue movements.

This paper presents preliminary results of an experimental study that aims at quantitatively assessing the influence of palatal contacts onto tongue displacement. It is based on the analysis of simultaneous EPG and EMMA recordings of alveolar stops in German. Relations between EPG data and kinematic properties of EMMA signals are investigated.

2. Method

2.1. Experimental material

Tongue movements and palatal contact patterns of three speakers (one female, SF, and two males, CG and JD) of Standard German were recorded simultaneously by means of EPG (Reading EPG3) and EMMA (AG100 by Carstens Medizinelektronik) systems. The acoustic signal was simultaneously recorded on DAT. Sample frequencies were 100 Hz for EPG data and 200 Hz for EMMA data.

The material consisted of VC and VC \emptyset -sequences, where the C was either the alveolar stop [t] or [d], located word-final or word-medial. The vowel V was varied to be one of tense [i:, a:, u:] or lax [I, a, u]. Lax vowels do not occur before a phonologically voiced final stop in German. The lax/tense variation was, then, only considered in the unvoiced consonantal context. The sequences were embedded in the carrier sentence “Ich habe geCVC \emptyset nicht geCVC erwähnt.” (I said geCVC \emptyset not geCVC.), and repeated 10 times.

2.2. Data analysis

In this study the following parameters were extracted from EPG recordings. The consonantal closure onset time was determined on the basis of the contact area located in the center of the coronal section in the first two rows, i. e. in the alveolar region. The corresponding contacts are depicted inside the ellipse on Figure 1. The closure onset was defined as the time where at least two contacts within the ellipse became “on”. If contacts were already found in the preceding vowel, the onset was chosen at the time where at least two

additional contacts became "on". An example of contact patterns before and at the closure onset time is shown in Figure 1.

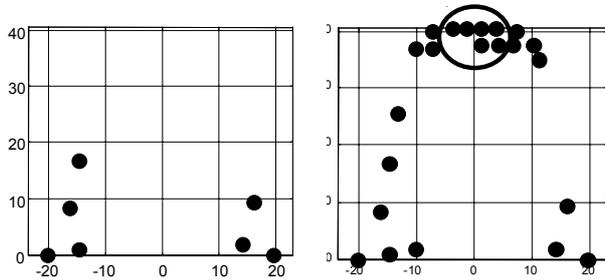


Figure 1: Contact patterns just before (left panel) and at (right panel) the closure onset time. The time interval between these patterns is 10 ms. The ellipse plotted on the right panel shows the contact area taken into account to assess the closure. X and Y axes are in mm.

In order to evaluate the importance of the contact area between the apical part of the tongue and the palate, an "Anterior contact" index was calculated as the percentage of active contacts in the anterior half of the EPG palate. The values of this index were estimated for the closure onset time as well as for all times defined by EMMA data.

The following procedure was used for analyzing EMMA data of the tongue tip sensor: the tangential velocity and the tangential acceleration were computed for the tongue tip sensor located at around 1 cm back from the tip by a three point differentiation followed by low-pass filtering at 20 Hz. The CV or closing gesture was defined according to the time variation of the tangential velocity. The gesture onset t_{on} was determined as the time location of the last velocity "zero-crossing" preceding a clear elevation of the tongue tip; the gesture offset t_{off} was defined as the time of the first velocity "zero-crossing" following the upward tongue tip movement. Within the closing gesture duration, the peak velocity V_{max} and the time t_{max} of the velocity peak were measured. A 20% threshold criterion of the tangential velocity signal was used following Kroos *et al.* [13]. It is determined between extrema, i.e. at 20% travelling from the t_{on} to t_{max} position and at 20% from t_{max} travelling back to t_{on} position. Similar 20% positions were calibrated for the interval t_{max} to t_{off} . The times associated to these thresholds were called t_{low1} , t_{up1} , t_{up2} and t_{low2} respectively (see Figure 2). Finally, an additional time landmark (see Figure 2) was determined by the location (t_{dec}) of the deceleration peak within the closing gesture. If two deceleration peaks occurred the highest one was chosen and if two peaks of similar amplitudes were observed, the first one was selected. For comparison purposes between closing gestures moving the tongue toward the palate and opening gestures moving the tongue away from the palate the deceleration peak of the CV gestures was also measured.

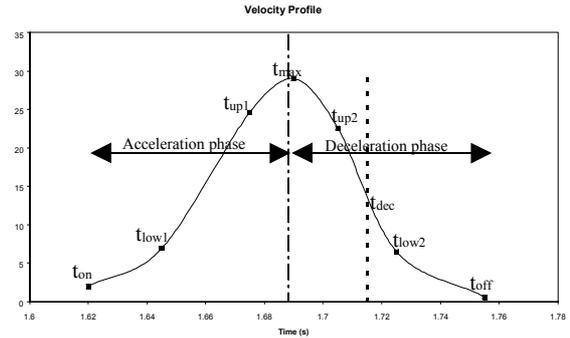


Figure 2: The time landmarks determined on the velocity profile of the closing gesture.

3. Results

3.1. Velocity profiles

A usual way to characterize the kinematic properties of speech movements consists in observing whether the velocity profile is symmetrical or not. A measure of symmetry for the closing gesture was provided by TTP, the proportion of total movement duration taken to reach peak velocity [2]. It was computed for each utterance and each subject according to the equation:

$$TTP = (t_{max} - t_{on}) / (t_{off} - t_{on}).$$

An analysis of variance (ANOVA) was calculated on the distribution of the TTP values, as a function of five independent factors, which are: (1) subject (SF, CG, JD), (2) voiced/unvoiced distinction of the consonant ([t] *versus* [d]), (3) vowel ([i:/I], [a:/a], [u:/u]), (4) lax/tense variation of the vowel, and (5) position of the alveolar consonant in the word (final *versus* medial).

Significant differences between subjects were observed ($p < 0.001$), but post-hoc analysis showed that no significant difference occurred between subjects CG and JD. Some general observations were valid for all subjects:

- (1) the position of the consonant (medial *versus* final) had no significant influence; hence, in the rest of the paper no distinction will be made between medial *versus* final cases;
- (2) the lax/tense factor had a significant influence ($p < 0.0001$) for vowel [u] and [a].

In addition, the lax/tense factor had also a significant influence for vowel [i] for subjects SF and CG. Significant differences ($p < 0.0001$) were observed between vowels ([i] *versus* [u] *versus* [a]) for subject CG and JD. And finally, significant difference were observed between [d] and [t] for subjects SF and JD.

In order to interpret the observed significant differences, we computed for each subject averaged velocity profiles on the basis of the 7 tangential velocity values corresponding to the 7 time landmarks shown on Figure 2. They were split by vowel, tenseness and consonantal context

Time landmarks were normalized by the closing gesture duration ($t_{off} - t_{on}$). We obtained, thus, 7 normalized time points within the closing gesture. They were averaged, together with the associated velocity amplitudes, across the ten repetitions of each utterance. As a result, average

representations were defined for each subject of time normalized velocity profiles sampled at the time landmarks.

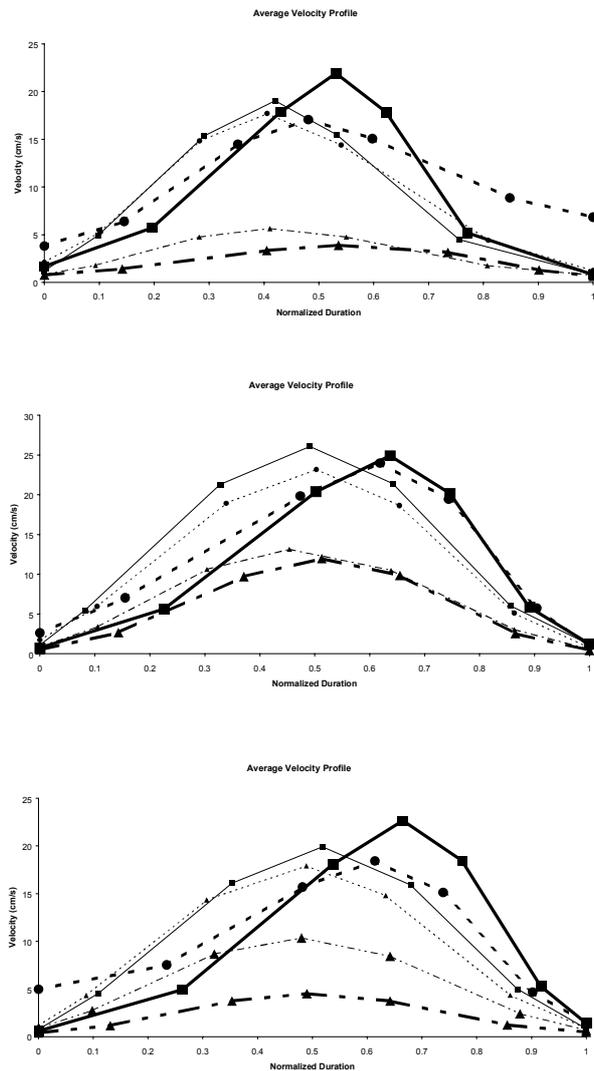


Figure 3: Averaged velocity profile for consonant [t]. Bold lines correspond to tense vowels; for both lax and tense variations: solid lines are used for [a], dotted lines for [u], dash-dotted lines for [i]. Top panel: Subject SF; Middle panel: Subject CG; Low panel: Subject JD

Figure 3 displays the average velocity profiles for the three subjects. In terms of symmetry *versus* asymmetry of the velocity profiles, it can be concluded from this figure, that for [t], beyond the inter-speaker and inter-vowel variability, a general significant difference can be related to the lax/tense variation for vowel [u] and [a]. Indeed, lax vowels are associated with symmetrical velocity profiles, while tense vowels are associated with asymmetrical ones. This is not true for vowel [i], which systematically corresponds to symmetrical velocity profiles. For [d], occurring only in the context of tense vowels, the velocity profiles are also systematically asymmetrical, but compared to [t] the amount of asymmetry was different. In the rest of the paper we will focus on the study of the differences associated with the

tense/lax variation, since this variation happens to be the most important factor in terms of symmetry *versus* asymmetry of the velocity profiles.

3.2. Relations between contact patterns and kinematic properties

From a theoretical point of view, the potential influence of the contacts between tongue and palate onto the kinematic characteristics of the tongue tip can be attributed to two different causes. First, lateral contacts can affect the damping factor of the movement. Second, contacts around the mid-sagittal plane will stop the vertical movement of the tongue and then dramatically reduce its velocity in the vicinity of the contact area.

For this study, only the data collected for subject CG and SF were taken into account. Indeed, for subject JD, some observations were obviously inaccurate due to false contact detections caused by an increased salivation.

We first analyzed the “Anterior contact” index defined in section 2. For both subjects no or very few contacts were noted for vowels [u] and [a] before the occurrence of the velocity peak. Hence, it can be concluded that the acceleration phase of the closing gesture from [a] and [u] to the consonant is not influenced by palatal contact. This is not the case for vowel [i], since around 10 % of the contacts for CG, and between 10 and 25% of the contacts for SF, were activated during the acceleration phase. These contacts could explain the fact that the velocity peak amplitude is clearly smaller for [i] than for [u] and [a]. Indeed, significant correlations were found (-0.680 for CG and -0.872 for SF; $p < 0.0001$) between the values of the “Anterior contact” index and the velocity amplitudes at time t_{max} . However, an alternative explanation could also be valid: since the articulation of [i] is close to the alveolar region, the movement amplitude toward the consonant is smaller, which can logically induce a reduction of the velocity without changing the duration. Hence, at this point, no conclusion can be made from the observation of the contact patterns for [i].

Now, for [u] and [a], the “Anterior contact” index increases after the velocity peak is reached. Up to the closure onset time, these contacts are mainly lateral ones, and no significant effect could be found on the velocity.

This is no longer the case for central contacts, since the beginning of the consonantal onset seems to have a strong influence on the velocity. This is suggested by the correlation coefficients computed between the normalized time of the deceleration peak and the normalized closure onset time as given in Table 1 for both subjects and for each vowel.

Table 1: Correlations between the normalized deceleration peak time in the closing gesture and the normalized closure onset time.

Subject/Vowel	Correlation
CG/[a]	0.689 ($p < 0.0001$)
CG/[u]	0.660 ($p < 0.0001$)
CG/[i]	0.544 ($p < 0.0001$)
SF/[a]	0.929 ($p < 0.0001$)
SF/[u]	0.943 ($p < 0.0001$)
SF/[i]	0.860 ($p < 0.0001$)

This result gives evidence in support of the idea that the consonantal contact with the palate in its central part is the

main factor responsible for the shape of the velocity profile in its deceleration phase.

The comparison of the deceleration peak amplitudes measured during the closing gesture with the ones measured during the preceding opening gesture provides another support to favor this conclusion. Indeed, for all vowels as well as for both consonants and for both subjects, the peak amplitude is significantly ($p < 0.0001$) larger in the closing gesture than in the opening gesture. Both findings are consistent with the hypothesis that in the VC sequences, studied in this paper, the palate stops the tongue movement as opposed to the hypothesis that the tongue would reach a target located at the palate. They also are in agreement with the observations made by Löfqvist and Gracco [14] from EMMA data for bilabial stops, who suggested that the lower lip would move toward an ideal target located above the upper lip, and that the inter-labial contact would stop the movement before the target can be reached.

3.3. Differences between lax and tense vowels

Now, to which extent does the role of the palate explain the differences in the velocity profile symmetry that were observed in our data? A possible explanation could be that the consonantal contact arises earlier in the deceleration phase for tense than for lax vowels. To check this hypothesis, we calculated the difference between the closure onset time and the velocity peak time (t_{\max}). However, given the accuracy of the time sampling for EPG data (100 Hz), no evidence for a significant difference could be found. For the three vowels and for both subjects, the duration was comprised between 20 and 25ms. Consequently, it can be concluded that, in spite of the fact that the palate seems to be responsible for the shape of the velocity profile in its deceleration phase, it does not explain by itself the differences between lax and tense vowels. Therefore, the origin of the observed differences has also to be found in the acceleration phase of the velocity profile. Actually, significant differences between lax and tense vowels were found for the duration going from the closing gesture onset (t_{on}) to the time of the velocity peak (t_{\max}). It is likely that the observed differences are related to the differences in tongue positioning associated to the lax/tense variation as evidenced by Mooshammer and Fuchs [15]. This will be further investigated, but it is beyond the scope of this study.

4. Conclusion

Simultaneous study of EPG and EMMA data during the production of VC sequences, where C is an alveolar stop, permitted to clarify the influence of the palatal contacts onto the kinematic properties of the tongue tip. Evidence could be found that the palate stops the movement of the tongue during the deceleration phase. This finding supports the hypothesis of Löfqvist and Gracco for bilabial stops that articulatory gestures could be directed toward a target that is beyond the contact location. It contradicts the hypothesis that the production of the stop could be associated with a target located on the palate.

The influence of the palate on the deceleration phase was found to be similar for all vowels. In combination with the lengthening of the acceleration phase this influence generates for tense vowels significant asymmetry of the velocity profile as compared to lax vowels.

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