WHAT ROLE DOES THE PALATE PLAY IN SPEECH MOTOR CONTROL? INSIGHTS FROM TONGUE KINEMATICS FOR GERMAN ALVEOLAR OBSTRUENTS

Susanne Fuchs[14], Pascal Perrier [2], Christian Geng[1] & Christine Mooshammer [3]

[1] Zentrum für Allgemeine Sprachwissenschaft (ZAS), Berlin
[2] Institut de la Communication Parlée & INPG, Grenoble
[3] Institut für Phonetik und Digitale Sprachverarbeitung, Kiel
[4] Queen Margaret University College, Edinburgh

ABSTRACT: The tongue moves in a narrow space which influences the speech planning process and affects the kinematic properties of the movement. In order to study the possible role of tongue-palate interaction we investigated tongue tip movement together with tongue-palatal contact patterns by means of simultaneous EMA and EPG recordings. Articulatory data for four German speakers were analyzed. Speech material consisted of VC and VC@ sequences with C being /t/ or /s/ and V being stressed tense /a/ or /u/. The relation between the kinematics of the tongue tip closing gesture and changes in tongue-palatal contact patterns in the anterior, posterior and lateral region were studied. Results for /t/ show a large movement amplitude and a short closing gesture duration whereas in /s/ production the movement amplitude is smaller and the duration longer than in /t/. We conclude that in /t/ the tongue tip hits the palate and this impact stops the movement. In /s/ production we suppose that a precise positioning of the tongue tip is achieved. Speaker dependent tongue-palatal contact patterns can be explained in terms of differences in the palatal shape.

INTRODUCTION

A particular characteristic of speech production compared to other motor systems is that the tongue moves in a narrow space delimited by the pharyngeal walls, cheeks, teeth, lips and palate. Hence, even if the basic principles that govern arm or limb motor control might also apply to speech, it seems reasonable to assume that in speech production specific strategies are used to deal with these additional constraints. In this paper we will further concentrate on the upper limit, the palate. Since tongue movements for oral consonants are most of the time produced in the presence of palatal contacts it is hypothezised that: (a) motor control strategies make use of palatal contacts for certain movements, and (b) the palate can passively influence the kinematic properties of speech movements. Both hypotheses are discussed in the following paragraph supported by findings from the literature.

(a) Motor control strategies make use of palatal contacts

Stone (1991) suggested that some tongue shapes, particularly in the production of alveolars, could not be produced by a free-standing tongue position. Additional support for our first hypothesis is provided by several perturbation studies. In 1978, Hamlet and Stone recorded tongue-palatal contact patterns for 10 speakers wearing a dental prothesis (4 mm thick) in the alveolar region. Data were observed immediately after the insertion of the prothesis, when the subject was still unfamiliar with it, and 2 weeks after adaptation. Results for the first condition give evidence for a tongue overshoot in /s,z,t,d,n/. Results for two weeks after adaptation did not show a greater variability than the production during the first condition, but tongue-palate patterns showed compensatory movements. The authors suggest "that the way sensory feedback is used in learning a compensatory form of speech is qualitatively similar to its use routinely. That is, all sensory information (from audition, proprioception, touch etc.) by which the status of the oral environment and relative positions of the articulators can be assessed, is continuously monitored, and planning the speech act" (p.246).

Baum and McFarland (1997) investigated acoustic and perceptual changes for /s/ production after structural modifications of the alveolar ridge using an artificial palate. Seven subjects were analyzed. In the beginning of the session they found that /s/ is acoustically and perceptually highly susceptible to perturbing effects. After a relatively short period of one hour practicing, a significant improvement of acoustic and perceptual characteristics were observed, although compensation was not complete. Baum and McFarland propose ”that speech adaptation to oral-articulatory perturbations may result from a recalibration of the speech motor control system and a common or adaptive mode of articulatory programming distributed across perturbed (adapted) and normal [s] production” (p. 2358).

Honda et al. (2002) and Honda & Murano (this conference) used another experimental paradigm, dynamic perturbations. They examined compensatory tongue movement for unexpected perturbations due to an inflatable artificial palate, combined with or without auditory masking. Their findings suggest that compensatory movements are actively produced due to tactile feedback information, and that auditory feedback is used in precise adjustment of the articulation with a longer time delay.

The importance of tactile feedback for unexpected perturbations of the oral cavity was also described in Linke (1980). A patient is discussed with bilateral loss of trigeminal sensitivity (after surgery), i.e. an absence of tongue surface sensibility. Although he was not able to control his lip and tongue movements during ingestion (only by using a mirror), he was able to produce speech relatively normally, even in an auditory masking condition. In a speech production task an unexpected perturbation to the OOS muscle (Orbicularis oris superior) was applied and the patient was unable to compensate for it. He started to articulate again after a break of up to 500ms whereas normal speakers were able to compensate immediately. Linke concluded that tactile feedback is of particular importance for a compensatory response to perturbations, but less for the serial organization of motor programs which would be highly pre-programmed.

(b) The palate can passively influence the kinematic properties in speech production

In Fuchs et al. (2001) it was shown that in alveolar stop production the onset of the oral closure (defined on EPG data) coincides with a relatively high deceleration peak of the tongue tip sensor. It was suggested that due to the collision of the tongue tip against the palate the actual movement is damped. These findings support the hypothesis of Löfqvist and Gracco (1997) for bilabial stops that articulatory gestures could be directed toward a target that is beyond the contact location. Generally, this seems to be a strategy for the production of stops and we suppose for the same final geometrical configuration, the control of an impact between tongue and palate could be more simple than the control of the fine positioning in contact with the palate. However, in other obstruents like alveolar fricatives, a much more precise positioning of tongue and jaw was observed, e.g. Mooshammer et al (2003).

The effects of target variations in stop production on tongue kinematics (a precise positioning of the tongue without the palate and a collision between tongue and palate) were modelled in Perrier et. al (2003) using a 2D biomechanical tongue model. It has been shown that the tongue-palate interaction could explain some of the direction of the counter-clockwise trajectories (so called loops) in /VkV/-sequences.

In our preceding studies we have mainly focused on tongue kinematics in relation to tongue-palatal contact patterns in alveolar stops. We aim to extend our previous work in two directions: first, we compare alveolar stops with fricatives, because fricatives should be based on a fine positioning of the tongue at the palate as well as tongue grooving. Since in stop production neither fine positioning at the alveolars nor tongue grooving is required we suppose a different control strategy. Second, we will not only focus on tongue-palate interaction in the central part of the palate, but also investigate the role of lateral contacts. Lateral contacts could also cause damping, and they might explain speaker dependent differences in tongue kinematics based on the shape of the palate (Tiede 1998). Hence we will further investigate central and lateral tongue-palate interactions during the production of alveolar stops and fricatives for 4 speakers of German.

METHOD

Tongue tip movements and tongue-palate contact patterns of four German speakers were recorded simultaneously by means of EPG (Reading EPG3) and EMMA (AG100, Carstens Medizinelektronik) systems. Tongue tip movement was associated with the movement of a sensor placed midsagittally approximately 1 cm behind the tip. Two sensors served as reference points to compensate for helmet movements, one at the bridge of the nose and one at the upper incisors. Speech signals were recorded on DAT. Sampling frequencies were 16 kHz for the acoustic data, 100 Hz for EPG and 200

Hz for EMMA data respectively. Four German subjects were recorded, three males (CG, DF, JD) and one female (SF). The speech material consisted of nonsense words ”geCVC2e” and ”geCVC3”, where C was for all C either /t/ or /s, z/. Since these data served also as material for another study different positions of the consonant were considered. C2 was defined as the post-stressed (i.e. the consonant occurred after the stressed vowel) word medial position and C3 as the post-stressed word final position. The fricative is phonologically voiced in C2 and voiceless in C3. The stressed vowel preceding C2 or C3 was either tense /a/ or /u/. Target words were embedded in the carrier phrase ”Ich habe geCVCe nicht geCVC erwähnt.” (I said geCVCe not geCVC.). Each sentence was repeated 10 times. The tongue tip closing gesture from the stressed V to C was taken into account. The on- and offsets were defined on the tangential velocity signal of the tongue tip sensor using a 20% threshold criterion. In addition, the velocity peaks (velpeak), the duration of the closing gesture (clgdur) and the movement amplitude ampl (as the integral from onset to offset of the closing gesture) were taken into account. In order to compare stop production with fricative production based on previous findings in Fuchs et al. (2001), we labeled the acceleration and deceleration peaks of the closing gesture (VC-sequence) as well as of the preceding opening gesture (CV-sequence). The latter was taken as a reference.

All EPG patterns in the closing gesture interval and at the acceleration, deceleration and velocity peak were considered. The percentage of contact in the anterior (4 most front rows) region = ANT, posterior region = POST (4 most back rows) and lateral region = LAT (2 most peripheral columns on the left and right side of the palate) were computed for each pattern. The velocity profiles of the tongue tip closing gestures were plotted against the corresponding time variation of the EPG parameters. To do so, for each subject and each repetition the whole closing gesture duration was defined as a time reference and all measured duration were normalized according to this reference. In a second step the values of the relevant EPG index were interpolated and over-sampled in order to have the same number of samples in each repetition. The palatal shapes of the artificial palate were taken into account by measuring the x, y, and z coordinates of each of the 62 electrodes. Two subjects (CG, DF) showed cross sectional palate shapes similar to a dome and the two other subjects (SF, JD) a rather flat palate.

RESULTS

For all subjects the duration of the closing gesture is significantly longer for /s/ than /t/ in all /a/-context conditions (C2: CG $p<0.001$, DF/JD/SF $p<0.01$; C3: CG/DF $p<0.001$, SF $p<0.01$, JD $p<0.05$), while the movement amplitudes and the velocity peaks are consistently larger for /t/ than /s/ in all contexts (velocity peak $p<0.001$ for all subjects, all conditions, movement amplitude $p<0.001$ for all subjects all conditions, except for JD /a/-context C2, $p<0.05$). Differences in movement amplitude are in agreement with work from Mooshammer et al. (2003) on German. They show a relatively high and invariable jaw position for /s/ and /t/, but a lower tongue tip position for /s/ compared to /t/. The smaller movement amplitude may also be a result of tongue grooving in /s/ (Narayanan, Alwan & Haler 1995) and due to the midsagittal placement of the tongue tip sensor in EMA.

In Fuchs et al. (2001) we found a high deceleration peak during the closing gesture for /d/ and /t/ which coincided in time with the EPG defined oral closure onset. We interpreted this result with respect to tongue-palate interaction, i.e. the tongue tip movement would be stopped due to the palate. In the current study we tried to apply a similar procedure. For /s/ however, constriction onset could not be labeled reliably using EPG measurements. In order to detect any possible influence of the palate onto tongue tip kinematics, another approach was applied. It is based on the comparison between the closing gesture (clg) and its preceding opening gesture (opg). The latter is taken as a reference since only a small or no tongue-palatal interaction is assumed for the vowel-directed movement. In this aim we analyzed the acceleration and the deceleration peaks in both gestures (opg and clg). Figure 1 shows the corresponding bar plots with +/- 1 std. error averaged over position (C2 & C3) and vowel (/u/ & /a/-context).

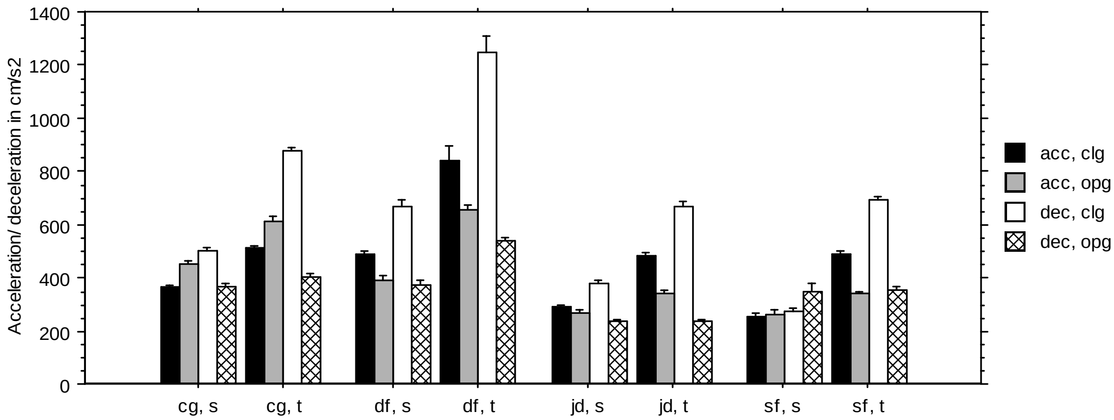

Figure 1: Bar plots of the averaged tangential acceleration in cm/s2 with +/-1 std. error; black bars = accel. peak during the closing gesture, grey bars = accel. peak during the opening gesture, white bars = decel. peak during the closing gesture, filled bars = decel. peak during the opening gesture; from left to right CG /s/, /t/ production followed by DF, JD, SF

As expected figure 1 shows consistently a higher deceleration peak during the closing gesture compared to the opening gesture for /t/. This is also true for /s/ (except from SF). In addition, the relative differences between deceleration peaks in the opening and closing gestures are greater for /t/ than /s/, e.g. for CG - the deceleration peak in /t/ during the closing gesture is 2.2 times greater than the one in the opening gesture whereas in /s/ it is only 1.4 times. Acceleration peaks do not exhibit comparable relations and vary rather speaker dependently. Therefore, it is hypothesized that the differences in deceleration peaks between the opening and closing gesture do not originate in differences in control, since than it should also influence the acceleration phase. They are rather due to the influence of tongue-palate interaction, which contributes to provoke the end of the closing gesture. Based on these results it is suggested that differences between /t/ and /s/ are not only a result of a smaller movement amplitude in /s/, but also due to a missing/limited impact between tongue and palate in /s/ production.

In order to investigate tongue-palate interaction for /s/ and /t/ we plotted the tongue tip velocity profiles of the closing gestures in relation to changes in tongue-palatal contact patterns (ANT, POST, LAT). Figure 2 exemplifies the corresponding graphs for the word final position. The word medial position shows similar results. Comparing tongue-palate interaction a trend can be noted that changes in the ANT (red line) are larger in /t/ production than in /s/. This result is mainly due to a higher percentage of anterior contact at the consonantal target in /t/, which is in agreement with a higher tongue tip position. Another trend in /s/ production is that lateral contacts increase earlier than anterior contacts (e.g. in CG, DF, SF /a/- context), but further statistical analysis is required. Nevertheless we assume that in the production of the fricative, lateral tongue-palatal contacts arise first and can contribute to the precise tongue positioning. In particular, they could help to produce tongue grooving in /s/ observed by Narayanan et al. (1995). In /t/ production another strategy underlies the increase of contacts between tongue and palate, since the full occlusion can be obtained through the tongue tip crashing in the alveolar ridge.

Vowel context (/a/ versus /u/) has a major impact particularly on the LAT and POST for both consonants (larger in /u/-context and starts already during the vowel). Since the amount of LAT and the POST are almost similar in the acceleration phase in /u/-context it can be concluded that the tongue touches the lateral margins of the palate already during the vowel and remains constantly in contact with the palate during the whole closing gesture. It is still unclear whether the relatively high amount of tongue-palatal contacts in /u/-context has an effect on the velocity profile in terms of damping. Smaller velocity peaks are found in /u/-context, except for CG in /s/ and JD in /t/, but these results can also be related to the smaller movement amplitudes.

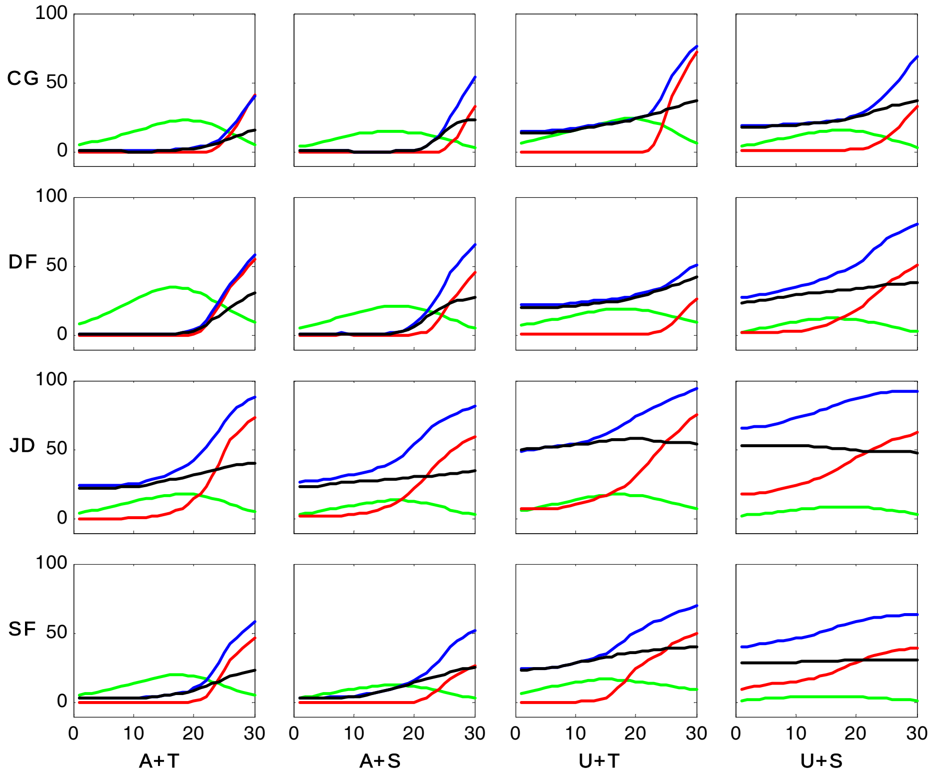

Figure 2: Averaged and time normalized values: green curves = velocity profiles of the tongue tip closing gesture in cm/s, red curves = ANT, black curves = POST, blue curves = LAT in %; x-axis = normalized time; the relevant condition of each graph is written below (A+T, A+S, U+T, U+S); subjects CG, DF, JD, SF (from top to bottom)

Speaker dependent differences are found with respect to changes in LAT and POST. In /a/-context all tongue palatal contact patterns increase after the velocity peak for CG and DF, but for JD and SF a small increase of LAT and POST is already found before the velocity peak for both, the fricative and the stop. These findings are interpreted with respect to differences in palatal shapes. For subjects with a flat palatal shape (SF and JD), the tongue back moves up, and in doing so, a larger amount of contact is produced than for subjects with a dome shaped palate. These findings might provide evidence that interindividual differences in posterior and lateral contacts are simply the result of anatomical differences in the shape of the palate.

CONCLUSION

Even though statistical analyses have been limited so far we like to propose that voiceless alveolar stops are produced due to an impact of the tongue at the palate whereas for fricatives a precise positioning of the tongue at the palate is required. We assume that it has been made use of tactile feedback information during the acquisition of these sounds, in particular in /s/ production. Depending on the shape of the palate (a dome versus a flat shaped palate), the time variation of the contact distribution differs among subject. Speakers with a flat palate showed an earlier and higher percent of contact in the posterior and lateral region compared to speakers with a dome shaped palate. These results suggest the possibility that subjects with a dome shaped palate could make use of the lateral contacts in order to stabilize the tongue in /s/ production. Subjects with a flat palate might have to control their tongue movements more accurately since their tongue positioning has a large effect onto tongue-palatal contacts. Further work is necessary to test this hypothesis. From the present study it is not certain to conclude that lateral tongue palatal contacts would damp the actual movement. Lower velocity peaks are found for /s/ than for /t/ as well for /u/ than for /a/, but these can also be due to smaller movement amplitudes.

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REFERENCES

Baum, S.R. & McFarland, D.H. (1997) "The development of speech adaptation to an artificial palate" *Journal of the Acoustical Society of America* **102 (4)** 2353-2359.

Fuchs, S., Perrier, P. & Mooshammer, C. (2001) "The role of the palate in tongue kinematics: an experimental assessment in VC sequences from EPG and EMMA data*" Proceedings of Eurospeech, Aalborg*, *Danemark* 1487-1480.

Hamlet, S.L. & Stone, M. (1978) "Compensatory alveolar consonant production induced by wearing a dental prothesis" *Journal of Phonetics* **6** 227-248.

Honda, K., Maeda, S., Hashi, M., Dembowski, J.S., & J.R. Westbury (1996) "Human palate and related structures: their articulatory consequences" *Proceedings of the 4th International Conference on Speech and Language Processing, Philadelphia, USA* 784-787.

Honda, M. Fujino, A. & Kaburagi, A. (2002) "Compensatory responses of articulators to unexpected perturbations of the palate shape" *Journal of Phonetics* **30** 281-302.

Honda, M. & Murano, E. "Effects of Tactile and Auditory Feedback on Compensatory Articulatory Response to an Unexpected Palatal Perturbation" [Abstract] Speech Production Seminar 6, Sydney.

Linke, D. (1980) "Vorprogrammierung und Rückkopplung bei der Sprache" In Spreng, M.(ed.) *Interaktion zwischen Artikulation und akustischer Perzeption*. Stuttgart: Thieme 50-57.

Löfqvist, A. & Gracco, V.L. (1997) "Lip and jaw kinematics in bilabial stop consonant production" *Journal of Speech, Language, and Hearing Research* **40(4)** 877-893

Mooshammer, C., Geumann, A., Hoole, P., Alfonso, P., van Lieshout, P. & Fuchs, S. (2003) "Coordination of lingual and mandibular gestures for different manners of articulation" *Proceedings of the International Congress on Phonetic Sciences, Barcelona, Spain* 81-84.

Narayanan, S.S., Alwan, A.A. & Haker, K. (1995) " An articulatory study of fricative consonants using magnetic resonance imagung" *Journal of the Acoustical Society of America* **98(3**) 1325-1347.

Perrier, P., Payan, Y., Zandipour, M & Perkell, J. (2003) "Influences of tongue biomechanics on velar stop consonants: A modeling study" *Journal of the Acoustical Society of America* **114(3)** 1582-1599.

Stone, M. (1991) "Toward a model of three-dimensional tongue movements" *Journal of Phonetics* **19** 309-320.

Stone, M. (1995) "How the tongue takes advantage of the palate during speech" In Bell-Berti F. & Lawrence J. R. (eds.*) Producing Speech: Contemporary Issues for Katherine Safford Harris*. New York: AIP Press 143-153.

Tiede, M. (1998) "Palate shape effects on characteristic vowel tongue postures" [Abstract] *Journal of the Acoustical Society of America* **103** 2893.