THE TROUGH EFFECT – AN AERODYNAMIC PHENOMENON?

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ABSTRACT
The trough effect is a phenomenon occuring in a VCV-sequence, where both vowels are identical and the consonant is produced with an articulator which is thought to be unspecified for vowel production. It can be described as a momentary deactivation of tongue movement when the consonant is a bilabial. Several interpretations have been given to the causes and implications of the trough with a speech material consisting of /b/ and /p/. In order to verify a possible aerodynamic effect we carried out three different experiments and included additionally /m/ in our corpus. Our results provide evidence that aerodynamic requirements play a role. Nevertheless, aerodynamics alone do not cause the troughs.

HORS-D'ŒUVRE: THEORETICAL BACKGROUND

The trough appears during the oral closure of the bilabial and has been described as a momentary deactivation of the tongue musculature responsible for the surrounding vowel production (Bell-Berti & Harris 1974, Gay 1975). Troughs have also been found for lip movements in /uCu/-sequences (Bell-Berti & Harris 1974, Perkell 1986), i.e. lip rounding for the vowel is deactivated during the consonant. In a recent paper by Lindblom et al. (2003) characteristics of the trough have been summarised: "(1) the trough effect clearly exists for both tongue and labial articulations; (2) the trough effect can most simply be described either as a 'turning off' or diminution of underlying articulator activity for the vowel; (3) the trough cannot be attributed to (aspiration induced) acoustic or aerodynamic constraints, and (4) the trough effect appears to exhibit language-specific effects, e.g. its absence in Turkish and French." (p.261). Lindblom et al. conclude that the trough effect would provide evidence for a segment-by-segment activation in opposition to Öhman's model of an underlying independent vowel cycle with a superimposed consonant gesture. Although we will further concentrate on the troughs found in tongue movements, we would like to mention a possible explanation for the troughs found in /utu/ and /usu/ for lip movements for which Perkell (1986) proposed a specific target production of the intervocalic consonants. Our explanation is related to the cross-sectional area at the two lips. The cross-sectional area is very small in /u/, resulting in a high frequency damping. This damping effect is counterproductive for the production and perception of the voiceless stop or fricative. For voiceless stop production Maeda (1996) has pointed out that the cross-sectional area of the supralaryngeal articulators has to be larger than the one at the glottal level in order to guarantee the appropriate noise magnitude. Hence, we propose that lip deactivation during /utu/ or /usu/-sequences could be a strategy to increase the cross-sectional area at the lips.

In opposition to what Lindblom et al. (2003) pointed out, there is evidence in the literature for possible aerodynamic effects on the tongue surface in a comparable dataset, even though it comes from a totally different perspective. Svirsky et al. (1997) tried to answer the question of whether oral cavity enlargement in the production of voiced stops is an active or passive mechanism. By means of EMA (4 subjects) and combined EMA/intraoral pressure recordings (1 subject) they observed tongue displacements and estimated tongue compliance during the production of /ama/, /aba/ and /apa/. Svirsky et al.'s results provide evidence for a significantly larger tongue displacement, i.e. tongue lowering in /b/. There was less lowering for /p/ and no significant differences from zero for /m/. In terms of the trough effect this could question its existence in /ama/. The intraoral pressure differences in Svirsky et al.'s result were in the p>b>m direction. The authors suggest "that tongue deformation may be passive and pressure driven for /apa/ and that active vocal-tract expansion is superimposed on the passive, pressure driven deformation for /aba/" (p.570).

Another intriguing aspect has been brought up by Vilain et al. (1999, 2000). They modeled /aba/ sequences with 2 linear anthropomorphic articulatory models which were based on 2 cineradiographic corpora of 2 French speakers. Using the first model, Vilain et al. found that "strikingly, [b] appears here to necessitate a complete recombination of the articulators…the new position of the tongue compensates for the high position of the jaw implied by the lip occlusion. And this new combination cannot be considered as an anticipation towards a new [a] configuration, since the second [a] is produced exactly as the first one was. The recombination is therefore specific for the consonant." (Vilain et al. 1999, p.2). With the second model (differing only in vocal tract morphology) tongue and jaw are not recombined, both articulators contribute to the vowel articulation and also to the bilabial with a less open jaw position. These findings support the hypothesis that the trough would have its origin at a motor control level and that tongue and jaw movements involved in the vowel production are not unspecified for the intervocalic consonant.

The theoretical implications of the trough effect seem to be remarkable and have often been discussed in the literature with respect to coarticulation, anticipation and speech motor control. We were interested in investigating the following questions: (1) Do troughs occur in VCV-sequences where C is a nasal? If so, an aerodynamic effect due to intraoral pressure differences could be excluded, since in nasals intraoral pressure does not rise as in voiced or voiceless stops. (2) Can troughs be explained by a recombination of tongue and jaw movements (as in Vilain et al. 1999, 2000)? If so, what happens when tongue-jaw coordination is perturbed due to a bite block?

PLAT PRINCIPAL: PRELIMINARY RESULTS FROM AN EMG EXPERIMENT

By means of hooked wire Electromyography (EMG) and acoustics we recorded 3 native speakers of German and 1 bilingual speaker of Japanese and German. Activity of the following tongue muscles was registered for all subjects: Genioglossus posterior (GGP), Genioglossus anterior (GGA), and Styloglossus (SG). The speech material consisted of VCV-sequences where V was either /i/, /a/ or /u/ and C /p/, /b/ or /m/. Each target word was embedded in the carrier sentence: *Habe X besucht* (*Visited X*) and repeated up to 17 times. Root mean square amplitudes were calculated and smoothed with a cut-off frequency of 25Hz. In a next step ensemble averages of the GGP signals were calculated by time-warping each consonant to the average length of the consonant in each vowel context, and then extending the averaging window by 100ms before the onset and after the offset of each consonant. Ensemble averages for GGP activity were lined up with the consonant onset, defined as the F2 offset in the acoustic data. Preliminary results from one subject for GGP activity are shown in figure1. The left graph corresponds to /u/-context and the right to /i/-context.

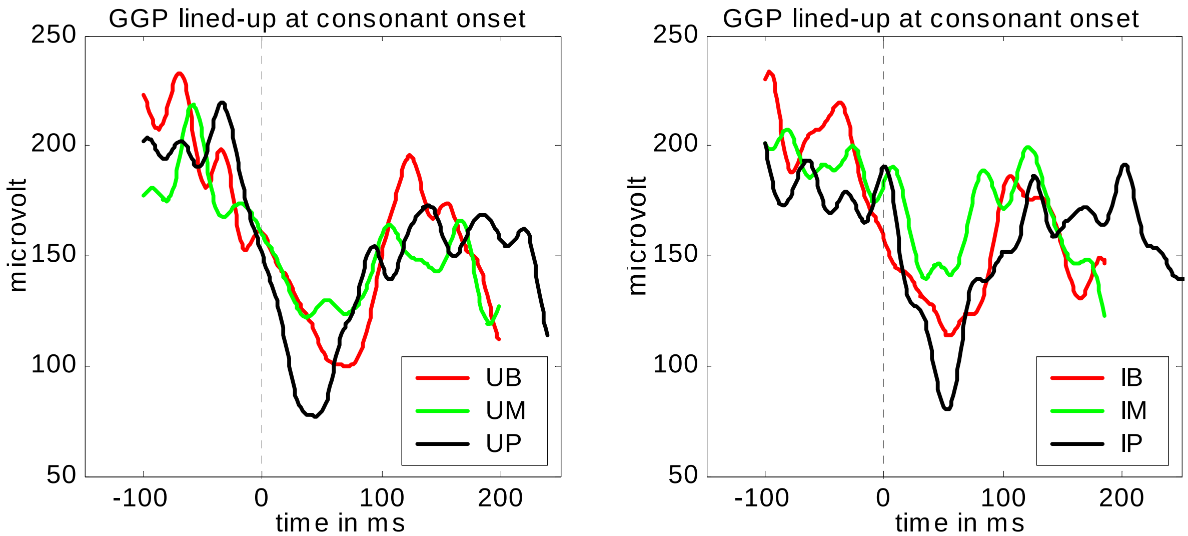

Figure 1. Averaged GGP activity lined-up at the acoustically defined consonant onset for 1 subject, left /uCu/, right /iCi/, green lines correspond to C=/m/, red lines to C=/b/ and black lines to C=/p/

Both graphs exhibit the trough as a deactivation of GGP at the beginning of the acoustically defined consonant closure. In both vowel contexts GGP deactivation is smallest for /m/ and largest for /p/. For /b/ an intermediate value between /p/ and /m/ can be seen although it also starts with slightly greater activation patterns for the first vowel. Our preliminary results from one subject provide evidence that GGP deactivation could differ with respect to intraoral pressure differences (largest pressure for /p/ and smallest for /m/), but aerodynamics may not be the only reason why speakers deactivate GGP, since troughs are also found in nasals. According to Feldman et al. (1990) EMG signals are a combination of central and feedback inputs. Changes of muscle length can be caused by external factors such as gravity or external forces and can induce changes in EMG activity. On this basis, it is possible to consider that air pressure forces could potentially modify tongue shapes and influence EMG activity.

In addition, it could be assumed that deactivation in /p/ is larger in amplitude than /m/, because it is longer in its overall consonant duration. By means of acoustic analysis we calculated consonantal duration as the difference between F2 offset of V1 and F2 onset of V2. For the subject presented here, /b/ and /m/ show a consistently shorter duration than /p/. Since /b/ and /m/ do not differ in duration, but do differ with respect to GGP activity it seems to be unlikely that the differences in GGP deactivation can be attributed to variations in time only.

DESSERT: RESULTS FROM A BITE BLOCK EXPERIMENT

By means of simultaneous EMA (Carstens Medizinelektronik AG 100), EPG (Reading EPG3) and acoustics recordings, acoustic and articulatory data from one German speaker were analysed in order to answer the second question of a recombination of tongue and jaw movements. The experiment consisted of 2 parts, one under a normal condition and the other with a 5mm wooden bite block inserted between the rear molars. Three coils were attached to the tongue (tongue tip around 1 cm from the tip, tongue blade approximately 2cm from the tip sensor and tongue back around 2 cm from the tongue blade sensor in the posterior direction), one coil at the lower incisors (*jaw*), one at the vermillion border of the upper lip, one at the lower lip and two coils to compensate for helmet movements (one at the upper incisors and one at the bridge of the nose). In both conditions coils were glued at the same place. We used the speech material from the EMG recording. All target words were repeated 19 times in the normal condition and 15 times in the bite block condition.

Two successive gestures were labeled (the lower lip closing gesture from V1 to C and the opening gesture from C to V2). For each gesture 7 time landmarks were defined using a 20% threshold criterion: 1: the left minimum, 2: the lower 20% threshold, 3: the upper 20% threshold, 4: velocity peak, 5: upper 20% threshold 2, 6: lower 20% threshold 2, 7: right minimum (2nd gesture starts with number 8 for the left minimum). In order to define an interval for the potential occurrence of the trough we selected the beginning of the lower lip closing gesture and the end of the lower lip opening gesture. We will further focus on the changes of the tongue blade coil in /a/-context since it showed most variations.

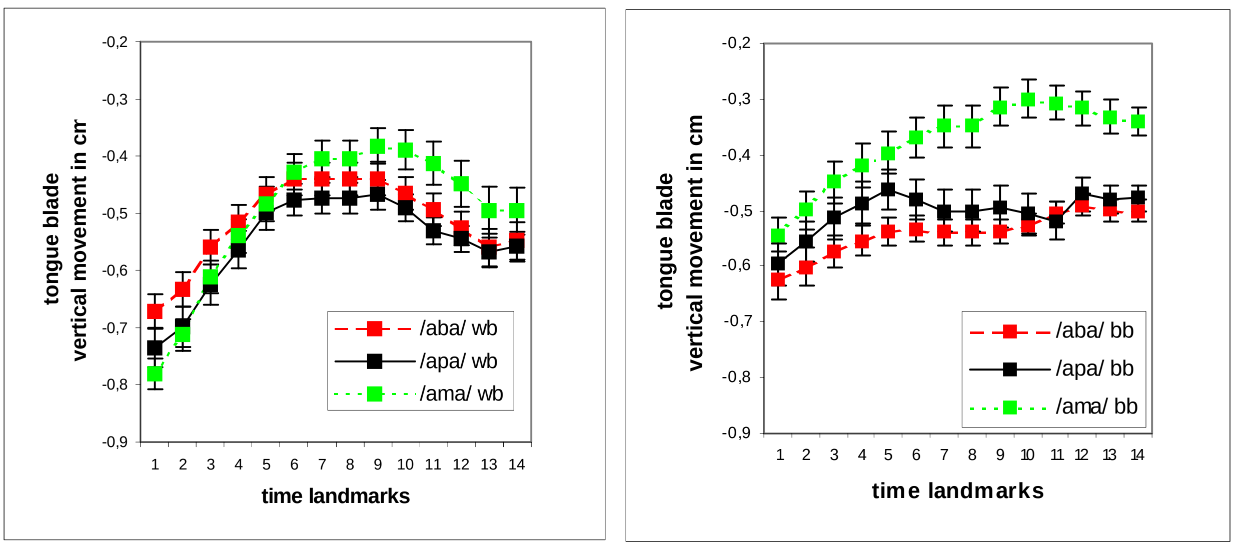

Figure 2. Average values with +/- 1 std. error for tongue blade vertical movement in cm for successive time landmarks in /aCa/, left graph corresponds to the condition without biteblock (wb) and right graph to the bite block condition (bb); dotted green line = /m/, dashed red line = /b/ and solid black line = /p/

In figure2 it can be seen that the tongue blade shows a small lowering during bilabial closure in /apa/ in the bite block condition, whereas in the normal condition the tongue moves further up. Since in the normal condition the tongue blade sensor also reflects jaw movement, the jaw is involved in the resulting tongue blade upward movement (particularly after time landmark 5 which can be associated with the beginning of the oral closure). Troughs are not found in /ama/ in either of the conditions. In /aba/ (bb) the downward movement is so small that it lies below the reliability range of EMA. Results for /iCi/ are similar in the sense that /imi/ does not show any troughs, whereas in /ipi/ troughs of 0.5-1mm are found. In /ibi/ the tongue moves slightly downwards, but not up again for V2. This is true for both conditions (bb and wb) with a generally lower tongue position in the bb-condition. The contribution of the jaw to the production of the bilabial seems to be less important than in /aCa/ since a relatively high jaw is already found in /i/.

Our results for /aCa/ are in general agreement with Vilain et al. and speak for a recombination of tongue and jaw movements. The relatively high jaw position in /apa/ coincides with a trough and a tongue lowering during the bilabial closure whereas in a lower jaw position (0,5-1mm for /ama/) no trough can be seen. Additionally, we found that the horizontal movement of the lower lip is fronter in /p/ than in /m/ which should be due to a greater compression of the lips (see next paragraph).

FROMAGE: LIP SHAPE EXPERIMENT

In a pilot experiment we recorded acoustic data together with lower face movies by means of a standard video camera (30 frames per sec) from the frontal view of the same speaker whos data are presented in the EMG section. We did not expect to find visual evidence for a trough in the images from the time before oral release (see figure 3), but rather a possible difference in lip shapes with respect to the intervocalic consonant, specifically for /m/ and /p/. For /p/ we suppose a small intraoral cavity in order to increase intraoral pressure for a more salient burst. This aim could be reached by a lip target position which is directed to a location beyond the upper lip (Löfqvist and Gracco 1997) and results in a greater lip compression. As shown in figure 3, lips are thinner in /VpV/-sequences than in /VmV/. Differences in compression might become more pronounced if the bilabials were placed in a word initial position.

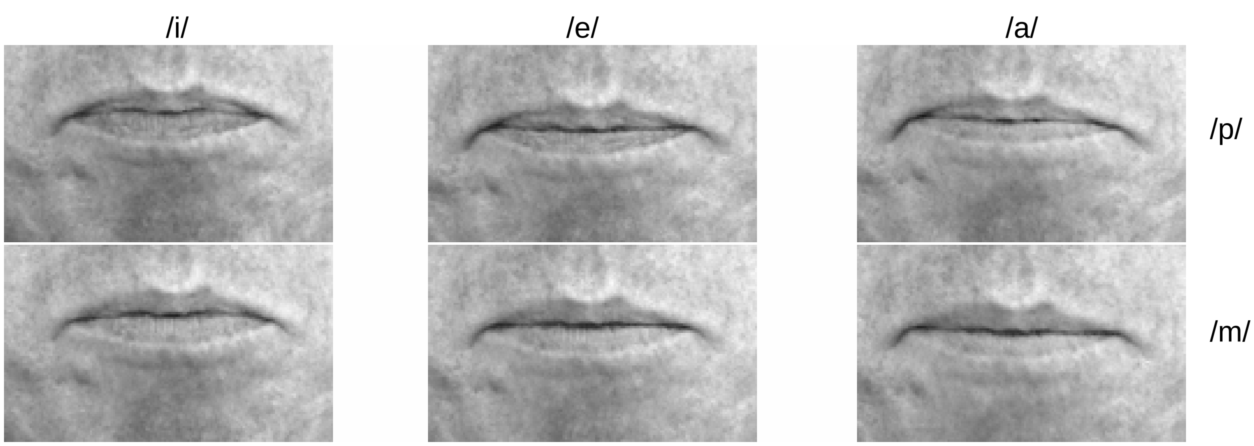

Figure 3: Images from lip shapes in VCV-sequences at the time of maximal closure before oral release; left column: /iCi/, middle: /eCe/, right /aCa/; first row: /VpV/, last: /VmV/

CAFÉ: CONCLUSION

By means of a EMG experiment we tried to answer the question of whether troughs could be a result of external factors such as a high intraoral pressure, e.g. for voiceless bilabial stops, and would therefore only occur in stops, but not in nasals. Results from one subject provide evidence that deactivation of GGP exists for nasals, even if it is smaller in /VmV/ than in /VbV/

and in /VpV/. Hence, intraoral pressure differences alone would not explain the trough effect. In order to verify Vilain et al.'s proposal that troughs can be explained due to a recombination of tongue and jaw movement, we carried out a bite block experiment and focused on EMA data. It could be shown that mostly /VpV/-sequences exhibit tongue lowering during bilabial closure whereas /VmV/-sequences do not. It can be concluded that troughs are most evident in voiceless stops and that even bilabials may involve quite specific lingual adjustments. Unlike Lindblom's conclusion we suggest that the trough may be attributable to some extent to aerodynamic constraints.

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