Glottal Timing in German Voiceless Occlusives

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1. Introduction

The coordination of laryngeal and lingual gestures in voiceless sounds has proved a fruitful area in which to study the motor organisation of speech (e.g. Löfqvist, 1980). However, little information is yet available on German. Preliminary investigations with one speaker, using isolated nonsense words of the type 'CV, suggested that both place of articulation of the consonant and height of the following vowel have an influence on the length of the interval from the moment of peak glottal opening (PGO) to release of the oral occlusion (/p/ > /t/, /i/ > /e/ > /a/).

The purpose of the present study was threefold; (1) to reproduce the place of articulation and vowel height results using material more typical of German word structure; (2) to determine to what extent differences in stress result in articulatory reorganisation, (3) to compare fricatives and stops.

2. Method

Glottal activity was registered by means of the photo-electric glottograph (F-J Electronics).

Oral air-pressure was recorded with a Hansen Manometer via a catheter inserted through the nose into the pharynx. The air-pressure trace was principally used as a means of identifying the moment of oral closure. These two signals together with the audio signal were digitalized and stored on magnetic tape. After recording, a segmentation program was used to measure the durational parameters of interest; the most important being Implosion to Glottal Abduction (GA), PGO to Release, the oral occlusion, and aspiration.

3. Material and Subjects

Six pseudo-German words with stress on the first syllable (/pi:pə/, /ti:tə/, /pe:pə/, /te:tə/, /pa:pə/, /ta:tə/) were embedded in the sentence frame 'Ist der fette/feste-da?'. Each word was produced ten times in randomized order, i.e. five times each after 'fette' and 'feste', the latter two words providing the material for the plosive/fricative comparison. Three male native-speakers from different parts of Germany acted as subjects.

4. Results

The pre-stress plosives

To set the scene the average values for occlusion and aspiration for the three subjects are given in Table I. The values conformed to expectations. The subjects had very similar occlusions but differed somewhat in aspiration. Fig. 1 shows the results for PGO to Release. For all subjects this interval is longer for /p/ than for /t/, quite clearly for HGT and KD, slightly less so for BPM who has rather large standard deviations. However, the effect of the following vowel shows no clear pattern. In view of the results for the consonants we tested for a correlation between PGO to Release and Occlusion. HGT and KD had highly significant correlations but BPM did not. The values for Implosion to GA were fairly constant over the different vowels and consonants:

BPM: 20 ms, sd = 4 ms; HGT: 35 ms, sd = 10 ms; KD: 58 ms, sd = 13 ms.

Most striking here is the very high value for KD.

The Post-Stress Plosives

The results for these plosives showed the widest range of strategies among the

Table I. Pre-stress plosives. Length of occlusion and aspiration in ms

		/pi/		/ti/		/pe/		/te/		/pa/		/ta/	
		mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
BPM	Occ	139	12	126	9	133	6	129	12	138	19	120	5
	Asp	62	10	74	7	44	5	60	13	45	8	53	12
HGT	Occ	137	14	129	21	134	17	114	12	122	14	98	9
	Asp	38	8	55	13	26	8	41	6	29	15	30	5
KD	Occ	144	20	115	15	144	17	112	13	127	14	104	10
	Asp	22	10	46	10	18	4	34	5	16	2	25	3

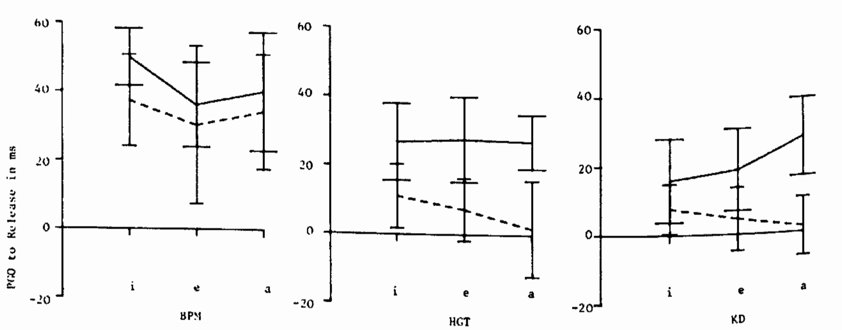

Fig. 1. Mean and sd for PGO to Release for the pre-stress stops; /p/ with unbroken line and with long horizontal bars delimiting the sd; /t/ with dashed line and with short bars.

subjects. All subjects had significantly shorter occlusions for the post- stress plosives and BPM and HGT also had much less aspiration but KD surprisingly did not.

The glottal parameters: for HGT no reliable measurments could be made as only slight glottal activity was observable. However, the air-pressure trace retained the typical form for voiceless plosives (quadrilateral) so we would guess that the subject actively slackened his vocal folds but adjusted the cartiliginous part of the glottis only very slightly. PGO to Release in the other two subjects showed the same consonantal dependencies as in the pre-stress case displayed in figure 1 but had overall lower values (a negative value means PGO comes after the release):

BPM /p/ mean = 13 ms, sd = 9 ms; /t/ mean = 0 ms, sd = 10 ms

KD /p/ mean = 12 ms, sd = 7 ms; /t/ mean = -8 ms, sd = 7 ms

This can probably be regarded as a fairly simple spin-off from the shorter occlusions. These results suggest that PGO amplitude must also have been less and a Wilcoxon test tended to confirm this. Implosion to GA revealed a striking example of articulatory reorganisation for KD. While BPM's values were much the same as in the pre-stress case (mean = 26 ms, sd = 10 ms) KD's values differed drastically: mean = 17 ms, sd = 8 ms.

This reorganisation was refected in the air-pressure curve; in the pre-stress case where tongue and glottal gestures are widely separated the air- pressure first rises quite steeply, followed by a shallower rise from the moment when the glottis begins to open up to the absolute pressure maximum. In the post-stress case where the gestures almost coincide there is a single, very steep rise.

'fette' vs. 'feste'

Other investigators (e.g. Yoshioka, Löfqvist and Hirose, 1980) have reliably found that fricatives are distinguished from plosives by a glottal opening gesture that is more vigorous and starts earlier with respect to oral closure. The present study confirmed this. Our specific interest here was to try and develop a simple motor plan for the vowel + consonant dyad (/et/ vs. /est/) by taking into account the above observation and the length of the vowel preceding the consonant (Fig. 2). The results for BPM and KD are given in Table II. BPM shows a very neat coincidence of the instants of GA for fricative and plosive when measured from the preceding vowel onset. KD has a similar overall trend but the coincidence is far from perfect. This can be attributed in part to his reorganisation of GA for post-stress plosives. HGT showed similar results for vowel length but once again the glottal signal for the post-stress plosive was too weak to be evaluated. This subject and KD also spoke an additional set of 12 sentences at a more deliberate pace (thus including 6 examples wach of 'feste' and 'fette'). The results, in Table III, for this very small sample showed some support for the hypothesis.

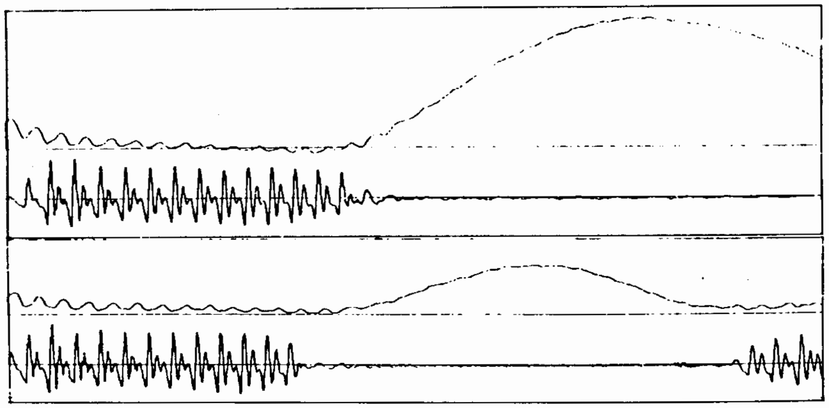

Fig. 2. Glottis signal and audio signal for /est/ (top) and /et/ (bottom), lined up at vowel onset to show the coincidence in GA.

Table II. 'feste' vs. 'fette'. Complete material

		Vowel duration		Implosion to GA		Vowel onset to GA	
		mean	sd	mean	sd	mean	sd
BPM	/est/	88 ms	5 ms	2 ms	3 ms	90 ms	6 ms
	/et/	69 ms	6 ms	19 ms	3 ms	88 ms	5 ms
KD	/est/	83 ms	4 ms	13 ms	4 ms	95 ms	5 ms
BPM	/et/	69 ms	5 ms	17 ms	4 ms	85 ms	6 ms

Table III. 'feste' vs. 'fette'. Additional material

		Vowel duration		Implosion to GA		Vowel onset to GA	
		mean	sd	mean	sd	mean	sd
BPM	/est/	196 ms	26 ms	6 ms	10 ms	202 ms	31 ms
	/et/	163 ms	26 ms	51 ms	13 ms	215 ms	28 ms
KD	/est/	106 ms	5 ms	14 ms	6 ms	121 ms	8 ms
	/et/	93 ms	12 ms	25 ms	7 ms	122 ms	9 ms

5. Discussion

Both the pre- and post-stressed plosives showed differences in the timing of PGO relative to release depending on place of articulation. This is a finding that theories of aspiration for German (e.g. Haag, 1979) must take into account. The difference in timing can be regarded as a largely passive effect of the difference in occlusion. A rather stereotyped glottal gesture is superimposed on a variety of oral articulations. A more active retiming would have had to be assumed if the following vowel had had an effect but no convincing evidence for this was found.

In a sense, the fricative/plosive comparison leads to the same conclusion. Within certain limits the articulatory mechanism seems to prefer to reorganize oral gestures rather than glottal ones. Though not perfect the coincidence in the timing of GA is worth investigating further and could lead to a simpler interpretation of the finding made for Japanese (Yoshioka, Lofqvist and Hirose, 1980) that the moment of maximum speed of glottal opening in fricatives and plosives coincide.

Of course, there is still a large fly in the ointment, namely KD's 'unnecessary' retiming of GA for post-stress plosives. This is a stable characteristic of his accent and manifests itself acoustically in an extremely abrupt decay in vowel amplitude before post-stress plosives.

References

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