ARTICULATORY STRENGTHENING IN INITIAL GERMAN /kl/ CLUSTERS UNDER PROSODIC VARIATION

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ABSTRACT

This study investigates the effects of varying prosodic boundary strength and lexical stress on domain initial /kl/ clusters in German by means of Electropalatography (EPG). Recordings of 7 speakers were analyzed using temporal and spatial parameters derived from the EPG data. Boundary effects are stronger for the first consonant and were observable in both temporal and spatial parameters, while stress effects are stronger for the second consonant and are only apparent in the temporal domain. Overlap was found to be greater in unstressed position and at lower prosodic boundaries. Furthermore, /kl/ appears to be more susceptible to stress effects when not preceded by a boundary.

1. INTRODUCTION

Apart from intonational means, prosodic phrasing is also marked by so-called articulatory strengthening. In this study, we analyze the effects of varying prosodic boundary strength and word stress on the internal organization of initial /kl/ clusters in order to gain a better understanding of the interplay between the segmental tier and higher levels of the prosodic hierarchy. By means of electropalatographic recordings we address the question of which parts or properties of the cluster are affected: the first consonant, the second consonant or the degree of consonant overlap.

Articulatory strengthening as a means of prosodic phrase marking or prominence enhancement has been investigated for a number of languages, segments and hierarchical levels, see e.g. [1, 10, 8, 5]. It involves temporal and spatial enhancement strategies, such as larger and/or longer gestures and less coarticulation across boundaries and at higher prosodic levels.

Analyzing singleton alveolar consonants domain initially by means of EPG, Keating et al. [10] found that linguopalatal contact increased with prosodic boundary levels for English, French, Korean and Taiwanese. They also found that closure duration increased in the same way for all these languages except for Taiwanese. Byrd and Choi [5] investigated English /kl sk sp/ sequences in word onset (among other positions) by means of EMMA. The duration of the first consonant increased with boundary strength, while the second consonant, being further from the prosodic edge, was hardly affected. Also, there was an effect of boundary strength on the degree of overlap within the clusters, as it decreased with increasing boundary levels. However, they found that overlap for /kl/ was relatively less affected than for the /sC/ clusters. Byrd and Choi explained these boundary effects using the π-gesture approach as a local slowing down of the clock. According to this, the effects of a prosodic edge are strongest at the edge itself and attenuate with increasing distance from it.

The first aim of this study is to extend the results reported above concerning boundary levels for German. We expect that the first consonant will be more affected by prosodic edges than the second. However, in contrast to former studies (cf. Byrd and Choi [5] for American English and Bombien et al. [3] for German) the boundary levels are determined empirically by their prosodic realization (e.g. occurrence of boundary tones and/or pause) rather than defining them beforehand by purely syntactic criteria. Secondly, we are also interested in the effect of lexical stress on the realization of /kl/ clusters. We speculate that the effects of stress will be strongest on the nucleus of the stressed syllable and will grow weaker with increasing distance from there. Consequently, we expect stronger effects of stress on the second consonant rather than the first. Thirdly, we want to consider the effect of prosodic variation on consonant overlap. No change is plausible if the temporal coordination is entirely determined by language specific grammar, see [9], or by perceptual demands, cf. [4]. The H&H theory [12] and the π-gestures approach [5] again would predict reduced overlap at higher prosodic levels as an enhancement of distinctiveness or a local slowing down of the clock.

2. METHOD

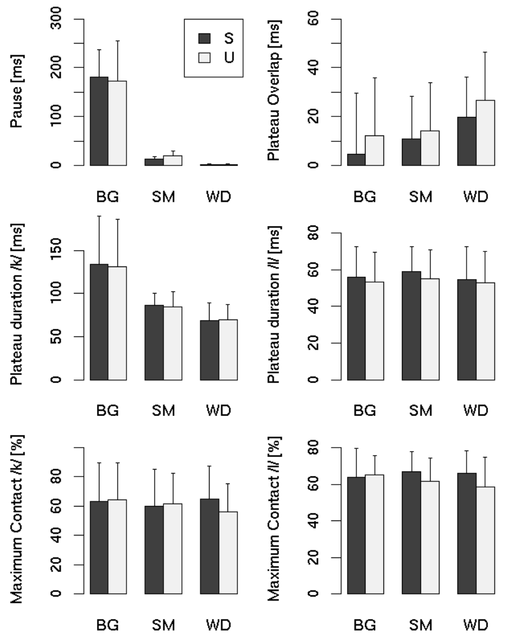
Seven native speakers of German (5 female: *sf, jb, nf, sk, mv*; 2 male: *dp, jd*) were recorded using the Reading EPG system. To analyze word initial /kl/ clusters, two target words differing in lexical stress (the name *Claudia* [ˈklaʊdia] and *Klausur* [klaʊˈzuɐ] 'written test') were embedded in four different prosodic environments each: (1) *Utterance initially (U)* in the second of two sentences, (2) *phrase initially (P)* in a sub-clause, (3) as the third of four *list (L)* items, and (4) as a phrase internal *word (W)*. The word preceding the target word always ended on an open vowel (either /a/ or /ɐ/). The entire set of utterances was presented to the subjects ten times in randomized order. The *Munich Automatic Segmentation System MAUS* [13] and the EMU Speech Database Tool [2] were used for acoustical labelling. EMU was also used for hierarchical and prosodical annotation and EPG processing. All utterances were classified by the strength of the phrase boundary preceding the target word determined by the absence or presence of a pause and a boundary tone (cf. [8]): big boundary (BG): boundary tone and pause; small boundary (SM): boundary tone and no pause; prosodic word (WD): no boundary tone and no pause.

Two EPG indices were calculated allowing for the analysis of the velar stop and the alveolar lateral: The dorsality index (DI) as a measure of dorsopalatal contact (rows 6-8) and the anteriority index (AI) indicating the amount of anterior contact (rows 1-5). DI was refined using speaker individual profiles (as in [6]). Both indices are computed as the sum of all active contacts in the respective region divided by the total sum of contacts in the active region yielding a value between 0 and 1. For both consonants, five events were semi-automatically determined in the time course of the respective index: gestural onset and offset at a 10 % threshold, plateau onset and offset at a 70 % threshold and maximum contact at the center of the plateau. All thresholds were calculated relative to maximum EPG contact in the respective region.

In total, four temporal and two spatial measures were extracted from the EPG data. For the first parameter *Pause* (P), the duration was hard to determine because it was often impossible to discern it from silence during /k/ closure. We operationally defined it as the sum of the acoustical duration of the pause (p_a) preceding the target word (if present) and the difference of the acoustical duration of /k/ (k_a) and its per-speaker mean ($\bar{k}_s$) (if positive):

$$(1)\quad P = \begin{cases} p_a + (k_a - \bar{k}_s) & \text{if } k_a > \bar{k}_s \\ p_a & \text{else} \end{cases}$$

Figure 1: Bar plots of the across-speaker means of Pause, plateau /k/, plateau /l/, maximum contact /k/, maximum contact /l/ and plateau overlap for stressed and unstressed tokens as a function of boundary strength.



As temporal measures of strengthening, *plateau /k/* and *plateau /l/* are defined as the duration of the respective constriction plateau. *plateau overlap* is the difference between plateau offset of /k/ and plateau onset of /l/, positive for overlap and negative for no overlap. In many studies temporal overlap is normalized in order to correct speaker-dependent speech tempo difference ([7, 9, 11]). Since Bombien et al. [3] found that some speakers lengthened /k/ to a great amount (i.e. constriction established within the pause) at higher boundary levels the plateau overlap was not normalized in this study. *Maximum contact /k/* and *maximum contact /l/* are spatial measures and indicate the percentage of maximum EPG contact in the respective region.

For statistics, the R-software in combination with the EMU/R package was used. Speaker individual ANOVAs were carried out using the independent variables *boundary* (BG, SM , WD, see above) and *stress*, the latter in correspondence with the stress of the syllable containing the /kl/ cluster: S – stressed (Claudia), U – unstressed (Klausur). Furthermore, repeated measures ANOVAs based on the cell means for each speaker were carried out. Individual pairwise t-tests were also calculated for the three-level factor *boundary* to detail the results of the ANOVAs.

3. RESULTS

3.1. Boundary categories

Table 1: Mapping of syntactically defined to prosodically determined boundary levels

	BG	SM	WD
Utterance	66	33	0
Phrase	28	86	3
List	18	67	33
Word	0	0	117

Table 1 gives an overview of how the syntactically defined boundary levels map the prosodically determined phrase groups. While all utterances of the *Word* condition were classified as WD, utterances of the *List, Phrase* and *Utterance* conditions are distributed across at least two prosodically determined levels each.

3.2. Boundary effects

Fig. 1 shows bar plots of all variables for stressed and unstressed tokens as a function of boundary strength calculated over all speakers. The upper part of table 2 displays the statistical results for boundary effects. For the variables *pause*, *plateau* /k/ and *plateau overlap*, the repeated measures ANOVAs returned significant boundary effects. Greater pause duration is found for the highest boundary level. As indicated in the discussion this result is a consequence of using pause in the definition of BG. *Plateau* /k/ is significantly larger in the BG condition than in the WD condition and – for unstressed tokens – also larger than in the SM condition. The boundary effect on *plateau overlap* is also limited to unstressed tokens: We find more overlap in the WD condition than in the BG condition. For *pause* and *plateau* /k/ the results for each speaker are reflected quite accurately in the results for the pooled data. In contrast to this, the differences for *plateau overlap* are only significant in two speakers.

For *maximum contact* /k/ the results are less systematic. Speakers *jd* and *nf* show an effect only for unstressed tokens, while for *sk maximum contact* /k/ is only affected for stressed tokens. However, all three effects go in the same direction as there is more contact at higher boundary levels than at lower.

Although *plateau* /l/ and *maximum contact* /l/ should by hypothesis be sensitive to stress rather than to boundary effects, there are actually a few significant boundary effects. Speaker *jb* has a longer plateau duration for the second consonant in stressed tokens. Speakers *dp* and *jd* have more contact in BG condition than in WD condition, the first for stressed tokens, the latter for unstressed tokens.

3.3. Stress effects

The lower part of table 2 shows the statistical results for stress effects, see also Fig. 1. None of the repeated measures ANOVAs reported any significant main effects for stress. We expected to find that the second consonant is more affected by stress than the second and this holds true for at least some speakers. Speakers *dp* and *sf* both have longer durations for *plateau* /l/ in the WD condition. Speaker *dp* has more contact for /l/ in all three prosodic conditions. The same holds for *jb* in SM and WD condition, for *jd* in WD condition and for *sk* in SM condition.

There are, however, also effects for *maximum contact* k and for *plateau overlap*. Speakers *sk* and *nf* produce /kl/ with more overlap for unstressed tokens in WD condition, *nf* also in SM condition. Speakers *jd*, *jb* and *nf* have more contact for /k/ in stressed tokens than in unstressed tokens in the WD condition.

Note that nearly all effects reported for stress are either restricted to or include the WD condition.

4. DISCUSSION

In accordance with our prediction, the effects of varying boundary strength are stronger on the first consonant than on the second. It comes as no surprise that *pause* and *plateau* /k/ are correlated ($cor = 0.58, p < 0.001$). For both variables, BG – being defined by the presence of a pause – is clearly separated from SM and WD. There are only very few cases for SM and WD condition with duration of *pause* greater than zero. As stated by [3], consonant constrictions for /k/ were often established within the pause at large boundaries resulting in very long plateau durations. Therefore, gestural onset and duration of C1 are largely dependent on the presence of a pause. For this reason the gestural duration of C1 at high boundary levels should not be used for normalization in relative overlap measures, as this would lead to deceptive overlap values when a (long) pause precedes the cluster. We mainly found significant differences which separated BG from the other conditions but the bar plots in Fig. 1 indicate a graded effect across all three boundary levels for *pause*, *plateau overlap* and *plateau* /k/. Overlap appears to be special in that it was only affected significantly in unstressed syllables indicating that the effects of boundary and stress interact (not in a statistical sense, see below). In stressed syllables, overlap appeared to be largely insensitive to boundary strength. This indicates that there is greater cohesion for /kl/ in stressed syllables allowing for less

Table 2: Results for boundary and stress effects, $p < 0.05$ (BG, SM, WD: boundary levels; S, U: stress levels).

Speaker	Pause	Overlap	plateau /k/	plateau /l/	max. contact /k/	max. contact /l/
Boundary effects						
dp	BG > SM, WD	n.s.	BG >WD	n.s.	n.s.	S: BG > WD
sf	BG > SM, WD	n.s.	BG > WD; S: BG > SM	n.s.	n.s.	n.s.
jd	BG > SM, WD	n.s.	BG > SM, WD	n.s.	U: BG > WD	U: BG > WD
jb	BG > SM, WD	n.s.	BG > SM, WD	S: SM > WD	n.s.	n.s.
sk	BG > SM, WD	U: WD > BG, SM	BG > SM, WD	n.s.	S: BG > SM	n.s.
nf	BG > SM, WD	U: WD > BG, SM	BG > WD; S: BG > SM	n.s.	U: BG, SM > WD	n.s.
mv	BG > SM, WD	n.s.	n.s.	n.s.	n.s.	n.s.
all	BG > SM, WD	U: WD > BG	BG > WD; U: BG > SM	n.s.	n.s.	n.s.
Stress effects						
dp	n.s.	n.s.	n.s.	WD: S > U	n.s.	S > U
sf	n.s.	n.s.	n.s.	WD: S > U	n.s.	n.s.
jd	n.s.	n.s.	n.s.	n.s.	WD: S > U	WD: S > U
jb	n.s.	n.s	n.s.	n.s.	WD: S > U	SM, WD: S > U
sk	n.s.	WD: U > S	n.s.	n.s.	n.s.	n.s.
nf	n.s.	SM, WD: U > S	n.s.	n.s.	WD: S > U	SM: S > U
mv	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
all	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Example: for speaker *sk* in WD condition, unstressed tokens have larger overlap than stressed tokens.

variance (cf. [4]). The influence of varying boundary levels on the second consonant were only few. All these findings are in accordance with Byrd and Choi [5].

Another indication for the interaction of boundary and stress effects is that most stress effects observed here are restricted to the WD condition. This indicates that the influence of stress is only effective when no boundary precedes the cluster, else it will be overruled by the strengthening effect of the boundary.

5. CONCLUSION

The results presented here show that initial German /kl/ clusters are affected by the strength of adjacent phrase boundaries as well as by lexical stress. However, it is largely speaker dependent how the properties of the cluster are affected. This study is limited to one cluster only. As Chitoran et al. [7] and Kühnert et al. [11] found out, simple constraints on the execution of the motor system also determine the internal organization of clusters (e.g. more overlap in /pl/ than in /kl/ because of different articulator stiffness). We therefore plan to analyze already recorded EPG patterns of /sk/ and /kn/ cluster. EMMA recordings of a variety of clusters in varying prosodic conditions are also in progress. Finally, there is need for a relative overlap measure independent of the initial lengthening effect.

6. REFERENCES

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