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Prosodic effects on plosive duration in German and Austrian German

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Abstract

This study investigates the acoustic cues used to mark prosodic boundaries in two varieties of German, with a specific focus on variations in production of fortis and lenis plosives. We extracted prosodic-boundary-adjacent and non-boundary-adjacent plosives from GRASS (Austrian German) and the Kiel Corpus of Read Speech (Northern German), and investigated closure duration, burst features, and duration characteristics of the surrounding segments. We find that closure and burst duration features, as well as duration of a preceding adjacent segment, vary consistently in relationship to the presence or absence of a prosodic boundary, but that the relative weights of these features differ in the two varieties studied.

Index Terms: phrase boundaries, plosives, phonetic detail, German, Austrian German

1. Introduction

The prosodic structure of utterances is manifested in the phonetic detail of the words (e.g., [1, 2, 3]). One well-studied phenomenon is *final lengthening*, which marks the boundaries of linguistic units, including the boundaries of words and of phrases (e.g., [4, 5]). In addition to longer segment durations before phrase boundaries, phrase initial sounds may be produced with stronger contact between the articulators and with less coarticulation with the previous context [6, 7]. Prosodic boundaries do not only condition lengthening but also define cross-word phonological rules. For example, /s/-assimilation in Greek applies in intervocalic context between a noun phrase and a verb phrase if the constituents on either side are short, but not if they are long [8]. [9] found similar effects of constituent length on /t/ deletion in Dutch. This study investigates the behavior of German plosives and their neighboring segments at phrase boundaries. In doing so, we analyze data from two varieties of German (Northern German and Austrian German) of different standard pronunciations of the fortis and lenis plosives [10] and different phonological coarticulation processes [11].

Two recent studies have shown that the relationships between phonetic reduction and prosodic status are not always straightforward. In their study on vowel durations in read American English, [12] found, in contrast to [2], that vowel durations are not entirely conditioned by prosodic structure; they suggest that several processes in complex interaction are responsible for phonetic reduction. The study by [13] on the phonetic detail of the Dutch word *eigenlijk* 'actually' showed that highly reduced variants of *eigenlijk* may also occur in prosodically strong positions and that forms which are reduced in their number of syllables may have longer duration than tri-syllabic forms, as influenced by local speech rate.

The set of acoustic cues used to mark prosodic boundaries may partly overlap with those marking phonological contrast. German fortis plosives have been shown to have longer closures, stronger bursts and longer voice onset time (VOT) than lenis plosives [14]. Not all of these acoustic cues are used straightforwardly for prosodic strengthening. [15], for instance, found that some acoustic cues suggest that intervocalic plosives become more fortis-like after stronger boundaries, whereas other cues associated with fortis plosives become more similar to those of lenis plosives after stronger boundaries (i.e., they show shorter VOT). In Austrian German read speech, however, the lenis-fortis distinction is only present in certain contexts. Moosmüller et al. [10] found that, in initial position, only velar lenis and fortis plosives differ in aspiration; bilabial and alveolar plosives do not have significant differences in aspiration. Furthermore, they found that lenis plosives are never aspirated in any position and that intervocalic fortis and lenis plosives are additionally distinguished by closure duration, which is longer for fortis than for lenis plosives.

For Austrian German, there is less knowledge than for German about prosodic effects on segmental variation. It has been found that prosodically weak positions are prone to monophthongization [16] and that vowel duration and quality are affected by whether they occur in stressed or unstressed syllables [17, 18]. [19] compared prosodic phrasing in different German varieties, finding that German speakers change their articulation rate across prosodic boundaries to a smaller degree than Swiss and Austrian speakers. Given that in German and Austrian German lenis and fortis plosives are distinguished by a different set of acoustic cues, and that they have different effects on the phonetic detail of the surrounding segments, we hypothesize that there are different strategies in these varieties for prosodic strengthening.

The current study aims to contribute to the body of work relating prosodic features to pronunciation variation in Austrian German, by specifically investigating plosives in the context of prosodic boundaries, and making further comparisons with northern German in order to aid comparability of this research with other existing findings. The current paper specifically investigates 1) which acoustic cues in word-initial plosives are affected by the absence vs. presence of a word stress and of a adjacent prosodic phrase boundary, 2) how these effects relate to whether an acoustic cue is also used for phonological contrast, and 3) whether strategies for marking stress and prosodic boundaries are different in German and Austrian German.

2. Materials and methods

2.1. Speech material

This study is based on read speech from two corpora, the Kiel Corpus of Spoken German [20] and the Graz Corpus of Read

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and Spontaneous Speech (*GRASS*) [21]. We chose these corpora because the speakers are typical of two different varieties of German (i.e., (northern) German and Austrian German), and because there is a substantial overlap in the read material collected in the corpora, making a relatively direct comparison possible. The read speech components of both corpora are divided into short chunks of one or two sentences each, which we refer to as *utterances*.

Whereas the Kiel Corpus was fully manually annotated phonetically and prosodically (cf. [20]), the *GRASS* corpus was automatically segmented using MAUS [22, 23]. Thus, word-initial plosives in *GRASS* were separated manually by the second author into closure and burst, and mis-alignments were corrected. On the prosodic level, *GRASS* was manually annotated for prosodic boundaries, using the same criteria as for the Kiel Corpus. Three phonetically trained transcribers created the prosodic boundary annotations, where always one transcriber created an initial annotation, which subsequently was corrected twice by one of the other transcribers.

From both corpora, we extracted sentences read by a total of 37 speakers from *GRASS* and 9 from the Kiel Corpus, as evenly split by gender as possible. From these sentences, we extracted a total of 1785 word-initial plosives from utterance-medial words. Some words immediately followed an intonation phrase boundary (corresponding to the annotation PG in the Kiel Corpus), while other words were intonation-phrase medial. Of these tokens, a disproportionate amount were /d/-initial function words, so we excluded articles (*der, die, das, den, dem, des*) in order to improve the distribution across different plosives. We also excluded outliers (tokens with measurements falling outside of a 97% confidence interval) and ended up with 1497 tokens for the analysis.

The size of the dataset at prosodic boundaries is relatively small since there are fewer boundary locations than phrase-medial locations. It is further limited since such boundaries are often marked by a silent pause, which generally meant that it was not possible to determine a closure duration at these locations and thus were not included in this analysis (e.g., [15]). For these reasons, the analysis includes substantially more plosive tokens at non-phrase-boundary locations (n = 1404) than at boundary locations (n = 93).

2.2. Acoustic measurements

Acoustic analysis was carried out using Praat [24]. Scripts were used to take acoustic measurements, including duration of the plosive closure and burst (if present), duration of the segments preceding and following the plosives, as well as other features which are not investigated here.

2.3. Statistical analysis

We built linear mixed effects regression models with the duration measurements as dependent variables: closure duration, burst duration and plosive duration. In all models, we included the independent variable *Plosive* (/p/, /b/, /d/, /t/, /g/, /k/) or *Fortis_Lenis* (with the values fortis and lenis), and variables describing the preceding (*Prev_*) and following (*Foll_*) segments of the token analyzed: their manner of articulation (*_Manner* with the values pause, nasal, vowel, fricative, plosive, approximant), whether they were voiced or not (*_Voicing*) and their duration in seconds (*_Duration*). The variable *Boundary* (yes, no) described whether the word-initial plosive occurred at a boundary or not. Given that the durational features may vary depending on whether a word is a content or function word [25] and that stressed syllables tend to have longer realizations [26], we added the independent variables *Word_Class* (i.e. content word or function word) and *Word_Stress*, which described whether the initial syllable of the plosive initial words contained canonical stress; though speakers do not obligatorily produce lexical stress on any given token in connected speech, this automatic classification enabled an improvement of our study without substantial annotator time investment. In addition, we added *Speechrate*, calculated as the average syllable duration in the utterance in which the plosive occurred. We included the variables *Sex* (male, female), *Variety* (German, Austrian), as well as the random variables *Speaker*, *Word*, *Sentence*.

To build the linear mixed effects regression models, we used the `lmer()` function of the `lme4` package in *R* [27]. We included all independent variables and their interactions (two and three-way) into the models and reduced the predictors and interactions using stepwise backward selection. Correlating variables were either added separately (e.g., *Plosive* and *Fortis_Lenis*) or orthogonalized. Non-significant factors and interactions were removed as long as the model would still significantly improve, given its AIC value, its degree of freedom and a model comparison using the `anova()` function [28, 29]. The threshold significance value is set at α = .05 for all tests.

3. Results and Discussion

In the following presentation and discussion of results, we will first report the models for the acoustic measures plosive, closure and burst duration separately and then analyze in detail certain effects across all models. Significant random factors, such as those controlling for the variation due to the segmental context, will not be discussed. The independent variable *Word_Class* was not significant in any model. The random variables *Speaker*, *Word* and *Sentence* significantly (p <.001) improved all models.

Our study purposely drew from two corpora with similar texts but speakers with different regional varieties. The models presented in the following section were built on the complete data set; where additional analysis was necessary, we modeled data from *GRASS* and the Kiel Corpus separately. However, a direct comparison of effect sizes and significance is not possible, as our sample set from the Kiel Corpus (n = 406) was much smaller than that from GRASS (n = 1091). Nonetheless, both samples are large enough to draw preliminary conclusions about possible differences in plosive production in these two varieties.

3.1. Total plosive duration

After reducing all non-significant factors and interactions, the final model for total plosive duration had the following syntax: $lmer((closDur + burstDur) \sim (Boundary + Variety)^2 + Word\_Stress + Speechrate + Follow\_Duration + (Fortis\_Lenis + Variety)^2 + Micro + Foll\_Manner + (1|Word) + (1|Sentence) + (1|Speaker) + (1|boundaryType))$.

The overall duration of the plosive (closure plus burst) is conditioned in both varieties by *Word_Stress* (β = 8.29e-03, t = 2.10e+02, p $<$ .01): stressed syllables have longer plosives and this is modulated by the presence or absence of an adjacent phrase boundary (β = -8.82e-03, t = -2.74, p $<$ .1). However, the latter appears to function differently in the two datasets; while in *GRASS* plosives at the onset of stressed syllables are shorter in phrase-medial position (β = -1.34e-02, t = -1.66, p $<$ .1), in the Kiel Corpus phrase-medial plosives are not significantly

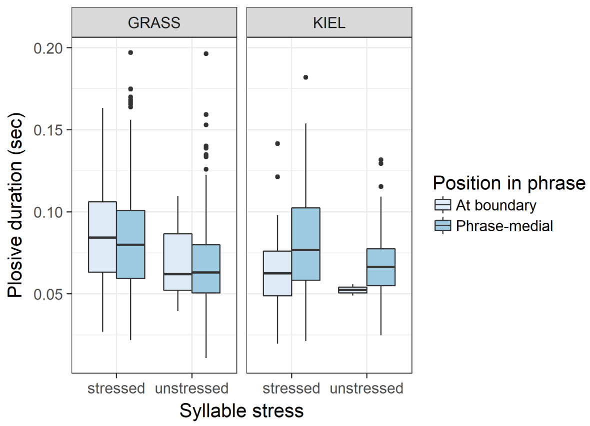

Figure 1: *Plosive duration (combined closure and burst) across both corpora.*

shorter than their phrase-edge counterparts (i.e., the interaction term *Boundary:Variety* was significant, β = 2.45e-02, t = 4.02, p $<$ .001). This result is in line with what Ulbrich [19] found in her comparison of prosodic phrasing in the different German varieties, namely that German speakers speed up at the beginning of phrases, and slow down at the end, to a smaller degree than Swiss and Austrian speakers of German (cf. Figure 1).

3.2. Closure duration

The final model for closure duration had the following syntax: $lmer(closDur \sim Speechrate + (Word\_Stress + Boundary)^2 + (Boundary + Corpus)^2 + Follow_{M}anner + (Plosive + Prev\_Dur)^2 + (Plosive + Follow\_Dur)^2 + (1|Word) + (1|Sentence) + (1|Speaker) + (1|boundaryType))$.

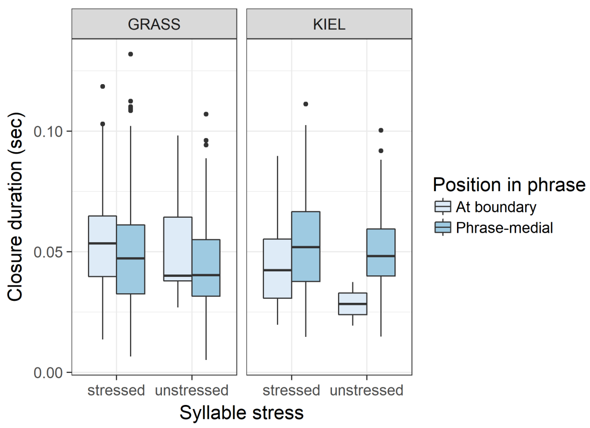

Figure 2: *Closure duration across both corpora.*

The pattern observed for the closure durations alone is similar to that observed for the full plosive duration. The effect of *Word_Stress* shows that overall closures tend to be longer for stressed tokens (μ = 0.05, β = 1.36e-02, t = 2.32, p $<$ .05) than for unstressed tokens (μ = 0.046). The significant interaction between *Boundary* and *Word_Stress* (β = -1.07e-02, t = -1.94, p $<$ .05) showed that the effect of *Word_Stress* is weaker for plosives in boundary-medial position than for plosives at the edge of phrase boundaries. Figure 2 illustrates this interaction.

3.3. Burst duration

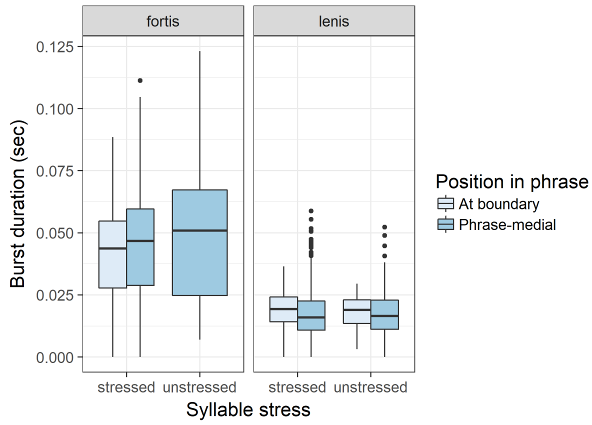

Figure 3: *Burst duration in fortis and lenis plosives (GRASS and Kiel Corpus data combined). No measurable unstressed fortis plosives at phrase boundaries were found in the current data.*

The final model for burst duration had the following syntax: $lmer(burstDur \sim (Variety + Boundary)^2 + (Variety + Word\_Stress)^2 + Speechrate + (Follow\_Manner + Follow\_Dur)^2 + (Fortis\_Lenis + Variety)^2 + (1|Word) + (1|Sentence) + (1|Speaker))$. Unlike closure duration, burst duration appears not to be conditioned by the prosodic boundary context. While burst duration differs between fortis (longer) and lenis (shorter) plosives, and on the basis of lexical stress and global speech rate, there was no effect of the boundary condition on burst duration in our data. Figure 3 shows that, similarly to plosive and closure duration, overall bursts tend to be longer in stressed than in unstressed tokens (β = 5.69e-03, t = 2.47, p $<$ .05).

3.4. The role of prosodic boundaries and word stress

Our results on the complete data set as well as on the subsets for *GRASS* and Kiel Corpus show that the total plosive duration and the closure duration are affected by whether there is a prosodic boundary or not. The burst duration, however, is similarly long in both boundary conditions. Burst duration results primarily from the position of the vocal folds at the time of closure release and their following movements (i.e. to restart phonation), so it appears that burst duration is an epiphenomenon of other articulatory features rather than something that speakers directly control to signal boundary strength. However, this also implies that the articulatory strengthening at prosodic boundaries (cf. e.g. [6]) is *not* only an epiphenomenon of articulatory organization, but that speakers more directly modify their articulation at these locations.

Separate analyses of *GRASS* and Kiel Corpus showed that whereas burst duration does not vary significantly with stress for the Austrian speakers, bursts are even highly significantly longer for stressed tokens than for unstressed ones in the German subset (β = 0.014, t = 2.87, p $<$ .01). Analyzing the effect of *Word_Stress* on closure duration in the two subsets separately, however, revealed the contrary tendency: whereas in the German subset, closures do not significantly differ in stressed and unstressed word initial syllables, in the Austrian subset they were even highly significantly longer (β = 1.95e-02, t = 2.90, p $<$ .01). These opposite results for closure and burst are in line with our results on the complete dataset: independent of the variety, stressed plosives tend to be longer than unstressed plosives, however the strategy for this lengthening is variety specific: whereas German speakers increase burst duration, Austrian speakers increase closure duration.

3.5. The role of local and global speech rate

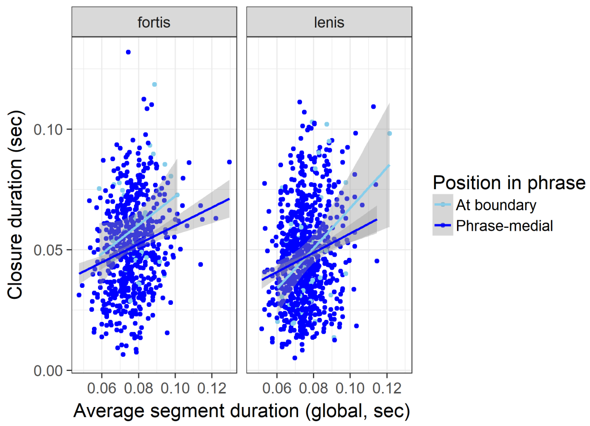

Figure 4: *Closure duration as conditioned by global speech rate of the utterance.*

We find evidence of both global and local speech rate effects on plosive duration; global speech rate refers to the average syllable duration of the whole spoken unit, while local speech rate refers to the duration of preceding and following (adjacent) segments. Correlation tests showed that global and local speech rate were only weakly correlated, but that this correlation was higher for following segments (r = 0.26) than for previous segments (r = 0.19). An increase in global speech rate leads to a significant increase in plosive duration in all contexts (β = 6.60e-01, t = 8.97, p $<$ .001) and in all varieties (cf. Figure 4). There appears to also be a separately-conditioned relationship at a local level, between the plosive and immediately adjacent segments. In the Kiel data, plosive duration was significantly longer if previous segments were longer (β = 0.68, t = 2.15, p $<$ .05), and this effect was weakened by *Speechrate* (β = -10.30, t = -2.42, p $<$ .05). This interaction can be interpreted such that plosive duration is conditioned by the previous segment, but if the overall and local speech rate are similarly high, the effect of local speech rate disappears.

In the models for closure duration, we observed significant interactions between type of plosive and local speech rate, meaning that the durations of the different plosives are significantly differently strongly affected by the local speech rate, but similarly conditioned by the global speech rate. The duration of /p/, for instance, is significantly stronger conditioned by *Previous_Duration* than /b/ (β = 1.57e-01, t = 2.91, p $<$ .01). /g/ and /k/, on the other hand, are significantly weaker conditioned by local speech rate than /b/.

3.6. Durational aspects of the lenis-fortis distinction

In both varieties, lenis plosives are shorter overall and have shorter bursts (if at all) than fortis plosives (Plosive duration: β = -2.73e-02, t = -10.22, p $<$ .001). However, the difference between fortis and lenis plosives is larger in the Kiel data (β = -5.838e-03, t = 3.097, p $<$ .05), cf. Table 1.

Table 1: *Fortis and lenis plosive durations (sec).*

	Fortis	Lenis
GRASS	0.0956	0.0646
Kiel	0.0961	0.0646

In both corpora, the fortis-lenis distinction appears to be driven by burst duration rather than by closure duration, which is not significantly affected. In contrast with [10], we find that burst duration is the feature which best distinguishes fortis and lenis plosives in our data. Our data, however, are in line with [15], who found that closure duration for word-initial plosives is not significantly different for lenis and fortis plosives. Given that [15] did not analyze burst duration, we make the additional contribution of confirming that burst duration functions separately from closure duration, and can signal this contrast even when closure durations do not differ.

4. Conclusions

Via a parallel investigation of plosives in two corpora, we compare the realization of these segments at prosodic boundaries and at non-boundary locations in two varieties of German, finding evidence of variety-specific variation in the use of closure and burst duration to mark distinctions between fortis and lenis plosives, as well as to mark prosodic features such as lexical stress and boundaries. As found in previous studies for different varieties of German as well as other Germanic languages, fortis plosives tend to have a longer duration than lenis plosives. However, stress marking in plosives is different in the two varieties studied, being driven more by burst duration in the Kiel Corpus data, and more by closure duration in the GRASS data. Additionally, plosive duration distinguishes stressed boundary-adjacent plosives from utterance-medial plosives in the GRASS data, but we do not find evidence of such a distinction in the Kiel data; this effect appears to also be driven by variation in closure duration. In both varieties, plosive duration is conditioned both by global speech rate (i.e. averaged over the whole utterance); local speech rate (i.e. duration of adjacent segments) also had an effect in the Kiel Corpus.

The differing results for these two varieties of German underline how essential it is to make specific comparisons across varieties, particularly for the purpose of developing automatic tools. A tool trained on our Kiel Corpus data might fail to correctly classify plosives as falling in stressed syllables and/or at prosodic boundaries in the GRASS data, since the durational features associated with these structural differences are not the same in our two datasets. Rather, such tools require variety-specific training materials, or else information from comparative studies such as the current work, in order to attain optimal function in specific varieties or dialects.

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