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# PROSODIC CONDITIONING OF PHONETIC DETAIL OF GERMAN PLOSIVES

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## ABSTRACT

The present study investigates the influence of prosodic structure on the fine-grained phonetic details of German plosives which also cue the phonological fortis-lenis contrast.

Closure durations were found to be longer at higher prosodic boundaries. There was also less glottal vibration in lenis plosives at higher prosodic boundaries. Voice onset time in lenis plosives was not affected by prosody. In contrast, for the fortis plosives VOT decreased at higher boundaries, as did the maximal intensity of the release.

These results demonstrate that the effects of prosody on different phonetic cues can go into opposite directions, but are overall constrained by the need to maintain phonological contrasts. While prosodic effects on some cues are compatible with a ‘fortition’ account of prosodic strengthening or with a general feature enhancement explanation, the effects on others enhance paradigmatic contrasts only within a given prosodic position.

**Keywords:** prosodic structure, phonetic detail, domain-initial strengthening, feature enhancement.

## 1. INTRODUCTION

Part of the variation in the speech signal is induced by the prosodic structure of the utterance. At the beginning of a prosodic domain, speech sounds are articulated more strongly than in medial position (e.g., [7]). In English, for instance, consonants are often produced with longer closures and VOT [4, 5] after a phrase than after a word boundary.

Importantly, some of these acoustic parameters affected by prosody are also cues to the phonological voicing contrast of lenis /b, d, g/ versus fortis /p, t, k/. In both English and German, fortis plosives are known to be produced with longer closures and longer VOT than lenis plosives [6]. If prosodic strengthening operates on the same

cues in a uniform direction – i.e., towards ‘fortition’ –, this raises the question of how prosodic structure and the need for phonological contrast interact in determining the fine phonetic detail of fortis and lenis plosives.

This issue has been addressed in only a few studies. Cho and McQueen [3], comparing Dutch and English, propose that distinctive features are enhanced in prosodically strong positions (feature enhancement account). Since languages differ in their phonetic implementation of distinctive features, the effect of prosody on phonetic detail is language specific. Thus, in English, fortis plosives have longer VOT at higher boundaries, whereas in Dutch they have shorter VOT.

The current study investigates the interplay of prosody and phonological contrasts in German, a language with its own specific cues to the fortis-lenis contrast, which allows us to evaluate the ‘fortition’ versus ‘feature enhancement’ accounts of prosodic strengthening. Whereas the fortition account predicts all plosives to become more fortis-like in higher prosodic domains, feature enhancement leads to a hypothesized increase in paradigmatic contrasts at higher boundaries.

## 2. METHOD

We recorded sentences read by ten speakers and examined the effect of prosodic boundary strength on four cues to the fortis-lenis contrast.

### 2.1. Speech materials

We investigated the German plosives /b, d, g, p, t, k/ and selected three minimal word pairs where the plosives occurred in word-initial position and were followed by the vowel /a/. All target words were bi- or polysyllabic with primary stress on the first syllable:

*backen* ['bakən] ‘bake’ vs. *packen* ['pakən] ‘pack’,  
*Dank-* ['daŋk] ‘thanks’ vs. *Tank-* ['taŋk] ‘tank’,  
*Garten-* ['ga:tən] ‘garden’ vs. *Karten-* ['ka:tən]  
‘cards’.

The target words were embedded in sentences with four different syntactic structures (see Table 1 for an example). The preceding context was the diphthong /ɪə/ in the pronoun *wir* [vɪɐ] ‘we’.

Note that we do not assume any direct mapping between syntax and higher-level prosodic structure. The prosodic realizations of each sentence token were classified later based on a prosodic analysis (see below).

a)	<i>Am Samstag wollen wir backen und <b>einkaufen</b>.</i> ‘On Saturday, we want to do baking and <b>shopping</b> .’
b)	<i>Gepfamt hatten wir, Backen und <b>Einkauf</b> zuerst zu machen.</i> ‘Our plan was to do baking and <b>shopping</b> first.’
c)	<i>Einkaufen müssen wir, backen für <b>morgen</b>, und aufräumen.</i> ‘We have to go shopping, bake for <b>tomorrow</b> , and tidy up.’
d)	<i>Heute segeln wir. Backen kann <b>Anna</b>.</i> ‘Today we go sailing. Baking can be done by <b>Anna</b> .’

**Table 1:** Speech materials for /b/: Target word ‘*backen*’ in four sentence types.

## 2.2. Participants

Ten native speakers of northern German, five female and five male university students, participated in the experiment.

## 2.3. Recording procedure

Participants were familiarized with the test materials prior to the recording, and read the sentences at their normal speech rate, in a fluent and natural way. They did not receive any instruction on prosodic phrasing. We induced deaccentuation of the target words by asking speakers to place a contrastive accent on a non-target word in the utterance (as indicated in bold in Table 1). Each sentence was repeated five times, in randomized blocks of four sentence types per plosive. In total, 1200 sentence tokens were recorded.

## 2.4. Prosodic categorization

We defined three prosodic categories to which we assigned our data: the *Major* category was characterized by the presence of a pause and a boundary tone between the target and the preceding word, the *Minor* category by a boundary tone, but no pause, and the *Word* category by the

absence of both (these boundaries correspond roughly to the intonation phrase, the intermediate phrase, and the prosodic word boundaries in [2].) Two trained native listeners coded boundary tones separately, with 92.7 % agreement. Three tokens that remained ambiguous after re-inspection were excluded from analysis, as were 19 accented target words. The final data set consisted of 1178 tokens.

## 3. RESULTS

For all analyses, we built linear mixed effects (lme) models [1] with Prosodic Category (henceforth: PCat; levels: Major, Minor, Word), Place of Articulation (Place; labial, alveolar, velar), and Phonological Voicing (Voice; fortis, lenis) as fixed factors and with Speaker as a random variable. Table 2 summarizes the results and the implications for the feature enhancement and fortition accounts.

Acoustic Cue	Prosodic Effect	Feature Enhancement	Fortition
<i>Closure</i>	longer closures at higher boundaries	pro	pro
<i>VOT</i>	shorter VOT for /p,t,k/ at higher boundaries	contra	contra
<i>Glottal Vibration</i>	less at higher boundaries	contra	pro
<i>Burst Intensity</i>	lower at higher boundaries	contra	contra

**Table 2:** Effects of prosody on four cues to the fortis-lenis distinction and their theoretical implications.

### 3.1. Preboundary lengthening

To evaluate our prosodic categorization, we first analyzed ‘final lengthening’, another well-known correlate of prosodic structure (e.g., [8]). Lme analysis of the preboundary syllable duration yielded significant main effects of PCat ( $F(2, 1160) = 1122.91$ ;  $p < 0.001$ ) and Place ( $F(2, 1160) = 3.19$ ;  $p < 0.05$ ), but no interactions. Additional analyses showed that the effect of Place was entirely due to /g/, for which the preboundary syllable was slightly longer (on average 9.65 ms) than before the other plosives. Importantly, all prosodic categories differed from each other (all  $p < 0.001$ ; means: Major 230 ms, Minor 118 ms, Word 99 ms). We take this result as evidence for the validity of our prosodic categorization.

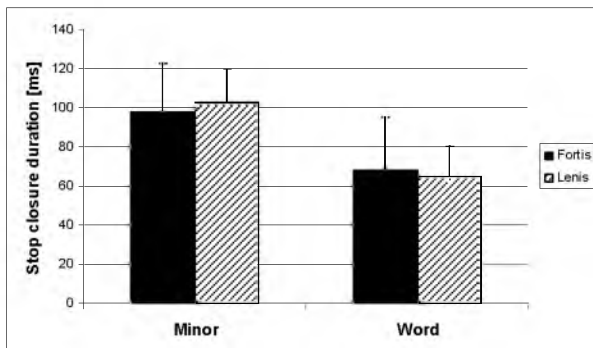
### 3.2. Closure duration

We analyzed the duration of the plosive closure for the prosodic categories Minor and Word only, since the beginning of the closure could not be determined after the pause in the Major condition. PCat ( $F(1,681) = 508.34$ ;  $p < 0.001$ ) and Place ( $F(2,681) = 73.55$ ;  $p < 0.001$ ) emerged as significant, as did the interaction between PCat and Voice ( $F(1,681) = 4.04$ ;  $p < 0.05$ ). To investigate the interaction, we split the data by Voice.

For fortis plosives, PCat and Place were significant predictors (PCat:  $F(1,352) = 211.64$ ;  $p < 0.001$ ; Place:  $F(2, 352) = 39.85$ ;  $p < 0.001$ ). As expected, closures were longer at the higher prosodic boundary (see Figure 1). Pairwise comparisons showed that closure duration differed significantly (all  $p < 0.001$ , Bonferroni corrected) for all places of articulation ( $p > t > k$ ).

The analysis of the lenis plosives also yielded a main effect of Place ( $F(2,329) = 32.97$ ;  $p < 0.001$ ). Similar to the fortis plosives, all places of articulation differed from each other (all  $p < 0.001$ ;  $b > d > g$ ). Additionally, we observed a main effect of PCat ( $F(1, 329) = 304.79$ ;  $p < 0.001$ ), with again longer closures in the Minor condition.

**Figure 1:** Closure duration of plosives as a function of Prosodic Category and Voice (fortis, lenis)



As illustrated in Figure 1, the effect of the prosodic category is slightly larger for the lenis plosives, which explains the interaction. As also reported by Kohler [6], closures were not longer for fortis than for lenis plosives in word-initial position, even though closure duration is known as an acoustic correlate of the Voice contrast in word-medial positions. In word-initial position, this distinction appears to be cued by other acoustic parameters.

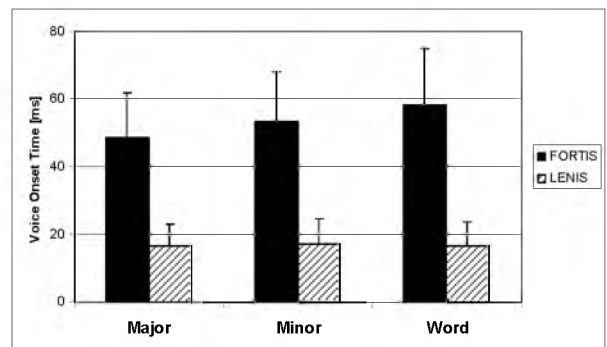
### 3.3. Voice Onset Time

For Voice Onset Time (VOT, Figure 2), there were main effects of PCat ( $F(2,1160) = 34.45$ ;  $p < 0.001$ ), Place ( $F(2,1160) = 139.32$ ;  $p < 0.001$ ), and Voice ( $F(1,1160) = 4084$ ;  $p < 0.001$ ), and an interaction of PCat and Voice ( $F(2,1160) = 25.40$ ;  $p < 0.001$ ). To investigate this interaction, we split the data by Voice.

For the fortis plosives, there were significant main effects of PCat ( $F(2,583) = 28.59$ ;  $p < 0.001$ ) and Place ( $F(2,583) = 57.78$ ;  $p < 0.001$ ). Pairwise Bonferroni comparisons showed different VOT for all three places of articulation ( $p < t < k$ ; all  $p < 0.001$ ). Across places of articulation, VOT was *longest* after Word boundaries (Major (mean: 48.5 ms)  $<$  Minor (53.4)  $<$  Word (58.1); all  $p < 0.001$ ). This is unexpected under a feature enhancement theory, which predicts longer VOT after higher prosodic boundaries, favoring perception of fortis.

For the lenis plosives, the main effect of PCat was absent ( $F(2, 585) = 1.19$ ;  $p > 0.1$ ). This explains the interaction in the overall analysis. The effect of Place was significant ( $F(2, 585) = 227.38$ ;  $p < 0.001$ ). Pairwise Bonferroni comparisons revealed that all places of articulation differed from each other (all  $p < 0.001$ ), showing a pattern of  $b < d < g$ , which is the same as for the fortis plosives.

**Figure 2 :** Voice Onset Time as a function of Prosodic Category and Voice (fortis, lenis)



### 3.4. Intensity of release noise (fortis plosives)

For the fortis plosives, we analyzed the intensity maximum [dB] during the first 15ms of the release noise as a function of PCat and Place. Both factors and the interaction emerged as significant (PCat:  $F(2, 579) = 4.23$ ;  $p < 0.05$ ; Place:  $F(2, 579) = 225.77$ ;  $p < 0.001$ , PCat \* Place:  $F(4,579) = 3.72$ ;  $p < 0.01$ ).

Because of the interaction, we analyzed the effect of PCat separately for each plosive. The effect was absent for /p/ ( $F(2,193) = 0.72$ ;  $p > 0.1$ ), but present for /t/ ( $F(2,190) = 3.21$ ,  $p < 0.05$ ) and /k/ ( $F(2,196) = 9.82$ ;  $p < 0.001$ ). For /k/, the release was slightly, but significantly softer (mean difference: 1.4 dB) in the Major condition than in the other two conditions (both  $p < 0.01$ ), which did not differ from each other ( $p > 0.1$ ). For /t/, the release was softer after a Major than after a Word boundary (mean difference: 0.8 dB). We found no effect for /p/, possibly because the estimation of the maximum release noise intensity was unreliable for 10% of these tokens, which had a very short VOT (<30 ms).

Both the fortition account and the feature enhancement account predict that release noises are louder at higher prosodic boundaries, that is, exactly the opposite of what we found for /t/ and /k/. We propose the following explanation. Since closure durations do not distinguish between fortis and lenis, and the presence of glottal vibration is difficult to detect in closures as short as normally attested for plosives at small prosodic boundaries, cues in the release are highly informative. Longer aspiration and louder release noise support the perception as fortis.

### 3.5. Glottal vibration (lenis plosives)

For the lenis plosives, we examined the percentages of the closures produced with glottal vibration as a function of PCat. Of all lenis plosives, 246 tokens (42% of the data) were realized without any glottal vibration. Most of these tokens were produced after a major boundary (221). This is unexpected under a strict feature enhancement account, but can easily be explained on aerodynamics grounds, as our Major boundary always implied a pause.

We then analyzed the percentage of the closure produced with glottal vibration as a function of PCat and Place for the Minor and Word boundary only. Place emerged as a main effect ( $F(2,272) = 3.89$ ;  $p < 0.05$ ,  $b < (d = g)$ ). The main effect of PCat was also significant ( $F(2,272) = 83.56$ ,  $p < 0.001$ ), with a mean of 35% of the closure duration produced with glottal vibration for Minor and of 52% for Word.

Assuming that glottal vibration is a cue to the fortis-lenis distinction, this direction of the effect of PCat is unexpected under a feature enhancement account. Given that closure duration is highly

correlated with PCat, it is possible that it is actually closure duration which is driving this effect of PCat on glottal vibration. Apparently, shorter closure durations favor higher percentages of glottal vibration.

## 4. GENERAL DISCUSSION

Prosodic structure does not affect the cues to the fortis-lenis distinction in a uniform way (see Table 2). Closure durations were longer at higher prosodic boundaries, confirming both the feature enhancement and the prosodic strengthening account. In contrast to both accounts, VOT as well as burst intensity increased for fortis plosives at smaller boundaries. Importantly, this increase helps maintaining the distinction between fortis and lenis plosives at smaller boundaries, where these plosives were found to hardly differ in their closure duration, and glottal vibration is often difficult to perceive due to masking from the surrounding vowels. Our data therefore suggest adaptation of the feature enhancement theory. Acoustic cues to a given phonological feature are not necessarily enhanced at higher prosodic boundaries, but in prosodic positions where this is necessary to maintain a clear distinction between different phonemes.

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