

Acoustic correlates of the fortis/lenis contrast in Swiss German plosives

Sean A. Fulop
University of Calgary

1.0 INTRODUCTION

Several of the High Allemanic dialects of German, collectively known as Swiss German, exhibit consonantal contrasts which differ in nature from those in other German dialects. Through spectral analysis, the nature of the two Swiss German plosive series (/p, t, k/ contrasting with /b, d, g/) will be investigated. The manner in which these series contrast is not one of voicing or aspiration, and can best be characterized as fortis versus lenis. The acoustic character of the fortis/lenis contrast in Swiss German plosives will be explored by examining the main spectral features of each plosive in three phonetic environments: word-initially, word-medially, and word-finally.

The problem to be addressed directly is one of speech production: what, if any, acoustic correlates can be found to distinguish fortis stops from lenis ones in (1) the closure phase, and (2) the release phase of the the plosives? Additionally, a consideration of possible articulatory gestures associated with fortis and lenis production will lead to a simple hypothesis predicting two spectral correlates of the vowels following fortis plosives, at least one of which has been clearly observed.

2.0 THE CONTRAST *fortis/lenis*

2.1 [\pm fortis] in a phonological system

A great deal of discussion has taken place in the past concerning the nature of consonantal contrasts. The features voiced/voiceless, aspirated/unaspirated, and tense/lax have variously been applied to the descriptive differentiation of consonant series. The opinion supported here is that put forth by Kohler (1979, 1982, 1984): the fortis/lenis opposition is most closely related to the tense/lax opposition. It will be shown that this explanation incorporates both the closure and release phases of stops as a single dynamic system, unlike the traditional account of such contrasts in terms of Voicing Onset Time alone.

The feature [\pm tense], phonologically speaking, has not traditionally met with unanimous reception. Catford (1977: 203) allows that tense/lax features may be productive for stops. H. Sweet (1877) was the first to suggest that a parameter of tension may be manifested by specific glottal gestures (such as voicing accompanying lax obstruents). This point of view was taken up by

Jakobson, Fant and Halle (1952), who suggested several articulatory gestures to accompany tenseness in stops, specifically the strength of the explosion, caused by muscular strain affecting the walls of the vocal tract and glottis. Catford (1977) has replied that it is doubtful if this exists, but reports that Malecot (1970) has singled out air pressure behind the point of articulation as being a reliable indicator of tense obstruents. The system of laryngeal features proposed by Halle and Stevens (1971) does not incorporate the tense/lax opposition as a separate phonatory dimension, placing voiced and plain (voiceless unaspirated) stops together under the rubric of a "neutral" glottal state ([spread glottis, -constricted glottis]). Clearly, the parameter (or perhaps several parameters) of tenseness in obstruents has never been definitively described in relation to articulation or acoustics.

Kohler (1984) has argued for the adoption of the feature [\pm fortis] in general phonological description. He singles out the atemporal nature of conventional descriptions of the /b, d, g/ versus /p, t, k/ opposition as a major weakness. Specifically, he characterizes much past work as a "translation theory" which maps static, discrete phonological elements like [\pm voiced] and [\pm aspirated] onto dynamic and continuous processes (i.e. the speech chain). He argues for the integration of the time dimension into the phonology via a specific agenda for linking the phonological categorization of obstruents with the terms *fortis* and *lenis*, stressing that [\pm fortis] is not proposed as an abstract feature, but rather one with a phonetic base provided by degrees of articulatory power.

2.2 The Temporal Nature of Fortis/Lenis Plosives

Through perceptual and acoustic studies (Kohler 1979, 1982, 1985) it has been demonstrated that the fortis/lenis plosive opposition in New High German is manifested as acoustic and articulatory features in two distinct temporal frames. These properties will now be reviewed, along with current results concerning the perceptual relevance of each such feature with respect to the maintenance of a productive contrast between the two plosive classes in the language.

2.2.1 The Closure Phase

The period of silence immediately preceding the release burst of the plosive (but following the preceding segment) will be referred to as the closure phase. It is here that the perceptually salient correlates of articulatory tension are manifested. It has been suggested (Jakobson, Fant and Halle 1952) that greater articulatory power is present in the articulation of fortis plosives, which manifests itself in more extensive movements as well as greater peak and average velocities of the articulators (Kohler 1984). This leads to the well-documented tendency of the length [preceding vowel plus closure phase] to remain constant over fortis and lenis

segments. It has been shown (Kohler 1977) that the duration ratio vowel/(vowel + closure) is important for the fortis/lenis distinction. Specifically, in NHG a ratio above 0.70 is a clear indication of a lenis stop (in the case of a phonologically stressed /a:/ before a plosive), while a ratio below 0.60 is unequivocally related to a fortis plosive (Kohler 1979).

In addition to the durational features of the closure phase, it has been found that, in V₁CV₂ contexts, V₂ is prepared through coarticulation at an early stage in the speech chain (Öhman 1966). If C is a fortis plosive, and thus quite long, the articulation for V₂ will be mainly shaped during the closure, whereas in the case of the much shorter lenis plosive the coarticulatory effect will extend into V₁ and be apparent in different formant transitions (Kohler 1984). Kohler identified the two dimensions of duration ratio and formant transitions as perceptually salient for the contrast, but placed duration ratio above formant transitions in a saliency hierarchy.

The effect of the manner of plosive articulation on the local F₀ (fundamental frequency) contour has also been investigated. The experimental results of Kohler (1985) show that a higher pre-closure F₀ within the final 100 ms period of the preceding vowel is associated with a fortis plosive, as against a lenis one, providing the global intonation pattern can incorporate such a modification without losing its characteristic F₀ macrostructure. This F₀ feature can be a cue to stop manner in perception. Kohler suggests that the local F₀ effect is connected with different degrees of vocal fold tension in the production of the two stop manner classes of German.

2.2.2 The Release Phase

The release phase of the plosive begins at the end of the plosion itself, as soon as the articulators have been separated. It is here that any glottal activity occurs which may contribute to the category separation in perception of fortis from lenis. In stops, aspiration and voicing can be seen to be glottal reinforcements of the fortis and lenis actions at the oral valve to produce the necessary intensity differences (Kohler 1984). In standard High German, fortis stops are accompanied by aspiration during their release. In other languages the fortis/lenis contrast may be manifested by voicing accompaniment in the lenis stops. The importance of these release features must not be underestimated, for in utterance-initial stops the closing movement can add very little to the differentiation. In this case, the distinction is carried by the release phase, meaning the accompanying glottal activity.

¹ The effect is observed in English in CVC syllables (*bat, bad; back, bag*), where there appears to be a certain fixed 'quantum' of duration available for the monosyllable, the vowel being lengthened when the consonant is shortened (Catford 1977; 200).

For plosives in initial position, then, it is clear that the fortis/lenis distinction in perception must shift its salient features from the closure to the release. What remains unclear is precisely what release features can be perceptually salient. It is the opinion of Kohler (1984) that only strongly recognizable glottal features such as voicing and aspiration may be of importance. While a perceptual study has not been undertaken here, it does seem reasonable to extrapolate from Kohler's findings regarding the perceptual salience of pre-closure formant transitions to the suggestion that post-release formant transitions may also be perceptually salient.

2.2.3 Global Tension in Fortis Manner

It has been stated above that an increase in power expended by the articulators at the oral valve accompanies the stronger closure of a fortis plosive. Evidence has been found which supports the notion that the larynx also experiences a certain increase in tension during the production of a fortis plosive. Investigations by Catford (1977) have indicated that an increase in "phonatory tension" accompanies fortis obstruents in Javanese, while Ohde (1983) has made reference to vocal cord tension to explain F_0 increases associated with voiceless (fortis) stops in General American English. Ohde cites Honda (1981) for physiological data showing the relationship between increased longitudinal vocal cord tension and higher fundamental frequency. Kohler (1982) has summarized the fortis—tension relationship in global articulatory terms: "Different levels of muscular activity (articulatory effort) seem to be set for the vocal tract in its entire extension from the larynx upwards."

The effects of this global tension in each temporal phase of the fortis plosive are distinct. The closure phase is affected primarily by articulatory tension at the oral valve (point of articulation), causing increased closure speed and duration. These tension features of the closure provide perceptual indications of the plosive contrast in word-medial and word-final position. The release phase, where glottal features are found, is primarily affected by tension in the vocal folds. The precise acoustic correlates of this phonatory tension in fortis obstruents are not clearly known.

Kohler and van Dommelen (1987), however, explored the possibility that global voice quality may influence fortis/lenis judgements in obstruent perception, and found that "tense voice" shows a fortis bias. They created stimuli in which fortis and lenis stops were placed within one of three voice quality frames: tense voice, neutral voice, and breathy voice.

Across all the utterances, the spectra of "tense voice" differ from those of the other two voice qualities by having a less prominent first spectral peak in relation to the higher-order peaks and/or a less steep spectral tilt. This reduces the lower-frequency energy concentration and, therefore, the ratio between the lower portion of the spectrum [below 1000 Hz]

and the upper one; it also defines the peaks more sharply. This corresponds to the narrow formant bandwidths in the laryngealized as against the plain vowels described by Ladefoged (1982) for !Xóó, a Khoisan language of southern Africa. [pp. 367-369]

Subjects showed an increased tendency to judge plosives as fortis when they were presented within a tense voice quality frame. They found the effect to exhibit both a pre-closure and a post-closure component, with the differing spectral energy distribution of tense voice manner cueing the opposition.

3.0 SWISS GERMAN PLOSIVES

At this point, given the literature that has been reviewed above, it is possible to formulate a hypothesis predicting certain acoustic (spectral) features of the release phase of fortis plosives, aside from those associated with voicing and aspiration.

1. increased articulatory power (and speed) will result in faster formant transitions from plosive release to vowel stasis;
2. increased glottal tension will result in increased intensity of high frequency formants in the post-release sonorant region, as a source phenomenon.

3.1 General Phonetic Properties

While Swiss German dialects have never been widely studied in a phonetic context, their general phonetic properties, in comparison with those of standard High German, have been recognized. Specifically, it is known that all obstruents are in general voiceless and all stops (there are six: /p, t, k, b, d, g/) are unaspirated (Moulton 1983; Dieth 1950). There is no syllable position in which the commonly recognized release features (voicing and aspiration) differentiate between fortis and lenis. In all word-medial and word-final cases the distinction is carried by articulatory timing, the fortis consonant being substantially longer (Kohler 1984). The question then remains as to what fortis plosive features could possibly carry the distinction in utterance-initial position. It is the opinion of Kohler (1984) that the fortis/lenis contrast in such positions is in fact neutralized. However, the experimental results presented below indicate quite clearly that other acoustic properties of the release and post-release phase can be directly associated with the [+fortis] feature.

3.2 Analysis of Swiss German Speech

3.2.1 Methods

A native speaker of Zürichtötsch, the Zurich dialect of Swiss German, was provided with a small corpus of words in list form. The words were carefully read aloud by the speaker, and recorded on tape.¹ The corpus included several examples of each type of Swiss German plosive (/p, t, k, b, d, g/) in each of three phonetic environments (word-initial, word-medial, word-final). From the tape recording, a wide-band spectrogram of each word in the corpus was produced, using the Kay Digital Sonograph 7800. Through examination of the spectrograms, the spectral features common to each of the six plosive varieties were deduced. Statistical analysis was applied where necessary to show the significance of the results; however, any noted features associated with a particular type of segment were invariably manifested in all relevant examples in the corpus.

3.2.2 Results

The following features of Swiss German plosives were evident from the spectrograms:

Voicing Onset Time (VOT) was virtually identical for fortis as against lenis stops: mean VOT for both /t/ and /d/ was approximately 14 ms and showed no significant variance from fortis to lenis.

Voicing of the stops was not evident, with the exception of [p] in a lateral plosion ([pɫV]). In such cases, VOT diminished to zero.

Aspiration was clearly evident only in final position, where it occurred to the same degree in fortis and lenis stops, and was accompanied by low-level vocalization.

Closure duration of fortis stops was clearly longer than that of lenis stops (evident in medial and final positions only); the fortis closure was on the order of 4 times the length of the lenis closure.

Occurrences of [t] and [d] in initial position show that an F₂ locus at 2 kHz is generally associated with both classes of alveolar stop.²

¹ The speaker was female, in her thirties, and was not entirely phonologically fluent in English.

² A clip-on condenser microphone was used, with a Technics 2-track reel-to-reel (quartz-locked, isolated loop design).

Post-release sonorant formants above F_2 show increased intensity, movement, and clarity following all types of fortis stop, as against lenis stops.

With respect to the closure phase, these results demonstrate the validity of closure duration as a distinguishing feature of fortis as against lenis stops. The commonly recognized release features of aspiration and voicing, however, clearly do not carry the fortis/lenis distinction. Formant loci as well have been shown to be non-distinctive. The release and post-release phase of the observed stops do differ in the "activity" level (includes intensity and movement in transition) of high formant frequencies. The observed effect is strikingly similar to the features of global tense voice used in the perceptual study by Kohler and van Dommelen (1987). It remains to be determined whether fortis plosive production in Swiss German in fact exploits the perceptual salience of tense voice demonstrated by these authors.

4.0 GENERAL DISCUSSION

Kohler (1984) states:

Word-initial stops must be characterized generally by the presence or absence of voice or aspiration, if [\pm fortis] distinctions are to be maintained in the language.

In isolated words [of Swiss German] the opposition is only signalled intervocalically.

Kohler is essentially claiming that voicing and aspiration are the only viable plosive release features to carry a fortis/lenis distinction in the absence of the perceptually powerful closure duration cue. Beyond that, he claims that the fortis/lenis opposition in Swiss German word-initial plosives is only maintained where connected speech provides the necessary intervocalic environment for the perception of a closure duration cue. This is equivalent to the aforementioned claim that, in isolated word production, word-initial plosive classes are neutralized.

The spectral features of Swiss German plosives described above clearly exhibit the increased formant activity predicted earlier. Whether this is actually the result of increased glottal tension, as proposed, remains to be determined. The likelihood of this seems high, however, in light of the spectral features of tense voice employed by Kohler and van Dommelen (1987). No evidence has been found to support the first hypothesis, concerning the speed of formant

³ Kewley-Port (1982) has shown that F_2 and F_3 loci are an invariant correlate of place of articulation only for alveolar plosives, and not for bilabials or velars.

transitions into post-release sonorants. In any case, the observed formant features can be directly associated with the fortis stops, and could be interpreted as a secondary perceptual cue which would become the primary cue in utterance-initial position. Such an analysis prevents the otherwise inevitable neutralization word-initially of the fortis and lenis plosives.

If vocal fold tension is indeed the articulatory factor responsible for the observed spectral correlates of the feature [+fortis], it becomes necessary to include tension as a variable in the laryngeal feature framework to be applied in phonological description. Thus far, no such feature system has been put forth which permits the treatment of glottal tension as an autonomous dimension in the framework, separate from other glottal states responsible for voicing and aspiration.

5.0 CONCLUSION

The spectral features of the various plosive segments in Swiss German have been examined, and the results indicate the presence of distinctive [+fortis] correlates in both the closure and release phases. While the durational cue in the closure has been shown (Kohler 1979) to be perceptually salient for the fortis/lenis contrast, such a cue cannot operate in word-initial position. Abramson (1986) suggests that, in such cases, a secondary feature present in the plosive release operates as a perceptual primary to facilitate the distinction. It is suggested here that the observed formant features associated with fortis stops may be sufficient to adopt the role of perceptual primary cue in initial position. The existence of such spectral features is not easily reconciled with Kohler's statement that the fortis/lenis opposition in Swiss German is entirely dependent on the features of the closure, and therefore will only manifest in word-medial or word-final position. A stronger statement in this regard will require positive evidence from a perceptual study investigating the possible perceptual salience of such contrasting features of the post-release formants. Given Kohler and van Dommelen's findings regarding the salience of global tense voice manner in fortis/lenis perception, such evidence does not seem unlikely.

While Swiss German is rare in that its fortis/lenis contrast is unsupported by strong release features (voicing and aspiration), it is unsubstantiated that such features are necessary to the maintenance of the contrast. Clearly, phonological systems in general are not so strictly constrained. This may relate to the notion that the laryngeal dimension of tension exists as an autonomous factor. Were this so, it would then clearly be possible to define a system in which fortis/lenis contrasts remained productive when tension alone provided a distinction.

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