# Plosive-related glottalization phenomena in read and spontaneous speech. A stød in German?

Klaus J. Kohler

# 1 Introduction

## 1.1 Definitions and linguistic functions of glottalization phenomena

In this paper, *glottalization phenomena* are to comprise the glottal stop and any deviation from canonical modal voice, i.e.

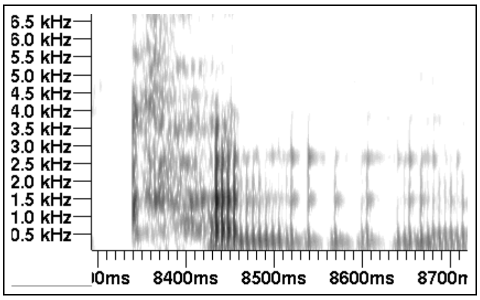
- glottal stop or low frequency irregular glottal pulsing (variable in frequency, amplitude and waveform) = *glottalization* (see Figure 1)
- *breathiness* (see Figure 2)
- *breathy voice* (see Figure 3)

These glottalization phenomena fulfil a number of different linguistic functions in the languages of the world:

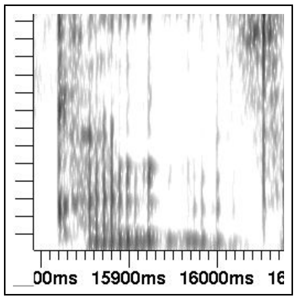
(a) *Vowel-related glottalization phenomena* signal the boundaries of words or morphemes beginning with vowels, typically in German, but also in other languages, e.g. English or French. The occurrence and phonetic manifestation of this function is also controlled by prosodic features, such as sentence accentuation, resulting in specific glottalization patterns for different languages (see Rodgers 1999 for German, and Dilley and Shattuck-Hufnagel 1995 for English). The variation between glottal stop and any other glottalization phenomenon observed for this boundary signalling occurs along a scale of phonatory strength, associated with, e.g., degrees of sentence stress (cf. the link with 'accent d'insistance' in French).

(b) *Plosive-related glottalization phenomena* occur as reinforcement of plosives by a glottal stop or as replacement of plosives along a scale of phonatory weakening from glottal stop to any other glottalization phenomenon, e.g. in German (Kohler 1995a, 1996a, 1996b) or in English (Grice and Barry 1991; Higginbottom 1964; Pierrehumbert and Frisch 1994; Roach 1979).

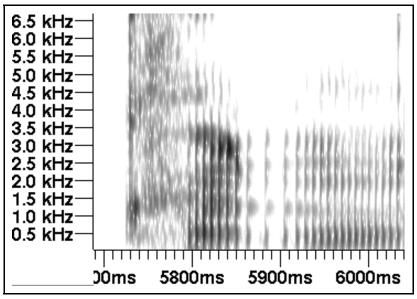
(c) *Syllable-related glottalization phenomena* occur as chracteristics of particular syllable types along a scale of phonatory weakening from glottal stop to glottalization, e.g. in the Danish stød (Fischer-Jørgensen 1989a, 1989b). The "tense vs. lax larynx syndrome" set



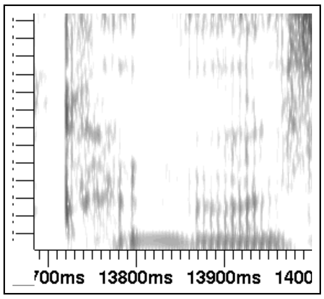

(a) g086a004 KAK [œnn̰n]



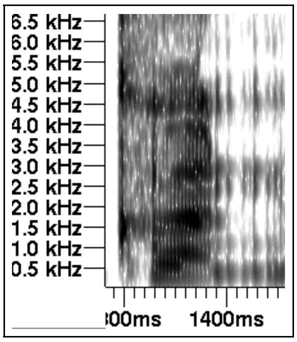

(b) g077a002 TIS [œ̃nm̰]



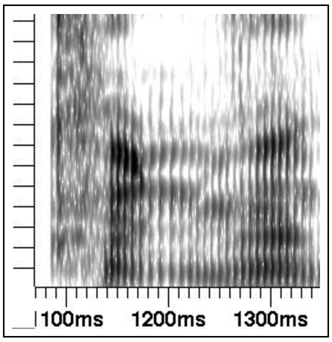

(c) g074a000 HAH [œ̃n̰n]




(d) g075a008 TIS [ʰn̰n]




(e) g091a014 FRS [œ̃n̰n̰]




(f) g072a014 HAH [œ̃n̰]

Figure 1: Different manifestations of glottalization in "kö**nnten**" from the Kiel Corpus of Spontaneous Speech, 1 female (FRS) and 3 male speakers

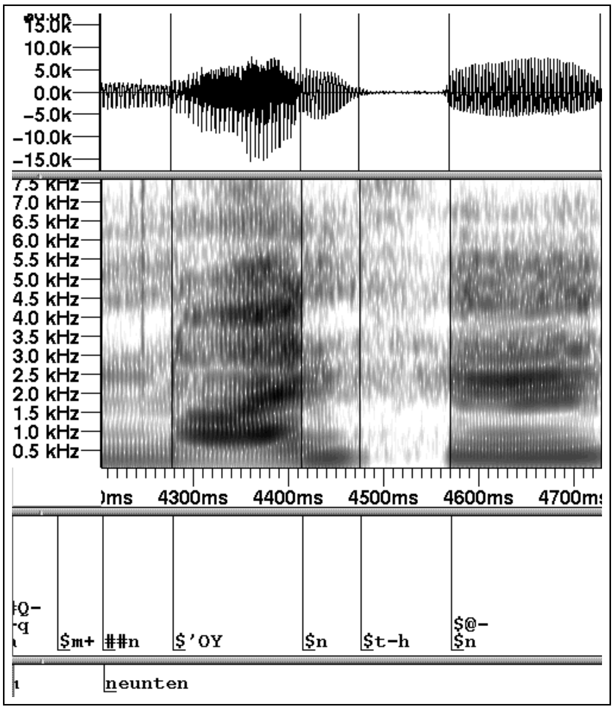



Figure 2: Breathiness in "neu**nten**", Kiel Corpus of Spontaneous Speech, g106a014 NAR, female speaker; speech wave, spectrogram and SAMPA labels

up for south-east Asian languages by Matisoff (1973) also relates to whole syllables, combining glottalization phenomena with prosodic and segmental features in phonological opposition.

(d) *The paralinguistic function of glottalization phenomena* manifests itself at the utterance level in two ways:

- as *laryngealization* in prosodic phrase-final *relaxation* of phonation, where the vocal folds prepare for abduction and where glottalization, therefore, alternates with breathiness and breathy voice, but not with a glottal stop (see Figure 4(b));

- as *truncation glottalization* in prosodic phrase-medial *tensing* of phonation at utterance breaks, where the vocal folds are adducted and where glottalization, therefore, alternates with a glottal stop (Nakatani and Hirschberg 1994; Local and Kelly 1986; see also Figures 4(a) and 5).

The question now arises as to whether these glottalization phenomena, which are controlled independently for these four linguistic functions but may nevertheless occur in the same utterances, are kept separated in speech production as sequential or superimposed events and whether they can then also be distinguished in speech perception. Figure 6 (top) shows an instance of clearly distinct sequential vocal tract resonances for plosive and vowel-related glottalizations in the German sentence "wir könnten ihn fragen" ("*we could ask him*"). This contrasts with the presence of only vowel-related glottalization in "wir können ihn fragen" ("*we can ask him*") of Figure 6 (bottom). Similarly, in Figure 7 the manifestations of plosive and vowel-related glottalization are separated temporally in "achtzeh**nten e**lften" ("*18th November*"): the glottalization for [ntn] is shifted left into the preceding vowel, and the glottalization for the vowel [ɛ] occurs well inside it, thus ensuring a clear separation between the two. This temporal indeterminacy of glottalization will be discussed in 2.1. Finally, Figure 8 shows the sequencing of plosive and vowel-related glottalization as well as phrase-final laryngealization; the former, although contiguous in time, are also distinguished spectrally and are auditorily attributable to two different functions.

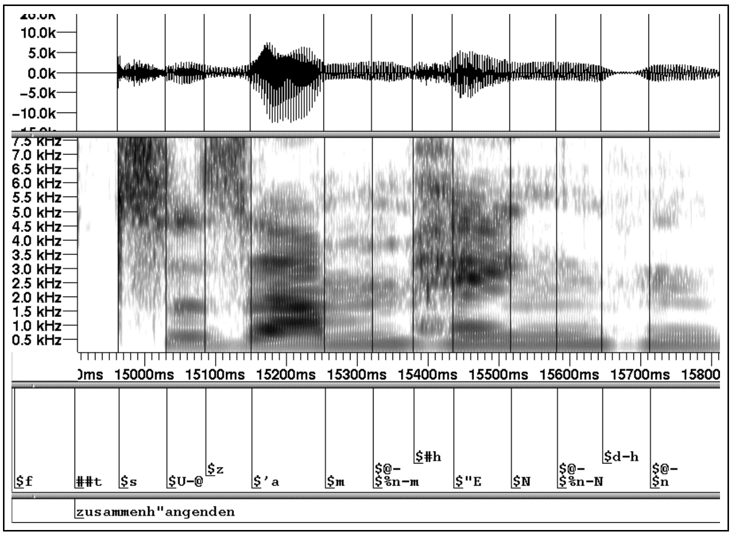
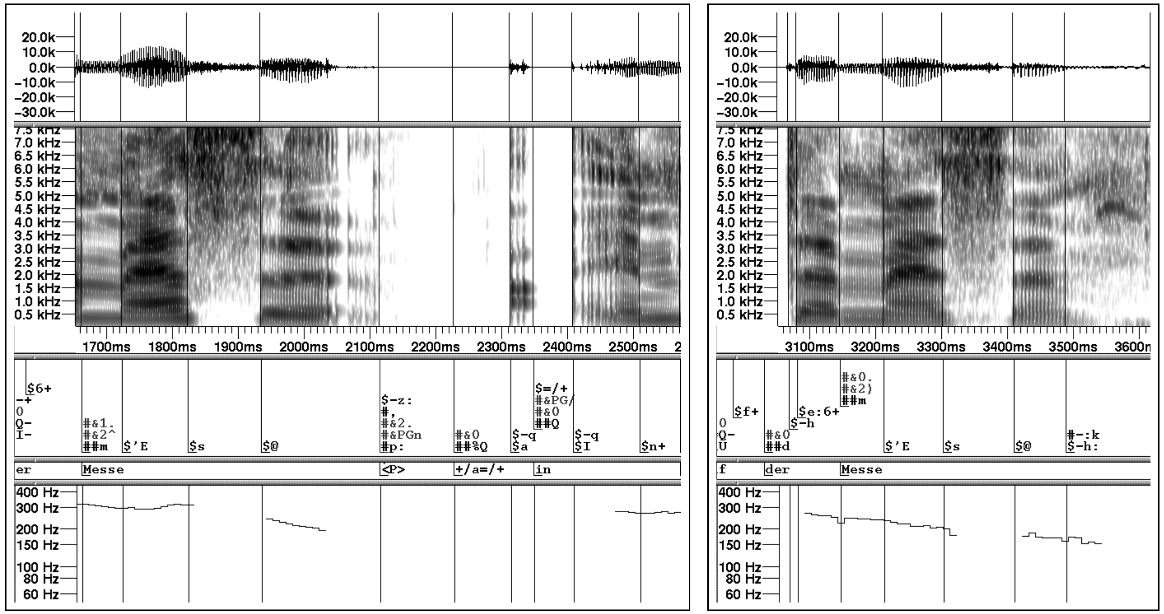



Figure 3: Breathy voice in "-hänge**nden**", Kiel Corpus of Spontaneous Speech, g105a009 NAR, female speaker; speech wave, spectrogram and SAMPA labels




(a)

(b)

Figure 4: Truncation glottalization and final breathiness. Figure 4(a) shows truncation glottalization in "(in einer) Mess**e**/+ a=/+ in (Hannover auf der Messe)", Kiel Corpus of Spontaneous Speech, g274a008 SIH, female speaker; speech wave, spectrogram, SAMPA labels, and fundamental frequency. Figure 4(b) shows final breathiness in 2nd occurrence of "Mess**e**" in utterance of Figure 4(a)

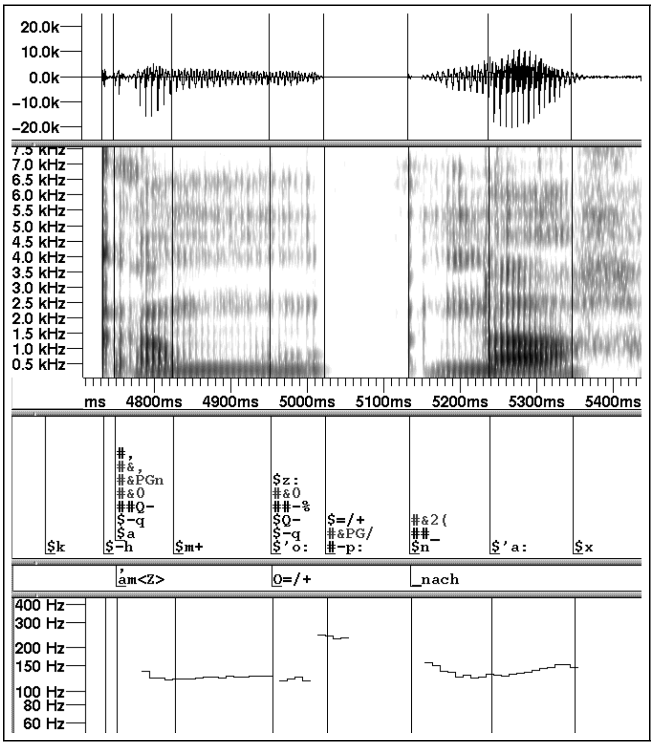



Figure 5: Truncation glottalization in "am O=/+ **n**ach (Ostermontag)", Kiel Corpus of Spontaneous Speech, g315a009 SVA, male speaker; speech wave, spectrogram, SAMPA labels, and fundamental frequency

## 1.2 Physiological explanation of glottalization phenomena

Physiological data on the Danish stød (Fischer-Jørgensen 1989a, 1989b) show different degrees of medial vocal fold compression, due to increased/decreased vocalis and lateral crico-arytenoid muscle activities for glottal stop as against glottalization. So the glottal stop

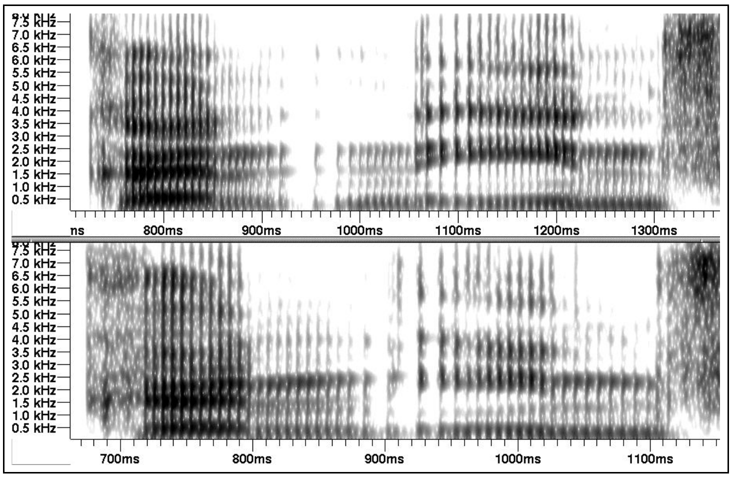



Figure 6: Spectrograms of "(wir) könnten ihn (fragen)." (top) and "(wir) können" ihn (fragen)." (bottom); scripted lab speech, male speaker KJK

can be associated with a feature of reinforcement, compared with one of weakening in other glottalization phenomena. Extrapolating from these data of one particular language to the comparable alternation of glottal stop and glottalization in vowel and plosive-related phenomena in other languages we may hypothesize that the same strength relationship obtains there as well.

Phrase-final laryngealization ('creak' or 'creaky voice') and its alternation with breathy voice or breathiness fits in with low-F0 utterance-final relaxation in preparation of glottal opening for the non-speech function of vegetative breathing; this relaxation excludes the glottal stop.

Utterance-internal speech truncation before correction is most effectively achieved by cutting off the air stream at the glottal valve; thus tensing of the vocal folds for a glottal stop would be the most natural process.

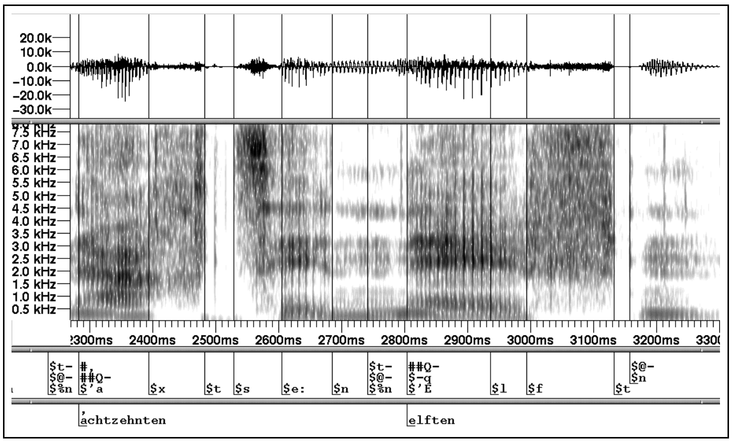


Figure 7: Shift of plosive and vowel-related glottalization to the left and right into each vowel, respectively, in “achtzeh**nten e**lften”, Kiel Corpus of Spontaneous Speech, g411a004 HEE, female speaker; speech wave, spectrogram and SAMPA labels

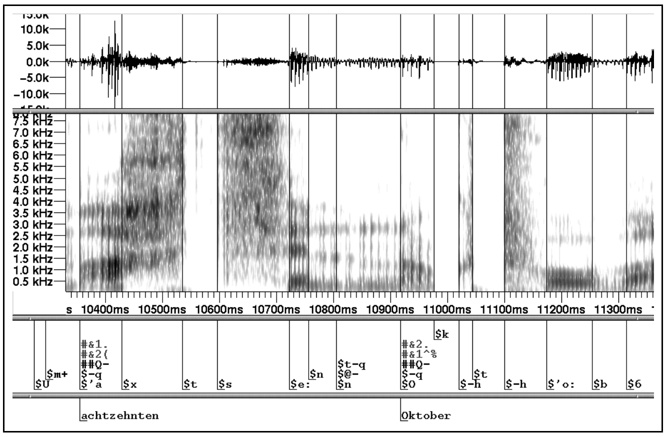



Figure 8: Plosive and vowel-related glottalization and phrase-final laryngealization in "achtzeh**nten O**ktob**er**", Kiel Corpus of Spontaneous Speech, g083a003 KAK, male speaker; speech wave, spectrogram and SAMPA labels

## 1.3 A database and processing tools for investigating glottalization phenomena in German

Two large phonetically labelled acoustic corpora of read and spontaneous speech have been compiled for German at IPDS Kiel, containing 31,382 and 37,777[1] running regular lexical words, respectively: '*The Kiel Corpus of Read/Spontaneous Speech*' (IPDS 1994, 1995, 1996, 1997a; Kohler, Pätzold, and Simpson 1997). The transcription is basically linear segmental phonemic with componential additions (marking glottalization phenomena amongst others), using the *SAMPA* alphabet (Kohler, Pätzold, and Simpson 1995). The read corpus and about one half of the spontaneous corpus have also been labelled prosodically using *PROLAB* (Kohler 1995b, 1997) based on the *Kiel Intonation Model* (*KIM*) (Kohler 1997).

[1]In this word count of the 117 dialogues of spontaneous speech, the following items were excluded: hesitation particles, neologisms, slips of the tongue, word-internal truncations and false starts, and stretches difficult or impossible to identify.

For signal analysis and labelling the software environment *xassp* (IPDS 1997b) has been used. The signal and label files are distributed on CD-ROM: one for read speech and three for spontaneous speech so far. The database is increased and updated continually. From the label files lexicon-oriented databanks can be generated with the help of the data bank utilities *KielDat* (Pätzold 1997), which also contain frequently applied, standardized *awk* retrieval tools. In addition, a library of awk search scripts has been set up for a large number of phonetic questions, including glottalization phenomena. A wide array of phonation features related to their various linguistic functions have been examined in these two databases (see also Rodgers 1999), at the symbolic as well as the signal level. As regards the former, frequency distributions of the various phenomena have been established and compared for possible speaking style effects between read and spontaneous speech. This paper looks at signal manifestation and symbolic representation of plosive-related glottalization in the labelled Kiel databanks of read (R) and spontaneous (S) speech, and provides statistics on the occurrence of labelled glottalization phenomena in different plosive contexts, also in relation to unreduced plosive productions.

## 1.4 Perception experiments

In addition to the corpus analyses of plosive-related glottalization phenomena, this paper also discusses data from perception experiments with systematically spliced natural stimuli of sentence size, viz. "die könn(t)en uns abholen" ("*they can/could collect us*"), "wir könn(t)en ihn fragen" ("*we can/could ask him*", "sie könn(t)en uns fragen" ("*they can/could ask us*"). On the basis of the production data found in the two large data bases of connected speech, sentences containing "können" or "könnten", respectively, were constructed and presented orthographically to speakers for oral reproduction. Typical instances of /ə/ reduction with glottalization for "könnten" [kœnn̰n], of reduced "können" [kœnn], and of initial vowel glottalization in "ihn" were selected for stimulus generation, using the splicing technique in xassp to insert varied durations and vocal tract resonances of glottalization into different positions (initial, medial, final, total) of varied durations of the nasal. The factors to be tested in perception were the timing, the absolute and relative duration and the resonance of the glottalization, thus checking whether the patterns found in production are also relevant in perception (for details of method see Kohler 1999).

# 2 Plosive-related glottalization phenomena in German speech production

## 2.1 The state-of-the-art of research into the phenomenon

Plosive-related glottalization phenomena in German were first noticed in the acoustic and auditory processing and in the labelling of speech files within the Phondat (Kohler 1992) and later-on the Verbmobil project (Kohler, Pätzold, and Simpson 1997). A systematic symbolic representation for glottalization was devised (Kohler, Pätzold, and Simpson 1995) and applied to the data of the '*Kiel Corpus of Read/Spontaneous Speech*' (IPDS 1994, 1995, 1996, 1997a). Several studies of the phenomenon have since been presented on the basis of the connected speech data from these two projects (Kohler 1994, 1995a, 1996a,b,; Kohler and Rehor 1996). The conditions of occurrence and the manifestation of plosive-related glottalization phenomena can be summarized as follows:

**(1) glottalization: glottal stop and low-frequency glottal vibration**
***general conditions***

- A simple glottal valve action is used to cut off the air stream for stop articulation, added to, or instead of, a more complex combination of supraglottal oral/velic closures.
- The stop is not released into a vowel but is, in most cases, followed by another complete or partial oral occlusion - nasal, plosive or lateral.
- Irregular glottal pulsing instead of a glottal stop reduces, rather than blocks, the air stream. The frequency of this vibration

differs from that of the (quasi)periodic environment; it is higher for tensing, lower for relaxation, the latter being typical, but Figure 9 shows several instances of the former.

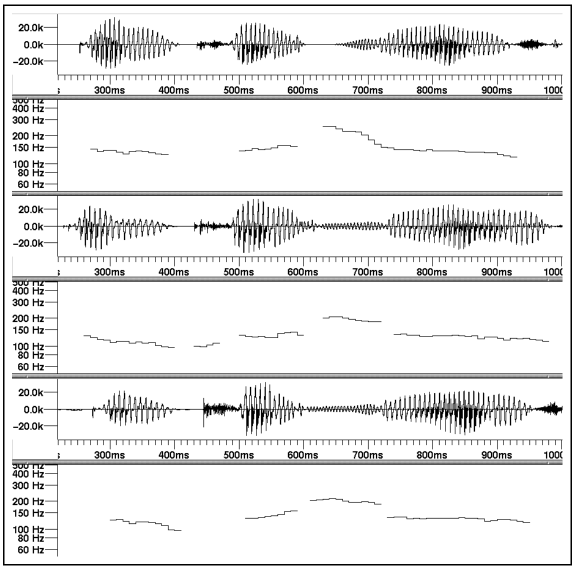



Figure 9: Speech waves and F0 traces in 3 repetitions of "dem kö**nnten** wir uns (anschließen)", scripted lab speech, illustrating high-frequency glottalization for tensing; male speaker

***specific contexts***
(a) '*sonorant – plosive – sonorant*' (especially *nasal*)

- Glottalization occurs for fortis and lenis stops at all places of articulation, word-internally or across word boundaries.
- The word-internal sequence results from [ə]-elision before nasals/laterals of canonical forms.
- The oral closure in nasal – plosive and plosive – nasal sequences is adjusted to the plosive place of articulation throughout.

- This oral closure is accompanied by velic opening as the complete or partial interruption of the air stream is transferred to the glottal valve.

- The following examples of low-frequeny glottal vibration illustrate the various conditions: "könnten" [kœnn̰n], "Lampen" [lamm̰m], "halten" [hal̰n], "Stunden" [ʃtʊnn̰n], "sind noch" [zɪnn̰ nɔx], instead of the more elaborated canonical pronunciations [kœntʰən], [lampʰən], [haltʰən], [ʃtʊndən], [zɪnt nɔx]. Glottal stops are equally possible in these contexts.

- As regards the timing of glottalization there are four possible temporal alignments with the sonorant, e.g. /n/ in "könnten" (for further details see Kohler 1996a):

  medial, [nn̰n], is most common in all contexts

  final, [nn̰], is next frequent for lenis stops

  initial, [n̰n], is next frequent for fortis stops

  complete, [n̰n̰].

  Glottalization may also extend, or be shifted, into the preceding vowel (e.g. in Figure 7).

- With respect to the *duration* of glottalized nasal stretches, it has also been found to be quite variable (Kohler 1996a). On the other hand, when glottalized sonorants were compared with sonorants that had modal-voice throughout, e.g. [kœnn̰n] vs. [kœnn], the former turned out to be consistently longer in a specially collected contextually comparable corpus of "könnten" and "können" sentences. They were read by three speakers (with 10 repetitions of the sentence set). The duration increase for "könnten" again varied a great deal from speaker to speaker, between averages of 30% and 60%.[2] So it may be assumed that, from the production point of view, a canonical plosive unit can be represented in the signal by a duration trace as well, at least in systematically elicited lab speech data.

[2] These data were collected in an experimental phonetics course for advanced students at IPDS Kiel in the summer semester of 1999 by J. Beckman.

(b) '*vowel – (fricative) fortis plosive – consonant*' (esp. *nasal*)

- There is a higher probability of glottally reinforced plosives (with velic raising) in this context than in context (a).
- In plosive – nasal sequences the same place adjustment occurs as in (a).
- In plosive – nasal sequences velic opening may occur very early after the oral occlusion, accompanied by glottal stop or low-frequency vibration.
- Examples for this context are *zweiten* [tsvaɪ̯(ʔ)n], *Leipzig* [laɪ̯ʔ͡ptsɪç], *hat nicht* [ha̰ʔnɪç].

**(2) breathiness and breathy voice**

- In the complete nasal context of (a), voiceless or breathy-voiced nasals instead of plosives are also possible, breathy-voiced especially for lenis; see Figures 2 and 3.
- This must be due to glottal (interarytenoidal) opening, which preserves the plosive phonation features, again combined with velic lowering, as required for the environment.
- Thus the modal-voice context of the nasal is still interrupted by different types of phonation, reflecting more complex plosive articulations.

**(3) modal voice with(out) F0/amplitude modulation**

- For lenis in the nasal context of (a), a further progression towards modal voice may be found, e.g. a reduction to [nn] in "einverstanden", "Stunden". For fortis this is only possible in unstressed function words, e.g. "könnten", and elements of compounds, e.g. "-zehnten" in numerals; see Figure 10.
- This process may be complete, or there may be a weak trace of the plosive in the form of a medial amplitude and/or F0 dip in the nasal stretch; see Figure 11. So the speaker can still signal a break, albeit towards the low effort end of a reduction scale ranging from plosive to complete nasalization.

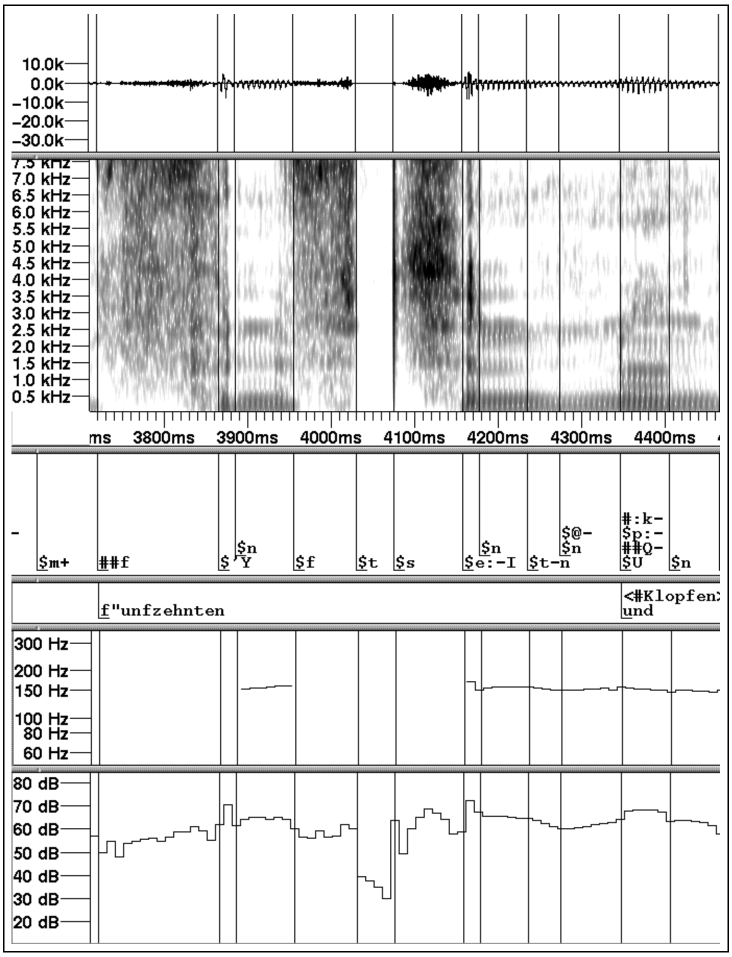



Figure 10: Amplitude and F0 dips in "-zeh**nten**", Kiel Corpus of Spontaneous Speech, g115a002 REK, male speaker; speech wave, spectrogram, SAMPA labels, fundamental frequency, and energy

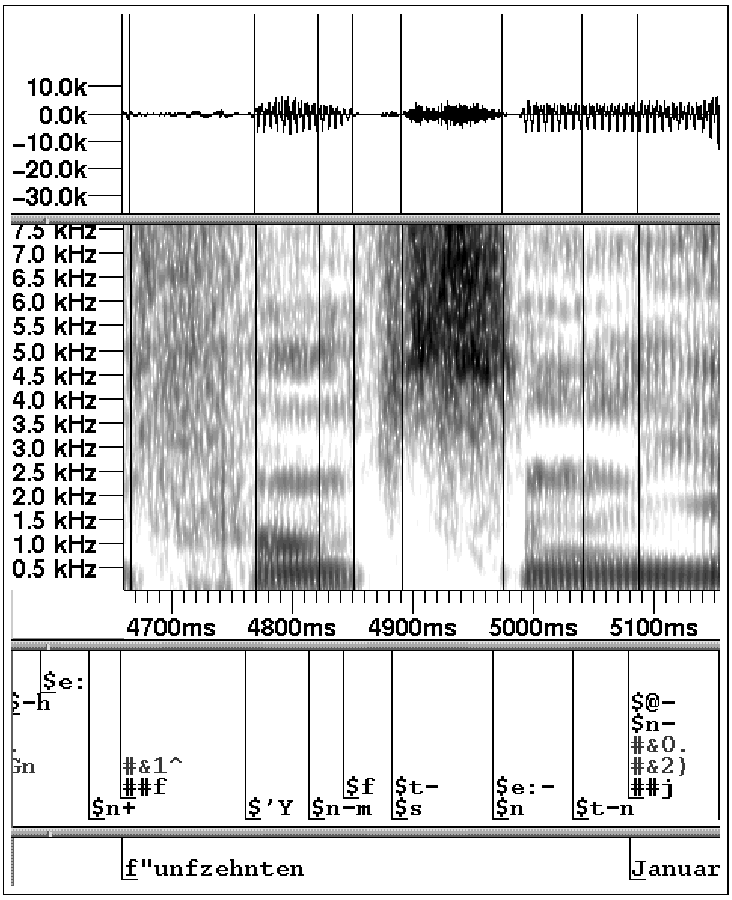



Figure 11: No plosive reflex in "-zeh**nten**", Kiel Corpus of Spontaneous Speech, g146a000 BAC, male speaker; speech wave, spectrogram, and SAMPA labels

## 2.2 Results of the corpus analysis

### 2.2.1 Data search and data presentation

In addition to canonical phoneme-type transcriptions and the marking of word boundaries, the label files of the '*Kiel Corpus of Read/Spontaneous Speech*' contain symbolic information about /ə/ and plosive deletion, about aspiration, glottalization, breathy or breathy-voice or modal-voice nasalization of plosives, also about interchanges between the lenis and fortis categories and, indirectly, about nasal or lateral plosion (in the absence of any of the other plosive attribute markers). Specific *awk* scripts were written to search the entire data base of the '*Kiel Corpus of Read/Spontaneous Speech*' for these features of plosive realization within words, containing one or two consecutive post-stress /ə/ + sonorant syllables, and also across word boundaries in the single-syllable type. As the prosodically labelled data files provide phrase boundary markers the occurrence of glottalization phenomena inside phrases or at their boundaries constitutes a further factor in this data bank search. It will help to answer the question of a possible link between plosive-related glottalization and its position in the utterance. Since all label files have the orthographic punctuation characters [.?!] as well as labels for pauses, breathing, laughing and various other paralinguistic sequential events, such phrase boundary searches can even be carried out with a high degree of validity on files without specific prosodic labels.

Table 1(a) presents the frequencies in the different categories of phonetic manifestation for the words with a single 'plosive + /ə/ + sonorant' syllable following a sonorant. The realizations range along an elaborated/reduced scale from aspiration + schwa to just schwa or aspiration to nasal/lateral plosion to glottalization or nasal breath or modal-voice nasalization. The sonorants on either side of the canonical plosive are predominantly nasals; there are no cases with laterals on both sides. In the single syllable category with post-plosive lateral the following frequencies are found:

- in R there are 38 instances of (aspiration +) schwa, 52 of lateral plosion, 18 of plosive nasalization (17 with schwa), 2 of breathy nasal,

- in S 6 instances of lateral plosion;
- so glottalization does not occur in this context.

Words with pre-plosive lateral show the following distribution:

- in single syllables there are 156 cases of nasal plosion in R and 93 in S,
- 4 cases of glottalization in R ("gelten", "stellten") and 49 in S ("halten", "sollten", "wollten"),
- 5 cases of plosive nasalization (without schwa) in R ("Oldenburg") and 5 in S ("halben", "halten", "sollten", "folgendes");
- in di-syllables S has 6 cases of nasal plosion in "folgenden".

Table 1(b) presents the frequencies in the sequential patterns of schwa preservation/deletion in di-syllables. In Table 2 the frequency distributions for lenis and fortis plosives, which are conflated in Table 1(a), are separated.

Table 3 lists the frequencies of phrase-final and phrase-internal occurrences of items in four phonetic classes corresponding to those of Table 1a, where the data are conflated with regard to the phrase boundary factor. The two sets of Table 3 have been tested, separately for R and S, for an association between phrase boundary and phonetic manifestation of the canonical plosive syllables in a $2 \times 4\ \chi^2$. The test values are 10.3592 for R and 9.000 for S, which, with 3 d.f., is not significant at $p =\ .01$. This statistical proof suggests that the phonetic exponents — glottalization among others — are independent of the incidence of phrase boundaries. However, the data also show that the frequency distribution across the four classes is different in the two speaking styles: S favours the glottalization, R the more elaborated *rest* category, but they do so finally and internally in the phrase.

Table 4 provides the frequency distribution across the categories of phonetic realization for the canonical pattern 'vowel – (fricative) fortis plosive – /ə/ – sonorant'. Again the sonorant is typically nasal.

Table 5 compares the frequencies for the presence and absence of glottalization across word boundaries before initial nasals and after sonorants, vowels or other segments preceding the word-final canonical plosive. There are no instances in the corpus where glottalization occurs before an initial lateral, and it is only in R that an example of this phonotactic structure occurs ("Haushalt lernen"). There are, however, a few cases with a lateral preceding the plosive; they have been incorporated in the table. The relative frequencies in each of the four contexts are based on the total number of occurrences in each of the two manifestation categories ±glottalization. They show that glottalization is most frequent after sonorants, much less so after vowels and negligible after other segments, and that this applies to both R and S in very similar proportions. The distribution of non-glottalized forms across the three contexts is, however, quite different from the distribution of glottalization, and it is also different between R and S.

### 2.2.2 Discussion of the results

1. Pattern (a): '*sonorant – plosive – /ə/ – sonorant*'

/ə/ realization is rare in either corpus, but is even less frequent in S than in R (0.9% vs. 11.3%). But the decisive difference between the two speaking styles is the proportion of plosives vs. glottalization phenomena (glottalization + breathy nasalization) and modal nasalization:

| | | | |
|---|---|---|---|
| R | 63.1% plosives | 26.1% glottaliz | 36.9% glottaliz phen + nasaliz |
| S | 32.5% plosives | 52.7% glottaliz | 67.5% glottaliz phen + nasaliz |

This still holds for fortis and lenis plosives separately and points to a greater degree of articulatory reduction in S vs. R.

| | | | | |
|---|---|---|---|---|
| | *fortis* | | | |
| R | 14.3% /ə/ | 75.5% plos | 23.1% glott | 24.5% gloph + nas |
| S | 1.1% /ə/ | 35.0% plos | 53.1% glott | 64.9% gloph + nas |
| | *lenis* | | | |
| R | 7.3% /ə/ | 46.6% plos | 30.1% glott | 53.4% gloph + nas |
| S | 0.0% /ə/ | 19.1% plos | 51.1% glott | 80.8% gloph + nas |

Table 1: Frequencies of glottalization phenomena in the canonical pattern 'sonorant – plosive – /ə/ – sonorant' in read (R) and spontaneous (S) speech, set against other realizations; (a) one /ə/ syllable (b) two /ə/ syllables in succession

| | **R** | | **S** | |
|---|---|---|---|---|
| **1 syll** | **abs** | % | **abs** | % |
| ***total*** | 479 | 100.0 | 874 | 100.0 |
| −schwa | 425 | 88.7 | 866 | 99.1 |
| *glott* | 125 | 26.1 | 461 | 52.7 |
| *nas breath* | 4 | 0.8 | 76 | 8.7 |
| *nas* | 48 | 10.0 | 53 | 6.1 |
| *nas/lat plos* | 224 | 46.8 | 272 | 31.1 |
| *asp* | 24 | 5.0 | 4 | 0.5 |
| +schwa | 2 | 0.4 | 0 | 0.0 |
| asp +schwa | 52 | 10.9 | 8 | 0.9 |

(a)

| | **R** | | **S** | |
|---|---|---|---|---|
| **2 syll** | **abs** | % | **abs** | % |
| ***total*** | 16 | 100 | 25 | 100 |
| −schwa +schwa | 12 | 60 | 10 | 40 |
| −schwa −schwa | 0 | 0 | 15 | 60 |
| +schwa +schwa | 4 | 40 | 0 | 0 |

(b)

Table 2: Frequencies of glottalization phenomena in the canonical pattern 'sonorant – plosive – /ə/ sonorant' of monosyllables in read (R) and spontaneous (S) speech, for /ptk/ (1) and /bdg/ (2), set against other realizations

| | **R** | | | | **S** | | | |
|---|---|---|---|---|---|---|---|---|
| | **abs** | | % | | **abs** | | % | |
| | **(1)** | **(2)** | **(1)** | **(2)** | **(1)** | **(2)** | **(1)** | **(2)** |
| ***total*** | 273 | 206 | 100.0 | 100.0 | 733 | 141 | 100.0 | 100.0 |
| -schwa | 234 | 191 | 85.8 | 92.7 | 725 | 141 | 98.8 | 100.0 |
| *glott* | 63 | 62 | 23.1 | 30.1 | 389 | 72 | 53.1 | 51.1 |
| *nas breath* | 0 | 4 | 0.0 | 1.9 | 50 | 26 | 6.8 | 18.4 |
| *nas* | 4 | 44 | 1.5 | 21.4 | 37 | 16 | 5.0 | 11.3 |
| *nas/lat plos* | 143 | 81 | 52.4 | 39.3 | 245 | 27 | 33.4 | 19.1 |
| *asp* | 24 | 0 | 8.8 | 0.0 | 4 | 0 | 0.5 | 0.0 |
| +schwa | 0 | 2 | 0.0 | 1.0 | 0 | 0 | 0.0 | 0.0 |
| asp +schwa | 39 | 13 | 14.3 | 6.3 | 8 | 0 | 1.1 | 0.0 |

Table 3: Frequencies of prosodic boundaries occurring after items in the phonetic classes of Table 1a; *nas/lat plos, asp (+schwa)*, and *+schwa* have been combined to *rest*. Numbers in brackets are the frequencies of phrase-internal occurrences of the 4 classes; both numbers in each abs field add up to the sums of phrase-internal and phrase-final occurences listed in corresponding classes of Table 1a.

| | **R** | | **S** | |
|---|---|---|---|---|
| **1 syll** | **abs** | **%** | **abs** | **%** |
| ***total*** | 140(339) | 100.0(100.0) | 207(667) | 100.0(100.0) |
| *glott* | 26 (99) | 18.6 (29.2) | 110(351) | 53.1(52.6) |
| *nas breath* | 3 (1) | 2.1 (0.3) | 21 (55) | 10.2 (8.2) |
| *nas* | 12 (36) | 8.6 (10.6) | 6 (47) | 2.9 (7.1) |
| *rest* | 99(203) | 70.7 (59.9) | 70(214) | 33.8 (32.1) |

Table 4: Frequencies of glottalization phenomena in the canonical pattern ‘vowel – (fricative) fortis plosive – /ə/ – sonorant’ in read (R) and spontaneous (S) speech, set against other realizations.

| | **R** | | **S** | |
|---|---|---|---|---|
| | **abs** | **%** | **abs** | **%** |
| ***total*** | 524 | 100.0 | 1069 | 100.0 |
| −schwa | 483 | 92.2 | 1053 | 98.5 |
| *glott* | 9 | 1.7 | 68 | 6.4 |
| *nas/lat plos* | 426 | 81.3 | 878 | 82.1 |
| *asp* | 26 | 5.0 | 10 | 0.9 |
| *vd nas/lat plos* | 15 | 2.9 | 14 | 1.3 |
| */t/ del after /s/* | 7 | 1.3 | 80 | 7.5 |
| */t/ del in 'guten'* | 0 | 0.0 | 3 | 0.3 |
| vd plos +schwa | 0 | 0.0 | 1 | 0.1 |
| asp +schwa | 41 | 7.8 | 15 | 1.4 |

Table 5: Frequencies of glottalization (1) and of its absence (2) across word boundaries before initial nasals and after sonorants, vowels or other segments preceding the word-final canonical plosive in read (R) and spontaneous (S) speech

| | **R** | | | | **S** | | | |
|---|---|---|---|---|---|---|---|---|
| | **abs** | | **%** | | **abs** | | **%** | |
| | **(1)** | **(2)** | **(1)** | **(2)** | **(1)** | **(2)** | **(1)** | **(2)** |
| ***total before nasal*** | 87 | 614 | 100.0 | 100.0 | 36 | 497 | 100.0 | 100.0 |
| *after sonorants* | 67 | 83 | 77.0 | 13.5 | 26 | 64 | 72.2 | 12.9 |
| *laterals* | 1 | 6 | 1.2 | 1.0 | 5 | 7 | 13.9 | 1.4 |
| *after vowels* | 18 | 403 | 20.7 | 65.6 | 9 | 148 | 25.0 | 29.8 |
| *after other segments* | 2 | 128 | 2.3 | 20.9 | 1 | 285 | 2.8 | 57.3 |

The data comparison for fortis and lenis in each speaking style shows an increase of /ə/ deletion and a substantial increase of plosive reduction for lenis, due to stop nasalization. This supports the hypothesis that in a nasal context, the shorter and weaker lenis plosive articulations lose their stop character achieved by velic raising more readily irrespective of speaking style.

In R, sequences of two /ə/ syllables always keep the second /ə/ and in 40% of the cases also the first; in S the first /ə/ is never preserved, the second only in 40% of the cases. Although the absolute frequencies are rather small, these data again point to more elaborated articulation in spontaneous than in read speech.

The realization of /ə/ syllables in words occurring before prosodic boundaries shows comparable distributions across four phonetic categories along the reduced/elaborated scale as phrase-internal syllables within each speaking style. This supports the independence of plosive-related glottalization phenomena from their position in the prosodic phrase. But in R 2/3 of the syllables are realized with plosives, whereas in S 2/3 exhibit glottalization phenomena. Since these proportions also apply to the manifestation inside prosodic phrases in each speaking style, they underline the greater degree of plosive reduction in spontaneous as against read speech.

2. Pattern(b): '*vowel – (fricative) fortis plosive – /ə/ – sonorant*'

/ə/ realization is again rare in either corpus, but there are again more deletions in S. In both corpora nasal/lateral plosion is the predominant pattern with ca. 80%.

Glottalization is rare, but more frequent in S, i.e. the frequency of glottalization is completely different for the two segmental patterns in either speaking style.

3. *Glottalization across word boundaries*

It occurs in both speaking styles before a nasal at the beginning of the next word and is most frequent in Pattern (a), after sonorants, predominantly nasals, which provides ca. 75% of the cases in both R and S. Although the context patterns after vowels and after other segments are represented by a great deal more data than Pattern (a) in both speaking styles (with reversed rank orderings of vowels and other segments in R and S), the instances of glottalization are concentrated on the bilateral sonorant, i.e. mainly nasal, context.

### 2.2.3 Explaining the data with reference to general principles of speech production

The analysis and statistical assessment of plosive-related glottalization phenomena in two extensive annotated acoustic corpora of German have been presented here to buttress the state-of-the-art account given in 2.1 with quantitative data from a representative data base of a sufficiently large number of speakers of Standard Northern German. We are now in a position to draw some conclusions for speech production.

In both contextual patterns for plosive production — (a) and (b), two steps can be postulated for the simplification of the articulatory program:

(1) the elimination of a central oral opening-closing gesture, resulting in nasal or lateral plosion,

(2) the elimination of velic raising during the oral occlusion and the transfer of air stream control to the glottis, resulting in glottalization phenomena.

In a bilateral nasal context of Pattern (a), (2) eliminates the need for a synchronization of velic control with other vocal tract components; the velum can remain lowered in the entire sequence, but the listener still receives a signal break for a canonical plosive through a glottal stop, glottalization or some other change in phonation. So articulatory reorganization takes place, with the same communicative function.

The statistical data support this view. The frequency distribution of plosive-nasal realizations across word boundaries (in 2.2.2.3) as well as the scarceness of glottalization word internally in Pattern (b) (see 2.2.2.2) show that the (homorganic) nasal context is particularly conducive to the occurrence of glottalization. This quantitative empirical fact fits in with the argument that this contextual pattern provides the most natural environment for articulatory economy through reorganization of stop production: glottal control can take over the function of air stream interference from velic control, allowing all other supraglottal settings - oral occlusion, place of articulation and velic lowering — to stay the same as needed for the nasal environment. Moreover, reducing the extent of velic movement and giving greater flexibility to its synchronization with other articulatory gestures accords very well with a sluggish articulator.

The temporal indeterminacy of velic action is further heightened by a temporal flexibility of phonation changes, as found in the extremely variable position and duration of glottalization within a sonorant (see 2.1). Although the duration of glottalized as against modal-voice sonorants can be longer this increase also varies a great deal from speaker to speaker (see 2.1). So in view of this enormous temporal variability in connected, and especially in spontaneous speech, it is doubtful whether the longer duration of glottalized sonorants is a generally established production pattern, and even more doubtful whether it plays an important role in speech communication (see 3.).

In the short closure of lenis stops, this flexible timing of the velum triggers an even greater reduction of its movement, resulting in complete assimilation to modal-voice nasality (see 2.2.2.1). In all the modifications of 'plosive + nasal' syllables, found in the data base, the demands on articulator coordination are reduced; this helps to ease production whenever called for by context of situation. In particular, unscripted dialogue speech, as against a reading style, sets a frame for greater articulatory imprecision; so there are more articulatory reductions of the types described under this condition (see 2.2.2.1).

# 3 Plosive-related glottalization phenomena in German speech perception

## 3.1 Some hypotheses

The corpus analysis has shown that nasal glottalization is a consistent and prominent production pattern for canonical 'nasal + plosive + nasal' syllables in read and spontaneous speech in German. It contrasts with completely modal-voice nasals. The realization of this sonorant glottalization was found to vary in the following four factors:

- position of the glottalized section within the nasals — medial, initial, final, total
- total duration of glottalized nasals, compared with that of modal-voiced nasals
- duration of the glottalized section within nasals
- vocal tract resonance of the glottalized section differentiating plosive-related from vowel-related glottalization.

The question that now has to be asked is how German listeners process the variability in these factors for the recognition of utterance-embedded words containing glottalization or modal-voice features. The hypotheses, derived from the production data, and to be tested in perception experiments, are:

(1) the consistent opposition pattern of presence vs. absence of glottalization found in German speech production is mapped onto speech perception,

(2) the indeterminacy of temporal position of glottalization within the nasal is reflected by perceptual irrelevance,

(3) the increased total duration of glottalized vs. modal-voice nasals is perceptually irrelevant,

(4) the duration of the glottalized section has a perceptual effect if it transgresses a threshold,

(5) vocal tract resonances are perceptually relevant to separate plosive-related from vowel-related glottalization.

Two experiments were carried out by the author (Kohler, 1999), a third experiment under the author's supervision by a student

(M. Hein)[3]. The method used is sketched in 1.4 and described in more detail in Kohler (1999). All the experiments test hypothesis (1). Experiment 1 adds hypotheses (2) and (3), Experiment 2 hypotheses (4) and (5), Experiment 3 hypotheses (2), (3) and (4). The test of hypothesis (3) and its interrelation with the other hypotheses still requires a more elaborate and more stringent experimental design. The results referring to it are only preliminary.

## 3.2 Experiment 1: Temporal position of glottalization and nasal duration

### 3.2.1 Stimuli

There are eight stimuli in this experiment, based on the utterances "die könn(t)en uns abholen" (*kab*), produced by a male speaker (KJK) without vowel-related glottalization.

***kab1*** is an original "können" utterance with a modal-voice nasal of 105ms;

in ***kab2*** the nasal of *kab1* was lengthened to 120 ms by period doubling;

in ***kab3*** the nasal of *kab1* was shortened to 75ms by excising single periods;

in ***kab4*** the final 75ms of the nasal in *kab2* were replaced by glottalization taken from an original "könnten" utterance;

in ***kab5*** the initial 70ms of the nasal in *kab2* were replaced by glottalization;

in ***kab6*** the medial 65ms of the nasal in *kab2* were replaced by glottalization, with 25ms of modal voice at the beginning;

in ***kab7*** the complete 120ms of the nasal in *kab2* were replaced by glottalization;

[3]In an experimental phonetics course for advanced students at IPDS Kiel in the summer semester of 1999.

***kab8*** contains the original “könnten”, whose glottalization was used for stimulus generation, spliced into the same sentence frame as the other stimuli; the duration of the nasal was 187ms, with 81ms of medial glottalization.

Stimuli **kab2,4,5,6,7** have the same total utterance and nasal consonant durations; they differ with regard to the factors ‘±glottalization’ and ‘position of glottalization within the nasal’. Stimuli **kab1,3,8** introduce the factor ‘nasal duration’; **kab8** combines a longer nasal with a similar duration of medial glottalization as stimulus **kab6**.

#### 3.2.2 Results

Table 6 presents the results of “können” vs. “könnten” identification in a formal listening test (8 stimuli × 10 repetitions × 23 listeners).

All stimuli that contain glottalization in the nasal of at least 65ms, irrespective of its position and the total length of the nasal are uniquely identified as “könnten” (*kab4,5,6,7,8*). All stimuli that have only modal voice in the nasal, irrespective of the nasal duration, are uniquely identified as “können”.

### 3.3 Experiment 2: Vocal tract resonance of glottalization

#### 3.3.1 Stimuli

There are 9 stimuli in this experiment, based on the utterances “wir könn(t)en ihn fragen” (*kfr*), produced by a male speaker (KJK).

***kfr1*** is an original “können” utterance with a nasal of 105ms (mostly modal voice but 2 periods of nasal glottalization at the end), followed by a 60ms [i] glottalization (see Figure 6 (bottom));

***kfr2*** is derived from *kfr1* by deletion of the entire glottalized section (vowel and nasal) and a slight lengthening of the modal-voice nasal to 111ms;

in ***kfr3*** the nasal of *kfr2* is lengthened to 172ms;

Table 6: Absolute frequencies in the 2 response categories of Experiments 1 and 2; N=230

Stim kab1-3 with modal-voice nasal (kab1 = original "können", kab2/3 = lengthened/shortened)
Stim kab4-7 with glottalized nasal (final, initial, medial, complete)
Stim kab8 = original "könnten";
Stim kfr1-3 with modal-voice nasal
kfr1 = original "können", modal-voice nasal + [i] glottalization
kfr2/3 = modal-voice nasal lengthened/shortened
Stim kfr4-6 with final nasal glottalization (increasing length)
Stim kfr7 with final nasal glottalization + [i] glottalization
Stim kfr8 with shortened modal-voice nasal + lengthened [i] glottalization
Stim kfr9 = original "könnten" with medial glottalization

| Stim | können | könnten | Stim | können | könnten |
|---|---|---|---|---|---|
| kab1 | 230 | 0 | kfr1 | 222 | 8 |
| kab2 | 230 | 0 | kfr2 | 230 | 0 |
| kab3 | 229 | 1 | kfr3 | 230 | 0 |
| kab4 | 3 | 227 | kfr4 | 3 | 227 |
| kab5 | 1 | 229 | kfr5 | 0 | 230 |
| kab6 | 0 | 230 | kfr6 | 2 | 228 |
| kab7 | 1 | 229 | kfr7 | 65 | 165 |
| kab8 | 0 | 230 | kfr8 | 220 | 10 |
| | | | kfr9 | 0 | 230 |

in ***kfr4*** the entire glottalized section of *kfr1* is replaced by nasal glottalization taken from an original "könnten" utterance (see Figure 6 (top)), resulting in 115ms of modal-voice followed by 60ms of glottalization in a nasal of 175ms;

in ***kfr5*** the nasal glottalization of *kfr4* is extended to 150ms within the 175ms nasal;

in ***kfr6*** the nasal glottalization of *kfr4* is extended to the total length of a 172ms nasal;

in ***kfr7*** the modal-voice nasal of *kfr4* is cut back to 60ms, followed by 90ms of nasal glottalization, in turn followed by 60ms of [i] glottalization;

in ***kfr8*** the modal-voice nasal of *kfr1* is cut back to 60ms followed by an extended section of 120ms of [i] glottalization;

***kfr9*** is another original utterance “wir könnten ihn” spliced into the frame before “fragen” of *kfr1* to regularize the sentence prosody; here the nasal is 205ms with 115ms of medial glottalization (ending in a glottal stop), after 40ms and before 50ms of modal voice, without [i] glottalization.

Stimuli ***kfr1,3,4,5,6,8*** have approximately the same duration up to the onset of modal [i], ranging between 165ms (*kfr1*) and 180ms (*kfr8*). They differ with regard to the presence of [i] or nasal glottalization or with regard to their absence. This is combined with increasing durations of nasal glottalization within the same total length of the nasal in ***kfr4,5,6*** (60ms, 150ms, 172ms) or with increasing durations of [i] glottalization in ***kfr3,1,8*** (0ms, 60ms, 120ms). Nasal glottalization is final in ***kfr4,5,6***. This contrasts with medial glottalization and a longer nasal duration in ***kfr9***. In ***kfr2,3*** the modal-voice nasal is varied in its duration. Finally, ***kfr7*** combines nasal and [i] glottalizations in sequence.

### 3.3.2 Results

Table 6 presents the results of “können” vs. “könnten” identification in a formal listening test (9 stimuli × 10 repetitions × 23 listeners). All stimuli that contain nasal, but not [i] glottalization are uniquely identified as “könnten” (*kfr4,5,6,9*), and as in Experiment 1, this is again irrespective of the duration or position of glottalization or the total length of the nasal. A nasal glottalization duration of at least 60ms is clearly on the “könnten” side of the threshold, no matter what the total length of the nasal is. All stimuli that contain [i], but no, or very short (ca. 20ms), nasal glottalization are uniquely identified as “können” (*kfr1,8*), its length being again irrelevant. The same also applies to complete modal-voice nasals (*kfr2,3*), irrespective of their duration. However, when nasal and [i] glottalizations are contiguous and both are at least 60ms long, judgement is no longer unique, but “könnten” predominates.

## 3.4 Experiment 3: Temporal position and duration of glottalization

### 3.4.1 Stimuli for Experiment 3

There are 14 stimuli in this experiment, based on the utterances “sie können uns abholen/könnten uns fragen” (*kabfr*), produced by a female speaker (SH). The signal portion from the beginning of the stop to the beginning of the fricative in “können uns” was excised from “sie können uns fragen” and spliced into the equivalent position in ”sie könnten uns abholen”, thus producing “könn(t)en uns” in the same sentence frame, neither having vowel-related glottalization.

***kabfr1*** is original “können” with a modal-voice nasal of 104ms;

***kabfr2, kabfr3*** were derived from *kabfr1* by lengthening and shortening its nasal to 154ms and 54ms, respectively;

for ***kabfr4, kabfr5, kabfr6*** 19ms of nasal glottalization from the “könnten” stimulus were spliced into the nasal of *kabfr1* initially, medially and finally, with a complementary shortening of modal voice to the same total nasal duration of 104ms;

for ***kabfr7, kabfr8, kabfr9*** the same stimulus manipulations were carried out with 37ms of glottalization;

for ***kabfr10, kabfr11, kabfr12*** the same stimulus manipulations were carried out with 57ms of glottalization;

in ***kabfr13*** the 37ms-glottalization was copied 3 times (111ms) to replace the entire modal-voice nasal;

***kabfr14*** is original “könnten” with 37ms of medial nasal glottalization and a total nasal duration of 220ms.

Table 7: Absolute frequencies in the 2 response categories of Experiment 3; N=100

Stim kabfr1-3 with modal-voice nasal (kabfr1 = original “können”, kabfr2/3 = lengthened/shortened)

Stim kabfr4-6 with short glottalization in the nasal (initial, medial, final)

Stim kabfr7-9 with longer glottalization in the nasal (initial, medial, final)

Stim kabfr10-12 with longest glottalization in the nasal (initial, medial, final)

Stim kabfr13 with complete glottalization in the nasal

Stim kabfr14 = original “könnten” with medial nasal glottalization

| Stim | können | könnten | Stim | können | könnten |
|---|---|---|---|---|---|
| kabfr1 | 99 | 1 | kabfr8 | 19 | 81 |
| kabfr2 | 92 | 8 | kabfr9 | 70 | 30 |
| kabfr3 | 99 | 1 | kabfr10 | 5 | 95 |
| kabfr4 | 53 | 47 | kabfr11 | 9 | 91 |
| kabfr5 | 34 | 66 | kabfr12 | 31 | 69 |
| kabfr6 | 98 | 2 | kabfr13 | 6 | 94 |
| kabfr7 | 14 | 86 | kabfr14 | 0 | 100 |

Stimuli ***kabfr1,4–13*** have the same total nasal durations. They differ in the temporal position and the duration of glottalization inside the nasal. Stimuli ***kabfr1,2,3*** vary the duration of the modal-voice nasal. Stimuli ***kabfr8,14*** contrast the same duration of medial nasal glottalization in a shorter and a longer nasal.

### 3.4.2 Results

Table 7 presents the results of “können” vs. “könnten” identification in a formal listening test (14 stimuli × 10 repetitions × 10 listeners).

The two-way comparison of the responses to the 3 glottalization durations in each of the 3 sonorant-internal positions — *kabfr4,7,10* vs. *kabfr5,8,11* vs. *kabfr6,9,12* — shows that there is an interaction between these two factors. In each position the number of "könnten" answers increases with glottalization duration, but in different proportions for the three positions. The weakest position is final, followed by initial. For the longest durations, initial (*kabfr10*), medial (*kabfr11*) and complete (*kabfr13*) glottalization practically equalize above 90% "könnten", but the final position still produces 30% "können" responses. This result differs from the one in Experiment 1. However, since there the final glottalization duration was 30% longer, it is very likely that we are dealing with a duration threshold beyond 60ms for the final position, whereas for the other two positions it is lower, and lowest for medial. As *kabfr7* and *kabfr14* have the same length of medial glottalization their different "könnten" frequencies may point to a nasal duration effect which becomes relevant when glottalization duration is small. Lack of glottalization is again a clear cue for "können" perception in all nasal durations.

## 3.5 Discussion

Of the initially postulated hypotheses (1), (4) and (5) have clearly been confirmed. The linguistic contrast between glottalization and modal voice, consistently found in plosive-related production data in German, at least of the North German variety, has its counterpart in perception data. There is a duration threshold in the perception of glottalization, and vocal tract resonances are relevant for the perceptual separation of plosive and vowel-related glottalization. But these two factors interact with each other and with the factor of hypothesis (2).

The initial, medial or final positioning of glottalization within a nasal is only irrelevant for plosive-related perception when its duration transgresses a threshold, which is different in each of these positions, and is highest finally. A value of more than 60ms seems to be necessary to trigger a plosive-related percept there, in the context before a word-initial vowel at any rate. So a successful auditory discrimination of spectral properties of glottalized stretches connected with plosive or vowel productions at word boundaries would also seem to require a minimum duration. That would explain the weakness of this effect in Experiment 3 but the very strong effect in Experiment 2, and it also explains the much more efficient signalling power of glottalization in medial position.

There are indications in the results of Experiment 3 that hypothesis (3) is also dependent on hypothesis (4): the increased total duration of nasals may only be indiscriminate for plosive-related perception if the duration of glottalization is above threshold. If glottalization is too short it seems to get auditorily enhanced by a long phonation contrast (Diehl, Kluender, and Walsh 1990). This would mean that a deviation from modal voice can be made perceptually salient either by lengthening its duration above threshold, or - when it is too short - by enhancing it through lengthening its phonatory environment.

# 4 Conclusion

This paper has knit together the analysis of production and perception data on a phenomenon of the phonetics of German that has only recently been observed: plosive-related glottalization. It has been presented as an array of regular and consistent phonetic manifestations of a phonological structure. It has also been the aim to show that the production patterns of glottalization find their close parallel in perception and that the phonetic feature therefore plays an important role in speech communication. It escaped notice for so long because phoneticians and phonologists have been preoccupied with citation form pronunciations of lexical entries and with their segmental representations. But the increasing interest in connected, more specifically spontaneous speech data bases has made it mandatory for researchers to enter into the phonetics and phonology above the word in real-life communication, and it is in this domain that glottalization phenomena abound. In dealing with such phrase-level features it also becomes necessary to develop a new paradigm for speech analysis that moves away from a strictly linear phonemic framework towards a componential analysis (Kohler 1999) to accommodate the temporal indeterminacies of speech production and perception successfully. This paper also wishes to set an example of dealing with phonetic data in this way, for an insightful explanation of observed speech behaviour.

From this general phonetic and linguistic point of view, it is now a great task for future research to investigate glottalization phenomena and their communicative functions in a large number of phonetically and phonologically diverse languages. What I would like to see is a comprehensive study of vowel, plosive, syllable and utterance-related glottalization phenomena across languages to arrive at phrase-level typologies and universals of phonation and of its coordination with supraglottal articulation under different conditions of communication. We can already draw on a substantial corpus of descriptions; we need to pool this knowledge, expand it considerably and integrate it into a coherent descriptive and explanatory cross-language frame.

With her comprehensive investigation into the Danish stød over many decades, Eli Fischer-Jørgensen has already contributed towards this goal more than any other scholar. Her work has been a source of inspiration for my own research in this area. It triggered the question "Is there a stød in German?"I think I can now give an answer. Danish *vennen* (definite form of *ven* "friend") is [vɛnṉ̰n], besides emphatic [vɛnʔn], which coincides phonetically with the very common realizations of German *wenden* "to turn", having a glottalized nasal or glottal stop inside the nasal. So from the phonatory point of view German has a stød. And American English has one as well, for example in the pronunciation of the name *Fenton.* The distributions of this phonetic feature and their phonological functions are, of course, completely different. Let's pick up Eli's example and find out more about glottalization phenomena in human speech and language!

# References

Diehl, R., K. Kluender, and M. Walsh (1990). Some auditory bases of speech perception and production. In W. Ainsworth (Ed.), *Advances in Speech, Hearing and Language Processing*, pp. 243–268. London: JAI Press.

Dilley, L. and S. Shattuck-Hufnagel (1995). Variability in glottalization of word onset vowels in American English. In *Proc. XIIIth ICPhS*, Volume 4, Stockholm, pp. 586–589.

Fischer-Jørgensen, E. (1989a). Phonetic analysis of the stød in Standard Danish. *Phonetica 46*, 1–59.

Fischer-Jørgensen, E. (1989b). *A phonetic study of the stød in Standard Danish.* University of Turku Phonetics.

Grice, M. and W. J. Barry (1991). Problems of transcription and labelling in the specification of segmental and prosodic structure. In *Proc. XIIth ICPhS*, Volume 5, Aix-en-Provence, pp. 66–69.

Higginbottom, E. (1964). Glottal reinforcement in English. *Transactions of the Philological Society*, 129–142.

IPDS (1994). *The Kiel Corpus of Read Speech*, Volume 1. Kiel: IPDS, Kiel. =Kiel CD-ROM #1.

IPDS (1995). *The Kiel Corpus of Spontaneous Speech*, Volume 1. Kiel: IPDS, Kiel. =Kiel CD-ROM #2.

IPDS (1996). *The Kiel Corpus of Spontaneous Speech*, Volume 2. Kiel: IPDS, Kiel. =Kiel CD-ROM #3.

IPDS (1997a). *The Kiel Corpus of Spontaneous Speech*, Volume 3. Kiel: IPDS, Kiel. =Kiel CD-ROM #4.

IPDS (1997b). *xassp* user's manual (*A*dvanced *S*peech *S*ignal *P*rocessor under the *X* Window System). *Arbeitsberichte des Instituts für Phonetik und digitale Sprachverarbeitung der Universität Kiel (AIPUK) 32*, pp. 31–115.

Kohler, K. J. (1992). Sprachverarbeitung im Kieler PHONDAT-Projekt: Phonetische Grundlagen für ASL-Anwendungen. *Arbeitsberichte des Instituts für Phonetik und digitale Sprachverarbeitung der Universität Kiel (AIPUK) 26*, pp. 81–95.

Kohler, K. J. (1994). Glottal stops and glottalization in German. Data and theory of connected speech processes. *Phonetica 51*, 38–51.

Kohler, K. J. (1995a). The realization of plosives in nasal/lateral environments in spontaneous speech in German. In *Proc. XIIIth ICPhS*, Volume 2, Stockholm, pp. 210–213.

Kohler, K. J. (1995b). PROLAB - the Kiel system of prosodic labelling. In *Proc. XIIIth ICPhS*, Volume 3, Stockholm, pp. 162–165.

Kohler, K. J. (1996a). Phonetic realization of German /ə/-syllables. *Arbeitsberichte des Instituts für Phonetik und digitale Sprachverarbeitung der Universität Kiel (AIPUK) 30*, pp. 159–194.

Kohler, K. J. (1996b). Glottal stop and glottalization - A prosody in European languages. *Arbeitsberichte des Instituts für Phonetik und digitale Sprachverarbeitung der Universität Kiel (AIPUK) 30*, pp. 207–216.

Kohler, K. J. (1997). Modelling prosody in spontaneous speech. In Y. Sagisaka, N. Campbell, and N. Higuchi (Eds.), *Computing Prosody*, pp. 187–210. Berlin/Heidelberg/New York/Tokyo: Springer.

Kohler, K. J. (1999). Articulatory prosodies in German reduced speech. In *Proc. XIVth ICPhS*, Volume 1, San Francisco, pp. 89–92.

Kohler, K. J., M. Pätzold, and A. P. Simpson (1995). From scenario to segment: the controlled elicitation, transcription, segmentation and labelling of spontaneous speech. *Arbeitsberichte des Instituts für Phonetik und digitale Sprachverarbeitung der Universität Kiel (AIPUK) 29*, 1–141.

Kohler, K. J., M. Pätzold, and A. P. Simpson (1997). From the acoustic data collection to a labelled speech data bank of spoken Standard German. *Arbeitsberichte des Instituts für Phonetik und digitale Sprachverarbeitung der Universität Kiel (AIPUK) 32*, 1–29.

Kohler, K. J. and C. Rehor (1996). Glottalization across word and syllable boundaries. *Arbeitsberichte des Instituts für Phonetik und digitale Sprachverarbeitung der Universität Kiel (AIPUK) 30*, pp. 195–206.

Local, J. and J. Kelly (1986). Projection and 'silences': notes on phonetic detail and conversational structure. *Human Studies 9*, 185–204.

Matisoff, J. (1973). Tonogenesis in Southeast Asia. In L. Hyman (Ed.), *Consonant Types & Tones. Southern California Occasional Papers in Linguistics*, Volume 1, pp. 71–95. Los Angeles: Linguistics Program University of Southern California.

Nakatani, C. and J. Hirschberg (1994). A corpus-based study of repair cues in spontaneous speech. *Journal of the Acoustical Society of America 95*, 1603–1616.

Pätzold, M. (1997). *KielDat* – data bank utilities for the *Kiel Corpus*. In *Arbeitsberichte des Instituts für Phonetik und digitale Sprachverarbeitung der Universität Kiel (AIPUK) 32*, pp. 117–126.

Pierrehumbert, J. and S. Frisch (1994). Source allophony and speech synthesis. In *Proc. ESCA/IEEE Workshop on Speech Synthesis*, pp. 1–4.

Roach, P. (1979). Laryngeal-oral coarticulation in glottalized English plosives. *Journal of the International Phonetic Association 9*, 2–6.

Rodgers, J. (1999). Three influences on glottalization. In K. J. Kohler (Ed.), *AIPUK34*, Arbeitsberichte des Instituts für Phonetik und digitale Sprachverarbeitung der Universität Kiel (AIPUK) 34.