# Gradient dorsal nasal in Northern German[1]

**Caroline Féry, Constance Hohmann & Katharina Stähle**

## 1. Introduction

There has been in the past a large agreement among researchers of spoken language that phonetics studies gradient facts whereas phonology investigates categorical phenomena. It is true that phonologists tend to elaborate tidy inventories of phonemes, syllables or accent patterns, whereas the distribution of the really existing consonants in the consonantal space or of the vowels in the vocalic space are more variable (see Cohn 2006, Keating 1987, Ohala and Ohala 1995 among others). But the distinction between categorical phonology and variable phonetics has been questioned in the last decades, and an increasing number of researchers investigate the claim that phonology should be able to account for variation and gradience (see for instance Pierrehumbert 2003, Pierrehumbert, Beckman, and Ladd 2000, Frisch 2000, Boersma and Hayes 2001, Bybee 2000a,b, 2001, 2003, Cohn 2006 and many others).

If this view is adopted, gradience can be said to originate at different places in phonology. One of the main reasons for gradience is that language continuously evolves and successive generations or groups of individuals may have slightly different grammatical systems from their parents' or neighbors' ones (see for instance Jacewicz et al., this volume). It may also be the case that some social groups implement the changes earlier or more readily than others (see among others Labov 1994, Bybee 2003, Kiparsky 2000, Kroch 2001 and Šimáčková, this volume). As a second source of gradience, categories are not always invariant: the acoustic and articulatory correlates of 'continuant' and 'stop' obstruents, for instance, can be gradient according to context or dialect. Spirantization can also emerge as a lenition effect which is more or less completed, depending on the environment (see for instance Bybee 2001 and Kirchner 2001 for lenition). Our articulatory organs are such that some segments may be unambiguously realized in some contexts, but be more variable or resemble other segments in different contexts (see Guimarãrens and Cristófaro-Silva, this volume, for an example). Neutralization of contrasts between voiced and unvoiced segments is achieved in some environments but not in others, as the acoustic cues differ (Steriade 2001, Darcy et al., this volume). A third source of variation is to be found in the application of allophonic rules. In some cases, distinct categories are targeted, as in t/d deletion in English, or the dorsal nasal in German investigated in this paper. T/d is deleted in English as a dependent variable of morphological category, syllable structure, prosodic phrasing and so on. To mention some examples, it is more frequently deleted in words like *West* or *breakfast*, where the final coda is complex and does not stand for an inflectional morpheme than in *played* and *fed*, where the coda is simple and is morphemically meaningful. It will be shown in this paper that the emergence of [k] after a dorsal nasal in German, the subject of investigation in this paper, is also influenced by a number of phonological factors, like the prosodic category that the word containing [ŋ] ends, the presence of an accent, and the quality of the vowel preceding the dorsal nasal. In short, phonological gradience is not random. Rather the factors weighing on the variation are to be made part of the grammatical model responsible for the variation.

If it is true that phonology is gradient as we think it is, we need a grammar which can account for the gradient effects. It seems that standard generative theories, despite many deep insights about grammatical mechanisms, are ill-equipped to account for such phenomena because the output of re-write rules or of standard constraint interactions is categorical. There have been a number of proposals in classical generative phonology of how the outputs of grammar can be variable, like co-phonologies as proposed by Anttila 2001, or stochastic approaches in OT (Boersma 1998, Boersma and Hayes 2001) as well as older accounts along the line of variable transformational rules (Sankoff and Labov 1979). It will be shown in this chapter that a stochastic optimality theoretic approach is appropriate for the data investigated. But first, the phenomenon is introduced in a derivational framework, as well as the experimental results.

## 2. Alternation between [ŋ] and [ŋk] in a derivational perspective

In the generative tradition of German phonology, the emergence of [ŋ] and [ŋk] has been accounted for with the help of ordered derivational rules which change an underlying form into a surface one. Isačenko (1963) was the first to propose that some instances of the dorsal nasal are the consequence of a derivation from the sequence /n+g/, the remaining ones being the result of an assimilation to a following voiceless dorsal stop, as in *Bank* 'bank' or *schenken* ‘to give as a present’. This insight has been adopted and further developed by many German phonologists (see for instance Wurzel 1980, Hall 1992, Ramers and Vater 1992, Yu 1992, Wiese 1996, Ito and Mester 2003 and Féry 2003). In a linear derivational model, Nasal Assimilation, Final Deletion and g-deletion are ordered rules, which apply successively in a given order, one rule providing a new structural description, to which the next ordered rule may or may not apply. In the standard dialect of German, Nasal Assimilation applies first and *g*-deletion second. Nasal assimilation changes a coronal nasal into a dorsal one before a dorsal stop, and *g*-deletion deletes /g/ after a dorsal nasal in some environments. A third rule, Final Devoicing, cannot apply because it is ordered after *g*-Deletion, at a stage of the derivation at which its structural description has been bled by application of *g*-deletion. At this point, the [g] to be devoiced is no longer present.[2]

The derivation of the words *Bank* ‘bank’ and *lang* ‘long’ in the standard dialect is illustrated in (1).

(1) Derivation of *Bank* and *lang* in Standard German:

| | | |
|---|---|---|
| /bank/ | /lang/ | |
| baŋk | laŋg | Nasal Assimilation |
| — | laŋ | *g*-deletion |
| — | — | Final Devoicing |
| [baŋk] | [laŋ] | |

In the Northern variety, by contrast, the order of application of Final Devoicing and *g*-deletion is reversed. Final Devoicing applies just after Nasal Assimilation, and it is now *g*-deletion which cannot take place because its structural description has been bled. This derivation is illustrated in (2). As a result, *Zeitung* is pronounced [t$^{s}$ai̯tʊŋk]. Notice that *Bank* is pronounced the same in both dialects, since there, only Nasal Assimilation takes place, and *k* is not deleted.

(2) Derivation of *Bank* and *Zeitung* in Northern German:

| | | |
|---|---|---|
| /bank/ | /t$^{s}$ai̯tʊng/ | |
| baŋk | t$^{s}$ai̯tʊŋg | Nasal Assimilation |
| — | t$^{s}$ai̯tʊŋk | Final Devoicing |
| — | — | *g*-deletion |
| [baŋk] | [t$^{s}$ai̯tʊŋk] | |

Though interdialectal variation is well accounted for in the derivational approach, variation in a single dialect is not. The rules apply categorically, as soon as their structural description is met, and their order of application is not subject to change. According to the rule sequences in (1) and (2), all occurrences of /ng/ are realized phonetically as [ŋ] in the standard dialect, and all occurrences of this sequence emerge as [ŋk] in the Northern dialect. But, as will be documented in the next section, this categoriality does not correspond to reality. Instead, we also find variation in the dialects themselves.

Subsequent generative approaches, like the autosegmental framework, or the standard OT model, do not solve the problem caused by the strict categoriality of the derivational rules. Both the representational model and the optimality-theoretic framework predict a similar invariant application of phonological processes. In a nonlinear pattern (see for instance Hall 1992 and Wiese 1996 for autosegmental accounts of nasal assimilation and *g*-deletion), the place of articulation of the stop spreads regressively, which causes the underlying coronal nasal to become dorsal. After having triggered assimilation, the whole segment slot is deleted, which is expressed by delinking of the major features of this segment or the skeletal slot. Though the format of the rule has changed drastically, the spirit has not. As soon as the structural description of a rule is met, the rule applies and a categorical structural change is the result.

In standard OT, constraints on the surface representation of phonological forms determine which one among a large set of candidates fulfills the constraints best (or violates them least). Constraints are universal, violable and ranked, and the evaluation of the candidates applies in parallel. We return to an optimality-theoretic model of the nasal dorsal in section 4.

## 3. Experimental study

When listening to a speaker of Northern German, it is conspicuous that the categoriality assumed in standard generative accounts is not supported by the data. Speakers realize both [ŋ] and [ŋk] in a way that can first appear as random. However, half a century of quantitative phonological research, starting with Labov (1966), has taught us that the impression of randomness may be an illusion, and that a precise survey of the data according to relevant parameters may considerably reduce the freedom of variation. It could even be the case that, if it is possible to pin down all factors playing a role in the choice of one allomorph over the other, we find ourselves in a deterministic situation in which variation is completely eliminated. With this idealized hypothesis in mind, an experiment was conducted in order to identify the factors bearing on the choice of one or the other variant in Northern German.

### 3.1. Experimental set-up

In designing an experiment for studying the factors influencing the distribution of [ŋ] and [ŋk] in Northern German, efficiency and economy were aimed at, in the manner of sociolinguistic surveys. The experimental set-up had to meet several criteria. It was intended to elicit spontaneous but comparable material, a consideration leading to the elimination of spontaneous speech. It was also crucial that the speakers would utter a reasonable number of words containing a dorsal nasal within a short period of time. Instead of using completely free and thus random speech, an experiment was elaborated in which the speakers narrated a story in their own way, but in which some of the lexical material was imposed. To meet these aims, we wrote a short story which contained a large number of words with [ŋ] or [ŋk]. The informants first read the story silently, and in a second step told the story in their own way and rhythm. Recordings were made in a quiet room on a DAT tape-recorder, after the experimenter had given initial instructions as to the procedure of the session. The speakers were naive as to the aims of the recordings. To make sure that they would use the intended words, accompanying drawings were presented. There were also some rare interventions and questions from the experimenters in order to elicit a missing word. The story telling took between 2 minutes 26 seconds and 3 minutes 49 seconds, depending on the speaker. Altogether 18 minutes 48 seconds of speech were analyzed, containing 201 occurrences of words ending with a dorsal nasal.

### 3.2. Subjects

The results of six informants were evaluated, three men and three women from Potsdam or from the East of Berlin who had lived there all their life. Except for gender, the speakers were quite homogeneous in their social class and age. They were from the middle class and were between 31 and 37 years old. They were friends or relatives of the experimenters. All informants spoke a relatively standard language with only few other dialectal characteristics.

### 3.3. Analysis

The recordings were first evaluated auditorily by the experimenters. They decided on the basis of what they heard whereas the sound produced was [ŋk], [ŋ] or an intermediate realization with a lenited [k]. In a second step, the first author as well as a fourth, independent listener reevaluated the data, partly auditorily and partly on the basis of spectrograms. These two latter judges classified all items in only two categories, [ŋk] or [ŋ]. They agreed on every single realization, and the evaluation presented below is based on this second evaluation. It must be mentioned at this place that the realization involved a great deal of variation, with many lenited stops. However, a categorical decision as to whether the stop was there or not, was always available, and this guiding line was used for the final decision. At this place an important difference between t/d deletion in English and [ŋk] in German should be mentioned. According to Bybee (2001), t/d deletion is an historical process, whereas [k] is not in the process of being deleted in the phonology of German. Rather, if anything, it is an epenthetic segment, or an excrescent one.

The complete list of words uttered by the informants is reproduced in (3), given in tokens, together with the number of their allophones.[3]

(3)

| | Word | Gloss | Total | [ŋ] | [ŋk] |
|---|---|---|---|---|---|
| [a] | Wolfgang | 'name' | 25 | 13 | 12 |
| | Hang | 'slope' | 3 | 3 | 0 |
| | Gang | 'walk' | 3 | 1 | 2 |
| | schwang | 'swang' | 1 | 1 | 0 |
| | klang | 'sounded' | 1 | 1 | 0 |
| | lang | 'long' | 12 | 3 | 9 |
| | gelangweilt | 'bored' | 3 | 2 | 1 |
| | Fischfang | 'fish catch' | 6 | 6 | 0 |
| | langweilig | 'boring' | 5 | 4 | 1 |
| | entlang | 'along' | 4 | 1 | 3 |
| | sprang | 'sprang' | 5 | 5 | 0 |
| | Gesang | 'singing' | 3 | 1 | 2 |
| | sang | 'sang' | 2 | 2 | 0 |
| [ʊ] | Wohnung | 'appartment' | 8 | 5 | 3 |
| | Ahnung | 'presentiment' | 2 | 1 | 1 |
| | Tageszeitung | 'newspaper' | 2 | 1 | 1 |

*continue*

| | Word | Gloss | Total | [ŋ] | [ŋk] |
|---|---|---|---|---|---|
| | Mietwohnung | 'appartment for rent' | 2 | 0 | 2 |
| | Kreuzung | 'crossing' | 5 | 2 | 3 |
| | Achtung | 'attention' | 5 | 3 | 2 |
| | Zeitung | 'newspaper' | 4 | 0 | 4 |
| | Umleitungsschild | 'detour sign' | 1 | 1 | 0 |
| | Begrüßung | 'greeting' | 6 | 2 | 4 |
| | Umleitung | 'detour' | 6 | 0 | 6 |
| | Beschilderung | 'sign' | 2 | 0 | 2 |
| | Wohnungstr | 'door of the flat' | 1 | 1 | 0 |
| | Wohnungsannoncen | 'newpaper advertisement' | 1 | 1 | 0 |
| | Wohnungsinserate | 'newpaper advertisement' | 1 | 1 | 0 |
| | Wohnunganzeigen | 'newpaper advertisements' | 1 | 0 | 1 |
| | Zeitungsinserate | 'newpaper advertisement' | 1 | 1 | 0 |
| | Richtung | 'direction' | 3 | 3 | 0 |
| | Unterhaltung | 'entertaining' | 1 | 1 | 0 |
| [ɛ] | Peng | 'name' | 52 | 52 | 0 |
| | eng | 'narrow' | 3 | 3 | 0 |
| | ging | 'went' | 7 | 7 | 0 |
| [ɪ] | Belling | 'name' | 13 | 12 | 1 |

In a second step, a phonological analysis was performed. The recordings were transcribed and Phonological Phrase and Intonation Phrase boundaries were indicated. Breaks in the timing were also localized. Word-medial and word-final occurrences of [ŋ] and [ŋk] were divided into two classes, as mentioned before. Decisions were also taken as to the accent status of the words.

### 3.4. Results

The main factors bearing on the distribution of [ŋ] and [ŋk] belong to a small group of phonological properties: the boundaries of prosodic domains, the quality of the preceding vowel and the accent, both individually and in relation with each other. Although number of syllables, morphemic structure (root, stem, word) and lexical categories (nouns, adjectives, verbs and preposition) were also examined, no effect was found for these factors. Taking all word final dorsal nasals together, the distribution indicates a clear preference for a realization without a voiceless stop (141 of 201 or 70%), as indicated in (4). In 60 cases (or 30% of the total realizations), a voiceless stop was present. Table (4) shows first the distributions of the two variants for each speaker separately. It can be noticed from this table that the speakers show a wide range of variation as to the proportion of dorsal nasals with or without voiceless stop (between 17% and 42% of their total occurrences), though no speaker had more [ŋk] than [ŋ]. No gender specific tendency is noticeable.[4]

(4) Contextless distribution

| | [ŋ] | [ŋk] | Total |
|---|---|---|---|
| Speaker 1 (f) | 34 (79%) | 9 (21%) | 43 |
| Speaker 2 (m) | 26 (65%) | 14 (35%) | 40 |
| Speaker 3 (f) | 19 (58%) | 14 (42%) | 33 |
| Speaker 4 (m) | 18 (67%) | 9 (33%) | 27 |
| Speaker 5 (m) | 25 (83%) | 5 (17%) | 30 |
| Speaker 6 (f) | 19 (68%) | 9 (32%) | 28 |
| All Speakers | 141 (70%) | 60 (30%) | 201 |

### 3.4.1. *The influence of prosodic boundary, accent and vowel on [k]*

The first factor examined in this section is the prosodic boundary following [ŋ] and [ŋk]. The prosodic domains assumed in this paper are rather traditional and have been proposed by Nespor and Vogel (1986) and Selkirk (1984). The prosodic hierarchy for higher levels is reproduced in (5).

(5) Prosodic hierarchy

| | |
|---|---|
| Intonation Phrase | (IP) |
| Phonological Phrase | (PhP) |
| Prosodic Word | (PW) |
| Foot | (F) |

Both the speaker and the hearer have to rely on indicators of phrasing in order to parse the utterances in prosodic phrases (see for instance the experimental results of Schafer 1997 for English and Bader 1998 or Muckel 2001 for German). A certain number of cues can be used to this aim, like duration and tones in the form of breaks and boundary tones. Segmental alternations also signal prosodic boundaries. Glottal stops, aspiration and final devoicing are well-known phenomena in German for the delimitation of the foot and higher levels (see Féry 1995, 2003), and the alternation between presence and absence of a stop after a dorsal nasal can be added to this list. The probability of finding a devoiced obstruent, a glottal stop and so on, increases with the height of the prosodic domain. The higher the prosodic domain, the more probable is the presence of such cues. It can be speculated that the release accompanying a voiceless stop is an additional cue to finality of a prosodic domain. On the contrary, the articulation of a nasal, a following stop plus possibly the first consonant of the following word in the middle of a phonological phrase involves the coordination of several articulators which have to be positioned rapidly after each other, without being separated by vowels. This may take too much time to be consistently and reliably executed. A realization without stop is thus explained by articulatory efficiency and hearer-oriented speech.

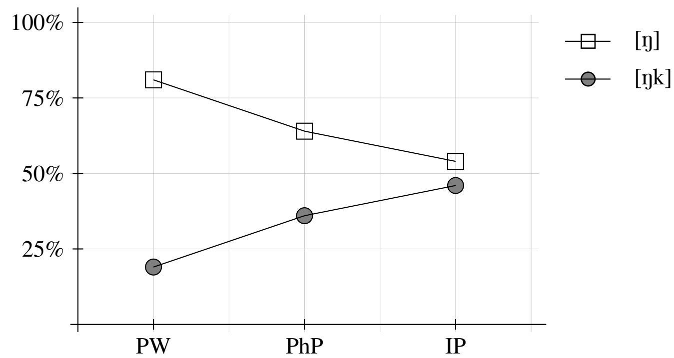
As far as the data examined here are concerned, decisions were taken as how to assign prosodic domains to utterances. In the data examined in this paper, the prosodic words were straightforward, since all realizations of the dorsal nasal considered for the results were realized at the boundary of a word which can be unambiguously analyzed as a prosodic word. The phonological phrases were decided on the basis of the syntactic structure: the right edge of a major phrase was assigned a boundary of a phonological phrase. The intonation phrases were uncontroversial since they are the locus of boundary tones and clear breaks between utterances (Pierrehumbert 1980, Pierrehumbert and Hirschberg 1990). Moreover boundaries of sentences fall together with boundaries of IPs.

A clear correlation between the kind of prosodic boundary and the presence of a stop could be established. The stronger the prosodic boundary, the more probable the occurrence of a voiceless stop. The proportion of realizations with a voiceless stop increases from 19% for a prosodic word (PW) boundary to 36% for a Phonological Phrase (PhP) boundary and 46% for an Intonation Phrase boundary (IP), as shown in (6) and (7).

(6) Prosodic domains

| | [ŋ] | [ŋk] | Total |
|---|---|---|---|
| PW | 87 (81%) | 21 (19%) | 108 |
| PhP | 25 (64%) | 14 (36%) | 39 |
| IP | 29 (54%) | 25 (46%) | 54 |

(7) The distribution of [ŋk] and [ŋ] according to prosodic domains




The next factor investigated is the role of a pitch accent. We postulated that being accented increases the probability to find [k], since a voiceless stop enhances the perceptivity of the word it ends.[5] And indeed, we found a confirmation of this hypothesis in our data, as shown in (8). A large proportion of target words were accented (184 words as opposed to 17 unaccented), reflecting the fact that in free speech, speakers tend to realize more accents than strictly necessary for information structural needs. All words with [ŋk] were accented, whereas 12% of the words ending with [ŋ] were unaccented.

(8) Distribution of [ŋ] and [ŋk] according to accent

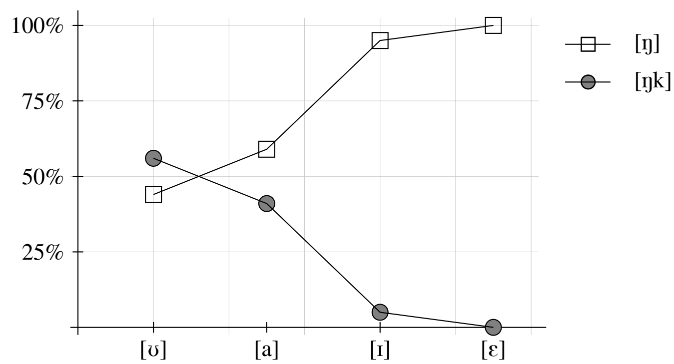
| Stressed | Stressed | Unstressed |
|---|---|---|
| [ŋ] | 124 (88%) | 17 (12%) |
| [ŋk] | 60 (100%) | 0 |

The third factor playing a crucial role in the distribution of the allophones is the quality of the vowel immediately preceding the dorsal nasal. Compare table (9) which partitions the occurrences of [ŋ] and [ŋk] according to the preceding vowel, [ʊ], [a], [ɪ] and [ɛ]. [k] emerged much more often in the corpus after a back vowel than after a front one: 56% after [ʊ] and 41% after [a], as compare to 5% after [ɪ] and 0% after [ɛ].[6] Important is the proportion between the realizations of [ŋ] and [ŋk] after each vowel, given here in percentage, not the absolute number of occurrences since these are biased by the large number of occurrences of *Peng* and of *Wolfgang*, both names which appeared very often in all narrations see the figures in (3). Words ending in [ʊŋ] are also very frequent, but words ending in [ɪŋ] are definitely less so, as can be gathered from table (9). Figure (10) is a graphic illustration of the distribution of [ŋ] and [ŋk] after vowels.

(9) Distribution of [ŋ] and [ŋk] according to the preceding vowel

| | after [ʊ] | after [a] | after [ɪ] | after [ɛ] | Total |
|---|---|---|---|---|---|
| [ŋ] | 23 (44%) | 43 (59%) | 20 (95%) | 55 (100%) | 141 |
| [ŋk] | 29 (56%) | 30 (41%) | 1 (5%) | 0 | 60 |
| Total | 52 | 73 | 21 | 55 | 201 |

(10) The influence of the vorwel




The fact that in most cases no stop is realized after a front vowel is not the result of an accidental gap due to the absence of words with a front vowel at the end of a PhP or IP. In a comparison between the number of words ending in the different vowels at each prosodic boundary, no crucial difference can be found. At the end of a PW, we find 46% of the words ending in [ʊ], 60% of those ending in [a], 67 % of those ending in [ɪ] and 47% of those ending in [ɛ]. For a PhP, we have 23%, 16%, 9% and 24% of the words with [ʊ], [a] [ɪ] and [ɛ] respectively. At the end of an IP: 31%, 23%, 24% and 29%. In other words, the proportion of words at the end of each prosodic domain does not differ dramatically for each vowel.

Table (11) shows the proportion of the allophonic variants after each vowel and for each prosodic category.

(11) Distribution according to vowels and prosodic domains

| | after [ʊ] | after [a] | after [ɪ] | after [ɛ] |
|---|---|---|---|---|
| **Word finally:** | | | | |
| [ŋ] | 16 (66,6%) | 32 (57%) | 13 (93%) | 26 (100%) |
| [ŋk] | 8 (33,3%) | 12 (43%) | 1 (7%) | - |
| **PhP finally:** | | | | |
| [ŋ] | 7 (58%) | 3 (25%) | 2 (100%) | 13 (100%) |
| [ŋk] | 5 (42%) | 9 (75%) | - | - |
| **IP finally:** | | | | |
| [ŋ] | - | 8 (47%) | 5 (100%) | 16 (100%) |
| [ŋk] | 16 (100%) | 9 (53%) | - | - |
| **Total** | **52** | **73** | **21** | **55** |

An interesting result of table (11) is that at the end of an IP, there is a 100% probability to find [ʊŋk] (and 0% to find [ʊŋ]).

To sum up, we think that there is a real effect of the vowel quality on the two allophones, and that the distribution of the words ending with the different vowels at different prosodic domains in our small corpus cannot explain the difference we find.

### 3.4.2. *Word length, stress location, and morphemic structure: the factors which play no role in the emergence of [k]*

Turning now to the factors which do not seem to play any role for the distribution of [ŋk] and [ŋ], no correlation between the number of syllables and the presence of [k] could be established. In longer words, the lexical stress was nearly always on a nonfinal syllable (the only exceptions being *Gesang* singing' and entlang, 'along'), and, of course, monosyllabic words are stressed on their unique syllable. However, the relationship between the number of syllables and the presence of a stop will be marginal at best, since words with final [ʊ] are always multisyllabic, and always have nonfinal stress, whereas a large amount of our words ending with [ɪ] or [ɛ] were monosyllabic. Since words with final [ʊ] are more often stressed on a non-final syllable than words with final front vowel, it cannot be the case that the presence of a stress on the syllable itself is decisive. A final question arises for words with [a]. An evenly distribution of monosyllabic and finally-stressed *lang, Fang, Hang*, on the one hand, and polysyllabic and initially-stressed *Wolfgang*, on the other hand is found in all contexts, a fact leading to the conclusion that there is no correlation between number of syllables and distribution of [ŋk] and [ŋ].

It has been shown that the pattern of final *t* deletion in English is sensitive to the morphological structure of the words. Simple roots are more subject to *t*-deletion than stems which in turn are more often affected than derived words (see for instance Guy 1991). It might be interesting to find out whether a similar pattern is acting in the variation examined here.

Of the words listed in (3), some are just roots, but many are morphologically complex, like *langweilig* or *Achtung*. The majority of complex words are derived with a suffix and/or are compounds (*Fischfang, Mietwohnung*).

It is evident that, depending on the final vowel, words are distributed into different word classes. Words ending with [ʊ], for instance, are always derived with the suffix *-ung*. Words ending in [a], on the other hand, display more variation. Monomorphemic words do not seem to show any preference for the one or the other realization: *lang*, and *Wolfgang*, for instance, are found in both variants. The same is true for most complex words, like those derived with the suffix *-ung*. The only interesting generalization that seems to emerge from our limited set of data is the fact that strong verbs with ablaut (like *schwang, klang, sang* and *ging*) are always realized without stop.

The corpus used in this experiment is unfortunately much too small to be conclusive, and we leave it to further research to find out whether the morphological structure, the number of syllables and the location of lexical stress could influence the realization of the dorsal variant in one way or another.

### 3.5. Discussion

The result of this investigation is that a contextually conditioned distribution of the variable realizations of the dorsal nasal in the Northern German dialect could be established. Some of the variables identified deliver categorical results, and some are just tendencies. Putting together the results presented in the preceding section, the following factors play a role in the distribution of [ŋ] and [ŋk].

- First, there is an interindividual variation. Speaker 5 had the fewest occurrences of [ŋk] with 17% and speaker 3 the most with 42%.

- Second, the prosodic boundary: the stronger it is, the more probable is an occurrence of [k]. This is true for back vowels to a larger extent than for front vowels.

- Third the accent: the presence of [k] correlates with pitch accent. There were, in the corpus, not a single unaccented word with [k]. But the reverse is not true: there were accented words without [k].

- Fourth, the vowel quality: the emergence of a final [k] correlates with the preceding vowel. Only back vowels are regularly followed by a voiceless stop, [ʊ] more than [a]. A front vowel is nearly always followed by just a dorsal nasal, though the correlation is not necessary. Speakers of Northern German do sometimes realize *eng* 'tight' as [ɛŋk] or *Ding* 'thing' as [dɪŋk].

No correlation between word length and presence of [k] could be established. Other factors playing no role in the corpus were the place of the lexical stress, and the morphological category. These factors are accordingly ignored in the presentation of the model in the next section.

## 4. OT-CC and factor-driven gradient model

The preceding section has shown that different phonological factors influence the distribution of [ŋ] and [ŋk], and the aim of this section is to sketch a model of phonology, based on McCarthy's (2007) OT-CC, as well as on Boersma (1998) and Boersma and Hayes' (2001) Gradual Learning Algorithm, which can take these factors into consideration.

As has been discussed in section 2, traditional generative models are inappropriate for the treatment of variable and gradient data. Rules and constraints determine a unique surface form, or a unique optimal candidate, and leave no place for variation or optionality between different candidates.[7] In its standard version, Optimality Theory is as categorical as any other generative model, though constraint violability and rankability renders it a potentially more flexible framework to account for optionality. And indeed, there have been a number of proposals in the literature taking advantage of these properties in order to integrate variation into generative phonology. First, the recent Maximum Entropy model of Hayes and Wilson (2008), a model of acquisition of phonology loosely based on OT, but relying on the idea that no constraint is innate. This approach is not further considered in this section, mainly because it has appeared after completion of the present paper. Second, the multiple grammar approaches of Anttila (2001) and Reynolds and Nagy (1994), which envisage tied constraints as multiple grammars. Variation arises from the competition of distinct grammars. In Anttilas's wording:

”The number of grammars that generate a particular output is proportional to the relative frequency of this output.” The main idea of such approaches is that a candidate which emerges as the optimal one in the majority of competing grammars is realized more often than a candidate only seldom selected as optimal.

Boersma’s stochastic model relies on the same idea, although its formal architecture is radically different. Before introducing the factor-driven gradient model to be proposed, the main features of stochastic OT are sketched in the next subsection.

### 4.1. Stochastic OT: Functional OT and Gradual Learning Algorithm

Functional Grammar (Boersma 1998), as well as Boersma and Hayes’ 2001 Gradual Learning Algorithm, GLA, have been specifically conceived to take care of free variation, gradient grammaticality judgments and frequency dependent time ordering in the process of acquisition. These variants of OT are similar to the standard version of OT in many ways, but instead of being based on a complete ranking of the constraints, they assume that constraints have a ranking value on a continuous scale of constraint strictness. In Functional OT, the distance between two constraints is meaningful. A shorter distance implies that the relative ranking between the two constraints is less fixed. At a certain point of time, the constraints may occupy partly the same space in the scale, a fact that Boersma and Hayes explain by constraints’ overlap. This is to be understood as follows: At the time of a particular evaluation, the constraints’ values are temporarily perturbed by a random factor and constraints behave as if they were associated with a range of values rather than with single points. This effect is called the ‘evaluation noise.’ It is an amount of normally distributed noise and is temporarily added to the ranking value of each constraint. The amount of noise is calculated independently for each evaluation.

If the ranking values of two constraints, A $\gg$ B, are close, the ranking of the constraints at evaluation time will sometimes be the reverse of their “normal” ranking, depending on the accidental values of the noise component. In other words, in a certain percentage of the evaluations, B will outrank A although it is ranked somewhat lower, and, when this happens, the second best candidate wins. At a given moment (as for instance in language acquisition), the noise value of the constraints which are further apart can be so large that even a constraint which is usually dominated, can temporarily become dominant. If the ranges of two constraints overlap, there will be free variation. Constraint ranges are thus interpreted as probability distributions, and account in this way for noisy events. A normal distribution has a single peak in the center, with values around the center being most probable, and declining toward zero on each side. Values are less probable the further they are from the center.

As an extension of Functional Phonology, Boersma and Hayes (2001) develop the Gradual Learning Algorithm, an OT algorithm for learning constraint ranking. They illustrate its working with examples of free variation in the distribution of glottal stop and glides in Ilokano, of output frequency in the Finnish genitive and of gradient well-formedness judgments in the distribution of light and dark [l] in English. The Gradient Learning Algorithm needs two kinds of inputs, frequencies of distribution and OT constraints. The output of the algorithm is a ranking of the constraints on a continuous scale, as explained above. The GLA calculates the strictness of the constraints relatively to each other. The ranking is expressed in terms of values, which can thus be closer or further apart.

The data examined in this paper can be accounted for by a stochastic model, as will be shown in section 4.3, but the allophony between [ŋ] and [ŋk] is not free. Rather it is influenced by different factors, a fact which introduces a complication for the model.

### 4.2. OT-CC and the allophony between [ŋ] and [ŋk]

Before we can discuss the model of variation in the next subsection, it is important to introduce the constraints necessary to account for the allophony between [ŋ] and [ŋk]. An additional difficulty related to this allophony is that one of its allophones, namely [ŋ], results from an opaque process (see also van Oostendorp, this volume for opacity in OT).

Assuming first that [ŋ] is always the product of an assimilation of a coronal nasal to a following dorsal stop, a constraint AGREE(dorsal) in (12a) is needed. In German monomorphemes, this constraint is inviolable. To illustrate the effect of this constraint, a word like *Bank*, which preserves the final [k], is used in (13). A constraint against deletion of [k], MAX[k], formulated in (12b), is also needed. A third constraint, IDENT(coronal), formulated in (12c), which requires that an input feature [coronal] is preserved in the output, is violated by the grammatical candidate. Tableau (13) illustrates the effect of (12) with a non-alternating word.

(12)

a. AGREE(dorsal): Adjacent nasal and dorsal stop agree in dorsality.
b. MAX[k]: No deletion of the segment [k].
c. IDENT(coronal): No change of the feature [coronal].

(13) OT account of *Bank* 'bank'

| /bank/ | AGREE(dorsal) | MAX[k] | ID(coronal) |
|---|---|---|---|
| ☞ a. baŋk | | | * |
| b. bank | *! | | |
| c. ban | | *! | |

More intricate is the account of the allophony between [ŋ] and [ŋk/ŋk]. The first variant, without [g] or its finally devoiced correspondent [k], is the product of an opaque counterbleeding interaction (overapplication), since the trigger of the assimilation [g] is not present on the surface. Opaque situations are notoriously difficult to account in an optimality theoretic model, and have been the cause of many amendments to the standard OT model (see MCarthy 2003, Kiparsky 2003, Ito and Mester 2003 to cite just a few). We propose to use McCarthy's (2007) Candidate-Chain version of OT (OT-CC) for the case at hand. This extension of standard OT represent candidates as ordered chains of candidates with minimal faithfulness violations of increasing harmony.[8] OT-CC makes a crucial use of constraints responsible for precedence relations between violations, called Prec(A,B), which demand that both violations are present and that A is violated before B in the candidate chain. In the case of [ŋ], the violation of IDENT(coronal) must precede the violation of MAX[g], thus assimilation must take place before deletion, see (14b). The trigger for deletion is the constraint *[ŋg], as in (14a), which has been proposed by several phonologists, in this special variant (see Ito and Mester 2003) or in a more general variant prohibiting a sequence of a nasal plus voiceless obstruent (Pater 1996). The effect of these constraints is illustrated in Tableau (15).

(14)

a. *[ŋg]: A sequence of a dorsal nasal plus stop is prohibited.
b. Prec(ID(cor),MAX(g)): In a candidate chain, the violation of IDENT(coronal) must precede the violation of MAX[g].

Candidate a. is the winner because it fulfills not only *[ŋg] which is violated by candidate b., but also the Prec constraint, which is violated by the transparent candidate c.

(15) OT-CC account of the [ŋ] variant

| /ding/ | Agr (dors) | *[ŋg] | Prec(Id(cor), Max(g)) | Max[g] | Id(cor) |
|---|---|---|---|---|---|
| ☞ a. diŋ <ding, diŋg, diŋ> | | | | * | * |
| b. diŋg <ding, diŋg> | | *! | * | | * |
| c. din <ding, din> | | | *! | * | |

If input /g/ is realized, as it is in the allophone [ŋk], it has no choice but to become a voiceless stop because of Final Devoicing (FD), as formulated in (16a). This constraint must be ranked higher than both Max[g] and Ident(voice), in (16b-c), see Tableau (17).

The second allophone [ŋk] is not opaque and thus does not require a Prec constraint. However, since it is in an allophonic relation with [ŋ], its evaluation interacts with the evaluation shown in (15). We propose a second Prec constraint, namely (16d), which orders a violation of Ident(coronal) before a violation of Ident(voice), see candidate a. in Tableau (17). This Prec constraint requires a different chain of candidates, namely one in which final devoicing is ordered directly after assimilation. A violation of Ident(voice) bleeds a violation of Max(g) since if /g/ is devoiced to [k], it is no longer susceptible to be deleted under the influence of *[ŋg].

(16)

a. FinalDevoicing: A foot-final obstruent is voiceless.
b. Max[g]: No deletion of the segment [g].
c. Ident(voice): No change of the feature [voice].
d. Prec(Id(cor),Id(voi)): In a candidate chain, the violation of Ident(coronal) must precede the violation of Ident(voice).

Tableau (17) illustrates the choice of *diŋk*. It contains both the constraints necessary for *diŋ*, which were shown in Tableau (15), and the new constraints. Agr[dorsal] and *[ŋg] are not shown here for reasons of space.

(17) OT account of the [ŋk] variant

| | /ding/ | FD | Prec(ID(cor), ID(voi)) | Prec(ID(cor), MAX[g]) | MAX(g) | ID(voi) | ID(cor) |
|---|---|---|---|---|---|---|---|
| ☞ | a. diŋk <ding, diŋg, diŋk> | | | * | | * | * |
| | b. diŋ <ding, diŋg, diŋ> | | *! | | * | | * |
| | c. diŋg <ding, diŋg> | *! | * | * | | | |

Candidate b. is eliminated because it does not violate ID(voice), as required by PREC(ID(cor),ID(voi)). Candidate c. violates also FINALDEVOICING. We do not go back to the table (15), but it should be clear that the two Prec constraints are ranked in the opposite direction in (15) and in (17). In other words, the allophony is accounted for by different ordering of the two Prec constraints. (18) shows the ranking of the constraints delivering the allophone [ŋ], and (19), where the Prec constraints come in the reverse order, the one delivering [ŋk].

(18) Ranking for [ŋ]
FD, AGREE(dorsal), MAX[k], *[ŋg] ≫ Prec(ID(cor),MAX(g)) ≫ Prec(Id(cor), Id(voi)) ≫ MAX[g], IDENT(coronal), IDENT(voice)

(19) Ranking for [ŋk]
FD, AGREE(dorsal), MAX[k], *[ŋg] ≫ Prec(Id(cor), Id(voi)) ≫ Prec(ID(cor), MAX(g)) ≫ MAX[g], IDENT(coronal), IDENT(voice)

What determines the choice between (18) and (19) in Northern German is the subject of next section. We propose that the choice is determined by internal phonological factors, rather than by random noise.

### 4.3. Factor-driven gradient model (OT-FDG)

The preceding section has shown that it is the ranking of the two Precedence constraints that determines which of the two allophones are chosen in a particular evaluation. But it remains to be demonstrated how the factors bearing on the allophony and introduced in section 3, are formalized into the OT grammar, in order to influence the choice of one or the other candidate.

We do not propose a fully-fledged model of gradience in this paper, since this is beyond the scope of this paper. Instead, we sketch how the integration of different factors acting on the distribution of [ŋ] and [ŋk] can be part of the grammar itself. We propose an extension of Functional Phonology, based on the influence of each factor on the probability of the output, that we call factor-driven gradient model (FDG). The difference between GLA and FDG is that the latter model does not need the exact distribution of the allophones in all instances, but rather the probability of each allophone is calculated by the grammar itself. It relies on a baseline and a knowledge of the effect that each of the factors exerts on the probability to get one or the other variant.

The initial situation, shown in (20), is the default distribution: the total amount of [ŋk] and [ŋ], as given in table (4). In 70% of the cases, Prec(ID(cor), MAX(g)) dominates Prec(ID(cor),ID(voi)), as (18) and in 30% of the cases, the reverse ranking is active, as in (19). The two Prec constraints have a variable ranking which is best accounted for in a stochastic version of OT, with overlapping constraints. This overall distribution of the two variants is considered here as the baseline.

(20)

| ŋ | ŋk |
|---|---|
| 70% (ranking (18)) | 30% (ranking (19)) |

However, as was shown in section 3, the preference for one or the other variant can be increased depending on several context-dependent factors, like prosodic boundary strength, pitch accent and vowel quality. In other words, the optionality is not random or created by momentary noise, but rather it is triggered and motivated by factors which have a direct influence on the grammar. Specific constraints influence the ranking of the Prec constraints.

Considering in a first step the prosodic domain boundary, it was shown that a strong prosodic boundary increases the probability of an occurrence of [k]. Both the end of a PhP and of an IP have a positive effect on [k], and a PW boundary has a negative effect. A markedness hierarchy (Prince and Smolensky 1993-2004) can be assumed, that correlates the realization of a final stop with the end of different prosodic domains, as in (21b-e). If there is no stop (or, in our case, if the allophone [ŋ] is chosen), the constraint is violated. As usual for such hierarchies, they express universal generalizations, and are supposed to be ranked in the same order in all languages. The ALIGN constraints in (21) explicitly ask for a realized stop at the end of prosodic constituents, and imply that, if a stop is realized optionally, it will be found more often at the end of a higher prosodic domain than at the end of a lower one. In German, this constraint hierarchy is relevant only for the sequence /ng/, since this is the only consonant sequence which can be optionally realized with or without a stop (see Féry 2003). All other consonants are obligatorily realized, so that the hierarchy is vacuous for them: they are protected by higher-ranking faithfulness constraints. In the ranking (21a), DEP, the constraint prohibiting epenthesis, is ranked higher than the alignment constraints, and this hierarchy has the effect that no stop will ever be inserted just to satisfy them.

(21) Aligment constraints
  a. DEP ≫ ALIGN(IP, Stop, R) ≫ ALIGN(PhP, Stop, R) ≫ ALIGN (PW, Stop, R)
  b. DEP: No epenthesis.
  c. ALIGN(IP, Stop, R): The right boundary of an IP is aligned with a stop.
  d. ALIGN(PhP, Stop, R): The right boundary of a PhP is aligned with a stop.
  e. ALIGN(PW, Stop, R): The right boundary of a PW is aligned with a stop.

Since the ALIGN constraints have the effect to favor the presence of a stop in the relevant environment, we can think of the Alignment constraints as changing the proportion of [ŋ] vs. [ŋk]. In other words, the grammar of the language as a whole delivers a certain ranking value of two Prec constraints and some additional constraints have a contextual effect which changes their ranking in a given proportion.

As an illustration, consider first the end of an IP. In this case, the probability of finding [k] is 48%. This constraint increases the probability of [k] as compared to the default distribution shown in (22) by 18%.

(22)

| ŋ | ŋk |
|---|---|
| 52% (ranking (18)) | 48% (ranking (19)) |

In terms of ranking of constraints, the two Prec constraints are still ranked in the baseline order shown in (20), but ALIGN(IP, Stop, R) is ranked between them, and overlap with both of them. Since it requires a stop, it increases the probability of a realized [k] by a certain factor which is proportional to the amount of overlapping, and which can be calculate from the exact digits given in section 3.[9] In other words, two constraints are now ganging up for the realization of a final stop.

The effect of a PhP boundary is slightly different, since it increases the probability of realizing [k] by 8% only, relatively to the default 30%. Like ALIGN(IP, Stop, R), it is ranked between the two Prec Constraints, but overlap less with the first one than ALIGN(IP, Stop, R) does. And as far as ALIGN(PrW, Stop, Right) is concerned, it is active when only a Prosodic Word boundary is present after the word containing the dorsal nasal, that is when the word does not end a higher prosodic domain at the same time. In this particular context, the influence on the presence of [k] is negative.

The effect of specific preceding vowels has been quantified as well, and can be treated in the same way as the alignment constraints just examined. In the case of the vowel, too, the context is exactly defined. First, consider [ʊ]. In order to integrate the effect of this vowel on the distribution of [ŋk], we need a constraint to the effect that a back high vowel will be followed by the sequence [ŋk], which can be tentatively considered as a kind of backness harmony effect. A formulation is proposed in (23).

(23) BLACKHIGHVOWEL+[ŋ]+BACKOBSTRUENT (*ʊŋk):
A back vowel [ʊ] requires the realization of all back consonants.

According to table 17, 60% of words with [ʊ] are realized with [k], which means that this constraint has an even more dramatic effect on the presence of [k] than the IP boundary. The distribution of [ŋ] and [ŋk] because of [ʊ] is shown in (24).

(24)

| ŋ | ŋk |
|---|---|
| 40% (ranking (18)) | 60% (ranking (19)) |

If *ʊŋk is treated in the same way as ALIGN(IP, Stop, R), that is, it is ranked between the two Prec constraints, it overlaps them both and it increases the probability of realization of [k]. In some situations, the effects of ALIGN(IP, Stop, R) and of *ʊŋk will be added to each other, and a ganging up effect through overlapping will be obtained.

The corpus did not contain occurrences of [k] after a mid front vowel [ɛ], thus the effect of this vowel is categorical (as long as the corpus discussed above is the only source of distributional data). In association with such a vowel, only the variant [ŋ] is found. The constraint (25) might be undominated.

(25) *FrontMidVowel+[ŋ] +BackObstruent (*ɛŋk):
A front vowel [ɛ] blocks the realization of k after [ŋ].

To sum up, the factors that were shown to influence one or the other variant of the dorsal nasal, are expressed in the form of individual constraints. Their effect is to increase or decrease the probability of the two variants. Like the GLA, FDG does not deliver concrete outputs, but just probabilities for variable outputs. The difference between the two models is to be found in the controlled influence of the factors, as opposed to the effect of noise in GLA. The chance to utter [ŋk] or just [ŋ] is due to the impact of the individual factors. As in GLA, all constraints participating in an allophonic alternation are ranked in a fixed order, but in FDG, constraints come with a factor influencing the distance between two crucially conflicting constraints. Factors associated with different constraints can also be cumulative, and become so strong that the ranking of the crucial constraints is reversed, or as illustrated with (25), an undominated constraint can overrule the effect of the conflicting constraints. Two or more constraints, each with their own factor, can interact and increase the effect in an additional way. This happens if a word ending in /ʊng/ like *Zeitung* is at the end of an IP and accented. In this case, the probability to realize [ŋk] reaches 100%.

This section has just sketched some elements of an OT model based on concrete factors influencing allophony in a gradient way. It is far from being worked out, but we hope that it provides some elements for integrating internal factors of variation into the grammatical model itself.

## 5. Conclusion

It has been repeatedly observed that the Standard variety of German and its Northern variant differ in their realization of the word-final sequence [ŋg]. In the Standard variety of German, the final stop has been claimed to be deleted, resulting in opaque [ŋ], whereas it is assumed to be subject to Final Devoicing in Northern German, resulting in [ŋk]. This difference has been accounted for in categorical versions of generative phonology (see Wurzel 1980, Hall 1992, Ramers and Vater 1992, Yu 1992, Wiese 1996, Ito and Mester 2003 and Féry 2003 among others).

An OT analysis of the allophony between opaque [ŋ] and transparent [ŋk] is couched in McCarthy's new version of Optimality Theory, CC-OT, which contains elements of derivational phonology in the obligatory ordering of constraints. The two allophones require two different ordering of Precedence Constraints. This model can be used for the cross-dialectal difference, but also for some gradient data in a single dialect.

A detailed analysis of a corpus of spontaneous speech of speakers from the Berlin-Brandenbourg region (Northern German) reveals that the realization of this sequence is far from being categorical in the way assumed in the past. Both [ŋ] and [ŋk] are frequent in this dialect, though in different proportions. If all contexts are taken together, [ŋ] is more frequent than [ŋk], in a proportion of 70 to 30%. Additionally, the proportion of occurrences of the allophones is influenced by the contexts in which the segment sequences occur. A word ending in a dorsal nasal is often pronounced with a final voiceless stop [k] when it ends a higher prosodic boundary, such as an Intonation Phrase. An accented word is also more likely to be realized with a final stop, and the same is true for words whose last vowel is a back vowel.

An increasing amount of researchers (as for instance Pierrehumbert 2003, Bybee 2001, Cohn 2006, Frisch 2000, Anttila 2001, Boersma 1998, Boersma and Hayes 2001, Hayes and Wilson 2008, Labov 1994, Steriade 2001 and many others) have emphasized the need to integrate gradience and variation into formal generative phonology. Traditional generative models of phonology cannot account for the kind of conditioned variability found in the realization of /ng/. In this paper, it is proposed that stochastic Gradual Learning Algorithm (GLA) (Boersma 1998, Boersma and Hayes 2001), an OT model which has explicitly been conceived to account for gradient data, is a first step to account for our data. We sketch some ideas for an extension of this model, called factor driven gradient model (FDG). Instead of relying on random noise to explain temporarily optionality between two allophones, as in GLA, in FDG the factors bearing on the distribution of the data are part of the phonology formalism. Overlapping context-independent constraints define a baseline for the gradience, but the probability for the emergence of one or the other candidate is influenced by context-sensitive constraints.

## Notes

1. This paper is part of the project A1 of the Research Group "Conflicting Rules" of the University of Potsdam. Some of the results have been presented at the Meertens Institute in Amsterdam in September 2003 and at the DGfS meeting in Mayence in February 2004. Many thanks to Birgit Alber, Marc van Oostendorp, Tonio Green, Frank Kügler and Frans Hinskens for helpful comments and discussions. Thanks to Daniela Berger and Anja Arnhold for technical support. The experiment was designed and executed by the second and third authors, in the framework of a seminar on variation in phonology directed by the first one. The remaining of the work is the sole responsibility of the first author.
2. In this paper, only environments are considered which can be the locus of g-deletion, that is, syllable-final or onsets of non-moraic syllables. Cases in which [g] is pronounced because it is followed by a full vowel, as in *Tango, Pinguin or diphthongieren* 'to diphthongize' are ignored (see Féry 2003 for an OT account of obligatory [g] in terms of onset).
3. Words in which final [ŋk] is followed by further consonants, like in *singst* or *Angst*, as well as words with a medial ambisyllabic dorsal nasal followed by a schwa syllable, as in *singen, Klingel, engen, Wohnungen* and *gedrungene*, were not considered in the results and discarded altogether. In these words, the obstruent is never realized.
4. Some statistical test were performed to calculate the significance of the results, as for instance Wilcoxon-test and chi-square (thanks to Wang Bei and Robin Hörnig for advices), but due to the small amount of data, no really interesting statistical claims could be made, except maybe for the following one: for all speakers, the difference between [ŋ] and [ŋk] was significant.
5. Birgit Alber [p.c.] proposes that [k] is realized more often when the word is accented because accenting prevents fast speech phenomena (i.e. deletion) from happening.
6. In German, [a] patterns phonologically with the back vowels, as can be seen from different alternations, like the distribution of the dorsal fricative (*ach*-Laut and *ich*-Laut) and the umlaut which fronts back vowels, including [a].
7. There have been some proposals to integrate variability into the transformational format, as testified by Labov's so-called "variable rule" (1969), and mathematical modeling of it (Cedergren and Sankoff 1974, Sankoff and Labov 1979, see also Fasold 1991). Variable rules have been mostly used to integrate 'external' sociological variables into phonological rules. In the case at hand, the intention is different, namely the elaboration of a model of 'internal' phonological effects influencing the phonology.
8. In McCarthy (2007), the candidates are 4-tuples consisting of {input, output, the violations with their locus and the ordering between them} The version we present here is largely simplified.
9. We do not try to develop an exact mathematical model of FDG, but restrict ourselves to the outlines of the analysis.

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