Modeling regional variation in voice onset time of Jutlandic varieties of Danish

Hansen, R.P.; Velde, H. Van de; Hilton, N.H.; Knooihuizen, R.

CHAPTER 4

Modeling regional variation in voice onset time of Jutlandic varieties of Danish

Rasmus Puggaard
Universiteit Leiden

It is a well-known overt feature of the Northern Jutlandic variety of Danish that /t/ is pronounced with short voice onset time and no affrication. This is not limited to Northern Jutland, but shows up across the peninsula. This paper expands on this research, using a large corpus to show that complex geographical patterns of variation in voice onset time is found in all fortis stops, but not in lenis stops. Modeling the data using generalized additive mixed modeling both allows us to explore these geographical patterns in detail, as well as test a number of hypotheses about how a number of environmental and social factors affect voice onset time.

Keywords: Danish, Jutlandic, phonetics, microvariation, regional variation, stop realization, voice onset time, aspiration, generalized additive mixed modeling

1. Introduction

A well-known feature of northern Jutlandic varieties of Danish is the use of a variant of /t/ known colloquially as the 'dry t'. While the Standard Danish variant of /t/ has a highly affricated release, the 'dry t' does not. Puggaard (2018) showed that variation in this respect goes beyond just that particular phonetic feature and dialect area: the 'dry t' also has shorter voice onset time (VOT) than affricated variants, and a less affricated, shorter variant of /t/ is also found in the center of Jutland. This paper expands on Puggaard (2018) with the primary goals of providing a sounder basis for investigating the geographic spread of the variation, and to test whether the observed variation is limited to /t/ or reflects general patterns in plosive realization. I focus specifically on differences in VOT, and compare measurements of VOT from a large number of speakers on the Jutland peninsula. Testing is done on the basis of a large corpus of legacy recordings, which to a great extent manages to preserve an older stage of regional variation of Danish (Andersen 1981; Pedersen 1983;

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Goldshtein & Puggaard 2019). Parts of the corpus have been used as a source for the Dictionary of Insular Dialects (Gudiksen & Hovmark 2008), but the parts covering the Jutland peninsula have never before been used systematically for research.

There are many descriptions of Danish dialects available, including partial dictionaries, grammars, (morpho-)phonological descriptions, and topical descriptions of individual dialects (see references in Hovdhaugen et al. 2000). There are also holistic descriptions of the Danish dialect landscape (Bennike & Kristensen 1912; Brøndum-Nielsen 1927; Skautrup 1968) which define dialect boundaries on the basis of isogloss bundles. With few exceptions, however, the descriptive work has lain dormant since the 1970s, leaving much of the existing work somewhat theoretically dated.[1] A consequence of this is that progress in acoustic-phonetic methodology has barely improved our knowledge of regional phonetic variation in Danish (although see Ejstrup 2010; Goldshtein 2019); our knowledge of phonological variation is rich if spotty, while our knowledge of subphonemic systems is much poorer and mostly limited to what could be indicated with the notation systems of the early 20th century. Similarly, the recent great strides in available statistical computing has not improved our knowledge of geolinguistic variation in Denmark.

The initial hypothesis of this study is that the received knowledge about the 'dry t' variant is wrong: it is not limited to northern Jutland. A number of theoretically motivated hypotheses follow: given recent findings of Chodroff and colleagues (Chodroff & Wilson 2017; Chodroff et al. 2019) that variation in VOT tends to covary across laryngeal settings and places of articulation, I hypothesize that variation is not limited to /t/, but that all plosives follow similar patterns of variation. Early findings in VOT research (Lisker & Abramson 1964) showed that voiced, voiceless, and aspirated plosives form internally consistent categories across languages, but later research has prompted Ladd (2011) to hypothesize that in a large enough typological study, there will be no such internally consistent categories, but rather an unbroken continuum – suggesting that the only principal limit on VOT variation comes from limits on perceptual acuity. The Jutlandic data might be able to inform our notions of the limits of variation in VOT in a small geographical area shared by one language community with the same set of phonemic plosives. I use generalized additive mixed modeling to investigate what variation is attributable to geography, without needing the assumption that this relationship is linear (Wieling et al. 2011, 2014); this method allows me to simultaneously test a number of hypotheses about the influence of other factors on VOT.

1. The lexicographic work, however, is still very much ongoing, centered around *Jysk Ordbog* (Jutlandic dictionary; JO; Hansen 2008) and *Ømålsordbogen* (Dictionary of Insular Dialects; e.g. Hovmark 2006).

2. Theoretical preliminaries

2.1 Voice onset time

Measuring the relative time difference between the release of a plosive and the onset of voicing was popularized in a typological study by Lisker and Abramson (1964), who studied eleven languages and reported a relatively stable and neat three-way contrast between negative VOT indicating voiced plosives, near-null VOT indicating voiceless unaspirated plosives, and positive VOT indicating aspirated plosives. It has been confirmed by studies in psycholinguistics and neurolinguistics that VOT is responsible for categorical perception of laryngeal contrasts (e.g. Schouten & van Hessen 1992; Simos et al. 1998).

Findings from later typological studies (e.g. Cho & Ladefoged 1999) indicate that this neat three-way laryngeal distinction does not hold up against more data, and there are no known natural reasons why plosives would cluster in three groups on the basis of VOT. VOT has been shown to be affected by many different linguistic and extralinguistic factors, such as place of articulation (e.g. Docherty 1992; Cho & Ladefoged 1999), height of the following vowel (e.g. Klatt 1975), speaker ethnicity (Ryalls et al. 1997, 2004), age (e.g. Benjamin 1982, but cf. e.g. Neiman et al. 1983), and gender (e.g. Torre & Barlow 2009) – in addition to being highly speaker-specific (Allen et al. 2003). This leads to a number of specific hypotheses about the data under scrutiny (see Section 3.3). Consistent cues for laryngeal setting other than VOT have also been found, such as pitch onset (Hanson 2009; Kirby & Ladd 2016) and closure duration in the case of singleton-geminate contrasts (e.g. Kraehenmann 2001). This means that VOT cannot tell the full story of either phonological laryngeal contrasts in plosives or variation in the realization of laryngeal contrasts. It is, however, a powerful indicator. A recent literature review (Abramson & Whalen 2017) and a special issue of *Journal of Phonetics* (Cho et al. 2018) both celebrate 50 years of research on VOT, and show that VOT-related research is still very much ongoing. A recent major finding is that variation in VOT across speakers and across languages tends to covary for laryngeal settings and places of articulation; in other words, the range of across-speaker variation found for /p/ will on the one hand show parallels with that of /b/, and on the other hand show parallels with that of /t k/ (Chodroff & Wilson 2017; Chodroff et al. 2019).

2.2 Danish plosives

Standard Danish has six phonemic plosives in onset position /b d ɡ p t k/, with a laryngeal distinction that relies on distinctions in positive VOT; as such, the lenis series /b d ɡ/ is voiceless unaspirated, and the fortis series /p t k/ is voiceless aspirated. Previous studies which measure the VOT of Danish plosives (Fischer-Jørgensen 1980; Mortensen & Tøndering 2013) find relatively high VOT values for both laryngeal settings compared with other languages with an aspiration-based contrast, even in spontaneous speech. /t/ notably has strongly affricated release and is typically transcribed as [tˢ] (Grønnum 1998).

2.3 The dialects of Jutland

Although Standard Danish is now the primary means of communication throughout Denmark (Kristiansen 1998; Pedersen 2003), Kristiansen (2003a) judges that the majority of the speech community consisted of dialect speakers until the 1960s. In the late 1960s, however, Skautrup (1968: 96ff.) wrote that the dialects were in poor condition, and that the most likely features to survive were phonetic ones, which were unlikely to significantly influence mutual intelligibility. It was clear to Skautrup at the time that this development was more advanced on Zealand than on the Jutland peninsula or the smaller islands. The dialect leveling in Denmark had been long underway: in the 19th century, an obligatory education system was introduced and agrarian reforms led to increased mobility both in cities and rural areas (Skautrup 1968; Kristiansen 2003b), leading to disruption in the traditional dialects and the rise of the current standard language (based on High Copenhagen; Kristiansen 2003a). In the mid-20th century, dialect leveling was accelerated through the spread of national broadcasting in Standard Danish, and through government policies enforcing Standard Danish in the education system (Kristiansen 1990). While a recent research project finds that dialects are alive and well in parts of southern Denmark (Monka & Hovmark 2016; Monka 2019), that same project also finds complete leveling in other regions strongly associated with dialect use, and in yet other regions complete replacement of the traditional dialect by a regionalized version of the standard language (Maegaard & Monka 2019); dialect features may coexist with standard features, but take on different social functions that are not as geographically delimited as in the past (Scheuer et al. 2019).

Figure 1 shows the major dialect areas of Jutland as defined by JO (K.03).[2] Skautrup (1968: 97; 1937) bemoans the fact that there has been relatively little discussion of the basis of these divisions in Danish dialectology. He states that there are generally no sharp borders between Jutlandic dialect areas, but rather gradient phenomena running in parallel lines. Lines between areas are essentially drawn in transition areas between dialect "cores" (see Aakjær 1925). Skautrup judges that Danish dialects are mostly defined on the basis of isophones in the form of common phonological developments from previous stages of Danish or Norse. Differences in morphology and lexicon also play a role, but less so; syntax in particular seems to have played a very small role.

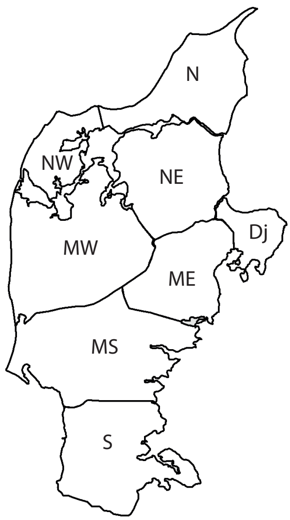


Figure 1. Traditional dialect areas of Jutland as defined by JO (K.03)[3]
N = Northern; NW = North-Western; NE = North-Eastern; Dj = Djursland;
MW = Mid-West; ME = Mid-East; MS = Mid-South; S = South

2. Dialect groups from this map will henceforth be written with initial capital letters.

3. Note that JO refers to the two Southernmost dialects as *sønderjysk* and *sydjysk* respectively; as there are no fitting English translations for these terms, Southern and Mid-Southern are used here.

Skautrup (1968: 97ff) provides the clearest diagnostics for the dialect areas. The most important diagnostic is the article boundary, dubbed the "most famous Danish isogloss" by Thorsen (1912/1927), which is responsible for the relatively strict division between eastern and western dialects. In eastern dialects, as in Standard Danish, definiteness in nouns is marked with a suffix, while in western dialects, it is marked with a phrase-initial article. This is an exception to the generalization that the defining isoglosses in Danish dialectology are essentially phonological, but it should be noted that the article boundary also has major implications for both sentence prosody and segmental phonology (Skautrup 1952). Phonological boundaries of particular interest here are ones referring to plosives. In the Southern group, for example, historic */-ɡ/ is realized as a fricative [-χ] where it is either lost or weakened to a glide in Standard Danish. The Mid-Southern and central eastern groups show strong reduction of coda /-t/. A number of dialects have *klusilspring* (parasitic plosives), where stød – a suprasegmental glottal constriction that is specific to Danish – is in some contexts realized as a plosive following the vowel (e.g. Andersen 1955; Ejskjær 1990); this applies to the Mid-Western and Northern groups (Jensen 1902; Skautrup 1930). Finally, both the Northern and North-Eastern groups show widespread palatalization of coronals.

The diagnostics for the primary dialect groups do not yield many specific hypotheses about VOT. One might assume that dialects with a lot of plosive weakening will also have low VOT in general; however, as Standard Danish has cross-linguistically rather high VOT and rampant plosive weakening, this clearly does not pan out.

2.4 Language variation and geography

In the late 19th century, dialectology took a geographical turn (e.g. Wrede 1919). Rather than focusing on individual dialects, scholars started drawing detailed maps of distributions of features or lexical items; dialect atlases were produced for Germany (Wenker & Wrede 1895) and France (Gilliéron & Edmont 1902–1910), as well as Denmark (Bennike & Kristensen 1912). In the wake of this work, a debate ensued about whether geolinguistic variation was of a purely continuous nature (Paris 1888) or whether individual dialects do, in fact, exist (Gauchat 1903). The conclusion seems to be that although the geographical distribution of features can be chaotic, there *are* adjacent bundles of important isoglosses, and there *are* areas not crossed by significant isoglosses. The field of dialect geography has yielded much rich descriptive work, but a commonality of studies of this era is that geography – in a pre-theoretical, Euclidian sense – is typically the only predictor of language variation (Chambers 2000; Britain 2010). Perhaps as a counterreaction, early variationist sociolinguistics (following Labov 1963) was relatively uninterested in geography, with the work of Trudgill (e.g. 1974) being a major exception.

Research into the relationship between geography and language variation is highly active in the rigorously data-driven field of dialectometry (Séguy 1973; see Wieling & Nerbonne 2015 for a recent overview). Dialectometry has made large strides towards estimating the geographic basis of language variation using aggregate features and modern statistical methods. An explicit goal is to estimate how much variation can be explained with reference to geography. By aggregating pronunciations of a large number of words in a single analysis of variation in northern Dutch rather than focusing on well-known loci of variation, Nerbonne and Heeringa (2007) find that geographical distance accounts for more than half of the variation found in their data, making it logically the most influential predictor.[4] While dialectometry often works with simple Euclidian space, the framework also allows for more socially influenced measures of space, as in e.g. Gooskens' (2005) study of variation in Norwegian using travel time rather than geographical distance as predictor. Furthermore, advances in statistics have made it possible to combine geographical predictors with large numbers of social predictors.

In this paper, I model geography simply using measures of longitude and latitude. As such, I implicitly make the assumption that there are no obvious differences between the natural area of Jutland and the organization of that area by humans. This is not a good assumption, but it is a highly practical one. The study is based on a legacy corpus recorded in the 1970s (see below), which is taken as the best available approximation of rural dialects in the early 20th century. Quantifying a human landscape is in itself a difficult task, and more so quantifying a human landscape as it looked a century ago.

4. Unless there are other predictors which are directly correlated with geographical distance.

3. Methodology

3.1 Corpus

The research questions posed above will be answered using data from an extensive corpus of audio recordings made by the Peter Skautrup Centre for Jutlandic Dialect Research (Andersen 1981; Goldshtein & Puggaard 2019). Recordings made during the most active years of data collection (1971–1976) have been digitized by the Royal Danish Library (RDL) and are available online in high quality.[5] These recordings generally consist of sociolinguistic interviews with a single dialect speaker in their home. The informants mostly conform to the NORM criteria (non-mobile older rural males) often found in dialectological studies (Chambers & Trudgill 1988), although a fair portion (22%) of the informants were women. The primary purpose of the recordings was to gather material for lexicographical studies (Andersen 1981; Pedersen 1983; Gudiksen & Hovmark 2008). A positive effect of this is that topics generally revolve around old cultural customs, and Hay and Foulkes (2016) report that speech about older events also tends to elicit older phonetic forms. Because speakers were explicitly chosen from a relatively uniform background – non-mobile, rural, previously employed in agriculture – there is little point in attempting to quantify social factors like class.

The RDL corpus contains recordings from 230 parishes in Jutland. 17 of these parishes were excluded from the study. There were three reasons for exclusion: (1) a small number of the recordings are group interviews, and these were excluded, unless they contained long stretches of speech from a single informant; (2) the quality was too poor; (3) the recording was too short to include a sufficient number of plosive tokens. This only affects areas with a reasonably high density of recordings. If a parish was represented with multiple recordings, one was chosen on the basis of either dialect authenticity judgments made by the original interviewers or audio quality. The audio quality of the recordings is generally similar across recordings, and relatively good.

The geographical coverage is shown in Figure 2; it is mostly fairly dense, but a bit thin in the center of the peninsula. The informants' median year of birth is 1896 (range 1871–1927), and their mean age at the time of recording was 77.4 years (range 45–101 years). This distribution is shown in Figures 3 and 4. For thirteen informants, no year of birth has been reported; these are expected to fall within the reported range. Most recording sessions consisted of multiple files (tapes), and the second file was generally chosen for analysis, so that the informant would have

5. https://dansklyd.statsbiblioteket.dk/samling/dialektsamlingen/

had time to accommodate to the presence of a recording device. All metadata and coordinates, including links to the original recordings, are available in the Dataverse repository (Puggaard 2020).

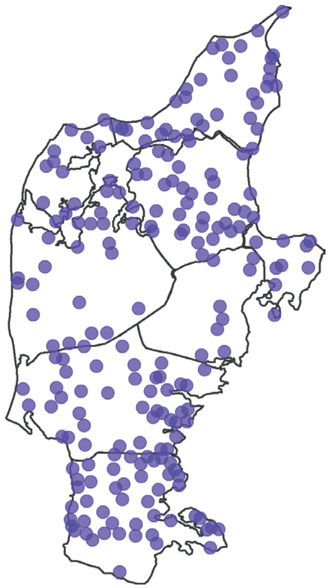
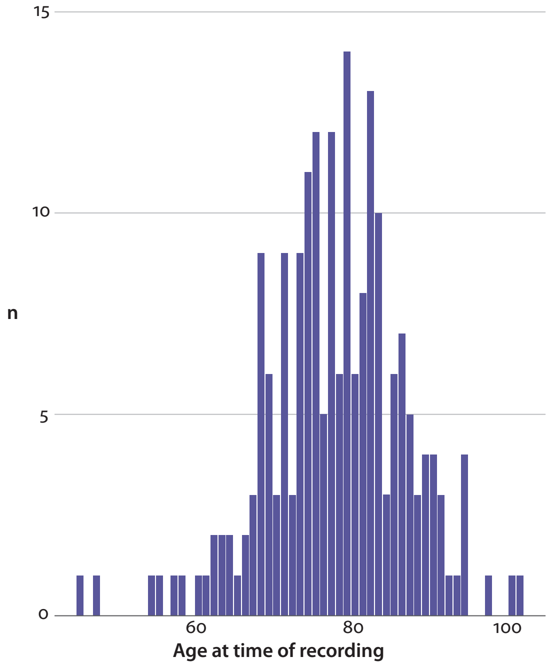


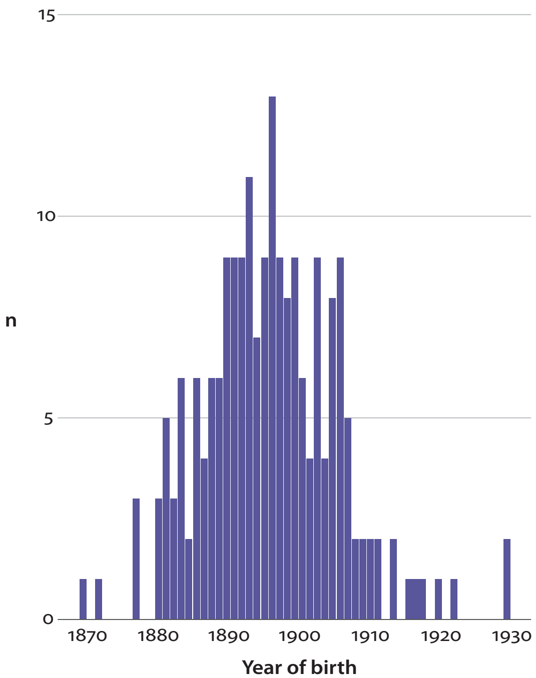
Figure 2. Geographical coverage in the current study

The distribution of informants across dialect areas by gender is seen in Table 1. Gender has been shown to have an influence on VOT (e.g. Swartz 1992), particularly among elderly speakers (Torre & Barlow 2009), and by including gender in the statistical model, we can check if this data can lend credence to those findings.

Table 1. Distribution of informants across dialect areas by gender

Dialect area	Informants	Male	Female
Southern	48	58.3% (*n* = 28)	41.7% (*n* = 20)
Mid-Southern	40	70% (*n* = 28)	30% (*n* = 12)
Mid-Eastern	9	66.7% (*n* = 6)	33.3 (*n* = 3)
Mid-Western	25	92% (*n* = 23)	8% (*n* = 2)
Djursland	9	66.7% (*n* = 6)	33.3 (*n* = 3)
North-Eastern	35	85.7% (*n* = 30)	14.3% (*n* = 5)
North-Western	12	91.7% (*n* = 11)	8.3% (*n* = 1)
Northern	35	91.4% (*n* = 32)	8.6% (*n* = 3)
Total	**213**	**77% (*n* = 164)**	**23% (*n* = 49)**





Figures 3–4. Age at the time of recording and year of birth of informants

3.2 Token selection

In analyzing the recordings, I distinguish between the fortis series /p t k/ and lenis series /b d g/ of plosives. This distinction is contrastive in all dialects, although the implementation of the contrast differs; I do not intend to make claims about possible phonological features responsible for the contrast. For each speaker, all plosives were segmented until the 50th fortis plosive had been located. This leads to more fortis plosives than lenis plosives being segmented. The motivation for this is both practical and theoretical; the hypotheses guiding the study relied more on fortis plosives, which led to lenis plosives being prioritized less, due to the time-demanding nature of segmentation.

The segmented plosives were restricted to simple onset position, with palatalized tokens included because several dialects show allophonic palatalization of /k/ and /g/ (e.g. Bennike & Kristensen 1912: 84ff.). Tokens in phonological /Cj/ clusters were included, because the phonetic implementation of these appeared phonetically identical to phonologically palatalized tokens. There were different criteria for the inclusion of fortis and lenis plosives. Since lenis plosives in function words (prepositions, pronouns, and high-frequency adverbs) were very often weakened to fricatives or fully voiced, segmentation was often difficult or impossible. For this reason, function words were excluded from the lenis category unless they were either stressed or clause-initial, since these prosodic environments enhance gestural features (Steriade 1994), and thus also increase VOT (Cho & Keating 2001). All instances of the pronoun *det* 'it, that' were excluded.[6] Function words were included in the fortis category, because they do not weaken as much, and because there are fewer high-frequency function words beginning with fortis plosives than lenis ones. A plausible result of this strategy is that the actual difference between lenis and fortis plosives is underestimated in this paper. Since we are generally more concerned with fortis plosives, this discrepancy is not too concerning. The distribution of plosives is shown in Table 2. While the lenis plosives are reasonably evenly distributed, the fortis ones are more skewed, with relatively few instances of (p), which was also the case in the study by Mortensen and Tøndering (2013).[7]

6. Due to this pronoun's extreme frequency in clause-initial position (Puggaard 2019), it would account for too many lenis tokens if included.

7. This is presumably due to /p/-initial words being rare in Old Germanic languages, although more have since entered Danish, mostly borrowed from Greek or Romance languages. For the same reason, the /b/ ~ /p/ contrast has historically been rather unstable in Danish (Hansen 1971: 165ff).

Table 2. Distribution of plosives used in the study

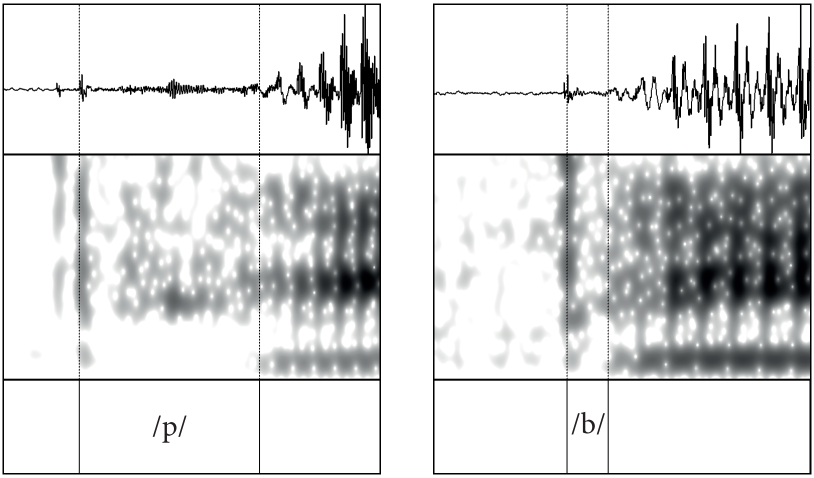
Consonant	Number
(b)	2,212
(d)	2,369
(g)	2,273
(p)	1,386
(t)	5,169
(k)	4,095
Total	**17,504**

3.3 Acoustic analysis

The plosives were segmented manually in Praat (Boersma & Weenink 2018).[8] The beginning of a plosive was indicated at the burst, which is identified in the waveform. If there were multiple bursts, which was often the case, the final one was chosen (following Cho & Ladefoged 1999: 215). The end of a plosive was segmented at voicing onset, which was identified at the onset of periodicity in the waveform, in accordance with Francis et al.'s (2003) findings that this landmark is most similar to physiological measurements of voicing onset. This choice of landmark leads to relatively short VOT measurements, and partially inflates the differences between dialects as reported in this study and Standard Danish as reported by e.g. Mortensen and Tøndering (2013), who use the onset of higher formants as their landmark. The delimitation is exemplified in Figures 5 and 6. The VOTs for all recordings were extracted using a Praat script. This script, along with all TextGrids and measurements, are available in the Dataverse repository (Puggaard 2020).

Strictly speaking, this paper only investigates voicing lag, or positive VOT. There are a number of difficulties in measuring prevoicing in running speech, particularly in rapid speech. For intervocalic plosives, the first portion of the closure is essentially always voiced, due to voicing bleed from the preceding vowel (Davidson 2016); in rapid speech, voicing bleed may continue throughout most or all of the closure. There is no logical place to start measuring prevoicing when voicing is continuous, and if there were, its duration would not in itself be particularly meaningful (Möbius 2004); it would be essentially a measure of closure duration, which may be affected in other ways by environmental context and social factors, significantly

8. Semi-automatic methods of measuring VOT have been developed, such as SemiVOT (Keshet et al. 2014); however, this method relies on training data, and due to the highly variable nature of plosive implementation in the Jutlandic data, it was not feasible to provide a suitable set of training data.



Figures 5–6. Delimitation of VOT exemplified for /b/ and /p/

complicating the modeling of the data. When a plosive is prevoiced, there is often still a brief pause in voicing around the release resulting in a short voicing lag. Other recent large-scale studies of VOT (e.g. Stuart-Smith et al. 2015; Chodroff & Wilson 2017; Chodroff et al. 2019) have also relied exclusively on voicing lag.

In addition to VOT, each token was also coded for a number of details about the phonetic environment, which previous studies indicate influence VOT. These all serve as linear predictors in the statistical modeling, which has the added advantage of allowing us to test their influence, potentially lending credence to previous findings. These factors are:

Vowel height
Vowel height has been shown to influence VOT by e.g. Fischer-Jørgensen (1980); Higgins et al. (1998), and Berry and Moyle (2011); cf. Mortensen and Tøndering (2013), who found an influence only on lenis plosives in Danish. Standard Danish has been claimed to have six phonological levels of vowel height (Grønnum 1998), but only three levels were included here. This decision follows Mortensen and Tøndering's (2013) study, which found roughly the same results using a simplified three-way classification of vowel height and Grønnum's (2005: 105) physiological four-way classification of vowel aperture.[9] Danish dialects further show a large degree of variability in vowel implementation (Ejstrup 2010), which means that coding more levels of vowel height would be either too impressionistic or much too time-demanding. The hypothesis is that higher vowels cause longer VOT.

9. Note that there are major differences between Grønnum's (2005) vowel height levels, which are based on acoustics, and her vowel aperture levels, which are based on articulation.

Vowel rounding
Vowel rounding has been shown to influence VOT in interaction with place of articulation. The hypothesis (following Fischer-Jørgensen 1972) is that bilabials have longer VOT before rounded vowels, while other plosives have longer VOT before unrounded vowels.

Vowel backness
Vowel backness has also been shown to influence VOT in interaction with place of articulation. The hypothesis (following Gósy 2001) is that bilabials have longer VOT before back vowels, while other plosives have longer VOT before front vowels. Vowels are coded as back or non-back.

Palatalization
We hypothesize that palatalization will increase VOT in adding complexity to the plosive. It is coded as a binary distinction on the basis of auditory impression; no distinction is made between allophonic palatalization and underlying /Cj/.

Stress
Stress has been shown to increase VOT (e.g. Lisker & Abramson 1967). Stress is coded as a binary distinction.

Place of articulation and phonological laryngeal setting
The phonological laryngeal setting (lenis/fortis) is trivially expected to account for most of the variation in the data. The literature further suggests that the place of articulation of a plosive influences its VOT. The results of Lisker and Abramson (1964) and Cho and Ladefoged (1999) indicate that a decent rule of thumb is that an occlusion further back in the oral cavity increases VOT, i.e. bilabial < alveolar < velar, although they also find a number of languages not following this pattern. In their study of Standard Danish VOT, Mortensen and Tøndering (2013) find longer VOT for /t/ than /k/. Plosives are coded by their phonological category, i.e. (b d ɡ p t k).

Speech rate
Speech rate has also been shown to influence VOT; measuring speech rate of these recordings is far from straightforward, due to the lack of systematic transcriptions of the data, the presence of both informant and interviewer(s), and the general problem with delimiting Danish phonetic syllables (Schachtenhaufen 2010). Allen et al. (2003) reported that speech rate only partially accounts for idiolectal differences in VOT, indicating that modeling the individual informant as a random effect should account for global speech rate effects.

3.4 Statistical modeling

In order to model the relationship between VOT and geography, the data was fitted to a generalized additive mixed model (GAMM), which can model a potentially non-linear influence of geographical area. Furthermore, descriptive statistics are provided based on the dialect areas. Statistics were calculated in the R statistical environment (R Core Team 2020) using a number of add-on packages.[10] All R code is available in the Dataverse repository (Puggaard 2020).

GAMM is a method of non-linear statistical analysis that is well-suited for data that is dynamic across time or space (see Wood for a general introduction, and Sóskuthy 2017 and Wieling 2018 for linguistics-themed introductions). While a linear analysis of e.g. vowel formants will have to either measure formants at a chosen landmark or normalize across time steps, a GAMM analysis can take into account a full formant trajectory (Sóskuthy 2017).[11] Similarly, rather than normalizing across dialect areas, it can take into account the full scope of possible geographical variation (see also e.g. Wieling et al. 2011, 2014).

The model has VOT as its dependent variable. Regional variation is included in the model through thin plate regression spline smooths (Wood 2003) for geographical area, modeled as the interaction between longitude and latitude; one smooth models the main effect of regional variation, and individual smooths model the individual phonemes. The model has separate random slopes for informants by phoneme, as well as the fixed effects alluded to above: vowel height, vowel rounding, vowel backness, palatalization, stress, informant gender, and phoneme. Stepwise likelihood ratio tests found this to be the most parsimonious model; each variable results in significantly improved model fit compared with nested models; versions with more elaborate random effects structures either resulted in insignificant changes to model fit, poorer model fit, or failure to converge. Recall from the previous section that we had specific hypotheses about interactions effects including place of articulation and backness and roundness, respectively. Such interactions did not significantly improve the model fit; I return to this point below. The model

10. The following packages were used: dplyr (Wickham et al. 2020a) for data management; ggplot2 (Wickham 2016; Wickham et al. 2020b) for visualizations; mgcv (Wood 2017, 2019) for generalized additive mixed modeling; itsadug (van Rij et al. 2020) for likelihood ratio tests, pairwise post-hoc tests, and two-dimensional visualization of GAMMs; and mgcViz (Fasiolo et al. 2019, 2020) for three-dimensional map-based visualization of GAMMs.

11. Other areas in linguistics where GAMMs have been fruitfully applied include pitch trajectories (Baayen et al. 2018), EEG trajectories (ibid; Meulman et al. 2015), eye tracking trajectories (Nixon et al. 2016), and articulatory trajectories (Wieling et al. 2016).

is run with fast restricted estimated maximum likelihood (fREML) with discretized values for covariates to decrease computing load (Wood et al. 2017) using the scaled-t family to account for heavy-tailed residuals. When relevant, pairwise post-hoc testing is done using the Wald test.

4. Results

4.1 Descriptive statistics

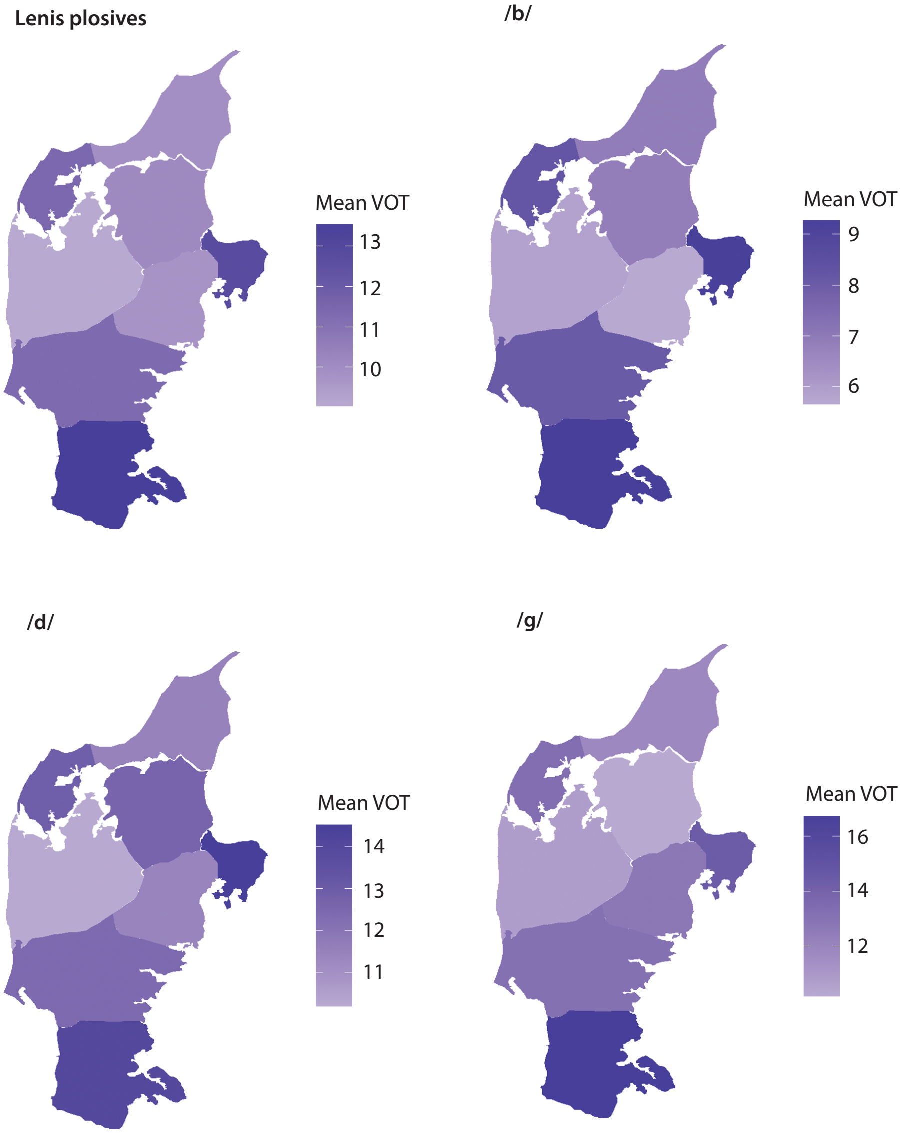
VOT values for the different phonemes as grouped by dialect area can be seen in Table 3, which also shows the VOT values reported for Standard Danish by Mortensen and Tøndering (2013) for comparison. The results are projected onto maps in Figures 7–14. For all dialects and all phonemes, it is the case that the VOT values found here are shorter than what has been found for Standard Danish; this is partially due to differences in segmentation, and the study of Francis et al. (2003) can point us toward the influence of these differences. Their study suggests that for lenis plosives, the difference between the two measurement methods is negligible and only constitutes a few ms; for fortis plosives, the difference is between 15–20 ms on average. This suggests that the differences in Table 3 are not purely methodological: in almost all instances, VOT is actually shorter in the dialects, but for some areas, (p) and (k) are not obviously different when taking methodological differences into account.

For the fortis plosives, dialect area clearly influences VOT. This is not limited to (t), and the pattern is roughly similar for all plosives. It is most pronounced for (t) and least for (k). The dialect areas seem to form clusters: essentially, south(-eastern) dialects have longer VOT, and north(-western) dialects have shorter VOT. The Northern dialect does not consistently have the shortest mean VOT values. Interestingly, in most cases, the minimum gap in VOT between a member of either dialect cluster seems to be approximately 10 ms, which was found by Blumstein et al. (2005) to be the lower limit of what the human neural system can perceive. This indicates that any perceptible difference can also constitute a regional difference. For the lenis plosives, the only thing approaching a distinct result is the relatively high values of the Southern dialect and Djursland, which approach VOT values of Standard Danish.

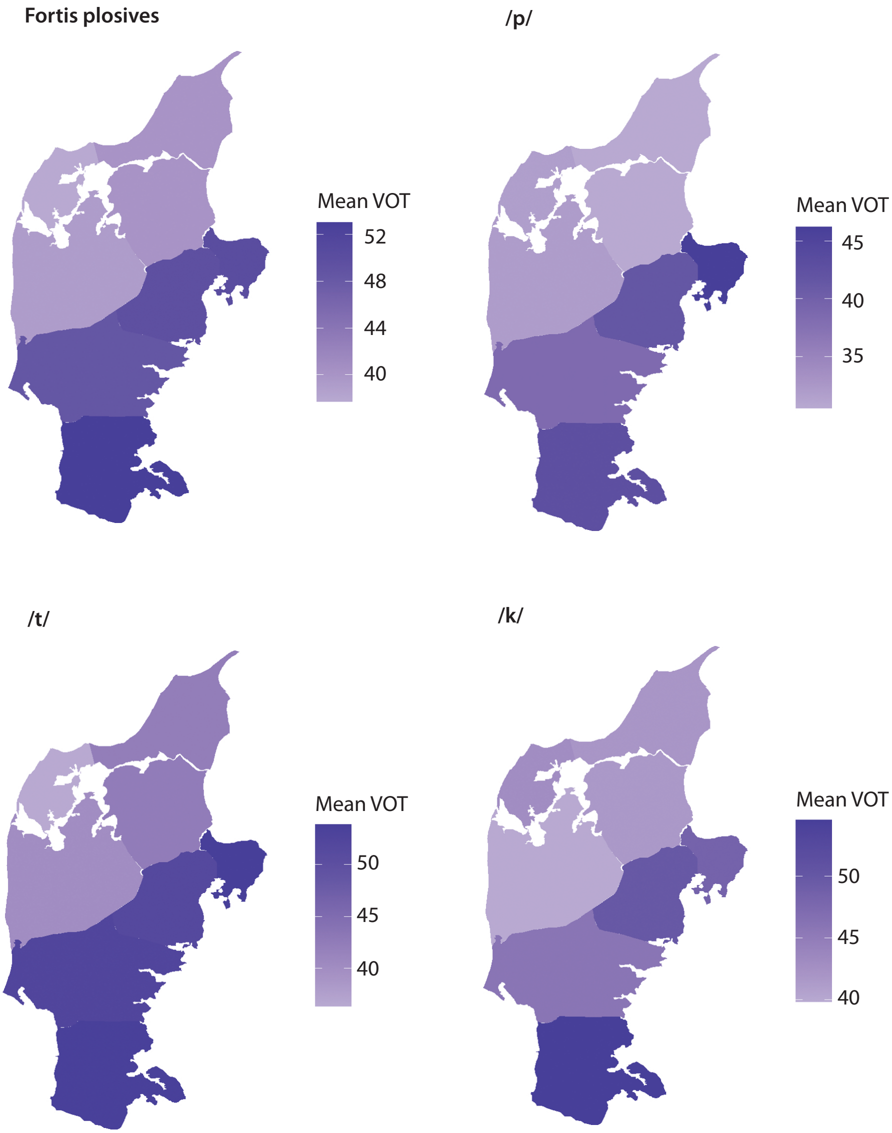
Table 3. VOT values in ms for each phoneme by dialect area. Displays mean values in msec as well standard deviation in parentheses () and interquartile ranges in brackets []

Dialect area	(b)	(p)	(d)	(t)	(g)	(k)
Southern	9.3 (SD: 5.5) [5.4–12]	42.7 (SD: 18.7) [28.3–55.4]	14 (SD: 8.9) [8.2–18.1]	53.7 (SD: 20.5) [39.6–66.3]	16.7 (SD: 8.5) [10.6–21.9]	54.5 (SD: 19.6) [40.8–65.8]
Mid-Southern	8.1 (SD: 5.6) [3.9–10.2]	38.5 (SD: 17.7) [25.8–47.5]	12.4 (SD: 8.9) [6–16.1]	52.3 (SD: 22.3) [37.5–63.6]	13.1 (SD: 9.7) [5.1–18.7]	45.9 (SD: 17.1) [34.2–57]
Mid-Eastern	5.7 (SD: 4.7) [2.6–6.9]	41.5 (SD: 22.9) [23–53]	11.4 (SD: 8.8) [5.3–15.4]	51.7 (SD: 29.3) [31.1–69.5]	12.7 (SD: 9.3) [5.8–17.2]	49.9 (SD: 20.3) [36.5–62.3]
Djursland	9.2 (SD: 8.1) [3.8–13.3]	46.2 (SD: 26) [29.5–60]	14.5 (SD: 8.5) [8.7–18.7]	53.8 (SD: 20.7) [39–67.4]	14.4 (SD: 9) [6.8–20.2]	48.3 (SD: 17.4) [35–60.1]
Mid-Western	5.8 (SD: 4.6) [3.2–7.1]	32 (SD: 18.5) [18.7–44.1]	10.2 (SD: 7.8) [4.3–12.9]	40.1 (SD: 17.2) [28.1–50]	10.8 (SD: 8.9) [3.3–15.4]	39.8 (SD: 18.1) [27–50.9]
North-Eastern	6.8 (SD: 5.4) [2.8–9.6]	30.6 (SD: 19.6) [16.5–40.1]	12.7 (SD: 10.3) [5–17.3]	42.5 (SD: 20.5) [28.7–52.7]	10.2 (SD: 8.3) [3.7–14.1]	41.5 (SD: 20.7) [27.4–52.4]
North-Western	8.2 (SD: 6.2) [3.8–10.7]	31.8 (SD: 17.1) [20.3–42]	12.9 (SD: 9.2) [6.1–15.8]	36.3 (SD: 16.2) [24.4–45.8]	13.3 (SD: 9.1) [5.8–20]	42.9 (SD: 17.2) [30.6–52.6]
Northern	6.9 (SD: 5.3) [2.9–9.8]	30.6 (SD: 17.5) [18–40.1]	11.5 (SD: 9) [4.9–15.5]	42.2 (SD: 20.8) [27.1–53.1]	11.8 (SD: 8.7) [4.3–16.3]	41.8 (SD: 17.8) [29.4–51.8]
Std. Danish*	11.7–19.2	58.1–77	18–29.2	81.6–88.7	25.1–34	60.5–81

* The values for Standard Danish are taken from Mortensen and Tøndering (2013), who report mean values per phoneme by degree of opening; the ranges reported here are the shortest and longest of these values, respectively. Recall that there are differences in segmenting methodology, so these should not be directly compared to the values reported for dialects.



Figures 7–14. Mean VOT values for lenis and fortis plosives and the individual plosives by dialect area projected onto maps


Fortis plosives
Mean VOT
52
48
44
40
/p/
Mean VOT
45
40
35
/t/
Mean VOT
50
45
40
/k/
Mean VOT
50
45
40

4.2 Generalized additive mixed model

This section presents the results of the GAMM. A likelihood ratio test found that a model which included the effect of area performed significantly better than a nested model without the effect of area, with $\chi^2(11) = 221$, $p < .001$. With an effect size of $R^2 = .66$, the model does a reasonably good job of explaining the data. The parametric coefficients and estimated significance of smooth terms can be seen in Tables 4 and 5. Table 4 shows the influence and significance of the linear predictors, and Table 5 shows the non-linear influence of geography. I unpack this information in the tables below, starting with the linear predictors.

Table 4. Parametric coefficients of GAMM

	estimate	**SE**	**t**	**p**	
(Intercept)	33.689	0.936	35.988	<0.001	***
gender=male	−0.461	0.328	−1.408	0.159	
palatalized=yes	7.341	0.578	12.699	<0.001	***
height=low	−2.371	0.235	−10.073	<0.001	***
height=mid	−2.170	0.240	−9.033	<0.001	***
backness=non-back	2.024	0.343	5.899	<0.001	***
roundness=round	2.367	0.310	7.633	<0.001	***
stress=yes	2.486	0.182	13.688	<0.001	***
consonant=b*	−28.079	0.852	−32.960	<0.001	***
consonant=d	−23.367	0.873	−26.754	<0.001	***
consonant=g	−23.150	0.881	−26.261	<0.001	***
consonant=t	9.027	1.084	8.777	<0.001	***
consonant=k	9.513	1.153	13.688	<0.001	***

* Reference level = p

Table 5. Approximate significance of smooth terms modeling geographical variation. edf = estimated degrees of freedom, ref.df = referential degrees of freedom

	edf	**ref.df**	**F**	**p**	
lon,lat	16.490	19.646	4.228	<0.001	***
lon,lat : b	4.145	2.000	1.198	0.300	
lon,lat : d	2.001	5.238	2.240	0.107	
lon,lat : g	5.178	6.278	1.369	0.228	
lon,lat : p	2.000	2.000	9.276	<0.001	***
lon,lat : t	2.539	2.572	11.319	<0.001	***
lon,lat : k	3.844	3.988	3.944	0.003	**

Gender: We hypothesized that male informants have shorter VOT than female informants. While the model shows a slight trend to that effect, it does not approach significance.

Palatalization and *stress*: The data strongly support the hypotheses that palatalized plosives and stress are associated with higher VOT.

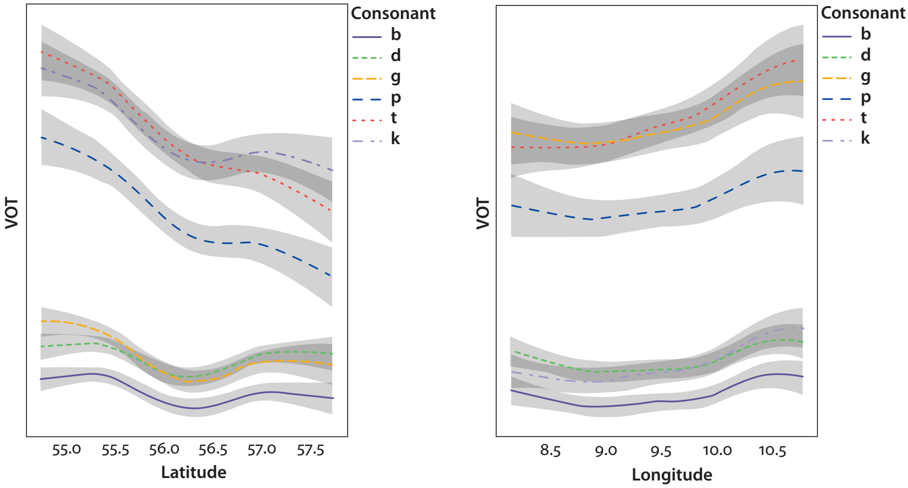
Vowel height: The data support the hypothesis that following high vowels increase VOT, but does not support a more complex continuum effect of vowel height; post-hoc pairwise comparison finds no significant difference between mid and low vowels.

Vowel backness: The hypothesis was that following vowel backness influences VOT in interaction with plosive place of articulation, such that bilabials have higher VOT before back vowels. Recall from Section 3.4 above that the inclusion of such an interaction does not improve the model fit; in effect, this means that the added complexity of such an interaction effect cannot be justified by its additional explanatory value. The data instead show that following back vowels significantly decrease VOT relative to front vowels.

Roundness: As with backness, the hypothesis was that following vowel roundness influences VOT in interaction with plosive place of articulation, such that bilabials have higher VOT before round vowels. Once again, including such an interaction does not improve the model fit. The model rather finds that rounding in the following vowel significantly decreases VOT.

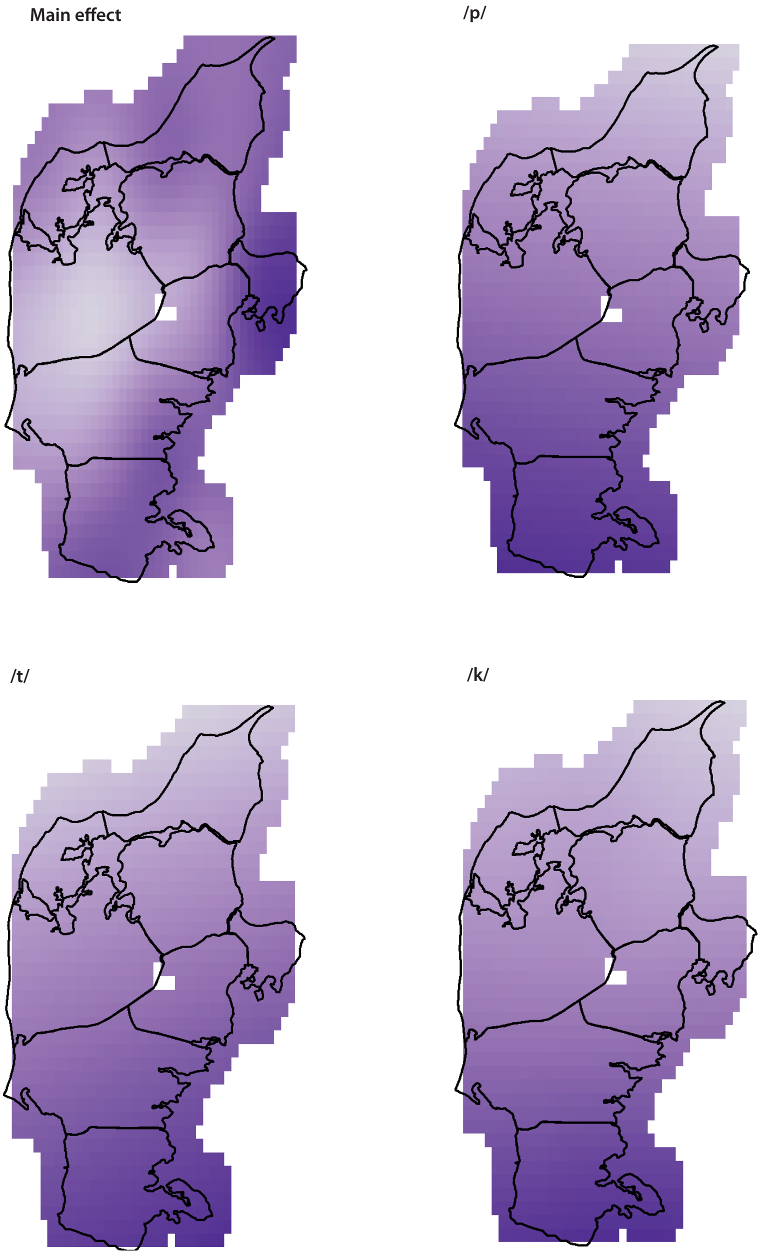
Phoneme: Post-hoc pairwise comparison of this factor strongly (and trivially) shows that phonological laryngeal setting has a large influence on VOT, with fortis plosives being longer than lenis ones. It partially supports the hypothesis that place of articulation has an influence on VOT, finding strong support for labial < alveolar/velar, but no support for alveolar < velar; all pairs are significantly different except (d ~ g) and (t ~ k). Mortensen and Tøndering (2013) found that /t/ was significantly longer than /k/ in Standard Danish; the descriptive statistics (see Table 3) suggest that this finding may also hold within some dialect areas, but this has not been tested further.

Geography: The findings related to the non-linear predictor of geography constitute the most significant findings of this study. There is a strong main effect of geography, suggesting that a primary geographical pattern is shared by all plosives. Additionally, all fortis plosives show further patterns of geographical variation. Table 5 only tells us that significant differences exist; in order to inspect these differences, we need to visualize the fitted values. In Figures 15 and 16, the effects of longitude and latitude are separated, and smooth curves are plotted for VOT by coordinates. These plots take the full fixed effects specification of the GAMM



Figures 15–16. Non-linear smooths of fitted values with 95% confidence intervals for VOT by latitude and longitude, respectively

into account, meaning that the plots reflect default values for the fixed effects (the same as those seen in Table 4 above). Figure 15 shows an overall dip in VOT going south-north, which is most pronounced for the fortis plosives; among the fortis plosives, the pattern is clearest for (t), least so for (k). There is a clear dip in the center of the peninsula. In Figure 16, going west-east, the main pattern is a general increase in VOT relatively far towards the east coast. This pattern is clearest for (t). In Figure 17, the main effect of geography on VOT is projected onto a map. In Figures 18–20, the specific effects of the individual fortis plosives are projected onto maps; note that these effects can *only* be interpreted in conjunction with the main effect. Very high VOT is found in a small area around Djursland; high VOT is also found in the Southern dialect area, as well as the eastern part of the Mid-Southern area; as well as in a small area covering parts of the Northern and North-Eastern areas; the far north has somewhat shorter VOT, and a large area in the mid-western part of the peninsula has very short VOT. The additional geographical effects of the fortis plosives seen in Figures 18–20 are very similar: more so than can be seen from Figure 17, there is also a continual effect of decreasing VOT going north-south for the fortis plosives. The main effect of geography is highly non-linear, and with a few exceptions does not follow the major traditional dialect areas. The results are discussed further below.



Figures 17–20. Fitted VOT values for main effect attributable to area, as well as effects of individual fortis plosives, plotted by coordinates. Darker shading indicates higher fitted values. Black lines indicate traditional dialect boundaries

5. Discussion and conclusions

The primary goal of this paper was to uncover the extent of regional variation in plosive realization in Jutland. This follows up on the results of Puggaard (2018), which showed that a variant of /t/ with short VOT is not, as previously assumed, limited to Northern Jutland. I have provided stronger support for that finding, and further found that variation is not limited to /t/, but reflects more general patterns, at least in the fortis plosives.

Shorter variants of plosives than in modern Standard Danish are consistently found across the Jutland peninsula. The longest values are found in southern Jutland, parts of mid-eastern Jutland, and Djursland. The long aspiration phases in southern Jutland are assumed to be part of the traditional dialect of this area, possibly due to areal influence from German, which has rather high VOT compared with the Jutlandic dialects (e.g. Hullebus et al. 2018). High VOT in eastern Jutland and Djursland may be due to Standard Danish influence from a number of major cities along the east coast, including Aarhus, the largest city of Jutland. This would be in line with Trudgill's (1974) gravity model of interdialectal influence, where sound change spreads on the basis of both population size and physical distance. However, there is no indication of a similar effect in the northern part of the peninsula, where the two largest urban areas at the turn of the 20th century (Aalborg and Randers) do not correspond to particularly high VOT.[12] Locations of major cities are shown in Figure 21.

Given the overt status of the short, non-affricated /t/ variant in the north of Jutland, it is further noteworthy that the shortest VOT values are not found in the far north, but rather in the center of the peninsula. At this point, there is no good explanation for why VOT values are so short in the center of the peninsula; we must assume that it was simply a feature of the local variety. On the basis of both the descriptive statistics and the GAMM output, it is clear that variation follows consistent complicated geographical patterns. The GAMM results in particular suggest multiple continua of variation.

Using a large corpus of legacy recordings of elderly dialect speakers, I have shown that plosives in the traditional Jutlandic dialects are generally shorter than in modern Standard Danish. The results further lend credence to previous findings: palatalization and stress were both shown to increase VOT. High vowels increase VOT, but no difference was found between mid and low vowels. Front vowels and round vowels increase VOT, and the results do not lend credence to

12. Likewise, the city of Esbjerg is in an area with rather low VOT. Esbjerg is a special case, as it was a very young city at the turn of the 20th century, settled only a few decades earlier.

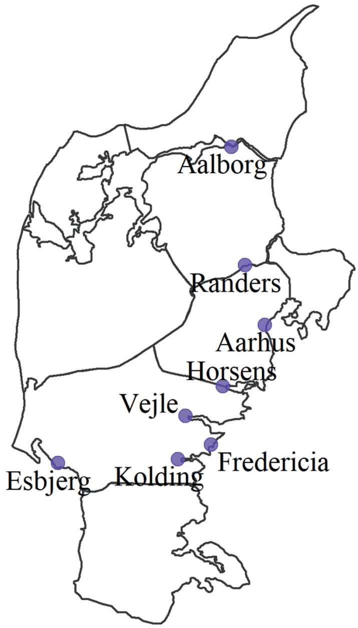


Figure 21. Cities with population sizes higher than 10,000 in the year 1901. Data from Matthiessen (1985)

previous findings about the influence of backness and roundness interacting with plosive place of articulation. The study also finds no effect of gender on VOT. Although the corpus used here was collected with lexicographic research in mind, I hope to have shown that it is also suitable for research in phonetics – and could potentially be suitable for a wide range of other research areas at all levels of linguistic description. A recent conference paper (Puggaard & Goldshtein 2020) investigated regional patterns of stop affrication in the data analyzed here, and suggested implications for underlying phonological representations; Goldshtein (2019) used the corpus in his investigation of tone in southern Jutland; Goldshtein & Ahlgren (forthc.) used the corpus to investigate discrepancies in the discursive constructions of dialect authenticity by dialect speakers and researchers in the interviews. No studies have used the corpus for research in syntax, but it should be well-suited for that as well. Finally, I hope to have shown the generalized additive mixed modeling can be fruitfully applied to studies of geographical distributions of phonetic variation.

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