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**A phonetically-based phoneme analysis of the Danish consonant system.
(Marie Skłodowska-Curie Action. Project: What makes the Danish sound
system so difficult for non-native learners? Acronym: LxDP')**

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A phonetically-based phoneme analysis of the Danish consonant system

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ABSTRACT

The traditional phoneme analysis of the Danish consonant inventory links onset and coda consonants on the basis of historical alternations and morphologically conditioned alternations within a small subset of the Danish lexicon. This traditional analysis proposes a system resulting in a large number of neutralizations that cannot be dissolved, and in which allophones of the same phoneme lack shared phonetic content. We argue that the system proposed by the traditional analysis is impossible to learn from the language input, which renders the analysis an implausible description of the Danish consonant system. On the basis of theoretical discussions, we offer an alternative phoneme analysis, which we believe to be learnable from the data available in the language input. Our analysis is based on insights from Natural Phonology and Bidirectional Phonetics and Phonology. We propose a system without undissolvable neutralizations, with shared phonetic content between allophones of the same phoneme, and without the need to rely on alternations that children are unlikely to learn in early childhood.

KEYWORDS Phoneme analysis; Danish; consonants; learnability; phonetics-phonology interface; Natural Phonology; Bidirectional Phonetics and Phonology

1. Introduction

A striking characteristic of Danish phonology is the substantial discrepancy between the consonant inventories in onset and coda. Presumably inspired by historical sound changes, this discrepancy is traditionally analysed in terms of synchronic consonant gradation, the core argument being that onset plosives are weakened to semivowels in coda position. Several phonologists have presented their version of this analysis and it has become a standard in the field. We present the origin of this analysis along with the three leading versions put forward by Rischel (1970), Grønnum (2005), and Basbøll (2005, 2015). While we agree that this traditional analysis presents

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a good diachronic description of the Danish consonant system, we will argue that it is a poor synchronic description, primarily because we believe that the proposed phonological system is impossible to acquire from the input. We identify three major problems with the traditional analysis, which together render it unlearnable for children acquiring Danish as their first language.

The first problem is that the traditional analysis results in a large number of neutralizations that cannot be dissolved. A coda [ɫ] is ambiguous between /g/ and /j/, while a coda [ʊ] is ambiguous between /b/, /g/, and /v/. This is a central problem for a phoneme analysis, which from a Natural Phonology perspective can be analysed as a result of low relational invariance between phonemes and their allophones (i.e., low uniformity and low transparency). We argue, with basis in the BiPhon Model (e.g., Boersma 2011), that undissolvable neutralizations present a serious obstacle to acquisition, as phonemes need to be constructed from the available phonetic forms encountered in the input, which is not possible for children acquiring the language when uniformity and transparency are so low that undissolvable neutralizations are ubiquitous.

The second problem is that the traditional analysis is based on historical alternations that no longer occur in standard Danish. Due to the loss of voicing in /b, d, g/ and the loss of the so-called *soft g* (the velar approximant [uɟ], previously a fricative and therefore often transcribed as [ɣ] in the Danish tradition), the traditional analysis establishes several phonemes whose allophones lack common phonetic content. The different realizations of /g/, for instance, i.e., [k, ɟ, ʊ, Ø], do not have a single phonetic property in common. We argue that the phonetic facts of present-day Danish renders the synchronic consonant gradation proposed by the traditional analysis untenable from a feature theoretic perspective. With respect to acquisition, the lack of phonetic similarity between allophones of the same phoneme leaves the language learner without any phonetic evidence suggesting that these sounds are indeed realizations of the same phoneme.

The third problem is that the traditional analysis is based on morphologically conditioned consonant alternations within irregular verbs and loanwords of primarily Graeco-Latinate origin, whereas the bulk of the Danish vocabulary does not exhibit any evidence for the proposed system. We are not in principle against the inclusion of morphologically conditioned alternations in the establishment of phoneme inventories, but we believe such alternations must be frequent and regular to play such a role, since they must be acquired by young children to play a role in phonological acquisition. We show that acquisition of the relevant irregular verb pattern cannot play a role in phonological acquisition as it is acquired later than the phonological system. We further suggest that the relevant loanwords are unlikely to play a role in phonological acquisition due to their low frequency, especially in the

language input young children experience. Consequently, the language learner is unlikely to encounter any morphophonological evidence for the proposed system.

As a consequence of our rejection of the traditional analysis, we present an alternative phoneme analysis of the Danish consonant system, which is firmly based on the phonetics of present day Danish. Our primary aim is to present a phoneme analysis that is a plausible description of the phonological system native speakers of Danish use in everyday comprehension and production. In Linell's (1975, 261) words: "We are not primarily interested in making all possible structural ('significant') generalizations about phonology (...) Instead, we are interested in those generalizations that a speaker-listener may reasonably make." Our analysis has a number of advantages over the traditional analysis. First, it is biunique when syllable position is taken into account and consequently, our analysis does not have a neutralization problem. Second, all allophones of a phoneme share at least one phonetic property, thereby making the connection between allophones of the same phoneme detectable in the input. Third, our analysis does not require children to base their phonological system on irregular verb patterns or loanwords they are unlikely to learn in early childhood. We believe our analysis presents a phonological system that is learnable from the input, unlike the system presented by the traditional analysis.

Before elaborating on our critique of the traditional analysis in [section 4](#), we present the relevant phonetic facts in [section 2](#) and a brief history of the origin of the traditional analysis along with an overview over the leading versions of the analysis in [section 3](#). The article ends with our proposed phonetically-based analysis in [section 5](#).

2. The phonetic facts

Danish has no voiced obstruents;¹ there are two sets of plosives, a voiceless aspirated set and a voiceless unaspirated set, and all fricatives are voiceless. The aspirated plosives occur only in onsets, whereas the unaspirated plosives occur in both onset and coda. Danish is rich in approximants and semi-vowels, some of which occur only in codas. [Table 1](#) presents an overview over the Danish consonant inventories in onset and coda. Dashes indicate positional restrictions. Throughout this article, we adopt a phonetic transcription that follows IPA rather than the Danish tradition, in order to make the transcription more accessible for readers less familiar with Danish. Specifically, we follow Schachtenhaufen ([forthcoming](#)) in transcribing the

¹An exception is that Danish plosives may be voiced inter-vocally. This has long been assumed to be essentially a categorical phonological process (Fischer-Jørgensen 1954, 1980; Fischer-Jørgensen and Hutters 1981), but has recently been shown to be much less frequent than previously thought (Puggaard-Rode, Horslund, and Jørgensen [forthcoming](#)).

Table 1. The Danish consonant inventories in onset and coda.

	Labial	Alveolar	Palatal	Velar	Pharyngeal	Glottal	Labial-velar	Alveolar-velar
Voiceless aspirated plosives	p ^h -	t ^s , ²		k ^h -				
Voiceless unaspirated plosives	p	t		k				
Voiceless fricatives	f	s	ç-			h-		
Central approximants	ʋ-		j-		ɣ-			
Lateral approximants		l						
Semivowels			-ɭ		-ɐ		-ʋ	ɰ ³
Nasals	m	n		-ŋ				

onset realization of /b, d, g/ as [p, t, k] and the so-called *soft d* as a centralized, alveolar-velar semivowel [ɰ].⁴ The soft *d* was previously an approximant and therefore often transcribed as [ð] in the Danish tradition. We transcribe this earlier version as [ð̥].

Table 1 presents 20 phones of which [p^h, t^s, k^h, h, v, j, ɣ] are restricted to onset position and [ɰ, ɭ, ʋ, ɐ, ŋ] are restricted to coda position. How exactly these 20 sounds are organized into phonemes is the topic of the present article. Some of the sounds are unproblematic to organize into phonemes. There is general agreement that onset [f, s, m, n, l] and coda [f, s, m, n, l] are realizations of the phonemes /f, s, m, n, l/. There is furthermore agreement that onset [h] is the only realization of the phoneme /h/. The analysis of the consonants [-ŋ] and [-ɐ] presents a separate issue not discussed in the present article. The topic of the present article is the organization of onset [p^h, t^s, k^h, p, t, k, v, j, ɣ] and coda [ɰ, ɭ, ʋ, ɐ], which poses a central problem in Danish phonology. The traditional analysis has been the dominant solution to this problem.

3. The traditional analysis

As mentioned above, the traditional phoneme analysis of the Danish consonant system is not a single analysis but a tradition in the field. Consequently, there are different versions, but as will be shown below, they have essentially the same content and differ mainly in the exact formalizations. Common to all versions of the traditional analysis is their matching of [p^h-, -p], [t^s-, -t], [k^h-, -k], [p-, -p/-ʋ], [t-, -ɰ], [k-, -ʋ/-ɭ] [v-, -ʋ], [j-, -ɭ], and [ɣ-, -ɐ] as corresponding strong and weak realizations of

²Note that the aspirated alveolar is affricated and is typically transcribed with a superscript s, [t^s].

³The so-called soft *d* is a centralized alveolar-velar semivowel (Juul, Pharao, and Thøgersen 2016; Schachtenhaufen forthcoming; Siem 2019).

⁴IPA lacks a diacritic for alveolarization, which makes Schachtenhaufen forthcoming transcribe the soft *d* as [ɰ̥] with a laminal diacritic. However, according to Schachtenhaufen (mail 25 November, 2021), apical pronunciations are also found, which has led us to not transcribe the alveolarization of the soft *d* in the absence of a fitting diacritic.

a set of underlying categories, be they phonemes or morphophonemes, a distinction we comment on below. The first phone in each pair is designated the realization in strong position, and the second pair the realization in weak position. In some environments, the weak realization is even a null-realization [Ø]. Strong position is generally considered to cover word-initial position and other syllable-initial positions before a full vowel, whereas weak position covers coda position and positions before unstressed central vowels. Note, however, that coda position before suffix *-t* typically behaves as a strong position in verbs, e.g., *ba*[ɪ]! – *ba*[k]t ‘bake’ (imperative – past participle), whereas in adjectives this position sometimes behaves as a weak position, e.g., *klo*[ʊ] – *klo*[ʊ]t ‘clever’ (common gender – neuter) and sometimes as a strong position, e.g., *ri*[Ø] – *ri*[k]t ‘rich’ (common gender – neuter), at least in some varieties. Coda position before suffix *-te*, on the other hand, always behaves as a strong position, e.g., *ba*[ɪ]! – *ba*[k]te ‘bake’ (imperative – past tense).

The traditional analysis moreover proposes a common underlying /g/ for words showing alternations between final [ɪ] and [ʊ], despite the fact that these consonants never surface as a velar plosive. This consonant alternation goes hand in hand with a vowel alternation between [æ] in front of [ɪ] and [ɑ] in front of [ʊ], which is in line with the vowel conditioning of the weak realization of /g/ in the traditional analysis; /g/ is realized as [ɪ] after front vowels and as [ʊ] after back vowels. The alternation is observed in words which have [æɪ] in their base form but [ɑʊ] in derivations and compounds. Some examples are listed in Table 2 below. However, this pattern seems to be lexically restricted. The words *svag* ‘weak’ and *smag* ‘taste/flavour’ never turn up as *[svɑʊ] and *[smaʊ] in derivations or compounds in modern Standard Danish; *smagfuld* ‘tasteful’, *smagløs* ‘tasteless’, *smagsstof* ‘flavours’, *svaghed* ‘weakness’, *svagstrøm* ‘low current’, *svagtsynet* ‘weak-sighted’ etc. are all pronounced with [æɪ].⁵

Table 3 presents an overview over the traditional analysis. Section 3.1. presents a brief history of the origin of the traditional analysis, which is followed by an overview over the leading versions of the analysis in section 3.2. The phonetic and phonological notation is

Table 2. [æɪ]~[ɑʊ] alternations.

[æɪ]		[ɑʊ]	
<i>bage</i>	‘bake’	<i>bagværk</i>	‘baked goods’
<i>lag</i>	‘layer’	<i>lagkage</i>	‘layer cake’
<i>dag</i>	‘day’	<i>daglig</i>	‘daily’
<i>fag</i>	‘subject/trade/craft’	<i>fagfolk</i>	‘professionals’
<i>sag</i>	‘matter/affair/business/cause/case’	<i>sagkyndig</i>	‘expert’
<i>tag</i>	‘roof’	<i>tagsten</i>	‘roof tile’
<i>flag</i>	‘flag’	<i>flagstang</i>	‘flagpole’

⁵Note that [smaʊ] was used in derivations like *smagfuld* and *smagløs* in conservative High Copenhagen varieties in the early 1990s (Brink 1991).

Table 3. The traditional analysis.

Phoneme/ morpho- phoneme	Morphophonological alternations			
	Initial realization	Weak realization		Strong realization
/p/	[p ^h ɪl]	galə[p]	'gallop'	galə[p ^h ɪ]ere
/t/	[t ^h ɪv]	və[t]	'cotton wool'	və[t ^h ɪ]ere
/k/	[k ^h ɪɒp]	lə[k]	'lacquer'	lə[k ^h ɪ]ere
/b/	[pɪl]	pləm[p]le	'seal'	pləm[pɪ]ere
		kə[ɪ]l/kə[p]l	'buy'	kə[pɪ]t
/d/	[tɪlɒg]	mətə[ɪ]le	'method'	mətə[tɪ]k
/g/	[kɪlɛm!]	bə[ɪ]l/	'bake!'	bə[kɪ]t
		bə[ɪ]lværk	'baked goods'	fənəlo[kɪ]
		fənəlo[ø]	'phonologist'	
/v/	[ʊ]s!	ɛfɛktr[ɪ]ʃ	'efficient'	ɛfɛktr[ɪ]ʃere
/ɪ/	[ɪ]ʃul	hø[ɪ]	'high' (common)	hø[ɪ]t
/r/	[ɛ]d	nəʃ[ɪ]ʃ	'nature'	nəʃ[ɪ]ʃt
		vɛgətə[ø]	'vegetarian'	vɛgətə[ɛ]ʃmɛ

kept constant in the description of different versions of the traditional analysis in order to allow for easy comparison between these versions. However, when referring to earlier versions of Danish, we transcribe in accordance with what is known about the pronunciation at these stages.

3.1. The origin of the traditional analysis

The challenge for a systematic description of the Danish occlusives has always been that certain sounds – [p^h, t^s, k^h] – only occur syllable-initially, whereas certain etymologically related sounds – [ɣ̥/ð,⁶ ɰ, ɥ] – occur only syllable-finally.⁷ Thus, there is a mutually exclusive distribution, but little point in identifying the mutually exclusively distributed sounds (cp. Martinet 1937, 205).

The earliest version of what we here call the traditional analysis *in nuce* may be found in a lecture given in London in 1936 by H.J. Uldall, Louis Hjelmslev's closest collaborator in the development of glossematics. Uldall states at the beginning that the lecture is the outcome of the committee on pronunciation within the *Cercle linguistique de Copenhague*; but since after 1934, this committee seems to have consisted of Uldall and Hjelmslev only with Paul Lier as a rather passive third wheel to the cart,⁸ the authorship must be attributed to Uldall and Hjelmslev equally. Though the report is very brief, it is clear that the analysis operates with six occlusive phonemes, distributed in such a way that the unaspirated occlusives [p, t, k] belong to the /b, d, g/ phonemes in initial position, but to the /p, t, k/ phonemes in final positions. The crucial non-occlusives, [ð] and [ɰ], are explicitly referred to the phonemes /d/ and /g/ respectively (Uldall 1936, 54). Furthermore, Uldall points out the neutralization⁹ between the phonemes /b/ and /p/ in final position (Uldall 1936, 56–57). This neutralization is compared to the situation of *g/k* and *d/t*, where the existence of [ð] and [ɰ] makes a binary distinction both in initial position ([k/k^h]; [t/t^h]) and in final position ([ɰ/k], [ð/t]) possible. Finally, Uldall briefly discusses the initial position after /s/. This is also a case of neutralization; only an unaspirated plosive is heard. Contrary to most later analyses, Uldall claims that in this position the phonemes /p, t, k/ are found, with the argument that the consonant cluster [skv] – *skvat* 'wimp', *skvulp* 'splash' – must be analysed as /skv-/, due to the fact that a cluster [k^hv-] exists

⁶[ð] is a central alveolar approximant with a prominent velar constriction (Basbøll 2005), which is a semivowel [ɣ̥] in modern Danish (Juul, Pharaoh, and Thøgersen 2016), cp. section 2.

⁷See Brink (2011) for some dubious cases, however.

⁸Fischer-Jørgensen 1967, III. That Lier's participation was peripheral, according to himself, relies on personal information from Frans Gregersen (mail 3 June, 2021).

⁹Uldall uses the term 'implication'.

in Danish – *kvase* ‘squash’, *kvist* ‘twig’, *kværn* ‘grinder’ – but Danish has no [kv-] cluster.¹⁰ From this, it is extrapolated that all plosive manifestations after /s/ represent the /p, t, k/ series (Uldall 1936, 57).

A different solution is reached in Martinet (1937). He acknowledges the neutralizations of aspirated and unaspirated plosives in all positions except absolute initial position and draws the interesting parallel between aspiration and non-aspiration in front of vowels ($\pm h$) and aspiration and non-aspiration in connection with plosives (Martinet 1937, 195). He is aware of the possibility of reducing the number of phonemes in all positions to two (Martinet 1937, 205), but in the long run prefers to maintain a 3×3 system, the ideal form of which would have been (Martinet 1937, 208; in IPA notation):

/p/ /b/ /β/
 /t/ /d/ /ð/
 /k/ /g/ /uq/

In the Danish material that Martinet analyses, the [β] is not found (although we may assume its presence in pre-recording stages of Danish). He is also aware of certain variational phenomena indicating that the fricative series will often turn into the semivowels [ɹ] and [ʊ] (Martinet 1937, 209–210).

The 1936 lecture was not the last foray from the Copenhagen circle into this matter, and contrary to Martinet, the tendency was to make the phoneme system as narrow as possible and only take a relatively distinct stylistic level of speech into account. Hjelmslev himself in his very sketchy analysis from 1948¹¹ suggests that there are only three occlusive phonemes, /b, d, g/ (Hjelmslev 1973, 255–257). The aspirated initials are seen as consonant clusters involving an /h/ phoneme. This phoneme was rejected by Uldall with the argument that it occurs only initially and hence cannot fulfill the definition of a consonant, which according to glossematics principles has to be found in both initial and final positions. By referring the aspiration to the /h/ phoneme, Hjelmslev is actually able to reduce the number of phonemes to three, but he continues to maintain the manifestation of /d, g/ by the non-occlusive sounds [ð, uq] (Hjelmslev 1973, 256). The commutation between *no*[t]e ‘note’ and *no*[ð]e ‘musical note’ and between *læ*[k]e ‘calves of legs’ and *læ*[uq]e ‘doctor’ (Hjelmslev’s examples, cp. Hjelmslev 1973, 256) is described as a commutation between /hd/ and /d/, respectively /hg/ and /g/. Remarkably, Hjelmslev

¹⁰The rule that complex clusters must always be resolved into existing simpler clusters was established by Hjelmslev in his theoretical paper at the London conference where Uldall’s analysis was presented, cp. Hjelmslev (1936) (Hjelmslev 1973, 164).

¹¹Published in Danish as Hjelmslev (1951), here quoted from the English translation in Hjelmslev (1973).

only gives bisyllabic examples, but monosyllabic examples with a final [t/ð] contrast may be found: *va*[t] ‘cotton wool’ and *hva*[ð] ‘what’, *gu*[t] ‘guy’ and *gu*[ð] ‘God’.¹² By referring the occlusive manifestations to the /hb, hd, hg/ consonant groups, Hjelmslev secures the /h/ a final position, thus fulfilling a demand in glossematics theory for a consonant to have both initial and final manifestations. That the pronunciation of the /h/ is only optional and furthermore restricted to absolute final position, does not disturb the system, and since system was everything to Hjelmslev and substance was nothing to him (cp. Hjelmslev 1943, 46), there is no theoretical problem with this, on the contrary. Thus, Hjelmslev’s solution is free to aggravate the problems concerning the manifestation of one phoneme by several only vaguely related sounds.

The analysis of [tʰ], [t] and [ʁ/ð] as a system with two phonemes crops up in a historically and theoretically interesting place, namely as one of the arguments in favour of distinguishing strong and weak positions in phonology in Jakobson, Fant, and Halle [1952] 1972, 5–6). No source is indicated, but Uldall’s 1936 version seems to be closest. It is worth noting that in a letter to Roman Jakobson immediately after the publication, the leading Danish phonetician of the period, Eli Fischer-Jørgensen, tries to raise doubt about whether the description of Danish is really a useful vehicle for such a theoretical development (Jensen and D’Ottavi 2020, 175). Probably, the 1936 Uldall-analysis also lived on elsewhere; just to mention one case, its distribution of the inventory is presupposed in Holt’s (1949) analysis of syllable boundaries in Danish.

Around 1970, The Hjelmslev-analysis was scrutinized by Hans Basbøll in a long unpublished paper in Danish, resumed in two English publications (Basbøll 1971, 1973). Basbøll’s reinterpretation and correction of hasty false notations in Hjelmslev’s original changes little in the analysis, but at the same time his reevaluation makes clear why the restitution of the traditional analysis, i.e., the original Uldall-analysis, might provide a better basis for further discussion. His analysis and his interpretation are in general confirmed by Fischer-Jørgensen (1973), based on her discussions with Hjelmslev from 1948 onwards. Meanwhile, Rischel had published his 1970 account, circulating many of the same points as Basbøll and Fischer-Jørgensen concerning the parallels between Hjelmslev’s phonological approach and generative phonology, which was on its way up in those years.

¹²Similar minimal pairs with a [k/ɰ] contrast seem not to exist; in all cases that we tested, like *myg* [myk/ my:ʔɰ] ‘mosquito/supple’, *hæk/hæg* [hɛk/ hɛ:ʔɰ] ‘hedge/bird cherry’, *klæk/klæg* [kʰlɛk/kʰlɛ:ʔɰ] ‘hatch/sticky’, *mukl/måg* [mɔk/mɔ:ʔɰ] ‘grumble/brother or son in law’, or *nik/neg* [nek/ne:ʔɰ] ‘nod/sheaf, such pairs also have a distinction between long and short vowel. The present-day reduction of [ɰ] into [ɪ] or [ʊ] is not taken into account in these transcriptions.

3.2. *Leading versions of the traditional analysis*

Three central versions of the traditional analysis are presented here: Rischel's (1970) analysis, which may be the first to explicitly analyse consonant gradation as a synchronic process accounting for the discrepancy between onset and coda inventories in Danish, as well as the analyses by the two currently leading researchers in the field of Danish phonology, i.e., Grønnum (2005) and Basbøll (2005; 2015).

3.2.1. *Rischel's analysis*

Rischel (1970) describes the traditional observation that despite the sizeable phonetic difference between the onset inventory and the coda inventory, the phones can be made to match by drawing on morphophonological alternations such as those presented in Table 2, in which the stem-final consonant alternates between its strong realization and its weak realization. On the basis of such alternations, Rischel postulates two sets of obstruent phonemes /p, t, k/ and /b, d, g/. /p, t, k/ are always realized as plosives. In onset they are aspirated and in coda they are not. /d, g/ are realized as plosives in strong positions and as fricatives or semivowels in weak positions. /b/ is a special case, since its weak version [ɸ] was not standard in 1970 (Rischel 1970) due to the rollback of the /b/-lenition (Skautrup 1944, 230). Note also that in Rischel's analysis, the velar approximant [ɰ] (typically transcribed as [ɣ] in the Danish tradition), i.e., the so-called *soft g*, is considered the standard realization of coda /g/ alongside the non-standard [ɪ, ɸ], which is indicative of the age of this analysis, since [ɰ] is no longer observed in standard Danish. Rischel's analysis thus covers an earlier stage in the diachronic process of consonant gradation, i.e., a point in time in which stylistic alternation between [ɰ] and [ɪ, ɸ] was observed.

Rischel does not consider his analysis a solution to the problem of how to organize onset and coda phones into phonemes but describes it as an attempt to show that the problem is essentially a morphological – perhaps a morphophonemic – issue rather than a question of arranging the phoneme system in the most economical way. A schematic presentation of Rischel's analysis is presented in Figure 1. Rischel does not discuss [v-, -ɸ], [j-, -ɪ], and [ɣ-, -ɸ] explicitly, but we assume that he would analyse [v-, -ɸ] as realizations of /v/, [j-, -ɪ] as realizations of /j/, and [ɣ-, -ɸ] as realizations of /r/. In order to present an exhaustive analysis of the problematic consonants, /v, j, r/ are included in Figure 1 in parentheses.

3.2.2. *Grønnum's analysis*

Grønnum (2005, 213) aims to present an analysis that has psychological or cognitive reality for the language users but recognizes that the psychological status of the phoneme is being questioned by many

Rischel's analysis			Grønnum's analysis			Basbøll's analysis		
Phonemes	Phonemes in positions	Phonetic realizations	Phonemes	Phonemes in positions	Phonetic realizations	Morpho-phonemes	Phonemes in positions	Phonetic realizations
/p/	/p-/	[p ^h]	/p/	/p-/	[p ^h]	p	/p-/	[p ^h]
	/-p/			/-p/			/-b/	
/b/	/b-/	[p]	/b/	/b-/	[p]	b	/b-/	[p]
	/-b/			/-b/			/-t/	
/t/	/t-/	[t ^h]	/t/	/t-/	[t ^h]	t	/t-/	[t ^h]
	/-t/			/-t/			/-d/	
/d/	/d-/	[t]	/d/	/d-/	[t]	d	/d-/	[t]
	/-d/			/-d/			/-s/	
/k/	/k-/	[ð]	/k/	/k-/	[ð]	k	/k-/	[ð]
	/-k/			/-k/			/-g/	
/g/	/g-/	[k ^h]	/g/	/g-/	[k ^h]	g	/g-/	[k ^h]
	/-g/			/-g/			/-v/	
/v/	/v-/	[k]	/v/	/v-/	[k]	v	/v-/	[k]
	/-v/			/-v/			/-u/	
(j/)	/j-/	[u]	/j/	/j-/	[u]	j	/j-/	[u]
	/-j/			/-j/			/-i/	
(r/)	/r-/	[ɪ]	/r/	/r-/	[ɪ]	r	/r-/	[ɪ]
	/-r/			/-r/			/-e/	

Figure 1. Three versions of the traditional analysis.

sociolinguists, which makes Grønnum consider her phoneme analysis an idealized description. On the basis of a discussion comparing structuralist and morphologically-based analytical principles, Grønnum (2005, chapter 16) adopts a morphologically-based phoneme analysis of the Danish consonant system. She explicitly states that she draws on knowledge of language history and of the phonologies of related languages in her analysis, which points to the idealized rather than the psychological or cognitive nature of her analysis.

Grønnum's analysis has two levels; a phonemic level and a phonetic level, despite her acknowledgment that there may be more levels differing in abstractness. However, as she finds the line between phonemes and morphophonemes in Danish hard to draw if these are to have psychological reality for the language users, she chooses to have her phonemic level cover both phonemes and morphophonemes and abstains from distinguishing between these two levels.

Despite the fact that Grønnum considers the lexicon to contain all irregular inflections and derivations, her analysis is thus similar to Rischel's in establishing phonemes on the basis of morphophonological alternations in loanwords and irregular verbs and adjectives. Grønnum postulates the same set of obstruent phonemes as Rischel does; /p, t, k/, which are always plosives, and /b, d, g/, which alternate between plosive realizations and semivowel realizations. Furthermore, Grønnum links [v-, -u] and [ɣ-, -e] as

realizations of the phonemes /v, r/ respectively. Grønnum does not distinguish between [j] and [ɹ] and postulates [j] as the only realization of /j/. A schematic presentation of Grønnum's analysis is presented in [Figure 1](#).

3.2.3. *Basbøll's analysis*

Basbøll (2005, 22–23) aims to present an analysis that is phonetically and psychologically interpretable. Phonetic interpretability is argued to be necessary for the phonological analysis to be testable and thus falsifiable – at least in principle – using phonetic methods. Likewise, psychological interpretability is required for the psychological content of the analysis to be principally testable. However, this latter goal is difficult to reach, and Basbøll does not claim to have reached it.

Basbøll's (2005, chapter 2; 2015) analysis differs from Rischel's and Grønnum's in establishing three levels of representation: a morphophonemic, a phonemic, and a phonetic level. He argues that the morphophonemic analysis should make phonological patterns simpler and more general. Whereas phonemic segments possess a cluster of distinctive features not found in any other sound, morphophonemic segments are candidates for lexical segments as units of word structure. This means that while different versions of a lemma may differ in the phonological mark-up of their stem, they all share the same morphophonemic structure of the stem. The relation between contrastive phonetic segments, phonemes, and morphophonemes is considered natural in the sense that the phonetic content is in principle the same at different levels of analysis. Basbøll adopts the principle of biuniqueness when establishing phonemes from contrastive phonetic segments. According to this principle, one sound can be identified phonemically in different ways provided that the phonemic context is different. The realization should be motivated by a systematic phonological principle, such as vowel-colouring by an adjacent /r/ in the direction of this /r/. Contrariwise, there is no biuniqueness requirement for morphophonemes, i.e., the same phoneme in the same phonemic context can represent different morphophonemes. Two phonemes can be identified as the same morphophoneme if they occur in parallel positions in different forms of the same morpheme if it applies to a significant set of morphemes in a systematic way.

Whereas Rischel and Grønnum analyse consonant gradation as a process affecting the link between phonetic segments and phonemes, Basbøll analyses it as a process affecting the link between phonemes and morphophonemes. Consequently, Basbøll's phonemic analysis does not link many onset and coda segments. The only onset and coda segments linked at this level are [v-, -ʊ] as realizations of the phoneme /v/, [j-, -ɹ] as realizations of the phoneme /j/, and [ɸ-, -ɸ] as realizations of the phoneme /r/. Defective distribution is claimed for /p, t, k/, which are restricted to initial position, and for /ɣ/, which is restricted to final position.

At the morphophonemic level, Basbøll establishes two sets of morphophonemes [p, t, k] and [b, d, g], whose phonemic realization overlap systematically, such that the final realization of [p, t, k] correspond to the initial realization of [b, d, g]. Basbøll moreover establishes the morphophonemes [v, j, r], which are always realized as the phonemes /v, j, r/, but since the phonemes /v, j/ can represent more morphophonemes in the same phonemic context, it is not generally possible to derive morphophonemes from phonemes in a given word form. It is, however, generally possible to derive phonemes from morphophonemes in a given word form by means of phonological principles. Regarding the psychological reality of morphophonemes, Basbøll (2015, 823) argues that “speakers’ knowledge and awareness of orthography must be expected to play a substantial role in alphabetized cultures”, which suggests that the consonant system proposed by Basbøll can only be acquired fully through the acquisition of literacy. A schematic presentation of Basbøll’s analysis is presented in [Figure 1](#).

3.2.4. *Phonemes and morphophonemes*

The main difference between Basbøll’s analysis on the one hand and the analyses by Rischel and Grønnum on the other hand is the number of levels of representation. Since Basbøll has three levels, his analysis distinguishes between phonetically motivated and positionally biunique relationships between phones and relationships between phones that do not fulfill these requirements. He places the former type of alternations in the interface between contrastive phonetic segments and phonemes on the basis of arguments that realization patterns of phonemes must follow certain principles. However, as the consonant gradation patterns do not follow these principles, he places them at the interface between phonemes and morphophonemes in order to integrate these alternations into his analysis without abandoning his principles concerning the relationship between phonetic segments and phonemes. Whereas the relationship between phonetic segments and phonemes is required to be biunique and thus acquireable bottom-up, the relationship between morphophonemes and phonemes is only predictable in the production direction and not in the perception and acquisition direction. Hence, while Basbøll’s solution may be superior in terms of formalization, it presents the same learnability issues as the two-level models: the proposed system is not learnable bottom-up from the language input. Consequently, unless explicitly stated, we do not distinguish between traditional accounts with two or three levels or between phonemes and morphophonemes in the following.

4. Problems with the traditional analysis

We identify three major problems with the traditional analysis: 1) it leads to a large amount of neutralizations that cannot be dissolved, 2) it proposes phonemes whose allophones lack common phonetic content, and 3) the

morphophonological evidence is limited and problematic. We argue that these characteristics make the proposed system unlearnable from the input, and the traditional analysis is hence an implausible description of the phonological system we expect native speakers of Danish to have. This section discusses each problem in turn.

4.1. Neutralizations that cannot be dissolved

The Danish coda inventory is characterized by a large number of neutralizations that cannot be dissolved. A coda [ɪ] can represent two different consonant phonemes (/g, j/) while a coda [ʊ] can represent three different consonant phonemes (/b, g, v/), meaning that [ɪ] and [ʊ] can represent the same phoneme /g/. Some of these neutralizations can be dissolved because the root shows alternation and some can be dissolved because the different realizations of /g/ are conditioned by the quality of the preceding vowel. However, due to lacking alternations for a large number of lexemes for which the /g/ vowel conditioning does not disambiguate, it is simply impossible to determine their phonemic form. That goes for [ɪ]s after front vowels that do not alternate with [k], e.g., *kage* ‘cake’, *mage* ‘mate’, *lage* ‘brine’, *læge* ‘doctor’, *væge* ‘wick’¹³ (they are ambiguous between /g/ and /j/), and [ʊ]s after back vowels that do not alternate with [k], e.g., *lov* ‘law’, *kogle* ‘cone’, *hagl* ‘hail’, *krage* ‘crow’, *krave* ‘collar’ (they are ambiguous between /g/ and /v/).

The impossibility of determining the phonemic form of a large number of lexemes is a central problem for a phoneme analysis as it conflicts with the widespread assumption that speakers store phonemic forms in their lexicon (see e.g., Hayes 2009, 58–59; Gussenhoven and Jacobs 2017, 94–95, 98–99).

From a Natural Phonology¹⁴ perspective, the problem stems from low uniformity and low transparency (Ács, Fenyvesi, and Jørgensen 2008). A completely uniform phonology has one single allophone of each phoneme, and the degree of uniformity decreases as the number of allophones increases. In a completely transparent phonology, each sound represents one single phoneme, and the degree of transparency decreases as the number of realizational overlaps between different phonemes increases. Uniformity is thus relational invariance in the production direction, while transparency is relational invariance in the comprehension direction. Simultaneous relational invariance in both directions, or in other words, simultaneous uniformity and transparency, is called biuniqueness (Galéas 2001). It is clear that uniformity is low in the traditional analysis: 9 out of the 12 oral consonants have more than one realization. Most consonants have one strong and one weak realization, but /r/ has one strong realization plus two weak realizations ([ʁ, Ø]), and /g/ has one strong realization plus three weak

¹³In words like these, [ɪ] is often dropped in fast speech and sometimes also in citation forms.

¹⁴Which evolved on the basis of Stampe (1969).

realizations ([l, ʊ, Ø]). Transparency is also low: final [ʊ] has three different sources (/b, g, v/), and final [l] has two (/g, j/). Consequently, biuniqueness is only observed for /f, s, m, n, l, h/.

Due to the large number of these undissolvable neutralizations in Danish, the problem is also a practical one for the language learner. The fact that the concrete realizations can be derived from the abstract categories, as Basbøll explains, does not help the language learner, since these abstract categories have to be built from the concrete realizations in the first place. This illustrates a fundamental problem, which the traditional analysis shares with many other linguistic analyses, namely the inability to account for acquisition of the proposed grammar. In the words of Eliasson (1997, 57): “The lack of a cognitive perspective lies at the heart of fundamental problems in twentieth-century linguistic theory. One of several issues of this sort is the abstractness of underlying representations. A high degree of abstractness was characteristic of some earlier process linguistics and hinged on the principled decision to describe interlevel relations in syntax, morphology, and phonology solely in the direction from underlying to surface form.” Such a one-directional perspective is unable to account for the acquisition of a grammar, since language learners must necessarily make the analysis in the opposite direction, i.e., they must construct the underlying form from the surface form, which is exactly what seems impossible within the traditional analysis, due to the large amount of undissolvable neutralizations. This acquisition problem can be formalized within the BiPhon Model (e.g., Boersma 2011), which is illustrated in Figure 2. As a bidirectional model of phonetics and phonology, the BiPhon Model addresses both directions of processing and is thereby able to account for acquisition. The model is built on the assumption that the production process and the comprehension process make use of the same grammar. From a BiPhon perspective, the learner hears phonetic forms

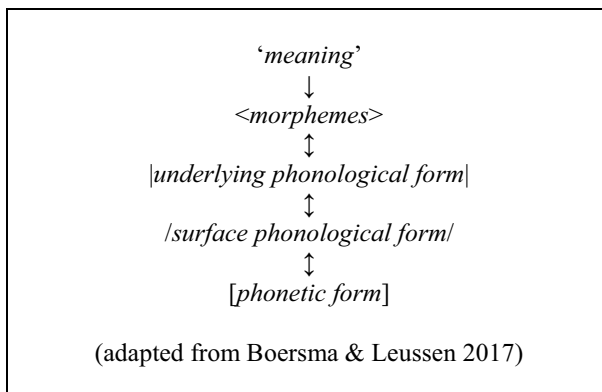


Figure 2. The five-level grammar of the BiPhon Model.

and may be able to infer the meaning connected to these phonetic forms. The learner thus obtains knowledge of pairs of [phonetic form] and ‘meaning’ and must construct the three intermediate levels (surface form, underlying form, and morpheme). A BiPhon perspective on the Danish system with morphological consonant alternations can be illustrated through a comparative case, French liaison. Similar to the traditional analysis of the Danish consonant alternations, the consonant alternations connected to French liaison are traditionally analysed as derived from the same underlying phonological form (e.g., Schane 1968; Selkirk 1972). However, in their computer simulation of the acquisition of French liaison, Boersma and Leussen (2017) found that most virtual learners avoided the establishment of a single underlying form for the masculine and feminine forms of the adjective *bon* ‘good’ contrary to what is traditionally claimed. Instead most virtual learners established suppletive underlying forms for the two versions of the adjective in order to arrive at the phonetic forms [bɔ̃] and [bɔn]. In other words, the virtual learners linked the two phonetic forms [bɔ̃] and [bɔn] to different phonological or morphological forms. Boersma and Leussen interpret this as evidence that a grammar that needs to produce these two phonetic forms is better off linking them to different phonological or morphological forms that share meaning than linking them to the same underlying morphological and phonological form. Due to the similarities between French liaison and Danish consonant alternations in *-te* verbs, we expect a computer simulation study of the Danish case to show that most virtual learners will establish suppletive underlying forms for different versions of the verbal stem in verbs like *bage* ‘bake’, i.e., [pæːɪ-], which is the form found in imperative, infinitive and present tense, [pak-], which is the form found in past tense and past participle, and [paʊ-], which is the form found in *bagværk* ‘baked goods’. Whether that is the case is an empirical question, which we plan to address in the future with a computer simulation study of the acquisition of Danish consonant alternations in verbs of the *-te* paradigm.

4.2. Lack of shared phonetic content between different allophones of the same phoneme

These undissolvable neutralizations are a result of changes in the Danish consonant system that make the traditional analysis outdated. Two sound changes are crucial here: 1) the loss of voicing in /b, d, g/ before the 1700s (Brink and Lund 2018, 200), and 2) the loss of the so-called *soft g*, the velar approximant [u], for people born later than approximately 1920 (ibid., 207). The loss of [u] has taken place during the 20th century. Jespersen (1922, 45) heard [j] instead of [u], but only 15 years later, Martinet (1937, 209–210) gives an interesting and detailed account of the dissolution of [u] into the

semivowels [ɪ] and [ʊ]. Without [u], the last remnants of a system in which coda [ʊ] can be disambiguated between /v/ and /g/ is found in the observation that some older speakers can pronounce the words with historical /v/, such as *krave* ‘collar’, with [v] instead of [ʊ] in clear speech, while this is not possible in words with historical /g/, such as *krage* ‘crow’ (Ács and Jørgensen 2016).

In the face of these two sound changes, any phonological theory that assumes a link between phonetics and phonology will have a hard time assigning /b, d, g/ to the same phonemic categories as semivowels. Basbøll (2005, chapters 3 and 4) represents phonemes and position-specific allophones of Danish using binary distinctive features, which he believes should be grounded in phonetics. Here, /b, d, g/ are represented as [+stop, –spread glottis] with the respective place features [+labial, +alveolar, +velar]. In order to derive his weak realizations, he proposes a rule [+stop, –spread glottis] → [+vocoid] in weak position. This is problematic for at least two reasons. First, oral stops and vocoids are essentially maximally different, in terms of both constriction in the oral cavity and sonority sequencing, and they are all the more different when they also differ in terms of voicing. Second, the place features for the weak realizations are not predictable from the underlying representations of the strong realizations. The process of /b/ → [ʊ], in Basbøll’s framework, entails a change from [+labial] to [+labial, +velar], with no way to explain the addition of [+velar]. Similarly, /g/ → [ʊ] entails the addition of an unexplainable [+labial] feature. All the more problematically, /g/ → [ɪ], in terms of Basbøll’s distinctive features, translates into [+stop, –spread glottis, +velar] → [+vocoid, +palatal]. These two representations do not share a single feature.

Basbøll’s formal apparatus is similar to that of Chomsky and Halle (1968), where distinctive features are phonetically grounded, but the rule system in itself is not constrained by phonetics, i.e., any operation is allowed. It is worth noting that they (1968, 400) explicitly recognize this as a problem with their framework, and Reiss (2018, 426ff.) suggests that their “call for a theory of markedness in generative phonology is perhaps responsible for inspiring most work in phonology for the last five decades”. In Optimality Theory, where markedness is one of the key guiding principles, it is unlikely that any ranking of constraints could account for an output realization which does not share a single phonetic property with the input.

If /b, d, g/ had still been voiced, the coda transformation would be more reasonable, as the two realizations would at least share the feature [+voice]. Similarly, as we saw in Section 3.1.1, the *soft g* played a central role in Rischel’s analysis of /g/, which is based on a pathway from a velar plosive over a velar approximant [u] to semivowels. The loss of [u] in the present standard Danish consonant inventory is detrimental to the traditional analysis as there is no longer an intermediate step between [k] on the one hand and [ɪ, ʊ] on the other. When /g/ was voiced, and [u] remained in the system, this was a perfectly reasonable synchronic gradation process, with

the steps [g] → [u] → [ɪ, ʊ]. Following the loss of voicing, the differences between [k] and [u] are already quite significant. With the subsequent loss of [u], the proposed gradation process from [k] → [ɪ, ʊ] simply skips too many stages to be plausible as a synchronic process.

We therefore argue that it is about time to abandon an analysis that is based on a historical version of Danish and thus no longer describes the present version of the language. In accordance with Hayes' (2009, 54–55) Criterion of Phonetic Similarity, "It is possible during language change that two allophones drift too far apart to count anymore as variants of the same basic linguistic unit", it is not plausible to propose that voiceless, unaspirated stops and semivowels are realizations of the same phoneme solely because they used to share phonetic content.

Table 4 shows a formalization in terms of phonological features of the phonological distance between the Underlying Form and Surface Form of the weak realization for the Danish consonants involved in the gradation processes suggested by the traditional analysis. This feature analysis is inspired by Basbøll's feature analysis (2005) but adapted to the phonetic description of the Danish consonants presented in section 2. Basbøll conceives of distinctive features as strictly binary, and all his features are designed such that only the positive-valued pole need be phonetically homogeneous. This means that [+alveolar] phonemes constitute a class of sounds with an alveolar place of articulation, but [–alveolar] does not (necessarily) constitute a particular class of sounds. Nevertheless, he assumes that all phonemes are specified for + or – values for all features. As such, [p] is technically specified as [+stop, +labial, –alveolar, –palatal, –velar, –pharyngeal, –fricative, –approximant, –vocoid, –spread glottis, etc.]. As is frequently done by Basbøll, we include only the informative positive-valued features below. Furthermore, in Basbøll's model of sonority sequencing, he maintains that some features logically imply others: [+vocoid] logically implies [+sonorant], which in turn logically implies [+voiced] (see e.g., Basbøll 1994). Similar implicational relationships hold for vocalic place features. We do not include features below if they are logically implied by other features. In other words, no redundant features are included.

The lack of phonetic similarity between different allophones of the same phoneme is a huge problem for acquisition. As argued above, language learners only have access to pairs of phonetic form and meaning. In order for them to be able to establish a phoneme inventory, they need evidence of which allophones belong to which phonemes. It should be clear from this section that phonetic evidence is scarce or completely lacking for several of the phoneme-allophone pairings proposed in the traditional analysis. As we shall see in the next section, so is morphophonological evidence.

Table 4. Feature changes in the traditional analysis. Only the relevant part of the feature specifications is shown.

Strong realization		Weak realization			
IPA	Feature specification	IPA	Feature specification	Feature changes	Unchanged features
[p ^h] [t ^h] [k ^h]	+stop +spread glottis (+place)	[p] [t] [k]	+stop (+place)	spread glottis	stop (+place)
[p]	+stop +labial	[ɸ]	+vocoid +labial +velar	stop vocoid velar	labial
[t]	+stop +alveolar	[ɬ]	+vocoid +alveolar +velar	stop vocoid velar	alveolar
[k]	+stop +velar	[ɮ]	+vocoid +palatal	stop velar vocoid palatal	none
[k]	+stop +velar	[ɸ]	+vocoid +labial +velar	stop vocoid labial	velar
[ʋ]	+vocoid +approximant +labial	[ɸ]	+vocoid +labial +velar	approximant velar	vocoid labial
[j]	+vocoid +approximant +palatal	[ɮ]	+vocoid +palatal	approximant	vocoid palatal
[ɣ]	+vocoid +approximant +pharyngeal	[ɣ]	+vocoid +pharyngeal	approximant	vocoid pharyngeal

4.3. Limited and problematic morphophonological evidence

Since the phonetic evidence for the traditional analysis is scarce, evidence from morphophonological alternations would be crucial for the acquisition of the proposed system. However, the morphophonological evidence is limited as the analysis does not apply to the bulk of the Danish lexicon. On the contrary, it is based on morphologically conditioned consonant alternations in a small subset of the Danish vocabulary, which can hardly be considered representative of the entire lexicon. Specifically, evidence is found in morphophonological alternations in irregular verbs, e.g., *ba*[ɮ] – *ba*[k]te, ‘bake! – baked’, and in loanwords of primarily Graeco-Latinate origin, e.g., *fonolo*[Ø] – *fonolo*[k]i ‘phonologist – phonology’, which we assume to be acquired at a point at which the phonological system is already in place.

In a picture naming experiment, Clausen and Fox-Boyer (2017) found that the vast majority of Danish children were able to produce all consonants except [ɛ] as early as between 2 and 3 years of age. Similarly, Heger (1979, 37) refers to a repetition study showing that 75% of the Danish children had acquired all

Table 5. Frequencies of verbs with *-te* past tense showing the relevant consonant alternations. Occurrences per million.

Alternation	<i>-te</i> verb (infinitive – past tense)		LANCHART	daTenTen17
[ʃ]~[Ø]	<i>svede</i> – <i>svedte</i>	'sweat'	1.3–1	1.75–0.73
	<i>lede</i> – <i>ledte</i>	'lead'	10.4–2	32.25–7.49
	<i>møde</i> – <i>mødte</i>	'meet'	77.2–112	145.63–40.2
	<i>føde</i> – <i>fødte</i>	'give birth'	5.7–3	15.77–7.32
	<i>støde</i> – <i>stødte</i>	'jar/poke'	2.3–5	6.38–7.81
	<i>bløde</i> – <i>blødte</i>	'bleed'	5.7–0.7	32.98–1.1
	<i>sprede</i> – <i>spredte</i>	'spread'	1.7–1	12.08–10.17
	<i>rede</i> – <i>redte</i>	'comb (hair)/make (bed)'	10.4–1	13.03–0.19
	<i>træde</i> – <i>trådte</i>	'tread'	5–14.4	19.8–19.38
	<i>klæde</i> (<i>sig på</i>) – <i>klædte</i>	'get dressed'	4–1	9.8–2.36
[p/ʊ]~[p]	<i>købe</i> – <i>købte</i>	'buy'	162.4–115.8	185.79–48.93
	<i>slæbe</i> – <i>slæbte</i>	'drag'	12.1–4.4	5.04–1.64
	<i>råbe</i> – <i>råbte</i>	'yell'	15.4–19.8	9.54–10.82
	<i>skabe</i> – <i>skabte</i>	'create'	14.8–2.7	209.88–23.83
	<i>tabe</i> – <i>tabte</i>	'lose/drop'	10.7–15.4	21.97–26.92
[Ø]~[k]	<i>søge</i> – <i>søgte</i>	'search'	52.7–69.5	78.92–24.78
	<i>sluge</i> – <i>slugte</i>	'swallow'	1–0.3	3.93–1.54
	<i>bruge</i> – <i>brugte</i>	'use'	286.3–66.4	398.62–72.9
[ʊ]~[k]	<i>koge</i> – <i>kogte</i>	'boil'	7.4–3.7	9.2–5.18
[ɪ]~[k]	<i>bage</i> – <i>bagte</i>	'bake'	5.7–4	9.25–3.92
	<i>smage</i> – <i>smagte</i>	'taste'	7.4–6	19.26–11.06
	<i>stege</i> – <i>stegte</i>	'fry'	1–1.3	6.06–3.08
[j/Ø]~[Ø] ^a	<i>følge</i> – <i>fulgte</i>	'follow'	68.8–19.1	194.5–38.23
	<i>sælge</i> – <i>solgte</i>	'sell'	53–71.5	54.19–26.98
	<i>vælge</i> – <i>valgte</i>	'choose'	94–64.4	185.31–79.63
[ʊ/Ø]~[Ø] ^b	<i>spørge</i> – <i>spurgte</i>	'ask'	67.5–122.5	47.02–52.13

^a/j/ does not normally vocalize after /l/ but is realized as [j] in that position (Basbøll 2005, 64). It is, however, common for this segment to be deleted in this position, such that these verbs are pronounced [fø], [sɛ], [vɛ] in their infinitival form.

^b[ʊ] is often deleted in this verb, such that the infinitival form is pronounced [spøɐ].

consonantal allophones by the age of 5.5 years. None of these studies have examined alternations, however. Even though Clausen and Fox-Boyer (2017, 442) are aware of the problem, they count consonant sounds produced in a wrong position as correctly produced. Despite methodological shortcomings, the ages suggested in these studies are corroborated by Dodd et al. (2003), who found that 90% of the British English-speaking children have acquired all English consonants except [ɹ] and the dental fricatives [θ, ð] by the age of 5.5 years. However, according to Bleses' (2000) study, Danish children from both Funen and Zealand get the past tense form wrong in a group of irregular verbs with past tense *-te* around half the time at the age of 8 years (Funen: 46%, Zealand: 53%). These results suggest that the relevant irregular verb pattern is acquired *after* rather than *before* the phonological system is in place, and thus irregular verb patterns cannot be used as a basis for acquiring the phonological system.

This late acquisition of the *-te* past tense may be related to frequency patterns. Research suggests that patterns with high type frequency are more productive while inflected forms with high token frequency are treated as unanalysed chunks

(see Ambridge et al. 2015 and references therein). 85% of the Danish verbs have the *-ede* past tense, while only 10–15% have the *-te* past tense (Jacobsen 2019). Table 5 shows frequencies of verbs with the *-te* past tense showing the relevant consonant alternations in the two corpora LANCHART and daTenTen17. LANCHART (Language Change in Real Time; Gregersen 2009; Gregersen, Maegaard, and Pharao 2014) is a large corpus of spontaneous spoken Danish, consisting of close to 2000 sociolinguistic interviews, of which approximately 600 are phonetically transcribed. A word frequency list based on the existing transcriptions (roughly 3 million tokens) was compiled by Nicolai Pharao (2009) in connection with his dissertation. daTenTen17 is a lemmatized corpus of stylistically varied written Danish published by Sketch Engine (see e.g., Kilgarrieff et al. 2014). It is based on a web crawler and contains roughly 2 billion tokens. Due to the combination of low type frequency of the irregular *-te* past tense and high token frequency of the *-te* verb forms and the fact that this verb pattern is unproductive, we consider the irregular *-te* past tense an implausible source for the acquisition of the phoneme inventory.

Loanwords of Graeco-Latinate origin are also unlikely to play a major role in phonological acquisition. There are two reasons for this: 1) these words are acquired late if at all and 2) the patterns they exhibit are not generally extended to other words. We are not aware of any studies of the acquisition of Graeco-Latinate loanwords in Danish, but research on English shows that knowledge of words of Graeco-Latinate origin shows significant differences between social groups in 15 years old native English speakers (Corson 1984), and we would expect this effect to be similar in native speakers of Danish. Research on English also sheds light on adult treatment of this word group. English trisyllabic shortening is a pattern observed only in Graeco-Latinate loanwords, in which the long vowel in the base word is shortened in derivations with three or more syllables. Examples are *serene* – *serenity* [i:]~[ɛ], *divine* – *divinity* [a:]~[ɪ], and *profane* – *profanity* [eɪ]~[æ]. Experimental evidence suggests that adult English speakers are very unlikely to generalize trisyllabic shortening to novel words, suggesting that trisyllabic shortening is not an active phonological process. On the contrary, research suggests that trisyllabic shortening is based on orthographic knowledge (see Jaeger 1984 and references therein).

While some of the alternations proposed in the traditional analysis of the Danish consonant system are observed in both Graeco-Latinate loanwords and the *-te* verbs discussed above, a subset of the proposed alternations are observed in Graeco-Latinate loanwords only. Since these are the only words for which derivations can move a coda consonant to the onset of a stressed syllable, alternations in this word group are central to the traditional analysis. Pharao (2004) investigated how often native speakers of Danish would generalize the consonant alternations observed in loanwords of Graeco-Latinate origin to nonsense words in a suffixation experiment. He found that 12 out of 30 participants generalized the alternations to nonsense words when producing the suffixed derivation. This

could be taken as evidence for the traditional analysis for a subset of speakers, but we argue that sound alternations observed only in a very restricted subset of the lexicon should not be taken as evidence of a global phonological system but should be treated at the morphological or lexical level. This is in line with the Latinate constraint in English morphology and other morphological approaches to English treating Graeco-Latinate roots and affixes as qualitatively different from Germanic roots and affixes (see Plag 1999, 54–60 and references therein). We believe a similar distinction is warranted for Danish morphology.

With these observations in mind, it seems implausible to suggest that Danish children build their notions of /b, d, g/ on the basis of alternations like *hydro*'fo[p] – *hydrofo*'[p]i 'person suffering from hydrophobia – hydrophobia', *fono*'lo[Ø] – *fonolo*'[k]i 'phonologist – phonology', and '*abbe*[ǰ] – *abbe*'[t]isse 'abbot – abbess' and their notion of /p, t, k/ on alternations like *mikro*'sko[p] – *mikrosko*'[p^h]i 'microscope – microscopy', *demo*'kra[t] – *demokra*'[t^s]i 'democrat – democracy', *patri*'ar[k] – *patriar*'[k^h]at 'patriarch – patriarchy'.¹⁵ This type of vocabulary has a low frequency in normal speech as illustrated in Table 6, and one can easily imagine that the frequency is even lower in child-directed speech, making alternations in these words a very implausible source for children's construction of a phonological grammar.

5. A phonetically-based alternative analysis

Our work is inspired by Ács and Jørgensen (2016), who proposed an alternative to the traditional analysis that postulates a different set of phonemes in onset and coda, thereby presenting a system that exhibits biuniqueness as each phoneme has one single realization. Figure 3 presents a schematic presentation of Ács and Jørgensen's analysis next to our analysis.

Ács and Jørgensen's analysis moves the complexity stemming from *-te* verbs and Graeco-Latinate loanwords from phonology to morphology under the argument that the complexities are better placed within the morphological domain than within the phonological one. Ács and Jørgensen's analysis is very similar to Basbøll's organization of phones into phonemes. Furthermore, both analyses see this complexity as closely related to morphology. The crucial difference between these two analyses is that Basbøll¹⁶ assumes morphophonological segments (morphophonemes) and thus one underlying form for each root for such words, whereas Ács and Jørgensen assume suppletive roots for such words.

While we agree with Ács and Jørgensen that these irregular morphological alternations are stored as suppletive roots and not derived from the same underlying form, we suggest that neither the phonological domain nor the

¹⁵Plosives may be aspirated in utterance final position, as may all sounds (Grønnum 2005, 310).

¹⁶Note that Basbøll (2005, 281, footnote 46) assumes suppletion in cases like *god* 'good' and *bedre* 'better'.

Table 6. Frequencies of a selection of loanwords showing the relevant alternations. Occurrences per million.

Alternation	Loanword	LANCHART	daTenTen17
[tʰ]~[t]	<i>vat – vattere</i> 'cotton wool – apply cotton wool'	0.7 – 0	2.24 – <.01
	<i>demokrati – demokratisk – demokrat</i> 'democracy – democratic – democrat'	2.7 – 2.3 – 0	26.39 – 16.67 – 0.78
[t]~[ʃ]	<i>abbed – abedissee</i> 'abbot – abbess'	0 – 0	0.95 – 0.01
	<i>metode – metodisk – metodik</i> 'method – methodological – methodology'	2.7 – 0 – 0	46.04 – 1.8 – 0.65
[pʰ]~[p]	<i>mikroskopisk – mikroskopi – mikroskop</i> 'microscopic – microscopy – microscope'	0.7 – 0.7 – 0	0.92 – 0.44 – 1.18
	<i>galop – galopere</i> 'gallop – to gallop'	1 – 0	2.04 – 0.14
[p]~[p]	<i>plombe – plombere</i> 'seal – to seal'	0 – 0	0.09 – 0.02
Including selected word pairs with -fob/-fobisk /-fobi	<i>hydrofob – hydrofobisk – hydrofobi</i> 'person suffering from hydrophobia – hydrophobic – hydrophobia'	0 – 0–0	0.05 – 0.02 – <.01
	<i>klaustrofob – klaustrofobisk – klaustrofobi</i> 'person suffering from claustrophobia – claustrophobic – claustrophobia'	0 – 0.3 – 1.7	<.01 – 0.55 – 0.39
	<i>homofob – homofobisk – homofobi</i> 'person suffering from homophobia – homophobic – homophobia'	0 – 0 – 0	0.07 – 0.22 – 0.73
	<i>akrofob – akrofobisk – akrofobi</i> 'person suffering from acrophobia – acrophobic – acrophobia'	0 – 0 – 0	0 – <.01 – 0.35
	<i>xenofob – xenofobisk – xenofobi</i> 'person suffering from xenophobia – xenophobic – xenophobia'	0 – 0 – 0	0.01 – 0.05 – 0.15
	<i>patriark – patriarkat – patriarkalsk</i> 'patriarch – patriarchy – patriarchal'	0 – 0 – 0.3	0.6 – 0.17 – 0.41
[kʰ]~[k]	<i>lak – lakere</i> 'laquer – to laquer'	1.3 – 0	7.43 – 0.42
[Ø]~[k]	<i>demagog – demagogisk – demagogi</i> 'demagogue – demagogic – demagogu'	0 – 0 – 0	0.08 – 0.11 – 0.17
	<i>pædagog – pædagogisk – pædagogik</i> 'pedagogue – pedagogic – pedagogy'	16.4 – 0.3 – 5.7	10.23 – 18.99 – 8.35
	<i>katalog – katalogisere</i> 'catalogue – to catalogue'	2.7 – 0	7.19 – 0.12
	<i>analog – analogi</i> 'analogue – analogy'	0 – 0	3.69 – 1.02

(Continued)

Table 6. (Continued).

Alternation	Loanword	LANCHART	daTenTen17
Including selected word sets with <i>-log/-logisk/-logi</i>	<i>antropolog</i> – <i>antropologisk</i> – <i>antropologi</i> 'anthropologist – anthropological – anthropology'	0.3 – 0 – 1	1.22 – 0.74 – 1.81
	<i>arkæolog</i> – <i>arkæologisk</i> – <i>arkæologi</i> 'archeologist – archeological – archeology'	2.7 – 0 – 1.6	1.45 – 1.59 – 2.09
	<i>astrolog</i> – <i>astrologisk</i> – <i>astrologi</i> 'astrologist – astrological – astrology'	0 – 0 – 0	0.4 – 0.29 – 1.19
	<i>biolog</i> – <i>biologisk</i> – <i>biologi</i> 'biologist – biological – biology'	2.3 – 0.7 – 15.4	1.83 – 8.56 – 6.63
	<i>etnolog</i> – <i>etnologisk</i> – <i>etnologi</i> 'ethnologist – ethnological – ethnology'	0 – 0 – 0.3	0.17 – 0.09 – 0.29
	<i>filolog</i> – <i>filologisk</i> – <i>filologi</i> 'philologist – philological – philology'	0 – 0 – 0	0.44 – 0.19 – 0.08
	<i>ideolog</i> – <i>ideologisk</i> – <i>ideologi</i> 'ideologist – ideological – ideology'	0 – 0.3 – 1.3	0.17 – 4.13 – 7.02
	<i>psykolog</i> – <i>psykologisk</i> – <i>psykologi</i> 'psychologist – psychological – psychology'	12.8 – 2.3 – 6.4	16.33 – 9.24 – 10.59
	<i>sociolog</i> – <i>sociologisk</i> – <i>sociologi</i> 'sociologist – sociological – sociology'	0.7 – 0.3 – 1.7	1.81 – 1.59 – 2.7
	<i>teknolog</i> – <i>teknologisk</i> – <i>teknologi</i> 'technologist – technological – technology'	0 – 1 – 6.4	0.09 – 10.94 – 48.46
	<i>teolog</i> – <i>teologisk</i> – <i>teologi</i> 'theologist – theological – theology'	0.7 – 0.3 – 1	2.09 – 2.89 – 5.26

morphological domain need to account for this complexity stemming from irregular alternations. We propose to move the load of these irregular verbs and alternations in loanwords to the lexicon, as we suggest that these alternations are rote learned on an individual basis. In correspondence with Ács and Jørgensen's analysis and our comparison to French liaison in [section 4](#) above, we suggest that the alternations presented as evidence for the traditional analysis has no impact on the phonological system as they are stored as suppletive forms in the lexicon. [Figure 3](#) presents a schematic representation of our analysis and that of Ács and Jørgensen.

We propose to keep the same set of phonemes in onset and coda with defective distribution of two plosives /b, g/, which only occur in initial position as [p] and [k] respectively. [ɪ] and [ʊ] are always considered allophones of the phoneme whose onset realization they most closely match, i.e., /j/ and /v/ respectively. For cases which show clear alternations, we suggest that these are a result of suppletive roots rather than a synchronic consonant lenition process.

Ács & Jørgensen's analysis			Our analysis		
Phonemes	Phonemes in positions	Phonetic realizations	Phonemes	Phonemes in positions	Phonetic realizations
/p/	————	/p-/	————	[p ^h]	
/b/	————	/b-/	————	[p]	
/t/	————	/t-/	————	[t ^s]	
/d/	————	/d-/	————	[t]	
/x/	————	/x-/	————	[ç]	
/k/	————	/k-/	————	[k ^h]	
/g/	————	/g-/	————	[k]	
/v/	————	/v-/	————	[v]	
/ʋ/	————	/ʋ-/	————	[ʋ]	
/j/	————	/j-/	————	[j]	
/ɹ/	————	/ɹ-/	————	[ɹ]	
/r/	————	/r-/	————	[r]	

Figure 3. Two phonetically-based analyses.

We argue above that the traditional analysis is an implausible description of the phoneme system we believe native speakers of Danish to possess because 1) it results in neutralizations that cannot be dissolved, 2) it postulates phonemes whose allophones lack common phonetic content and 3) it is based on morphological consonant alternations that only occur in a subset of the Danish lexicon. Here we argue how our analysis solves these problems.

5.1. No neutralization problem

By analysing all [ʋ] occurrences as realizations of /v/ and all [ɹ] occurrences as realizations of /j/, our analysis is positionally biunique and thus avoids the neutralization problem observed in the traditional analysis. The positional biuniqueness makes it possible to establish phonemic forms for all words in the Danish lexicon in correspondence with the general assumption that speakers store such forms (see e.g., Hayes 2009, 58–59; Gussenhoven and Jacobs 2017, 94–95, 98–99).

Due to the positional biuniqueness, our analysis enhances the naturalness of the Danish consonant system. As discussed above, naturalness is low in the system proposed by the traditional analysis. Uniformity is low, as 9 (i.e., /p, t, k, b, d, g, v, j, r/) out of the 12 oral consonants have more than one realization. Most consonants have one strong and one weak realization, but /r/ has one strong realization plus two weak realizations [ɾ, Ø], and /g/ has one strong realization plus three weak realizations [ɰ, ʊ, Ø]. Since we limit the number of weak realizations to one per phoneme and we establish two plosives that lack any weak realization, /b, g/, our analysis enhances uniformity slightly: 7 out of the 12 oral consonants have a strong and a weak realization, and no consonant has more than two realizations. In the traditional analysis, transparency is also low, as several phones have more phonemic sources; final [ʊ] has three different sources /b, g, v/, and final [ɰ] has two /g, j/. Our analysis severely enhances transparency since we establish a system in which no positional allophone has more than one source.

A consequence of an analysis without a neutralization problem is an analysis without an acquisition problem. In our BiPhon account of the acquisition problem related to the traditional analysis, we explained how the learner acquires pairs of [phonetic form] and ‘meaning’ and must construct the three intermediate levels (surface form, underlying form, and morpheme). Whereas the task of constructing the abstract forms proposed by the analysis seemed impossible due to the large amount of undissolvable neutralizations, the task of constructing the abstract forms we propose is doable due to the positionally biunique relationship between phonemes and allophones. Positionally biunique phoneme systems should be learnable for children as research has shown that infants are able to identify words in fluent speech by the age of 7.5 months (Jusczyk and Aslin 1995), probably due to their statistical learning abilities (Saffran, Aslin, and Newport 1996; Pelucchi, Hay, and Saffran 2009). This suggests that positional information is in place before children start acquiring the segments of their language.

5.2. Shared phonetic content between allophones of the same phoneme

Our analysis matches onset sounds and coda sounds that share phonetic content, thus proposing a phonological system that is detectable from the phonetic input. Table 7 shows an overview over the phonetic content shared by different allophones of the same phoneme in our analysis.

This increase in shared phonetic content between allophones of the same phoneme reduces the problems in accounting for the realization of the weak forms within a feature theoretic approach. As we saw above, Basbøll’s feature analysis has two problems, 1) it proposes a rule which links voiceless

Table 7. Shared phonetic content between allophones of the same phoneme in our analysis.

Phoneme	Onset	Coda	Shared phonetic features	Proposed coda gradation
/p/	[p ^h]	[p]	voiceless bilabial plosives	deaspiration
/t/	[t ^h]	[t]	voiceless alveolar plosives	deaspiration
/k/	[k ^h]	[k]	voiceless velar plosives	deaspiration
/b/	[p]	-	-	defective distribution
/d/	[t]	[ɿ̥]	alveolar oral consonants	vocalization
/g/	[k]	-	-	defective distribution
/v/	[ʋ]	[ʋ]	labial voiced oral continuants	vocalization
/j/	[j]	[ɿ̥]	palatal voiced oral continuants	vocalization
/r/	[ʁ]	[ʁ]	pharyngeal voiced oral continuants	vocalization

unaspirated stops in strong position with semivowels in weak position, and 2) the place features for the weak realizations are not predictable from the underlying representations of the strong realizations.

The process of /b/ → [ʋ] involves the addition on an unexplainable [+velar], the process /g/ → [ʋ] involves the addition of an unexplainable [+labial] feature, and the process /g/ → [ɿ̥] involves an unexplainable change in place feature from [+velar] to [+palatal].¹⁷ Our analysis does not need these problematic changes and additions in place features, since we view all [ʋ]s as realizations of /v/ and all [ɿ̥]s as realizations of /j/, both of which involve processes without changes in place features, as illustrated in Table 8. Our analysis has one problematic place feature change though, namely in the case of the [t]~[ɿ̥] alternation. As discussed above, the place of articulation for [ɿ̥] is not well established, but on the basis of what we know about [ɿ̥], it should be described as [+alveolar, +velar], which means that the process of /d/ → [ɿ̥] involves the addition of an unexplained [+velar] feature. Because the place of articulation for [ɿ̥] is still very debatable and addition means less change than complete change (as in the process /g/ → [ɿ̥]) and because the linking of [t-, -ɿ̥] does not result in any neutralizations, we decide to keep this link despite the place feature addition. If evidence shows that [ɿ̥] is in fact not alveolar, our analysis will need to be adjusted.

The rule [+stop, -spread glottis] → [+vocoid] in weak position is problematic because of the large difference between voiceless unaspirated oral stops and vocoids in terms of constriction in the oral cavity, sonority sequencing, and voicing. This problem is maintained in our analysis but only required for the [t]~[ɿ̥] alternation. For the reasons just mentioned, we accept this one process linking an unaspirated stop to a semivowel.

¹⁷In a wholly different context, Basbøll (2005, 138ff.) discusses the feature [grave] as encompassing both labial and velar consonants. He concludes that it is not used to distinguish Danish phonemes, although it does serve to explain the distribution of short /a, æ/ (see Basbøll 1972).

Table 8. Feature changes in our analysis. Only the relevant part of the feature specifications is shown.

Strong realization		Weak realization		Feature changes	Unchanged features
IPA	Feature specification	IPA	Feature specification		
[p ^h] [t ^h] [k ^h]	+stop +spread glottis (+place)	[p] [t] [k]	+stop (+place)	spread glottis	stop (+place)
[t]	+stop +alveolar	[ɿ]	+vocoid +approximant +alveolar	stop vocoid approximant	alveolar
[ʊ]	+vocoid +approximant +labial	[ʊ]	+vocoid +velar +labial	approximant velar	vocoid labial
[j]	+vocoid +approximant +palatal	[ɹ]	+vocoid +palatal	approximant	vocoid palatal
[ɤ]	+vocoid +approximant +pharyngeal	[ɤ]	+vocoid +pharyngeal	approximant	vocoid pharyngeal

5.3. Suppletive forms accounting for morphological consonant alternations

Instead of assuming that consonant alternations in *-te* verbs and loanwords of Graeco-Latinate origin are derived from underlying representations through complex rules that do not apply to the vast majority of the Danish lexemes, we suggest that the different phonetic forms of these words are stored in the lexicon as suppletive forms. This suggestion is supported by the computer simulation study of the acquisition of French liaison discussed above (Boersma and Leussen 2017), which showed that the majority of virtual learners of French liaison established suppletive forms for the masculine and feminine form of the adjective *bon* ‘good’ in order to produce the different phonetic forms [bɔ̃] and [bɔn]. Due to the similarities between the consonant alternations in French liaison and the consonant alternations in Danish *-te* verbs, we expect to find similar results in a planned computer simulation study on the acquisition of Danish *-te* verbs.

Suppletive roots for loanwords of Graeco-Latinate origin are also plausible, since the relationship between consonants participating in alternations in these words are not generally productive (Pharao 2004) and may be primarily orthographically induced as was found for the relationship between vowels participating in trisyllabic shortening in loanwords of similar origin in English (see Jaeger 1984).

For words showing alternations between [p] and [ɸ], we assume that speakers have two suppletive roots, one ending in /b/ and one ending in /v/. Such alternations are active in some speakers but not in others. Our own speech¹⁸

shows active alternations in words such as *at købe* ‘to buy’, *at tabe* ‘to lose/to drop’, and *at løbe* ‘to run’. We assume that all speakers have both underlying forms stored for passive usage, since it is our experience that [ʊ] realizations rarely cause comprehension problems. Speakers then differ in which words – if any – for which they use the /v/ form in production. The situation is thus similar to other words which have more pronunciations, such as the Danish noun *tunnel* ‘tunnel’, which can be pronounced with stress on either of the two syllables, and the classic example from English, the adjective *economic*, which can be pronounced with either [i:] or [ɛ] as the first vowel. We do not believe that such lexical idiosyncrasies play any role in the phonological grammar.

5.4. Summary

To sum up, our analysis has a number of advantages over the traditional analysis. First, it is largely biunique and consequently, our analysis does not have a neutralization problem. Second, all allophones of a phoneme share at least one phonetic property, thereby making the connection between allophones of the same phoneme detectable in the input. Third, our analysis does not require children to base their phonological system on irregular verb patterns or loanwords they are unlikely to learn in early childhood. We believe our analysis presents a phonological system that is learnable from the input, unlike the system presented by the traditional analysis. The advantages on Ács and Jørgensen are that we move a morphological load to a lexical load for words which already have extra lexical load due to irregular morphological patterns. Since they assume the semivowels to be individual phonemes and we do not, we can also reduce the number of phonemes, thereby making our analysis more economical, all things considered.

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