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Danish as a Window onto Language Processing and Learning

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Abstract

It is often assumed that all languages are fundamentally the same. This assumption has been challenged by research in linguistic typology and language evolution, while largely leaving aside questions of language learning and use. Here, we review recent work on Danish that provides new insights into these questions. Unlike closely related languages, Danish has an unusually reduced phonetic structure, which seemingly delays Danish-learning children in several aspects of their language acquisition. Adult language use appears to be affected as well, resulting, among other things, in an increased dependence on top-down information in comprehension. In this conceptual review, we build the argument that a causal relationship may exist between the sound structure of Danish and the peculiarities of its acquisition and use. We argue that a theory of language learning that accommodates the existing evidence from Danish must explicitly account for the interaction between learner-related factors and language-specific constraints.

Keywords: Danish, language processing, language acquisition, phonetics, top-down information, learnability

Danish as a Window onto Language Learning and Processing

Unlike the other North Germanic languages, Danish has since the Middle Ages developed a peculiar sound structure subject to pervasive phonetic reduction (Basbøll, 2005). The result is a speech stream characterized by long, uninterrupted sequences of vocalic sounds, which has been claimed to be "a harder nut to crack perceptually than most languages which it otherwise is reasonable to compare it to" (Grønnum, 2003, p. 129).

Danish is not the only language with a peculiar sound structure: for instance, Nuxalk and Tashlhiyt Berber have words that only comprise obstruents (Bagemihl, 1991; Dell & Elmedlaoui, 1985). However, what makes the phonetic idiosyncrasies of Danish particularly interesting is that Danish-learning children fall behind on some early linguistic milestones (e.g., Bleses et al., 2008a), compared to children learning other European and North-American languages. Danish children are delayed even in relation to children learning Norwegian and Swedish, which are both genetically and typologically closely related to Danish (see Bleses & Trecca, 2016, for a review). Spoken Danish is also relatively difficult to understand for adults in these neighboring countries, despite the three languages being very similar in written form (Gooskens, van Heuven, van Bezooijen, & Pacilly, 2010), and most foreigners find Danish hard to learn as a second language (Jespersen & Hejná, 2019; Normann Jørgensen, 2013).

Researchers have therefore speculated about whether the peculiar traits of the Danish phonetic structure may make the language intrinsically hard to understand and learn. Bleses and colleagues (Bleses & Basbøll, 2004; Bleses, 2008a; Bleses, Basbøll, & Vach, 2011) suggested that the frequent reduction of obstruents to vocalic sounds in

Danish speech may drastically reduce the salience of phonetic cues that listeners can use to extract linguistic units from the continuous sound stream. As a result, words become harder to segment from neighboring units. Moreover, because word endings are affected the most by reduction, inflectional morphemes may be also hard to identify in continuous speech. By reducing the availability of processing cues, the sound structure of Danish may ultimately hinder learning. Still, only a few studies have addressed this issue directly, and some of the available literature is either published in Scandinavian languages or is still unpublished/published in rare books.

The hypothesis of a relation between phonetic reduction and learnability in Danish seems to be in line with recent theories of language acquisition as a type of skill acquisition, in which the child learns to process language through engaging in conversational interactions with the adults (e.g., Chater & Christiansen, 2018). The incremental nature of language processing, together with our limited memory for auditory sequences and the fleetingness of the language input, constrains language processing to be fundamentally a "now-or-never" task (Christiansen & Chater, 2016). The highly reduced speech in Danish appears to provide the listener with ambiguous low-level information that requires more effort to process, and which is more likely to become subject to possible interference from subsequent speech input. Such difficulties in processing may make the language intrinsically harder to learn.

Still, the idea that some languages may be fundamentally harder to learn than others seems to be at odds with the often implicit presupposition that all languages are equally easy to learn and use (for reviews, see Newmeyer, 2003; Walkden, 2019). Some nativist-

generativist theories of language acquisition claim that the conditions of language learning are uniform across languages since these are constrained by the same underlying structure (e.g., Holmberg, 2017; Ringe, 2013; Roberts, 2017). Some functional-cognitive approaches make a similar assumption — albeit implicitly — in arguing that languages are complex adaptive systems that evolve toward global optima of learnability and usability, where hard-to-learn properties are likely to be compensated by other easier-to-learn ones (e.g., Bybee, 2007; Christiansen & Dale, 2004; Kirby, Cornish, & Smith, 2008). Similarly, some emergentist theories (which view language acquisition as the product of the child's domain-general learning capabilities and of the characteristics of the ambient language) implicitly assume that conceptual difficulty in language learning should be equal across languages, although with different language-internal distributions of simpler and more complex elements (e.g., MacWhinney, 2005; MacWhinney & Bates, 1989). In this theoretical landscape, the case of Danish seems puzzling and may shed new light on current theories of language learning and processing.

In this conceptual review, we discuss studies that suggest the existence of a psycholinguistic impact of phonetic reduction in Danish on higher levels of language learning and processing (including morphology and syntax) that makes the language intrinsically hard to process and learn. Our goal is twofold: First, we provide a comprehensive overview of the existing literature relating phonetic reductions to the acquisition of Danish.[1] After introducing the Danish sound structure and its peculiarities, we present evidence of delayed acquisition in Danish-learning children as well as the association between phonetic reduction and reduced processability in Danish speech. We

then discuss how this evidence can provide new insights into topical discussions about language learning. We examine initial evidence that the language system of native Danish speakers seems to adapt to the challenging sound structure of the language to facilitate processing. All the studies reviewed in these sections are summarized in Table 1, together with relevant methodological information. We conclude by arguing that the case of Danish may impose important constraints on any comprehensive theory of language learning: the theory must explicitly explain the (causal) relationship between surface properties of the language and its intrinsic processability; it must allow for cross-linguistic peculiarities in adult language use to emerge as a result of language-specific challenges in early acquisition; and it must explicitly account for the possibility that some languages are inherently harder to learn than others.

Phonetic reduction in Danish

Danish has a "complicated segmental phonology of reduction" (Bleses et al., 2008a, p. 623) resulting in high "phonetic opacity" (Bleses, Basbøll, & Vach, 2011, p. 1224). The vowel inventory is unusually large with 10 different short vowel phonemes and 10 different long vowel phonemes. Short-long vowel pairs most often have the same vowel quality (e.g., *hylde* [ˈhylə], Eng. shelf, vs. *hyle* [ˈhyːlə], Eng. to howl). Considering phonemic distinctions due to *stød* — a glottal stop-like or creaky voice suprasegmental feature (e.g., *køber* [ˈkʰøːˀb̥ʌ], Eng. (I) buy, vs. *køber* [ˈkʰøːb̥ʌ], Eng. (a) buyer; Grønnum, Vazquez-Larruscaín, & Basbøll, 2013) that may apply to all long vowels — the vowel inventory comprises 30 phonologically distinct vowels. However, the 10 short vowels have 16 conditioned allophones and the 10 long vowels have 13 conditioned allophones (see

Figure 1). Considering the possible *stød* in each of the long vowel and two conditioned schwa allophones, the phonetic vowel inventory contains 44 monophthongal vowel sounds. In addition, there are 18 falling diphthongs, and 31 rising diphthongs, which can, however, be analyzed phonologically as vowel-consonant or consonant-vowel sequences (Grønnum, 1998).

Several consonants are subject to lenition and often full-blown vocalization (Rischel, 1970) both diachronically and synchronically (Schachtenhaufen, 2013; Schachtenhaufen & Højen, in preparation). Lenition manifests itself through the loss of aspiration, as in the case of /p t k/, which are phonetically realized as the unaspirated/unvoiced [b̥ d̥ g̊] in non-initial syllable position and often further reduced to [β ɾ ɣ] in intervocalic position; and through the loss of closure, which turns phonetically-defined consonants or *contoids* into (non-syllabic) phonetically-defined vowels or *vocoids.* For instance, /b v/ are often realized as [u̯] (e.g., *løbe* [ˈløːu̯ə], Eng. to run; *kniv* [ˈkʰniu̯ˀ], Eng. knife), /g/ is realized as either [u̯] or [ɪ̯] (e.g., (at) *koge* [ˈkʰɔːu̯ə], Eng. (to) boil, and *kage* [ˈkʰæːɪ̯ə], Eng. cake), and /d r/ are mandatorily realized respectively as the non-lateral approximant [ð̞] (e.g., *mad* [ˈmað̞], Eng. food) and as the non-syllabic vowel [ʌ̯] (e.g., *bær* [bæʌ̯], Eng. berry).

Lenition adds to the already large inventory of voiced segments and results in highly vocalic speech characterized by a high ratio of vocoids to contoids, in which long uninterrupted sequences of vowels (e.g., *her er jeg* [ˈhɑ æ ˈjɑj], Eng. here am I) are common. Contributing further to the opacity of Danish speech are the frequent deletion of semivowels (e.g., *tog* [tsoːu̯ˀ] → [tsoːˀ], Eng. took) and the pervasive assimilation of

schwas to neighboring sonorants, which causes the assimilating segments to become syllabic (e.g., *gade* [ˈg̊æːð̞ə] → [ˈg̊æːð̞ð̞], Eng. street). Moreover, Danish is characterized by prosodic peculiarities like the absence of local signals to utterance function (e.g., no clear intonation falls or pre-boundary lengthenings at the end of utterances) and the absence of compulsory sentence accents (i.e., salient words are not prosodically marked; Grønnum, 2003), which add to the overall opacity of the language.

<Insert Figure 1 here>

Taken individually, these phenomena are not unique to Danish (e.g., pervasive consonant lenition and schwa assimilation are common in Spanish and German, respectively). However, their combination seems to constitute a *uniquely dangerous cocktail* (Basbøll, 2009a) for processing and learning. The comparison with Norwegian and Swedish is particularly appropriate here because the three languages have very similar morpho-syntax and overlapping vocabularies, and the three countries have a long common history, along with similar cultural and socio-economic conditions. Together, the three languages thus afford a well-balanced natural experiment (see Evans & Levinson, 2009) that supports the idea of Danish speech being particularly unclear. Danish is relatively hard to understand for speakers of Norwegian and Swedish, despite the three languages being very similar in written form (e.g., Bø, 1978; Gooskens & Kürschner, 2010; Maurud, 1976). Speakers of Swedish are particularly challenged in understanding Danish, as shown using both self-reported measures of mutual understanding (e.g., Bacquin & Zola Christensen, 2013) and language comprehension task (e.g., Gooskens et al., 2010).

There are no formal hypotheses in the literature about how phonetic opacity in Danish impedes processability and learnability. However, several ideas have been put forward in previous studies. One suggestion is that the long sequences of voiced segments with no clear acoustic intensity cues, which straddle syllable, morpheme, and word boundaries, lack clear acoustic-phonetic cues to word and/or morpheme segmentation (Bleses, Basbøll, Lum, & Vach, 2011; Bleses, Basbøll, & Vach, 2011; Bleses et al., 2008a). For instance, untrained listeners may find the eight adjacent vocoids — spanning three morpheme boundaries and one word boundary — in the Danish *røget ørred* [ˈʁʌjəðˌ ˈœɐ̯ʌðˌ] (Eng. smoked trout) (Figure 2) particularly hard to segment into constituent units. This is possibly because the lack of obstruents results in a virtually continuous signal without salient spectral discontinuities (e.g., Liberman, Harris, Hoffman, & Griffith, 1957; Mattys & Juszcyk, 2001; Nazzi, Dilley, Jusczyk, Shattuck-Hufnagel, & Jusczyk, 2005; Stevens, 1998). There is also initial evidence that the frequent assimilation of unstressed vowels (schwa) affects comprehension (Blom, Ejstrup, & Hopman, 2016) and that the lenition of intervocalic consonants impairs word recognition (Pharao, Malmstedt, & Veng, 2017) in spoken Danish. Processability may also be reduced because of the weaker sonority markers to syllable structure in Danish, which may affect syllable count (Kjærbæk, Thomsen, Lambertsen, & Basbøll, 2015; Trecca, McCauley, et al., 2019). Due to the high proportion of voiced segments, the difference in sonority between syllable nuclei (which are highly sonorous in most languages) and syllable onsets and codas (which have low sonority in most languages) is reduced. This factor seems to contribute to blurring the boundaries between syllables: for instance, the trisyllabic word like *lærere*

[lɛːʌʌ] (Eng. teachers) is most often reduced to the disyllabic [lɛːʌ] in casual speech (Schüppert, Hilton, Gooskens, & van Heuven, 2012); similarly, the pronunciation of the highly sonorous *badede* (Eng. bathed, Figure 3) can vary from the trisyllabic [ˈb̥æːð̥əð̥ə] to the virtually monosyllabic [ˈb̥æːðː] in casual speech (Bleses, Basbøll, & Vach, 2011). These processes are responsible for the fact that Danes do not tend to articulate around 25% of all canonical syllables in fluent speech, thus resulting in more semantic information being conveyed per time unit in Danish (Hilton, Schüppert, & Gooskens, 2011; Schüppert et al., 2012).

<Insert Figure 2 here>

<Insert Figure 3 here>

In what follows, we will offer the *Danish Opacity Hypothesis* (DOH) as an explanation for the possible causal connection between phonetically reduced speech and intrinsically lower processability and learnability in Danish. We will review studies of Danish acquisition and processing that provide evidence for the DOH, and we will offer possible explanations of the mechanisms resulting in the DOH in the Discussion section.

Note that the DOH only makes claims about the learnability of vocabulary and grammar as a function of phonetic opacity and does not predict that the acquisition of Danish phonology (i.e., learning basic sound contrasts) should be delayed. Clausen and Fox-Boyer (2017) found that Danish children are even ahead in their development of productive phonology compared to several other language groups, as they master all individual phones early on and resolve phonological processes often before other languages. This is because the challenges associated with Danish speech are not at the

level of individual sounds (paradigmatically) but rather seem to be rooted in difficulties with segmenting continuous speech (syntagmatically).

Early language acquisition

Inflectional morphology

Early experimental evidence in support of the DOH comes from a cross-Scandinavian experimental study of past tense morphology acquisition (Bleses, 1998; Ragnarsdóttir et al., 1998). Using a picture elicitation task, four-, six-, and eight-year-old children learning Danish, Norwegian, or Icelandic were tested on their knowledge of regular and irregular past tense forms. The prediction was that the phonetic opacity of the verb forms, quantified by the authors to be highest for Danish, would affect performance negatively for the Danish group. Danish performance was indeed lower than Norwegian and Icelandic in all age groups (Figure 4). Phonetic opacity explained much of the cross-linguistic differences in performance even when controlling for morphological complexity and type-token frequency in speech corpora.

Bleses, Basbøll, and Vach (2011) later updated these findings with data from a comparable group of Swedish children (Veres, 2004), who also outperformed Danish children on knowledge of past tense forms. The authors then combined these experimental findings with corpus data on the sonority of segments at morpheme boundaries to quantify the intrinsic processability of different past tense suffixes. They found that 29% of all word-internal morphological boundaries in Danish (vs. only 8% in Swedish and Norwegian) fall within vocalic sequences with no sonority boundary cues. Similar results were found in a corpus analysis by Trecca, McCauley et al. (2019), who showed that

vocoid-vocoid diphones occur three times more often in Danish than in US English child-directed speech and that these diphones contain word boundaries more than twice as often in Danish than in US English. Moreover, the study by Bleses, Basbøll, and Vach (2011) showed that the frequency of phonetically reduced past-tense forms in the children's input (derived from the Odense Twin Corpus, Basbøll et al., 2002, and from the Danish Plunkett corpus in the CHILDES database, Plunkett, 1985, 1986) correlated negatively with the number of correctly inflected verbs in the experiment ($r = -0.32$, $p < 0.001$).

<Insert Figure 4 here>

Vocabulary

Evidence in support of the DOH is also found in studies of vocabulary development. Using the *MacArthur-Bates Communicative Developmental Inventory: Words and Gesture* (MB-CDI: W&G) parental report (Fenson et al., 2007), Bleses et al. (2008a) carried out a cross-linguistic comparison study of 8- to 15-month-old children (Figure 5). Compared to 13 other languages, Danish children showed a smaller receptive vocabulary already at 8 months and a shallow learning curve throughout. At 15 months, Danish children had a median vocabulary score of 90 words, which is substantially smaller than the median for Croatian children, who were at the top of the distribution. The vocabulary of Danish children was also smaller than that of Swedish children by around 60 words at 15 months. Norwegian was not included in the original study, but data from a subsequent longitudinal MB-CDI: W&G study (Kristoffersen, Simonsen, Eiesland, & Henriksen, 2012; see also Kristoffersen et al., 2013) showed Danish children also falling

behind Norwegian children, who had a median receptive vocabulary score of 140 words at age 15 months.

Other interesting results emerged from the study. All languages but Danish showed a sizeable vocabulary spurt at age 11-12 months, whereas Danish children did not show a vocabulary spurt until around 15 months (Bleses et al., 2008b); median scores on phrase comprehension were also remarkably lower in Danish than in eight other languages (including Swedish) in the whole age range; Danish children had a lower frequency of imitation of words produced by adults and of labeling of objects compared to four other language groups, including Swedish; and they had among the lowest median vocabulary production scores in the cross-linguistic distribution and were delayed in the acquisition of expressive vocabulary by up to two months.

<Insert Figure 5 here>

Using the data from Bleses et al. (2008a), Bleses, Basbøll, Lum, and Vach (2011) correlated the vocoid-contoid ratio in seven of the 13 languages in the original study with their receptive vocabulary development rate in the whole age range (8-15 months). They found a strong negative correlation ($r = -0.9$, $p = 0.006$) between vocoid-contoid ratio and vocabulary development rate. Danish, which had the highest vocoid-contoid ratio in the study (1.29), was associated with the slowest learning rate.

Spoken language processing

Two recent experimental laboratory studies have used eye tracking to investigate the relationship between phonetic opacity, word segmentation, and acquisition delay. Trecca, Bleses, Højen, Madsen, and Christiansen (2020) used the Looking-While-

Listening paradigm (Fernald, Zangl, Portillo, & Marchman, 2008) to examine how sequences of adjacent vocoids affect word segmentation in spoken Danish. Twenty-four-month-old children were presented with pairs of familiar objects on a screen, while their eye movements were recorded as one of the two objects was named. The target objects were either consonant-initial or vowel-initial embedded in carrier phrases that were either contoid-final or vocoid-final. The speed of gaze shifts to the target object was taken as a measure of segmentability of the object label from the carrier phrase. On average, children oriented faster to the target object when consonants/contoids were on both sides of the target word boundary (e.g., *Find bilen!* [ˈfe̯nˀ ˈb̥iːˀlṇ], Eng. Find the car!), slower when vowels/vocoids occurred on either side of the word boundary (e.g., *Find aben!* [ˈfe̯nˀ ˈɛːb̥m̩], Eng. Find the monkey!, or *Her er bilen!* [ˈheˀʌ̯ æʌ̯ ˈb̥iːˀlṇ], Eng. Here is the car!), and slowest when vowels/vocoids occurred on both sides (e.g., *Her er aben!* [ˈheˀʌ̯ æʌ̯ ˈɛːb̥m̩], Eng. Here is the monkey!) (Figure 6). This result suggests that the presence of vocoids at word boundaries may reduce the acoustic-phonetic salience of the carrier phrase-target word boundary, thereby slowing down target object recognition.

Trecca, Bleses, Madsen, and Christiansen (2018) used a similar procedure to test the impact of vocoids on word learning. Danish children at 24-36 months of age were presented with two novel nonsense object-label pairings either ostensively (one object on the screen) or ambiguously (one novel object and one familiar object). As in the previous study, the labels were embedded in contoid-final and vocoid-final carrier phrases, with each novel word consistently associated with the same carrier phrase throughout the experiment for each child. After training, the children were tested on their ability to recall

the correct object-label pairings. The results showed that looks at the target picture increased more reliably across time for the words that were learned in the contoid-final carrier phrase than for words learned in the vocoid-final carrier phrase. Interestingly, the children's performance was generally poor on the task of mapping novel labels onto novel objects in ambiguous naming situations — a skill that is well-developed in English-speaking children of the same age (e.g., Halberda, 2006) — adding to the evidence that Danish-speaking children generally lag behind with regards to different linguistic milestones.

<Insert Figure 6 here>

Child-directed speech

Albeit peripheral to the DOH, there are a few peculiarities of Danish child-directed speech (CDS) that are worth noting, as they may exacerbate the issues described so far. Bohn (2013) analyzed Danish CDS data from native parent-child dyads in play situations in the laboratory. In contrast to several other languages (e.g., Burnham, Kitamura, & Vollmer-Conna, 2002; Fernald, 1992), Danish CDS was not significantly slower than adult-directed speech (ADS). Moreover, not only did parents not hyperarticulate vowels when talking to their children, but they even hypoarticulated in some cases. Recent spontaneous data from mother-child dyads in the home (Dideriksen, 2016; Dideriksen & Fusaroli, 2018) showed slower speech rates for CDS compared to ADS, conforming to the general cross-linguistic tendencies, but also a significantly reduced vowel space in CDS compared to ADS, as also found by Bohn (2013).

Possible compensatory cognitive strategies

Bleses et al. (2008a) report data from the *MB-CDI: Words and Sentences* parental report for 16-30-month-olds showing that Danish-learning children, though initially delayed, catch up with the average productive vocabulary size of 13 other European and North American languages around the age of 30 months. This upswing suggests two possible scenarios: (a) Danish children may catch up simply because of increased time and exposure to the language, or because the characteristics of Danish facilitate language acquisition in this age range; (b) Danish children may learn compensatory strategies that are long-lasting and may carry over into adulthood. Initial evidence from studies of adult Danish speakers seems to speak in favor of the development of compensatory mechanisms, such as increased reliance on top-down processing. These mechanisms may develop during childhood and leave a trace on the adult speech perception system. For instance, Ishkhanyan, Højen, Fusaroli, Johansson, Tylén, and Christiansen (2019), tested adult native speakers of Danish and Norwegian on a categorical perception paradigm designed to measure contextual (top-down) biasing on phoneme identification. The onsets of the Danish and Norwegian cognate words *sendt* ([ˈsɛnˀt], Eng. sent) and *tændt* ([ˈtˢɛnˀt], Eng. lit) were manipulated to generate target words whose initial phoneme varied on a continuum between [s] and [tˢ].[2] These words were then embedded in sentences that were contextually biased towards either *sendt* (e.g., "sent/lit an e-mail") or *tændt* (e.g., "sent/lit a candle"). Participants listened to sentences while the two target words appeared on screen, and were instructed to click on the word they heard. When the stimulus was phonemically ambiguous, Danes were significantly more inclined to click on the word that was semantically congruent with the context, compared to Norwegians. Furthermore, Danes

were slower than Norwegians in making a choice whenever the context was incongruent, indicating a stronger reliance on top-down processed contextual evidence to disambiguate the target word.

Trecca, Tylén, Fusaroli, Johansson, and Christiansen (2019a, 2019b) found a similar top-down reliance in sentence comprehension. Adult Danes and Norwegians listened to short stories consisting of a preamble (e.g., "the boy walked into the pet store") and a main event (e.g., "the boy bought a goldfish for the girl"), after which they were shown four drawings depicting the characters in different *who-did-what-to-whom* scenarios (e.g., a boy giving a fish to a girl). They were then asked to click on the picture that matched the story. In some trials, agent and object were switched around, creating internal incongruencies in the stories. In these cases, Danes were more prone than Norwegians to disregard the actual input and rectify the story to a more expectation-driven interpretation (e.g., when hearing "the goldfish walked into the pet store […] the boy bought a goldfish for the girl", they would select the *goldfish-gives-boy-to-girl* image, in accordance with the preamble). When signal noise was added to the auditorily presented stories to make the bottom-up signal less informative, Norwegians also changed their processing strategy to rely more on contextual information. This is taken as additional evidence that cross-linguistic differences in processing strategy may indeed be contingent on the relative opaqueness of the acoustic input.

Dideriksen, Fusaroli, Tylén, Johansson, and Christiansen (2019; see also Dideriksen, Fusaroli, Tylén, Dingemanse, & Christiansen, 2019) hypothesized that this adaptation to a more cost-efficient reliance on top-down information would also manifest

itself in the form of more solid pragmatic/semantic frames (common ground) in dialogue. The authors coded dialogue data from Danish and Norwegian dyads for occurrences of either backchannel (i.e., vocal tokens of understanding/agreement), alignment (i.e., re-use of lexical/syntactic/semantic forms), and repair (i.e., vocal tokens of communication issues). Danes showed a significantly and consistently higher degree of backchannelling and alignment, whereas conversational repair was more pervasive in Norwegian. This suggests that Danes may adapt to the pressure for more top-down driven processing by building robust common ground with higher redundancy. Evidence of a similar adaption is reported by Stivers and colleagues (2009). In a study of spontaneous conversations in ten language groups spanning from European, American, and Asian languages (such as English and Japanese) to indigenous languages (such as Tzeltal and Yélî Dnye), the authors observed that Danish dialogues had longer inter-turn pauses than dialogues in the other languages, with a mean transition time of 469 ms (vs. e.g., only 8 ms in Japanese). When the upcoming turns were answers to questions, the transition time was almost twice as high (~800 ms), and transition times for non-answer turns were also among the highest in the sample (~380 ms). Answers to questions were associated with shorter transition times when making eye contact with the interlocutor in all languages, except for Danish.

Together, these studies suggest that Danish may be processed differently than other languages even by adult speakers. The challenges associated with the acquisition of Danish in early childhood may carry over into adulthood by changing the processing system: Specifically, these changes may concern the relative weighting of bottom-up information (e.g., linguistic cues carried by the speech signal) and top-down information (e.g.,

expectations determined by contextual cues and previous cues; e.g., Ferreira & Chantavarin, 2018).

<Insert Table 1 here>

Discussion

We have reviewed a series of studies suggesting that the opaque phonetic structure of Danish may tax the learner's language system to a higher degree than other closely related languages, delaying children's language acquisition. Danish speakers may adapt to the opaque phonetic structure by developing compensatory processing strategies that can be observed in adult language use. Although evidence in support of the DOH is arguably still sparse, we propose that the findings presented in this review may have important implications for theories of language learning.

First, the reviewed evidence seems to suggest that theories of language learning in early childhood should explicitly make the connection between surface properties of different languages (e.g., various degrees of phonetic opacity) and different degrees of inherent processability and learnability. We argue that this link is intrinsic to a view of language learning and use as, on the one hand, determined by processing constraints ingrained in the language system (e.g., the *Now-or-Never bottleneck*; Christiansen & Chater, 2016) and, on the other hand, by the burden that particular types of linguistic input place on the system (e.g., O'Grady, 2015) . In this view of *processing determinism* (e.g., O'Grady, 2012), the course of development is predicted by processing pressures posed by different properties of the ambient language on the language system. In the abovementioned *Now-or-Never bottleneck*, the cognitive system deals with these

constraints by recoding the input in a quick and economic (i.e., compressed) way and integrating these representations into increasingly higher levels of linguistic analysis in a local and incremental way (*Chunk-and-Pass* processing). Languages that are harder to recode — for instance, because they suboptimally mark morpheme or word boundaries at the perceptual level, thus making word segmentation harder — impede the chunking and passing mechanisms, with possible cascading effects accumulating up through higher levels of linguistic representation. For example, delays at the word segmentation level may hold up detecting multiword combinations, which in turn might hamper phrase and sentence level processing, potentially resulting in partial failures of comprehension.

Second, the reviewed evidence suggests that challenges associated with the early acquisition process may be linked to idiosyncratic ways in which speakers use the language in adulthood. This may entail that dealing with difficult aspects of a language in the early stages of acquisition may force the language learner to adopt long-term language-specific compensatory cognitive solutions: for instance, learning to put more weight on top-down pragmatic and contextual cues, as it may be the case for Danish. The Danish data does not seem to speak in favor of a language-internal *structural* compensation: that is, different aspects of the language system do not seem to compensate for each other, such as morpho-syntax compensating for phonological ambiguities. Instead, the Danish data seems to point to compensation strategies developed within the *processing system*, such as changes in the relative weighting of bottom-up and top-down information. That is, the language system of the learner may be radically changed in the interaction with the ambient language as it adjusts to it. For instance, Danish-learning children seem to adapt

very early on to the highly vocalic content of their ambient language by exhibiting a "vocalic bias" in learning (i.e., better recall of minimal pairs contrasting by vowels, e.g., /dyːˀl/–/ duːˀl/, than by consonants, e.g., /fan/–/san/), in contrast with the *consonantal bias* typically found in other European languages (Højen & Nazzi, 2016). Thus, the development of processing strategies may be contingent on language-specific properties, like the relative distribution of consonants and vowels (cf., Keidel, Jenison, Kluender, & Seidenberg, 2007), already at an early age and possibly persisting into adulthood. We argue that current theories of language learning do not necessarily predict this possibility explicitly. In many generativist theories, much of the weight is put on the hard-wired linguistic knowledge of the learner, with processing and learning constraints being innate and the role of the ambient language being confined to helping the learner discover language-specific constraints (e.g., Biberauer & Roberts, 2017; Berwick & Chomsky, 2008). In functional approaches, the main explanatory burden is put on the learning process itself, with the learner absorbing language patterns from the environment through domain-general processing mechanisms (e.g., categorization, chunking, statistical learning) and generalizing to new situations (e.g., Ambridge & Lieven, 2015; Tomasello, 2015). Theories of associative learning concerned with the contingency and salience of cues to form-function mappings (e.g., Ellis, 2008; MacWhinney, 2005) acknowledge more explicitly the role of language-related factors in shaping the learner's language system.

Lastly, we take the reviewed evidence to suggest that theories of language learning and use must allow for the fact that some languages may be intrinsically harder to process and learn than others — even when compared with genetically and typologically related

languages. We believe that this is the case for theoretical frameworks that consider different languages as unique products of cultural evolution that impose different degrees of constraints on processing and learning. For instance, functional approaches that consider language change as driven by the interaction of cultural, ecological, and cognitive factors (e.g., Christensen, Fusaroli, & Tylén, 2016; Christiansen, 2013; Evans & Levinson, 2009; Lupyan & Dale, 2010; Nölle, Staib, Fusaroli, & Tylén, 2018) fulfill this criterion by explicitly predicting the emergence of differences in processability and learnability over time. Because individual languages have different historical trajectories of cultural evolution (Dunn, Greenhill, Levinson, & Gray, 2011; Everett, 2016), some may, at least temporarily, end up in sub-optimal local usage-based minima. Danish speech may have evolved an increasingly opaque structure — contrary to the predictions of most theories of language evolution (e.g., Beckner et al., 2009; Kirby, 2007) — and may currently be moving toward a local minimum of processability. For instance, there is evidence that Danish vowels have been diachronically moving closer to each other in the F1-F2 vowel space, gradually minimizing contrasts between, for instance, the phonemically-distinctive vowel qualities [a] and [æ] (Basbøll, 2009b; Reinholt Petersen, 2008). However, it is an open empirical question whether Danish is indeed moving toward a local minimum, what could be driving the change, and whether it will move away from the minimum.

Conclusion

The conditions of language learning and use are often assumed to be the same across languages, but the case of Danish would seem to question this assumption. We have argued that the puzzling nature of Danish acquisition and use should inform discussions

about whether all languages are cut from the same *universal cloth* (e.g., Hornstein & Boeckx, 2009; Pinker, 1994), or whether even closely related languages are unique historical products of cultural evolution (e.g., Christiansen & Chater, 2008; Evans & Levinson, 2009). From a societal perspective, addressing the issues related to learning Danish has potential implications for (1) language pedagogy in daycare/school and L2 instruction, for instance, to improve the general reading instruction in Denmark, where the percentage of readers at the top proficiency level is lower than the OECD average (OECD, 2010); (2) the linguistic rehabilitation of brain-damaged patients or the development of strategies for reading instruction for children with dyslexia, two cases that may be particularly affected by the indistinctness of Danish speech (e.g., Elbro, Borstrøm, & Petersen, 1998). Unfortunately, the current empirical evidence is still sparse and unsystematic. Research on the impact of the long sequences of voiced segments and the pervasive segment/syllable reduction on speech processing is required to provide a more nuanced understanding of the intrinsic processability of Danish speech. Moreover, empirical studies are needed to explicitly test the hypothesis that the structuring of the language system in early childhood in order to compensate for the opacity of the ambient language carries over into adulthood and determines how the language is used by adult speakers. Fully understanding the puzzle of Danish will require a cross-linguistic and cross-disciplinary effort to empirically tackle these remaining questions. We hope that this review will spark new empirical research into the relationship between learner-related and language-specific factors in language learning and processing, not only in Danish but also in other, equally exciting languages.

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Table 1. Overview of the reviewed studies (in the order in which they appear in the text).

Study	Age group (y;m)	n	Method	Linguistic focus	Main finding
Bacquin & Zola Christensen (2013)	adults	446	Comprehension (self-reported)	Cross-linguistic intelligibility in Scandinavia	Better performance for Danish speakers on comprehension of Swedish than vice versa
Gooskens et al. (2010)	adults	42	Spoken sentence comprehension test	Cross-linguistic intelligibility in Scandinavia	Better performance for Danish speakers on recognition on Swedish cognate words than vice versa
Blom, Ejstrup, & Hopman (2016)	adults	9015	Spoken sentence comprehension test	Comprehension of phonetically reduced linguistic units	Impaired comprehension of phonetically reduced words in semantically ambiguous, syntactically complex, and abstract sentences

Pharao, Malmstedt, & Veng (2017)	adults	32	Lexical decision task	Recognition of phonetically reduced words	Lower accuracy and longer reaction times in the recognition of segmentally reduced words presented in isolation
Kjærbæk et al. (2015)	children (0;9-2;5)	2	Longitudinal corpus analysis (CHILDES)	Receptive/productive vocabulary	Delayed acquisition for Danish words with ambiguous syllabic counts (resulting from strings of vocoids)
Trecca, McCauley, et al. (2019)	adults	186	Artificial language learning paradigm	Word segmentation	Possible negative effect of weak syllable sonority markers on word segmentation
Hilton, Schüppert, & Gooskens (2011)	adults	64*	Phonetic analyses of read-aloud speech data	Phonetic reduction in fluent speech	Higher omission of canonic syllables in Danish vs. Norwegian and Swedish
Schüppert, Hilton, Gooskens, & van Heuven (2012)	adults	19*	Phonetic analyses of read-aloud speech data	Phonetic reduction in fluent speech	Higher omission of canonic syllables in Danish vs. Norwegian and Swedish

Clausen & Fox-Boyer (2017)	children (2;6-4;11)	443	Picture-naming test	Phonological development	Faster acquisition of phones and clusters and faster resolution of phonological processes for Danish children
Bleses (1998)	children (3;11-8;4)	358	Picture elicitation task	Inflectional morphology	Lower performance on past tense for Danish vs. Norwegian and Icelandic
Bleses, Basbøll, and Vach (2011)	children (3;11-8;4)	445	Secondary analysis / Corpus analysis	Inflectional morphology	Lower performance on past tense for Danish vs. Swedish; Lower "segmentability" of past-tense suffixes in Danish vs. Norwegian, Icelandic, and Swedish
Bleses et al. (2008a, 2008b)	children (0;8-3;2)	19,848	MB-CDI parental report	Receptive/productive vocabulary	Slower acquisition of receptive and productive vocabulary, slower vocabulary spurt, lower median phrase comprehension, delayed

					imitation and labeling for Danish (vs. other western languages)
Bleses, Basbøll, Lum, & Vach (2011)	children (0;8-3;2)	19,848	MB-CDI parental report / Secondary analysis	Receptive vocabulary	Negative correlation between vocoid-contoid ratio and rate of vocabulary acquisition
Trecca et al. (2020)	children (1;10-2;1)	22	Looking-While-Listening	On-line language processing	Lower proportion of gazes to pictures named in highly vocalic sentences
Trecca et al. (2018)	children (2;0-2;11)	36	Looking-While-Listening	On-line language processing	Worse performance on retention of novel object names learned in highly vocalic sentences
Bohn (2013)	parent-child dyads	51*	Phonetic analyses of spontaneous speech data	Child-directed speech	No hyperarticulation and no slower speech rate in Danish child-directed speech
Dideriksen (2016)	parent-child dyads	5*	Phonetic analyses of spontaneous speech data	Child-directed speech	No hyperarticulation in Danish child-directed speech

Dideriksen & Fusaroli (2018)	parent-child dyads	23*	Phonetic analyses of spontaneous speech data	Child-directed speech	No hyperarticulation in Danish child-directed speech
Ishkhanyan et al. (2019)	adults	66	Categorical perception (discrimination)	Categorical perception of phonetic contrasts	Increased reliance on pragmatic-contextual information processing minimal-pair phonetic contrasts for Danish vs. Norwegian
Trecca et al. (2019a, 2019b)	adults	320	Sentence comprehension task (mouse tracking)	Sentence comprehension	Increased reliance on pragmatic-contextual information in spoken sentence processing for Danish vs. Norwegian
Dideriksen, Fusaroli, Tylén, Johansson, & Christiansen (2019)	adult dyads	77*	Quantitative conversation analysis	Common ground in conversation (backchannel, repair, alignment)	Higher backchannelling and alignment and lower conversational repair for Danish vs. Norwegian
Stivers et al. (2009)	adults	n.a.	Acoustic analyses of conversation data	Turn taking	Longer inter-turn pauses for Danish vs. other major European

					languages and indigenous languages
Højen & Nazzi (2016)	children (1;7-1;9)	64	Interactive word-learning task	Phonological development	Better retention of vowel contrasts vs. consonant contrasts in nonce word learning in Danish

***** n of subjects or dyads that provided speech material for the analysis.

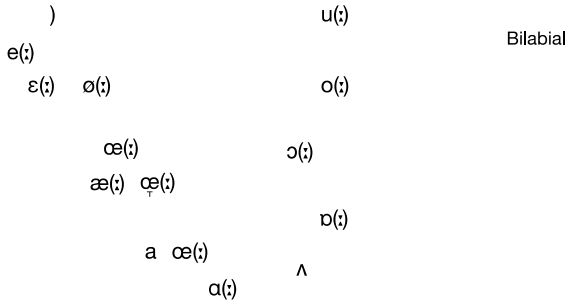

Figure 1. Danish full vowels (with length contrast :) (left) and Danish consonants (right). Reproduced from Grønnum (1998).

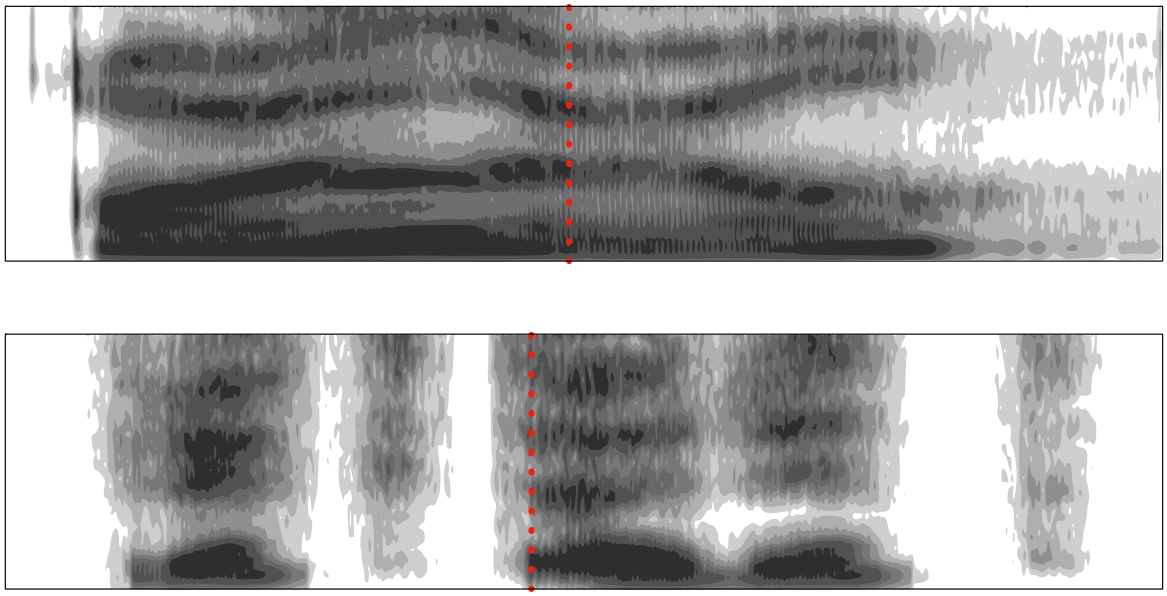

Figure 2. Spectrograms of the Danish and Norwegian cognates *røget ørred* (above) and *røkt ørret* (below) with red dotted lines indicating the approximate locations of word boundaries. Adapted from Trecca et al. (2018).

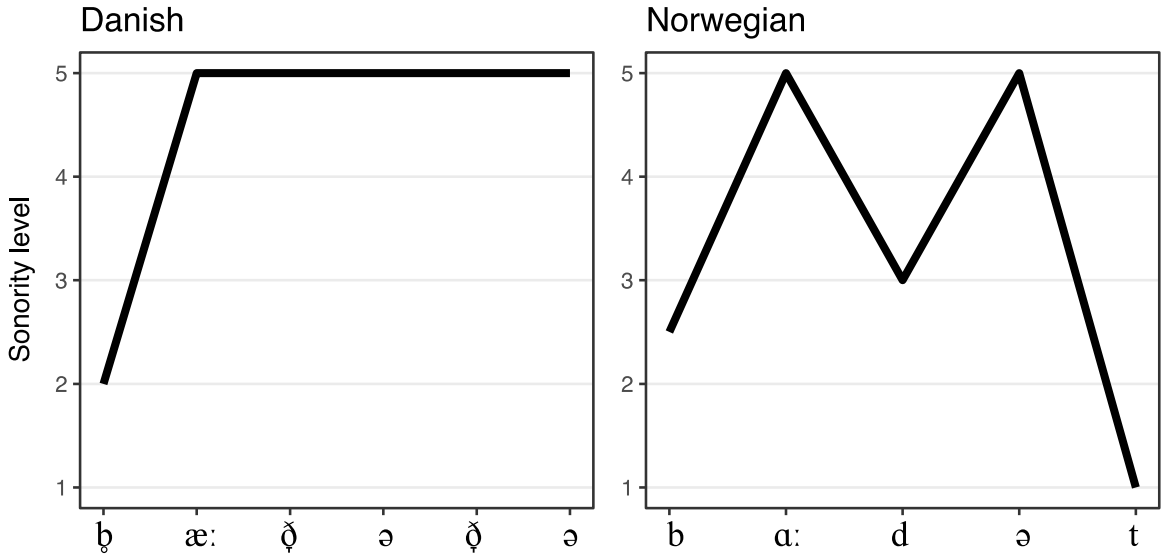

Figure 3. Stylized representation of segment sonority for the Danish *badede* (left) and the Norwegian *badet* (right). Adapted from Trecca, McCauley, et al. (2019).

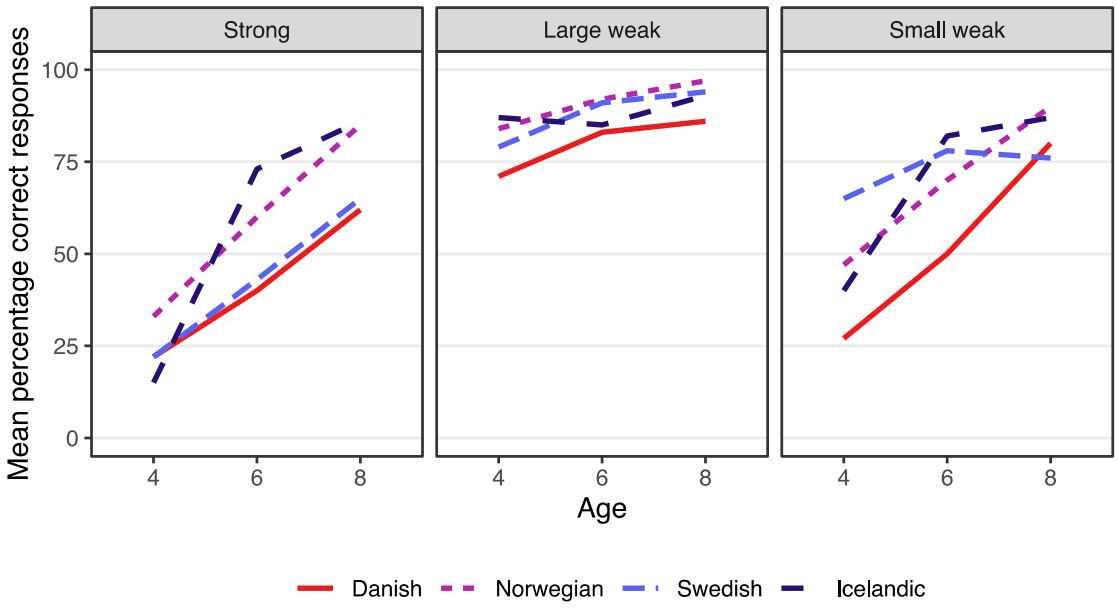

Figure 4. Mean percentage scores on a cross-linguistic picture elicitation task with past tense forms. The three columns refer to the irregular (strong class, e.g., *(at) ligge/lå*, Eng. (to) lie/lay) and regular (large weak class, e.g., *(at) bade/badede*, Eng. (to) bathe/bathed, and small weak class, *(at) råbe/råbte*, Eng. (to) shout/shouted) past tense classes. Adapted from Bleses, Basbøll, and Vach (2011).

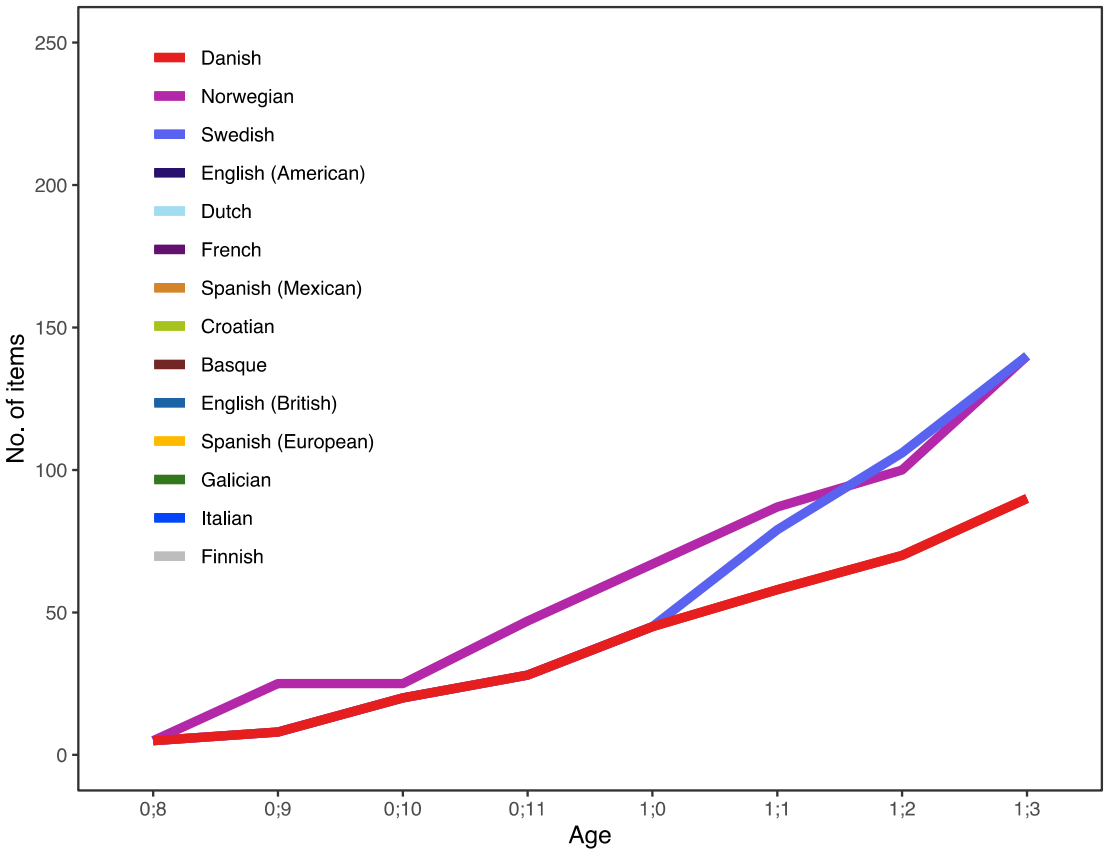

Figure 5. Cross-linguistic median vocabulary comprehension scores at 0;8 to 1;3 years in the *MB-CDI: W&G*. Adapted from Bleses et al. (2008a) with the addition of Norwegian data from Kristoffersen et al. (2012, 2013). Danish, Swedish, and Norwegian data are highlighted by thicker lines.

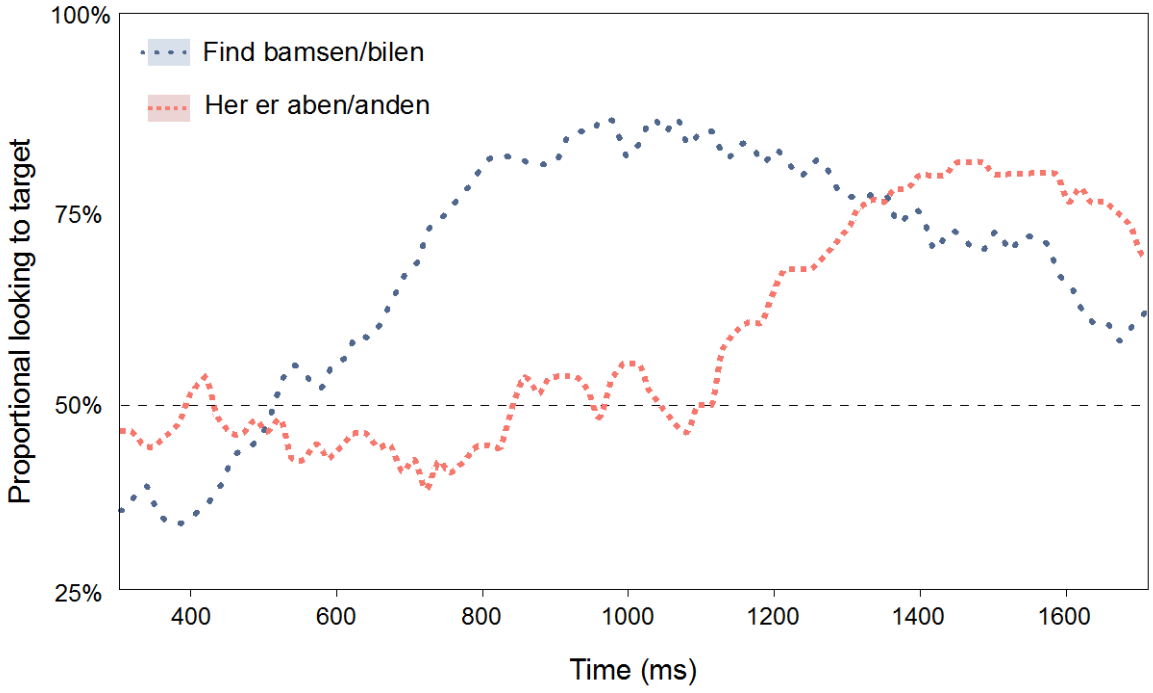

Figure 6. Processing time associated with sentences where contoids/consonants were on both sides of the carrier phrase/target word boundary (e.g., *Find bamsen* or *Find bilen*, blue/dotted line); and sentences where vocoids/vowels were on both sides of the carrier phrase/target word boundary (e.g., *Her er aben* or *Her er anden*, red/dashed line). Shaded areas represent the standard error of the mean. Adapted from Trecca et al. (2020).

Endnotes

[1] Note that this review is confined to research on phonetics, speech perception, and speech processing in Danish-learning preschool children as well as adult speakers of Danish, thus not including children of school age. Whereas issues related to literacy, orthographic depth, and reading are important for a complete story of how Danish is learned across the lifespan (e.g., orthographic depth hinders Danish-speaking 10-13-year-olds' performance on a range of linguistic measures compared to Swedish children of the same age; van Daal & Waas, 2017), they add an extra layer of difficulty on top of the much more fundamentally complex nature of the Danish sound structure, which is the topic of this review article.

[2] It should be noted that the Danish [t^s] often lacks proper closure and can become similar to [s], making Danes necessarily more context-dependent in this particular instance.