Creteling 2022: The phonology of nasal-stop sequences
July 18-19: questions of representation
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0. This is a very specific topic. Why are nasal-stop sequences interesting enough to merit a class?
   - They bear on *questions of representation*: how do we tell when a sequence of two distinct sounds is a segment? How do we tell when it's a cluster?
   - They bear on *questions of computation*: what must the phonological grammar look like to account for generalizations that govern their distribution?

1. The representational status of nasal-stop sequences is not uniform across languages.
   - In some languages, like English, they are considered to be clusters, or combinations of two segments.
   - In other languages, they are considered to be single segments (or, prenasalized stops). Like affricates, they have two components, one occurring before the other.

(1) Sample stop inventory (Lua, Niger-Congo, Boyeldieu 1985)

	Labial	Alveolar	Palatal	"Posterior"
Voiceless	p	t	c	k
Voiced	b	d	ɟ	g
Glottal	ɓ	ɗ	ʄ	ʔ
Prenasalized	mb	nd	nɟ	ŋg
Nasal	m	n	ɲ	

2. How does the analyst (and the learner) know when a nasal-stop sequence is a segment? a cluster?
   - This question is complicated by the fact that there is no known language that contrasts prenasalized stops and nasal-stop clusters (though cf. Kim et al. 2022).
   - There have been some cases reported, but all I am aware of have alternative explanations.
     - In Sinhalese, there appears to be a contrast between segment [nd] and cluster [nːd] (Feinstein 1979).

(2) Sinhalese NCs (Feinstein 1979:271)

a.	kanːdə	kandu	hill, hills
b.	homːbə	hombu	chin, chins
c.	hændə	hændi	spoon, spoons
d.	konːdə	kondu	backbone, backbones
e.	ændə	ændi	fence, fences

     - However, Sinhalese contrasts singleton and geminate consonants, so we can explain the contrasts in (2) as contrasts in length.
     - Other cases that appear to have a difference between short vs. long nasal-stop sequences can be explained similarly (see Maddieson & Ladefoged 1993 on Fula).
   - Because of the lack of intra-language contrasts, comparisons between nasal-stop segments and clusters must be made across languages. This is not ideal, because the phonetic implementation of nasal-stop sequences varies across languages.

3. Authors have come up with different criteria. We'll discuss three and illustrate with examples.
   - Phonotactic arguments: some nasal-stop sequences pattern like segments, so they're segments.
   - Distributional arguments: the two parts of nasal-stop sequences co-occur far more frequently than we might expect, so perhaps the learner interprets them as a single unit.
   - Phonetic arguments: nasal-stop segments have different phonetic properties than nasal-stop clusters.

Phonotactic arguments

4. There are no universally agreed-upon phonotactic diagnostics for whether a given nasal-stop sequence is a segment or a cluster. Decision is up to the analyst.

5. When deciding whether a given nasal-stop sequence is a segment or a cluster, analysts who appeal to phonotactics use one of two methods (Herbert 1986:61).
   - Sonority: if nasal-stop sequences are the only sonority-violating clusters that a language allows, many analysts will treat them as segments.
   - Syllable structure: if treating nasal-stop sequences as segments allows for a simplification of the description of syllable structure, many analysts will treat them as segments.

6. Herbert (1986:63,75) dismisses these diagnostics as "unmotivated and ad-hoc" as well as "methodologically indefensible". Maybe so, maybe not. Let's see.

Nasal-stop sequences in Western Dani (Trans-New Guinea)

- In Western Dani (Barclay 2008), nasal-stop sequences occur in parallel to voiceless stops. Barclay analyzes them as single segments.

(3) Western Dani consonant inventory

	Bilabial	Alveolar	Velar	Lab. Velar
Prenasalized	mb	nd	ŋg	ŋgʷ
Voiceless	p	t	k	kʷ
Nasal	m	n		
Approximant	w	ɾ		

- What are the arguments that these nasal-stop sequences are segments, not clusters?
  a. Clusters typically aren't allowed, except in words like [mbeɾe] 'two' and [pʰɐːndɔ].
  b. Voiced stops aren't attested in isolation. Neither are velar or labialized velar nasals.
- In your opinion, how good are these arguments?

Nasal-stop sequences in Mbabaram (Pama-Nyungan)

- Dixon (1991) notes that the distributional properties of nasal-stop sequences are segment-like.
  - Possible initial segments/clusters: "any single consonant (except the rhotics, r and ɹ) or any homorganic nasal-stop cluster (mb, nd, n̪d̪, ɲɖ, ŋg, ŋgʷ)."

- Possible medial segments/clusters:
  - "any single consonant" (with possible accidental gaps),
  - "any homorganic nasal-stop cluster"
  - "l or r followed by any of b, g, d̪, ɖ; m, ŋ; mb, ŋg, n̪d̪ or w"
  - "y followed by b or g"
  - (other combinations attested 1-2x in the lexicon)
- Possible final segments/clusters: only "any single consonant (except the labialised ones: d^w, n^w, g^w), or the clusters rb, rg, yg, and ɻg, lg."

- Dixon (1991) notes that analyzing nasal-stop sequences as segments could simplify the phonotactics:

> "The likely set of consonant phonemes for Mbabaram is given in Table 2.1. Homorganic nasal stop clusters (mb, n̪d̪, nd, nd^w, ɲɖ, ŋg, $ŋg^w$) could be regarded as a further series of consonant phonemes. Since they are the only clusters that occur word-initially, such a treatment would simplify the phonotactics – we could then specify that all words begin either with the vowel a- or with a single consonant." (Dixon 1991:354)

- What do you think? Would you analyze the nasal-stop sequences as segments or clusters?

Nasal-stop sequences in Muyang (Afro-Asiatic)

- Smith & Gravina (2010) analyze nasal-stop sequences as segments; the inventory they assume is in (4). They claim that there is one vowel, its realization conditioned by context.

(4) Muyang consonant inventory (Smith & Gravina 2010:7)

		Labial	Coronal		Velar
			Alveolar	Laminal	
Stops	*voiceless*	p	t	ts	k
	voiced	b	d	dz	g
	prenas.	mb	nd	ndz, nts	ŋg
Fricatives	*voiceless*	f	ɬ	s	x
	voiced	v	ɮ	z	
Implosives		ɓ	ɗ		
Nasals		m	n		
Liquids			l, r		
Glides		w		j	

- Nasal-stop sequences pattern like segments in a few ways. First: most word-initial clusters are broken up by epenthesis (6), but nasal-stop sequences (and affricates) aren't (5).

(5) No epenthesis with nasal-stop sequences and affricates

	Segment(s)	3P IMP. REALIS	2P IMPERATIVE	Gloss
		CV.CV(C)...	CV(C)...	
a.	[mb]	[ta-mbat]	[mbat]	'turn'
b.	[nd]	[tɪ-ndɛf]	[ndɛf]	'pierce'
c.	[ndz]	[ta-ndzəxaɗ]	[ndzəxaɗ]	'sit down'
d.	[ts]	[ta-tsax]	[tsax]	'draw water'

(6) Epenthesis with most other clusters

	Segment(s)	3P IMP. REALIS CVC.CV(C)	2P IMPERATIVE CV(C)...	Gloss
a.	[l], [b]	[ta-lbaj]	[ləbaj] (*[lbaj])	‘look for’
b.	[z], [g]	[ta-zgad]	[zəgad] (*[zgad])	‘knock over’
c.	[f], [k]	[ta-fkaɗ	[fəkaɗ] (*[fkaɗ])	‘put down one’
d.	[m], [ndz]	[ta-mndzaj]	[məndzaj] (*[mndzaj])	‘search along’

– The clusters in (6) are all falling-sonority. Rising-sonority clusters have optional epenthesis.

(7) Optional epenthesis in rising-sonority clusters
  a. /krV/ → [kra] ∼ [kəra] ‘dog’
  b. /plVɗ/ → [plaɗ] ∼ [pəlaɗ] ‘flat rock’
  c. /swV/ → [swa] ∼ [suwa] ‘well’

– The facts are more complicated than this, though, because whether or not epenthesis occurs is to some extent influenced by the tonal pattern of the word (which I haven’t transcribed).

- In summary, epenthesis has to target some clusters and optionally targets others. What makes nasal-stop sequences and affricates different is that they’re never targeted for epenthesis.

- Another way that nasal-stop sequences pattern like segments: partial reduplication. The final syllable onset and an epenthetic vowel are infixed immediately preceding the final syllable.

(8) Noun pluralization through infixing reduplication (Smith & Gravina 2010:75-6)

	C(s)	Singular	Plural	Gloss
a.	[j]	[mujaŋ]	[mu ji$_{\text{RED}}$ jiŋ]	‘Muyang’
b.	[d]	[adak]	[a də$_{\text{RED}}$ dak]	‘thorn’
c.	[kf]	[akfʊm]	[ak fʊ$_{\text{RED}}$ fʊm]	‘mouse’
d.	[dr]	[mədrəs]	[məd rə$_{\text{RED}}$ rəs]	‘pig’
e.	[mb]	[təmbak]	[tə mbə$_{\text{RED}}$ mbak]	‘sheep’
f.	[ŋg]	[alɔŋg^{w}o]	[alɔ ŋgʊ$_{\text{RED}}$ ŋgo]	‘donkey’
g.	[ts]	[xʊtsʊm]	[xʊ tsʊ$_{\text{RED}}$ tsʊm]	‘hyrax’

- Some nouns with modifiers pluralize through reduplication of the final syllable, and the behavior of nasal-stop sequences is consistent with (8).

(9) Noun pluralization through suffixing reduplication (Smith & Gravina 2010:77)

	Singular	Plural	Gloss
a.	batat	bata tat$_{\text{RED}}$	‘wide open’
b.	xabagarak	xabagarak rak$_{\text{RED}}$	‘with a flat surface’
c.	tsakɬaŋgaɗ	tsakɬaŋgaɗ ŋgaɗ$_{\text{RED}}$	‘semi-circular’

- Nasal-stop sequences behave like clusters, however, in conditioning variation in a preceding vowel.

  – There is a palatalization phenomenon that affects all segments within a word. The effect on an underlying initial vowel is that it is fronted to [e] or [ɛ].

- [e] and [ɛ] are in complementary distribution (10). (Focus on the initial vowels: medial vowels are supposed to behave similarly but that's less clear.) There are only a couple of exceptions.

(10) Palatalization allophony (Smith & Gravina 2010:59)

Vowel	Consonant(s)	Form	Gloss
[ɛ]	[mb]	[ɛmbeɬi]	'mucus'
	[nd]	[ɛndif]	'sweat'
	[dr]	[ɛdrɛm]	'horn'
	[st]	[ɛstɛnæ	'salt'
[e]	[m]	[emiɗ]	'beard'
	[w]	[ewi]	'tree (sp.)'
	[ɮ]	[eɮelik]	'snail'
	[z]	[eʒir]	'enemy'

- Do you think we should treat Muyang nasal-stop sequences as segments or clusters? (And why?)

7. Some of my thoughts on using phonotactic criteria to determine representational status:
   - Nasal-stop clusters aren't the only kinds of sequences that have odd distributional properties.
   - Another example: s-stop clusters in English and other languages. We'll focus on adult English (though see Barlow 2001 for some discussion of developmental and cross-linguistic data):
     - All triconsonantal onset clusters are s-stop initial (e.g. *spry*, *scrape*, etc.; **fpry*, *fcrape*, etc.)
     - s-stop clusters can be homorganic (e.g. *state*), which is otherwise dispreferred (e.g. **pw*).
     - s-stop clusters are the only sonority-violating onset clusters possible in English.
   - For nasal-stop sequences, two of these facts (sonority violation and exceptional patterning) are often enough to make an analyst call them segments. But English s-stop clusters are analyzed as clusters.
     - How people make sense of them: [s] in English can function as a sort of adjunct, which exists outside the syllable onset. See e.g. Kenstowicz 1994:258.
     - This doesn't get us all the way, though, as it doesn't explain further restrictions, e.g. *sb, *sd, *sg.
   - Not clear to me why the diagnostics used depend on the sequence type. But the division between nasal- and s-stop clusters speaks to the arbitrariness of the segment vs. cluster divide.
     - When a given cluster behaves phonotactically like a single segment, the analyst has two choices;
       (a) Complicate the analysis of the phonotactics.
       (b) Complicate the inventory.
     - Impression: for nasal-stop sequences the choice is usually (b). For s-stop sequences it's usually (a).
8. In the end, I'm really not sure what to make of phonotactic arguments for segmenthood. Part of me thinks they are useful, and part of me agrees with Herbert's (1986) criticisms.

Distributional arguments

9. Some authors have argued that segmenthood should be determined on distributional grounds: how likely are the two components of a nasal-stop sequence to co-occur?
10. Riehl (2008) proposes a criterion of inseparability (p. 16):

"If a particular phonetic entity does not occur independently but forms an indivisible unit with another sound in a predictable manner, then those sounds are understood to form a single phoneme."

11. This is a straightforward metric, but it's also pretty rigid, and can conflict with phonotactic reasoning.

- In Boumaa Fijian (Austronesian, Dixon 1988, inventory in (11)), most nasal-consonant sequences ([mb], [nd], [ŋg], [ndʒ]) are inseparable, in the sense that the language lacks voiced stops.

(11) Fijian consonant inventory (including nasal-stop sequences)

	labial	dental	post-alveolar	velar	glottal
nasal	m	n		ŋ	
stop	p	t		k	ʔ
prenas. stop	mb	nd		ŋg	
prenas. trill		nr			
fricative	f, β	s, ð			
affricate			tʃ, ndʒ		
liquid		l, r			
glide			j	w	

- However, both pieces of [nr] are independently attested, and Riehl's (2008) algorithm (which has more steps) would likely classify it as a cluster.
- I find this result strange. The only consonant sequences in the language are affricates and nasal-stop sequences. So following Riehl's logic, the only cluster would be [nr].
- In Mbay (Nilo-Saharan; Keegan 1996, 1997, inventory in (12)), all nasal-stop clusters are separable[1], so all would be treated as clusters.

(12) Mbay consonant inventory (Keegan 1997)[2]

	labial	alveolar	palatal	velar	glottal
stop	p, b, ɓ	t, d, ɗ	ɟ	k, g	
prenas. stop	mb	nd	nɟ	ŋg	
fricative		s			h
nasal	m	n	(ɲ)	(ŋ)	
liquid		l, r			
glide	w		j		

- This is at odds with the conclusions we might draw from the phonotactics of nasal-stop sequences.
  - Like single segments, and unlike other clusters, they can occur in word-initial position.
  - Evidence for this comes from loanword adaptation (13).

(13) Nasal-stop sequences vs. other clusters in Mbay (Keegan 1997)

a. ndà 'hit' kùndə́ 'millet drink'

b. pə̀lə́r̀ 'flower tree' (Fr. *fleur*) sèrbétè 'towel' (Fr. *serviette*)

12. In Gouskova & Stanton (2021), we explore the idea that Riehl was on the right track. Instead of treating inseparability as a categorical property, however, we treat it as gradient.

[1] Probably, anyway, if we count the nasals that are in parentheses...

[2] The palatal nasal [ɲ] only occurs in word-initial position when the following consonant is nasalized. It is in complementary distribution with [j] (Keegan 1997:1). I think [ŋ] is in parentheses because it only occurs word-finally (Keegan 1997:2).

13. We constructed a computational learner that decides whether a bisegmental sequence is a segment or a cluster, according to how likely the two consonants are to co-occur.

- It is easiest to demonstrate how the learner works by walking through a case study, here Fijian.
- The learner has access to a Fijian lexicon; ours is from the An Crúbadàn project (`crubadan.org`) and totals 17,600 words. (The lexicon provided is larger, but we cleaned it to exclude English words.)
- It also has access to a feature table, necessary for the learner to distinguish consonants and vowels.

Step 1: calculate inseparability for each consonant sequence (C_1C_2)

- To calculate this, the learner analyzes the lexicon for the following:
  - Probability of each C_1C_2 (number of C_1C_2 / total number of CCs).
  - Probability of each C_x (number of C_x / total number of C, in any environment).
- Inseparability takes into account the probability that both C_1 and C_2 occur in C_1C_2.
  - Forward inseparability is the probability of C_1 being in C_1C_2.

    (14) $Insep_{forward}\ (C_1C_2)$: $\frac{Prob(C_1C_2)}{Prob(C_1)}$
  - Backward inseparability is the probability of C_2 being in C_1C_2.

    (15) $Insep_{backward}\ (C_1C_2)$: $\frac{Prob(C_1C_2)}{Prob(C_2)}$
  - Bidirectional inseparability (or just inseparability) is the product of (14) and (15).

    (16) $Insep_{bidir}\ (C_1C_2) = Insep_{forward} * Insep_{backward}$
  - Why bidirectional inseparability? In some cases, one consonant has a restricted distribution but the other does not. The inseparability measure should reflect this.
- Bidirectional inseparability will be high when:
  - Numerators are high: consonants do not combine relatively freely; the language has few clusters.
  - Denominators are low: part of a sequence mostly or only occurs in that sequence (e.g. Fijian [mb]).
- Example: inseparability measures for Fijian C_1C_2 sequences.
  - Frequencies of individual phones are in (17).
  - Frequencies and inseparability measures for each C_1C_2 are in (18).

(17) Individual phone frequencies for Fijian (first iteration)

p	1137	b	2328	m	6339	f	394	β	8834	w	1202
t	8372	d	2512	n	7653	s	4871	ð	2467	r	4947
k	9824	g	1026	ŋ	2281	ʃ	1985	ʒ	320	l	6092
ʔ	14									j	1001
										total:	73,599

(18) Inseparability measures and CC counts for Fijian (first iteration)

sequence	inseparability	CC frequencies
ŋ g	30.91	1026
m b	25.23	2328
n d	22.55	2512
t ʃ	16.29	1985
d ʒ	8.75	320
n r	0.91	708
		total: 8,879

- The measure is pretty interpretable: /ŋg/ has the highest inseparability because /ŋ/ and /g/ are least likely to occur separately. /nr/ has the lowest inseparability because /n/ and /r/ occur independently.

Step 2: learner unifies eligible sequences into segments[3]

- Two criteria must be fulfilled for a sequence to be eligible for unification.
  - Cluster inseparability must be ≥ 1. (We chose this setting because it consistently leads to interpretable results. It could, however, be treated as a parameter of the model.)
  - Cluster frequency must be significantly different than zero. (This helps the learner remain robust in the face of residue like loanwords and errors. The test is a Fisher's Exact Test at α = .05.)
- After assembling a list of eligible sequences, the learner makes several sequenced changes to its inventory and representation of the learning data.

a. Learner modifies its inventory; adds new complex segments and their features.
   - For Fijian: learner adds [ŋg], [mb], [nd], [tʃ], [dʒ].

b. Learner modifies its lexicon by unifying eligible sequences from most to least inseparable.
   - Learner replaces [ŋ g] with [ŋg], then [m b] with [mb], and so on.
   - Possible for unification of one sequence to bleed unification of another. In Fijian, unification of [n d] bleeds unification of [d ʒ] in [n d ʒ], because [n d] has higher inseparability.

c. Learner checks that each segment included in its inventory is still present in the lexicon, and removes any absent segments from the inventory.
   - After unification of [ŋg], [mb], [nd], [tʃ]: [g], [b], [ʃ], and [d] are no longer attested.
   - Learner deletes these segments from its inventory.

Step 3: learner iterates the procedure

- First, the learner calculates frequencies (19) and inseparability measures (20).

(19) Individual phone frequencies for Fijian (second iteration)

p	1137	mb	2328	m	4011	f	394	β	8834	w	1202
t	8372	md	2512	n	5141	s	4871	ð	2467	r	4947
k	9824	ŋg	1026	ŋ	1255	tʃ	1985	ʒ	320	l	6092
ʔ	14									j	1001
											total: 65,748

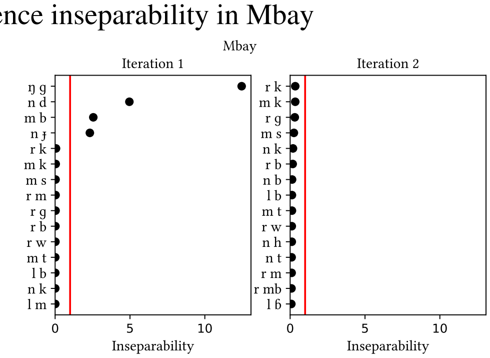
(20) Inseparability measures and CC counts for Fijian (second iteration)

sequence	inseparability	CC frequencies
nd ʒ	521.09	320
n r	80.62	708
		total: 1,028

- Second, the learner unifies eligible clusters.
  - [nd ʒ] and [n r] satisfy both criteria (both have inseparability measures over 1, and both have frequencies that are significantly different from 0), so both are eligible for unification.
  - In the lexicon, the learner replaces [nd ʒ] with [ndʒ], then [n r] with [nr].
  - Since [ʒ] is no longer attested in isolation, it is removed from the inventory.
- The learner continues to iterate until it finds no more eligible clusters to unify.
  - On a 3rd Fijian iteration, the learner finds no more clusters to unify.
  - The process terminates; the learner settles on the inventory from Iteration 2.
- Iteration is necessary for two reasons, both apparent in the Fijian simulation.
  - Some complex segments have more than two subparts (like Fijian [ndʒ]), so it is not possible for the learner to identify them on a first pass.
  - Complex segments sometimes contain phones that appear in more than one sequence (like [n] in Fijian [nd], [ndʒ], [nr]), so the inseparability of these sequences can be low at first.

14. We ran our learner on lexica from 25 languages (details on the project page, linked on our websites). In most cases, the learner finds the complex segments that are posited in grammatical descriptions.
    - Most cases are more interesting than Fijian. In Mbay, for example, the learner's task is more complex: all nasal-stop sequences are separable, and other clusters exist.
    - To run the learner on Mbay, we used a digitized version of Keegan's (1996) dictionary.
    - The learner performed two iterations, settling on the inventory proposed by Keegan (1997).
      - On the first iteration, the learner unifies all nasal-stop sequences.
      - On the second iteration, the inseparability of other sequences rises, but not enough to be unified (21).

(21) Sequence inseparability in Mbay



[3] We name this step "unification" as a nod to Herbert (1986); his proposal and ours are otherwise very different.

15. In other cases, the learner finds a set of complex segments not anticipated by grammatical descriptions. These often suggest that the learning procedure may need to be modified in some way.

   - The results for Quechua differ according to what type of data the learner is exposed to.
     - When the learner is trained on a corpus of words (from Gouskova & Gallagher 2020), it finds dozens of complex segments. We think this is likely not the right result.
     - When the learner is trained on a morpheme list (from Gouskova & Gallagher 2020), it finds only those complex segments that are recognized in grammatical descriptions ([tʃ'], [tʃʰ], [tʃ]).
   - In a few cases (like Sundanese), the learner finds a set of complex segments that is interpretable but not backed up by phonotactic argumentation or the literature. Not sure what to make of this!

16. This proposal may help explain existing observations, but also leaves open a number of questions.

   - A question: what level of transcription is appropriate to show the learner? Phonemic representations? Phonetic representations? If phonetic representations, broad or narrow transcription?
   - A promise: possible explanation for parallels in the composition of complex segments and clusters.
     - One parallel: languages disprefer [+nasal][-voice] sequences, whether segments or clusters (e.g. Hayes & Stivers 2000, Pater 1999, Riehl 2008).
     - Another parallel: languages prefer homorganic nasal-consonant sequences, whether these sequences are analyzed as segments or clusters. (I have only seen two heterorganic nasal-stop segments!)
     - The idea is that constraints on consonant sequencing hold for segments and clusters; segments are just sequences with specific distributional properties.
     - A fuller investigation into this idea may help answer a larger question (Herbert 1986, Steriade 1993, and others): why are only certain combinations of consonants attested as complex segments?

Phonetic arguments

17. There has been a long tradition of appealing to acoustic properties in an attempt to determine the segment vs. cluster status of a consonant sequence. One of these is overall duration.

   - An assumption that recurs (maybe due to Trubetzkoy 1939): in order for a nasal-stop sequence to be a segment, it must have a duration comparable to other single segments.

     > "A *prenasalized consonant* is formally defined as a necessarily homorganic sequence of nasal and non-nasal consonantal segments which together exhibit the approximate surface duration of 'simple' consonants in those language systems within which they function." (Herbert 1986:10)
     >
     > "...unary NC segments have duration equivalent to other comparable single segments in a language while NC clusters are substantially longer in duration than comparable single segments." (Riehl 2008:7)

   - This assumption is historically based on very little data.

     > "In terms of timing, the duration of prenasalized consonants is approximately the same as the duration of non-suspect unit consonants in many languages where they occur. This is not a particularly subtle point of observation and is easily verified by instrumental analysis. Unfortunately, not a great many instrumental studies of prenasalized consonants are available." (Herbert 1986:61)

   - Furthermore, throughout the literature, there is evidence that nasal-stop segments and nasal-stop clusters do not systematically differ in duration (though cf. Riehl 2008, Cohn & Riehl 2012).

– Maddieson & Ladefoged (1993) claim that there is no timing difference between nasal-stop segments and nasal-stop clusters.
– Hubbard (1995) shows that nasal-stop sequences analyzed as single segments in LuGanda, Runyambo, Sukuma are significantly longer than other single segments.
– In Javanese (Adisasmito-Smith 2004), nasal-stop sequences behave phonotactically like single segments, but are longer than other single segments.

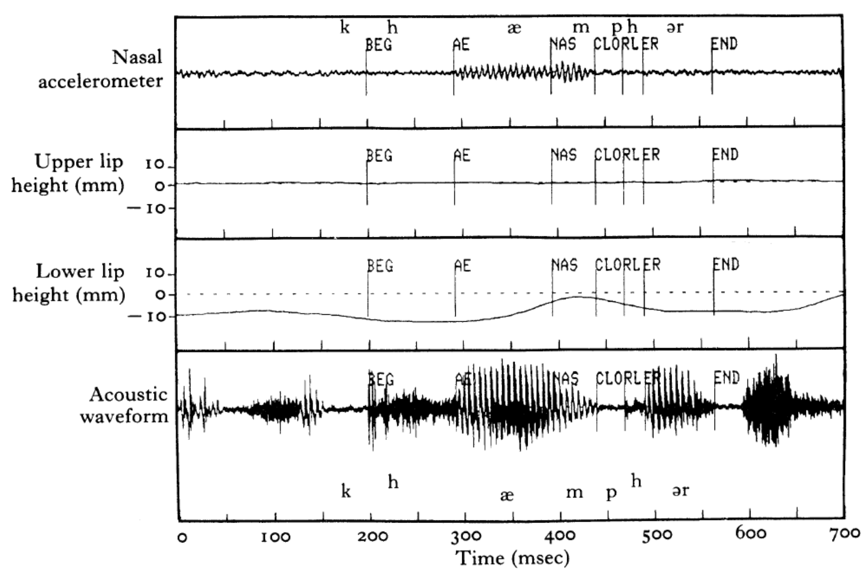
18. Other possible acoustic correlates to the segment vs. cluster divide have not been thoroughly investigated, probably because preliminary results are not promising.

- The duration of a preceding vowel, for example, has been identified as a possible way to differentiate nasal-stop segments and nasal-stop clusters.
- However, there isn't a clear connection. Vowels do not lengthen before Fijian nasal-stop segments, for example, but they do before Luganda nasal-stop segments (Maddieson & Ladefoged 1993).

19. Nasal-stop segments have not been shown to differ gesturally from nasal-stop clusters, though this potential difference has not been investigated systematically.

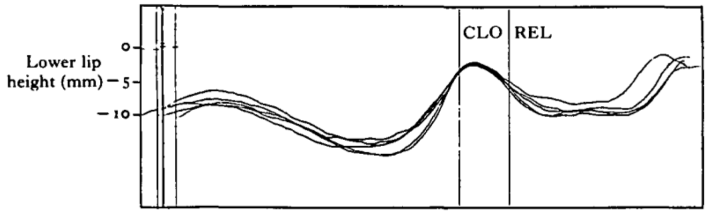
- Browman & Goldstein (1986) test two hypotheses about potential differences between nasal-stop segments and nasal-stop clusters.
  – Prenasalized stops might have one labial closure gesture and clusters might have two.
  – Clusters might have a longer labial gesture than segments.
- To test this, they collected articulatory data from an English speaker (with nasal-stop clusters) and a Chaga speaker (with voiced nasal-stop segments).
  – Participants had miniature infrared LEDs placed on their lips and chin, and the movement of these LEDs was tracked with a modified video camera.
  – An accelerometer, attached to the bridge of the nose, provided a gross measure of nasal airflow.
- The phonotactics of English and Chaga differ in crucial ways, so the stimuli differed too.
  – English words: capper, cammer, cabber, camper, camber.
  – Chaga words: /paka/ 'cat', /maka/ 'year', /mpaka/ 'boundary', /mbaka/ 'curse'.

(22) Waveform and articulatory measurements for *camper*



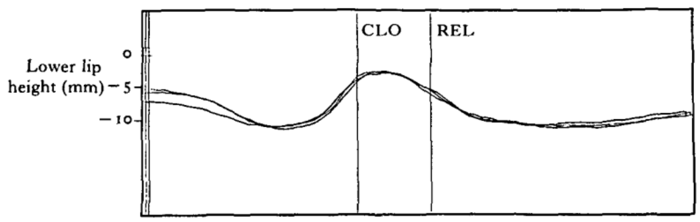
- For English, all labial segments and sequences had a single labial closure gesture.

(23) Comparison of lower lip trajectories for English words



- For Chaga, /mb/, /m/, and /p/ had a single labial closure gesture. (The cluster /mp/ patterns differently, but this isn't surprising; from Browman & Goldstein's description, I believe the nasal is syllabic.)

(24) Comparison of lower lip trajectories for Chaga words



- In both languages, regardless of the segment or sequence type, there is only one labial closure gesture.
- In English, the labial closure gesture of the clusters is not longer than that of the segments.

20. Recent work suggests it is possible to distinguish complex segments from clusters by investigating finer aspects of their articulatory coordination (Shaw et al. 2021).
    - Shaw et al. (2021) focus on labial-palatal sequences in Russian ([p^j], segments) and English ([pj], clusters) and show that they exhibit distinct patterns of articulatory coordination.
    - Their hypothesis, tested and verified experimentally: in complex segments, the second gesture is timed to the onset of the first gesture. In clusters, the second gesture is timed to the offset of the first gesture.
    - I think their metric would be difficult (maybe impossible?) to apply to nasal-stop sequences.
      - In Russian [p^j] and English [pj] segments, the two gestures are independent: it is possible for the palatal gesture begins before the labial gesture is finished.
      - I don't know how to investigate this possible difference in timing for nasal-stop sequences. Most are homorganic, and there's only one gesture: the velum raises.

21. It's not obvious to me how a study on nasal-stop sequences could follow Shaw et al. (2021), but the idea that segments and clusters might differ in aspects of their gestural organization isn't obviously wrong.
    - An idea from Byrd (1996): maybe "segments" are just collections of stably timed gestures.
    - How to apply her idea to nasal-stop sequences? Maybe, timing between the velum closure and the release of the oral constriction is more tightly coordinated in nasal-stop segments.

My thoughts

22. We've talked about a number of possible diagnostics that could help us form a hypothesis as to whether a given nasal-stop sequence is a segment or a cluster.

23. I doubt any of these is infallible. Phonotactic evidence can be hard to interpret. An inseparability metric does not always produce interpretable results, and even in some cases where it does, the results are at odds with the phonotactic evidence. There aren't established phonetic correlates (yet).

24. My suspicion is that, when the learner creates its inventory, it uses every segment vs. cluster diagnostic it can find and makes decisions that are based on the entire collection of evidence it has access to.

25. The analyst cannot do this yet because we don't know exactly what the learner pays attention to, or how it weights the various correlates it has access to.

Your thoughts?

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