To appear in *Phonology*

Constraints on contrast motivate nasal cluster dissimilation*

Juliet Stanton
New York University
June 2019

Abstract. Many languages exhibit nasal cluster dissimilation (NCD), in which an illicit sequence of co-occurring nasal-stop clusters is modified in some way (e.g. $NC_1VNC_2 \rightarrow N_1VNC_2$). This article discusses generalizations in the typology of NCD and claims that NCD is driven by constraints on contrast distinctiveness: it occurs preferentially in those environments where the first NC (NC_1, in NC_1VNC_2) is most confusable with a plain nasal consonant. I propose an analysis that appeals to auditory factors and provide acoustic and perceptual evidence that is consistent with it.

1 Introduction

In a number of languages, the distribution of nasal-stop sequences (NCs) is restricted. The focus of this article is on a class of effects termed nasal cluster dissimilation (NCD) by McConvell (1988), which together identify a cross-linguistic dispreference for the co-occurrence of NCs within a single word (so *ambada* and *abanda*, but **ambanda*). The two most common strategies to avoid such a configuration are deletion of the first NC's (NC_1's) oral component and deletion of the second NC's (NC_2's) nasal component; other strategies are discussed briefly in Section 6.1. In (1–2), italicized examples confirm that the alternations are conditional on the presence of multiple underlying NCs.

(1) Ngaju Dayak: deletion of NC_1's oral component (Blust 2012:372)

a.	/maN+bando/	→	[ma-mando]	'turn against'
	/maN+bagi/	→	*[mam-bagi]*	*'divide'*
b.	/maN+gundu/	→	[ma-ŋundul]	'wrap up'
	/maN+gila/	→	*[maŋ-gila]*	*'drive crazy'*

(2) Gurindji: deletion of NC_2's nasal component (McConvell 1988:138)[1]

a.	/kaɲɟu+mpal/	→	[kaɲɟu-pal]	'across below'
	/kajiɾa+mpal/	→	*[kajiɾa-mpal]*	*'across the north'*
b.	/kanka+mpa/	→	[kanka-pa]	'upstream'
	/kani+mpa/	→	*[kani-mpa]*	*'downstream'*

What kind of constraint drives NCD? Many analysts (e.g. Alderete 1997, Blust 2012) have argued that alternations like (1–2) are driven by a co-occurrence constraint that penalizes words containing more than one NC. Others (Jones 2000, to some extent Herbert 1986) argue that NCD is perceptually motivated: in NC_1VNC_2, NC_1 may be confusable with a nasal consonant, as its oral portion is preceded and followed by a nasal consonant, the latter of which likely induces some amount of anticipatory nasalization in the preceding vowel (so, $[NC_1\tilde{V}NC_2]$ is difficult to tell apart

* This article is a development on my dissertation's Chapter 4 and Stanton (2016a). For help getting it into its final form, I am grateful to Gillian Gallagher for advice and discussion, to Maddie Gilbert for assistance with the acoustic analysis in Section 3.2, and to three *Phonology* reviewers (Karthik Durvasula, Shigeto Kawahara, and one anonymous reviewer) and the editors for detailed and helpful feedback. The experiment in Section 4 is approved as NYU IRB-FY2018-2113.
[1] I use IPA transcriptions throughout the article; this means that the transcriptions in the cited sources are often adapted.

from [$N_1\tilde{V}NC_2$]). Repairs like (1–2), then, are motivated by a desire to avoid forms in which the contrast between NC_1 and a plain nasal consonant, N, is insufficiently distinct.

This article provides support for the claim that NCD is perceptually motivated. Sections 2–3 discuss several implicational generalizations that hold over the structures targeted by NCD, propose analyses that appeal to perceptual factors, and present two case studies supplemented with acoustic data. Section 4 presents results of a perceptual experiment that are largely consistent with assumptions of the analysis. Section 5 verifies a larger typological prediction of the analysis: if NCD does not reflect a dispreference for the co-occurrence of nasal clusters per se, but rather a dispreference for NCṼ, languages that exhibit NCD should ban NCṼ across the board (regardless of the source of the vowel's nasality) and languages that allow NCṼ should not exhibit NCD.

The results described in this article provide further support for the claim that constraints on the distribution of NCs are constraints on contrast (Stanton 2016b, 2018a), and by extension for the claim that constraints on contrast are a necessary component of the synchronic grammar (e.g. Flemming 2002, Gallagher 2010). Alternatives and broader implications for our understanding of the larger typology of dissimilatory processes are discussed in Section 6.

2 The right-hand context: generalizations and analysis

The next two sections present results of a typological survey consisting of 67 languages in which the distribution of NCs is restricted in the environment of Ns or other NCs.[2] These languages were identified from reference grammars and previous literature (e.g. Meeussen 1963, Herbert 1977, McConvell 1988); more details and references for each language are in the appendix. This section focuses on generalizations regarding the right-hand context (NC_2, in NC_1VNC_2) and proposes an analysis linking these generalizations to acoustic and perceptual factors: NCD is more likely when the post-NC_1 vowel is more nasalized.

2.1 Preconsonantal vs. prevocalic nasals

While the term "nasal cluster dissimilation" implies that the restriction holds only over co-occurring NCs, many languages that exhibit NCD also prohibit nasal-stop clusters from preceding onset nasals (also Herbert 1986, McConvell 1987, *a.o.*). The relationship between the two restrictions is implicational: almost all languages that ban NC_1VN_2V ban NC_1VNC_2, but the reverse does not hold. In (3–5), the surveyed languages are categorized according to the nature of the restrictions they impose. Decisions that led to these classifications were usually based on a combination of multiple sources; for more details see the appendix.

(3) Restrictions on NC_1VNC_2 and NC_1VN_2V
(21 languages, including Luganda; Herbert 1976)

a.	$*NC_1VNC_2$:	/n+bumba/	→ [mːumba], *[mbumba]	'I mould'
		cf. /n+bala/	→ [mbala], *[mːala]	'I count'
b.	$*NC_1VN_2V$:	/n+limi/	→ [nːimi], *[ndimi]	'tongues'
		cf. /n+lere/	→ [ndere], *[nːere]	'leather strips'

[2] I do not consider languages where bans on co-occurring Ns and/or NCs occur as part of a network of consonantal co-occurrence restrictions, as it is possible that more general considerations of identity or similarity avoidance are in play. For a representative example see Muna (van den Berg 1989, Coetzee & Pater 2008).

(4) Restriction on NC_1VNC_2 only
(43 languages, including Ngaju Dayak; Blust 2012)

a. $*NC_1VNC_2$: /maN+bando/ → [mamando], *[mambando] 'turn against'

b. NC_1VN_2V: /maN+deŋen/ → [mandeŋen], *[maneŋen] 'make deaf'

(5) Restriction on NC_1VN_2V only
(3 languages, including Bolia; Mamet 1960, gloss translations mine)

a. NC_1VNC_2: [lwáŋgá], pl. [ɲɟáŋgá], *[ɲáŋgá] 'thicket(s)'

b. $*NC_1VN_2V$: [loímo], pl. [ɲímo], *[ɲɟímo] 'honor(s)'

The languages in (5) – Bokote, Bolia, and Sango – are worthy of further discussion. The only basis for categorizing Bokote in this way is Meeussen's (1963:28) statement that evidence for NCD comes from "only a few cases of the type -boman-", and a footnote that lists five other relevant roots. There is no evidence of alternations and the cited dictionary (Hulstaert 1957) does not discuss restrictions on the distribution of NCs. Thus it is unclear what the strength of Meeussen's evidence is. In the case of Bolia, Mamet (1960:22) writes that the plural suffix is realized as [ɲɟ] before a vowel, but as [ɲ] "if the root has as its first consonant a singleton nasal" (translation mine). But the illustrative examples provided are consistent with an alternative analysis under which [ɲɟ] cannot precede [i].[3] Finally, it is unclear if Sango actually exhibits NCD. Meeussen's discussion provides one example ([imono] 'castor oil', cl. 12 [akavono]), but Samarin's (1967) grammar contains many words with co-occurring Ns and NCs (e.g. p. 35-6: [ngunzá] 'manioc leaves', [ndóndó] 'brain', [mbéní] 'some'). Treating these languages as "NC_1VN_2V only" is conservative, as it is quite possible that they do not exhibit NCD at all. These possible counterexamples aside, the generalization above is that a ban on NC_1VN_2V asymmetrically implies a ban on NC_1VNC_2.

2.2 Hypothesis and analysis

I hypothesize that the implicational generalization in (3-5) can be attributed to differences in the realization of the post-NC_1 vowel in NC_1VNC_2 vs. NC_1VN_2V. It has been documented for many languages that coda (or non-prevocalic) nasals induce more regressive nasal coarticulation than do onset (or prevocalic) nasals.[4] A survey of nasalization patterns by Jeong (2012) documents this pattern for French and Modern Greek; Krakow (1993) documents it for American English; Herbert (1977) documents it for a number of languages, including Pashto, Malagasy, and Delaware; and Schourup (1973:191) concludes, on the basis of a large survey, that "in no language examined are vowels nasalized before prevocalic nasals when they are not also nasalized before all pre-consonantal and word-final nasals." Thus in many languages, the first vowel in NC_1VNC_2 is likely more nasalized than the corresponding vowel in NC_1VN_2V.

This acoustic difference could lead to a difference in the relative perceptibility of the contrast between NC_1 and N (N–NC_1). Let us hypothesize that N–NC_1 is more confusable when NC_1 is followed by a nasalized vowel than when it is followed by an oral vowel. Furthermore, let us hypothesize that the greater the amount of nasalization, the more confusable N–NC_1 is. If this is

[3] A reviewer asks if there are comparable restrictions on [ɲɟi] sequences in other languages; I'm not aware of any. A reviewer further asks what the analysis of this case would be, if Mamet's description is in fact correct. Given that cases like Bolia cannot be derived by the analysis presented in Section 2.2, I would likely be forced to treat the Bolia pattern as an exception, driven by a language-specific markedness constraint.

[4] I use the term "coarticulatory nasalization" in this article to refer to all types of non-contrastive nasalization. The distinction between allophonic and true coarticulatory nasalization is not relevant here.

correct, two asymmetries should hold. First, the acoustic distance between N–NC$_1$ before an oral consonant (C$_2$, (6a)) should be greater than the acoustic distance between N–NC$_1$ before onset or coda N$_2$ (6b-c). Second, the acoustic distance between N–NC$_1$ before an onset nasal (6b) should be greater than the acoustic distance between N–NC$_1$ before a coda nasal (6c).

(6) Hypothesized perceptual asymmetries

	Comparison	Relative acoustic distance	
a.	Δ NC$_1$VC$_2$V–N$_1$VC$_2$V	Greater	
b.	Δ NC$_1$VN$_2$V–N$_1$VN$_2$V	Lesser	Greater
c.	Δ NC$_1$VNC$_2$V–N$_1$VNC$_2$V		Lesser

We can now derive the generalizations in (3–5) with constraints that penalize insufficiently distinct contrasts. The proposed analysis is framed in Dispersion Theory (Flemming 2002), as its MINDIST constraints allow the grammar to reference a contrast's perceptibility in different contexts. To capture the observed generalizations, I propose that NC must be followed by a sufficiently oral vowel for N–NC to be distinct, and I encode this requirement as a set of MINDIST constraints that penalize N–NC contrasts in which NC is followed by a vowel with increasing amounts of nasality.

To formalize these constraints, I assume that language learners divide vowels into a finite number of categories, according to the average amount of coarticulatory nasalization they exhibit. I refer to these categories as ORAL$_x$, where x is the category number. The referents of these category numbers are likely language-specific, as are patterns of coarticulatory nasalization (see Section 2.4 for more discussion on this point). For an analysis of the generalizations in (3–5), however, we only need to reference three categories: ORAL$_1$ (V/_N$_{coda}$), ORAL$_2$ (V/_N$_{onset}$), and ORAL$_3$ (V/_C).

(7) ORAL$_x$ values for analysis of (3-5)

ORAL$_x$ value	Referents	
1	V/_N$_{coda}$	(e.g. *am<u>a</u>nda*)
2	V/_N$_{onset}$	(e.g. *am<u>a</u>na*)
3	V/_C	(e.g. *am<u>a</u>da, amad<u>a</u>*)

Given three ORAL categories, we can formulate two constraints on the N–NC contrast: MINDIST N–NC: V-ORAL$_2$ and MINDIST N–NC: V-ORAL$_3$ (8–9).[5]

(8) MINDIST N–NC: V-ORAL$_2$:
Assign one violation for each contrast between N and NC in which the following vowel does not belong to category of 2 or higher along the ORAL scale.

(9) MINDIST N–NC: V-ORAL$_3$:
Assign one violation for each contrast between N and NC in which the following vowel does not belong to category 3 or higher along the ORAL scale.

Contrasts that satisfy and violate (8–9) are as follows. MINDIST N–NC: V-ORAL$_2$ is satisfied by contrasting pairs like *am<u>a</u>na-amb<u>a</u>na* (ORAL$_2$) and *am<u>a</u>da-amb<u>a</u>da* (ORAL$_3$), but violated by pairs

[5] The MINDIST constraints in (8–9) make the implicit assumption that only N–NC contrasts are affected by the amount of nasalization in a following vowel. I am not aware of evidence that any other consonantal contrasts are similarly affected.

like *amanda-ambanda* or *amanda-ambanta* (ORAL$_1$). MINDIST N–NC: V-ORAL$_3$ is satisfied by only *amada-ambada* (ORAL$_1$), and violated by any pairs with a nasal in second position (e.g. *amana-ambana*, ORAL$_2$). I assume that cross-linguistic differences in the righthand context for NCD reflect differences in the ranking of MINDIST constraints on the ORAL scale with respect to *MERGE (Padgett 2003), a constraint that penalizes neutralization.

(10) *MERGE (Padgett 2003):
No output word has multiple correspondents in the input.

The input-output mapping /amanda$_i$, ambanda$_j$/–[amanda$_i$, ambanda$_j$] satisfies *MERGE; the mapping /amanda$_i$, ambanda$_j$/–[amanda$_{i,j}$], with neutralization of N–NC, violates it. A factorial typology of (8-10) predicts three types of system. If *MERGE >> MINDIST N–NC: V-ORAL$_2$, MINDIST N–NC: V-ORAL$_3$, NCD will not occur. One language instantiating this ranking is English, where contrasting forms like *amanta-ambanta* are licit, even though *mb* is followed by a vowel whose ORAL category is 1 (11). I indicate ORAL values with numeric subscripts following the relevant segment, and correspondence indices with alphabetic subscripts.

(11) English: *MERGE undominated, no NCD

	/amanta/$_i$	/ambanta/$_j$	*MERGE	MD N–NC: V-ORAL$_2$	MD N–NC: V-ORAL$_3$
☞a.	[ama$_1$nta]$_i$	[amba$_1$nta]$_j$		*	*
b.	[ama$_1$nta]$_{i,j}$		*!		

In the second type of system, where *MERGE is ranked between MINDIST N–NC: V-ORAL$_2$ and MINDIST N–NC: V-ORAL$_3$, NCD occurs in only those contexts where N–NC is less perceptible. This is the case in Ngaju Dayak, for example, where N–NC is neutralized given a following coda nasal ((12a–b), though see Section 3 for a more detailed analysis of Ngaju Dayak NCD). In other contexts, N–NC is licit (12c–d).

(12) Ngaju Dayak: NCD only when N$_2$ is a coda (data simplified from (4))

	/mambando/$_i$	/mamando/$_j$	MD N–NC: V-ORAL$_2$	*MERGE	MD N–NC: V-ORAL$_3$
a.	[mama$_1$ndo]$_i$	[mamba$_1$ndo]$_j$	*!		*
☞b.	[mama$_1$ndo]$_{i,j}$			*	
	/maneŋen/$_i$	/mandeŋen/$_j$			
☞c.	[mane$_2$ŋen]$_i$	[mande$_2$ŋen]$_j$			*
d.	[mane$_2$ŋen]$_{i,j}$			*!	

Finally, systems where both MINDIST N–NC: V-ORAL$_x$ constraints dominate *MERGE are systems in which NCD occurs in all nasal contexts. Such a ranking characterizes languages like Luganda, where NCD occurs to repair any sequence in which NC is followed by onset or coda N (13).

(13) Luganda: NCD when N$_2$ is a coda or an onset (data simplified from (3))

	/mumba/$_i$	/mbumba/$_j$	MD N–NC: V-ORAL$_2$	MD N–NC: V-ORAL$_3$	*MERGE
a.	[mu$_1$mba]$_i$	[mbu$_1$mba]$_j$	*!	*	*
☞b.	[mu$_1$mba]$_{i,j}$				*
	/nimi/$_i$	/ndimi/$_j$			
☞c.	[ni$_2$mi]$_i$	[ndi$_2$mi]$_j$		*!	*
d.	[ni$_2$mi]$_{i,j}$				*

The constraints introduced in (8–10) cannot derive systems in which NCD occurs only preceding onset nasals, because MINDIST constraints are unable to penalize a more distinct contrast to the exclusion of a less distinct one. For example, there is no possible MINDIST N–NC: NC/_V-ORAL$_x$ constraint that can penalize (12c), [mane$_2$ŋen$_i$, mande$_2$ŋen$_j$] to the exclusion of (12a), [mama$_1$ndo$_i$, mamba$_1$ndo$_j$]. Given this, the implication that repair of NC$_1$VNC$_2$ implies repair of NC$_1$VN$_2$V is derived. More broadly, if two contexts (CONT$_1$ and CONT$_2$) differ in that some contrast *x–y* is better-cued in CONT$_1$ than it is in CONT$_2$, then the presence of *x–y* in CONT$_2$ (where it is less well-cued) asymmetrically implies its presence in CONT$_1$ (where it is better-cued) (see Steriade 1997).[6]

This analysis predicts that all languages with NCD should exhibit patterns of nasal coarticulation in line with the cross-linguistically common patterns described above. More specifically, it predicts that in languages that ban NC$_1$VNC$_2$ but not NC$_1$VN$_2$V, the intermediate vowel in NC$_1$VNC$_2$ is more nasalized than that of NC$_1$VN$_2$V. This larger point has not been established, and doing so would require large amounts of high-quality acoustic data from each language under consideration. Such data is not available at present.

2.3 Preconsonantal vs. word-final nasals

If the difference between the amounts of coarticulation induced by onset and coda nasals is responsible for the generalization expressed by (3–5), we might expect – all else being equal – that languages that allow NC$_1$VN$_2$V but ban NC$_1$VNC$_2$ should also ban NC$_1$VN$_2$ when N$_2$ is word-final. To test this prediction, I focused on the 10 surveyed languages that allow NC$_1$VN$_2$V, ban NC$_1$VNC$_2$, and permit word-final nasals. Of these, 6 ban NC$_1$VN$_2$ (14); 4 allow it (15).

(14) Restrictions on NC$_1$VNC$_2$ and NC$_1$VN$_2$, but not NC$_1$VN$_2$V
(6 languages, including Mudbura; McConvell 1988)
a. *NC$_1$VNC$_2$: /waɳʈa+ɳʈ+ɭa/ → [waɳʈa-ʈ-ɭa], *[waɳʈa-ɳʈ-ɭa] ‘he might/should get it’
b. *NC$_1$VN$_2$: /ja+nta+ɳ/ → [ja-na-ɳ], *[ja-nta-ɳ] ‘come here!’
c. NC$_1$VN$_2$: /ŋumpina/ → [ŋumpina], *[ŋumpita] ‘man’

(15) Restrictions on NC$_1$VNC$_2$, but not NC$_1$VN$_2$ or NC$_1$VN$_2$V
(4 languages, including Yindjibarndi; Wordick 1982)
a. *NC$_1$VNC$_2$: /munti+mpa/ → [munti-pa], *[munti-mpa] ‘really (topic.)’
b. NC$_1$VN$_2$: /kaŋkan/ → [kaŋkan], *[kaŋkat] ‘vee’
c. NC$_1$VN$_2$V: /kantu+ŋaɾa/ → [kantu-ŋaɾa], *[kantu-kaɾa] ‘low-lying cloud…’

[6] Note that this analysis also predicts that if we were to find a language that forbids NCs from preceding C, it should also forbid them from preceding N. Languages that ban NCs preceding C were not found in the survey.

There are independent factors in play for each of the languages in (15). In Yaunde, it is unclear what the scope of NCD is. Meeussen (p. 28) provides an example of NCD applying across an imperative suffix boundary (/lúmbu+ŋgu/ → [lúmu-ŋgu] 'bow, stoop'), but words like [ndàmbà] 'rubber (p. 48), [ndama] 'to be wide open (p. 45), and [mboŋ] 'palm flower' (p. 29) in Essono's (2000) grammar suggest that NCD is not fully general. The most straightforward interpretation of this discrepancy is that NCD only occurs across certain morphological boundaries; in this case it is not surprising that monomorphemic words like [mboŋ] exist. The situation in Gooniyandi (McGregor 1990) is similar. NCD occurs in forms suffixed by the ergative postposition [-ŋga] (/goːɳboː+ŋga/ → [goːɳboː-ga] 'by the woman', McGregor p. 98), but generally not within morphemes ([liɲbaɳɖi] 'a type of edible leaf') or across other morpheme boundaries.[7] It is possible to explain forms like [biɲbiɲ] 'crimson chat' (p. 61) by appealing to NCD's morphologically specific nature. In Yindjibarndi, the situation is somewhat different: NCD is general throughout the language but restricted to certain kinds of NC_1VNC_2 sequences (see Section 2.4). NCD occurs when NC_2 is labial (as in (8a)) or velar (/wuntu+ŋka/ → [wuntu-wa] 'river (loc.)', Wordick p. 33), but not otherwise (/kaŋkan+la/ → [kaŋkan-ta] 'in the fork', p. 35). All else being equal, we might expect NC_1VN_2 to be forbidden with labial or velar N_2, but permitted otherwise (as in (8b)). Yindjibarndi does not allow labial or velar nasals in word-final position (Wordick p. 13), so the second half of this prediction cannot be tested.

Finally, in Bilinara, NCD applies only when NC_2 is homorganic, with resulting deletion of N_2 (/ɲunu+ɲ+pa+ŋku+lu/ → [ɲunu-ɲ-pa-ku-lu], you-DAT-LINK-2s.o.-3p.s., McConvell 1988:152). In forms like [ŋumpin] 'man' (p. 149), the failure of [n] to denasalize (as in Gurindji [ŋumpit]) or delete (as in clusters) can be accounted for by adding several faithfulness constraints to the analysis proposed in Section 2.1.[8] First, NCD never results in denasalization, which is consistent with the claim that IO-IDENT[nasal] (16) dominates MINDIST N–NC: V-ORAL$_2$. Second, assuming that in a homorganic NC the place feature is shared between N and C, deletion of /ŋ/ from an input like /ɲunu+ɲ+pa+ŋku+lu/ does not result in the loss of the consonant's [dorsal] feature, because that place feature is still linked to the output [k]. By contrast, the /n/ of /ŋumpin/ has no following consonant to share its place feature with, so deletion of /n/ would result in the loss of its [coronal] feature as well. We can account for the failure of the final [n] in [ŋumpin] to delete by claiming that MAX[place] (17) also dominates MINDIST N–NC: V-ORAL$_2$.

(16) IO-IDENT[nasal]:
Assign one * for each input [αnasal] segment whose output correspondent is [-αnasal].

(17) MAX[place]:
Assign one * for each input place feature that lacks an output correspondent.

As shown in (18–19), the ranking IO-IDENT[nasal], MAX[place], MINDIST N–NC: V-ORAL$_2$ >> *MERGE predicts that NCD should occur in NC_1VNC_2 but not NC_1VN_2. To be concrete, I assume that deletion of N_2 violates MAX-SEG (= a * for each input segment without an output correspondent), but it would also be possible in (18) to view the loss of /ŋ/ as a consequence of

[7] In Gooniyandi, homorganic and non-homorganic NCs cannot co-occur within morphemes. This restriction is part of a larger ban on cluster co-occurrence, which also target stop-stop clusters, nasal-nasal clusters, and liquid-initial clusters. Patterns like Yaunde and Gooniyandi, where NCD only occurs given the presence of certain morphemes, could be analyzed by assuming that the constraints driving NCD are indexed to particular morphological classes (e.g. Pater 2009).
[8] It is an open question whether or not standard-issue Faithfulness constraints should coexist with *MERGE in Dispersion Theoretic analyses, but for expositional simplicity I assume this is possible.

fusion with /k/, which would violate UNIFORMITY (see Pater 1999). The identity of this faithfulness constraint is not crucial. (The ORAL$_x$ values in (18–19) are as assumed in Sec. 2.2. The tableaux below consider four-membered candidates so that *MERGE can be evaluated; the repair to insufficiently distinct N–NC$_1$ in Bilinara involves removal of the nasalization in the intervening vowel through neutralization of C-NC$_2$.)

(18) Bilinara: N$_2$ is deleted in NC$_1$VNC$_2$ (segments hosting the [velar] feature are underlined)

	/...ɲpa$\underline{\text{ŋk}}$u.../$_i$ /...ɲpa$\underline{\text{k}}$u.../$_k$	/...ɲa$\underline{\text{ŋk}}$u.../$_j$ /...ɲa$\underline{\text{k}}$u.../$_l$	IO-IDENT [nasal]	MAX [place]	MD N–NC: V-ORAL$_2$	*MERGE
a.	[...ɲpa$_1\underline{\text{ŋk}}$u...]$_i$ [...ɲpa$_3\underline{\text{k}}$u...]$_k$	[...ɲa$_1\underline{\text{ŋk}}$u...]$_j$ [...ɲa$_3\underline{\text{k}}$u...]$_l$			*!	
b.	[...ɲpa$_3\underline{\text{kk}}$u...]$_i$ [...ɲpa$_3\underline{\text{k}}$u...]$_k$	[...ɲa$_1\underline{\text{ŋk}}$u...]$_j$ [...ɲa$_3\underline{\text{k}}$u...]$_l$	*!			
☞ c.	[...ɲpa$_3\underline{\text{k}}$u...]$_{i,k}$	[...ɲa$_1\underline{\text{ŋk}}$u...]$_j$ [...ɲa$_3\underline{\text{k}}$u...]$_l$				*

(19) Bilinara: N$_2$ remains in NC$_1$VN$_2$ (segments hosting the [coronal] feature are underlined)

	/ŋumpi$\underline{\text{n}}$/$_i$ /ŋumpi/$_k$	/ŋumi$\underline{\text{n}}$/$_j$ /ŋupi$\underline{\text{n}}$/$_l$	IO-IDENT [nasal]	MAX [place]	MD N–NC: V-ORAL$_2$	*MERGE
☞ a.	[ŋumpi$_1\underline{\text{n}}$]$_i$ [ŋumpi$_3\underline{\text{t}}$]$_k$	[ŋumi$_1\underline{\text{n}}$]$_j$ [ŋupi$_1\underline{\text{n}}$]$_l$			*	
b.	[ŋumpi$_3\underline{\text{t}}$]$_i$ [ŋumpi$_3$]$_k$	[ŋumi$_1\underline{\text{n}}$]$_j$ [ŋupi$_1\underline{\text{n}}$]$_l$	*!			
c.	[ŋumpi$_3$]$_{i,k}$	[ŋumi$_1\underline{\text{n}}$]$_j$ [ŋupi$_1\underline{\text{n}}$]$_l$		*!		*

In sum, the data are consistent with an analysis where MINDIST constraints penalize NC$_1$VNC$_2$ and NC$_1$VN$_2$ equally. The four cases in which only NC$_1$VNC$_2$ is dispreferred are plausibly analyzed by reference to morphological factors or high-ranked faithfulness constraints.

2.4 Further asymmetries and evidence from Yindjibarndi

The hypothesis introduced above has the potential to help us understand further language-specific restrictions on NCD. In Mori Bawah, for example, NCD only occurs when NC$_2$ is voiceless (that is, when NC$_2$'s oral component is voiceless; (20)). In Yindjibarndi, NCD only occurs when NC$_2$ is [mp] or [ŋk] (21).[9] (Note that in (21a.i), the mapping from /ŋka/ to [wa] occurs due to an interaction between NCD and lenition: NCD maps /ŋka/ to /ka/, and lenition maps /ka/ to [wa]. Examples like /paʈu+kaɭaː/ → [paʈu-waɭaː] 'bird' demonstrate that this lenition process is fully general; see Wordick 1982:28.)

[9] NCD applies near-exceptionlessly both across and within morphemes in Yindjibarndi. The only apparent exception is [jantimpuɾwa], a proper name (Wordick 1982:35). The associate editor notes however that, given the data in (15) and (21), one could also characterize NCD as occurring only when NC$_2$ is within the same morpheme. It is impossible to distinguish the predictions of this alternative from the claim that NCD applies exceptionlessly, due to independent facts about Yindjibarndi phonotactics. NCD occurs only when NC$_2$ is [mp] or [ŋk], but /m/ and /ŋ/ cannot appear root-finally (Wordick 1982:13) and I am not aware of any affixes that end with these segments. This restriction makes it impossible to determine whether or not NCD requires a tautomorphemic NC$_2$, as all relevant NC$_2$s necessarily are.

(20) NCD in Mori Bawah (data from Blust 2012:369)

a. Applies when NC_2 is voiceless

i. /moN+soŋka/ → [mo-soŋka] 'arrange'

ii. /moN+tampele/ → [mo-tampele] 'hit, smack'

b. Does not apply when NC_2 is voiced

i. /moN+sombu/ → [mon-sombu] 'connect, join'

ii. /moN+tonda/ → [mon-tonda] 'follow'

(21) NCD in Yindjibarndi (data from Wordick 1982:33-35)

a. Applies when NC_2 is [mp] or [ŋk]

i. /wuntu+ŋka/ → [wuntu-wa] 'river (loc.)'

ii. /munti+mpa/ → [munti-pa] 'really (top.)'

b. Does not apply otherwise

i. /kaŋkan+la/ → [kaŋkan-ta] 'in the fork'

ii. /kaŋkan+kaɾa/ → [kaŋkan-kaɾa] 'forked'

The hypothesis above allows us to predict that vowels in Mori Bawah should be more nasalized preceding voiceless NCs than preceding onset Ns or voiced NCs, as is true for English (Cohn 1990, Beddor 2009). It also allows us to predict that vowels in Yindjibarndi should be more nasalized preceding [mp] and [ŋk] (or "peripheral" NCs, to use Australianist terminology) than preceding non-peripheral (coronal) NCs, heterorganic NCs, or onset nasals. Below I verify that the prediction regarding Yindjibarndi is correct, and leave further investigation of Mori Bawah to future work.

To quantify patterns of nasal coarticulation in Yindjibarndi, I selected 36 words from the UCLA Phonetics Archive where a primary-stressed initial /a/ is followed by an oral stop, an onset N, a peripheral NC, or a non-peripheral cluster. Each word was repeated several times, for a total of 100 tokens. Tokens are divided in (22) into four categories: those with a following oral stop (22a), an onset nasal (22b), a peripheral cluster (22c; subdivided into labial and velar), or a non-peripheral cluster (22d). These words are limited to those in which a nasal appears only post-stress; nasal-initial words like [m**a**n̪t̪u] were not considered to avoid potential confounding effects of perseveratory nasalization. All tokens are produced by a single male speaker.

(22) Yindjibarndi tokens by following context (vowel of interest bolded)

	Following context	Number	Examples
a.	Oral stop	21	[p**a**caɾi], [k**a**ɖaː]
b.	Onset nasal	34	[k**a**mu], [k**a**na]
c.	Peripheral cluster: Labial Peripheral cluster: Velar	9 3	[t̪**a**mbi], [c**a**mbu] [k**a**ŋkaj]
d.	Non-peripheral cluster	39	[c**a**nda], [p**a**ɳɳa]

The measure chosen to quantify acoustic nasality was compensated A1-P0, as measured by the Nasality Automeasure Script Package (Styler & Scarborough 2015; see Chen 1995, 1997 on A1-P0) for Praat (Boersma & Weenink 2017). A1-P0 is a measure of the amplitude of the first oral formant (A1) relative to the amplitude of a low-frequency nasal peak (P0). A1-P0 is "robust, well-studied, and well-correlated with nasality" and claimed to be "the best single-number measure of nasality currently available" (Styler & Scarborough 2015). The vowels considered here were limited to /a/ because A1-P0 is mostly useful for non-high vowels, and the only non-high vowel in Yindjibarndi is /a/. Measurements were taken at five equally-spaced timepoints throughout each vowel. Timepoints 1 and 5 were offset 5 ms from the beginning and end of the vowel, to avoid influence from neighboring consonants. Of 500 possible measurements, the script took 496.[10]

Results are in Figure 1 (plots in this article were created with R's ggplot2 package, Wickham 2009). The *y* axis reflects the average compensated A1-P0; lower A1-P0 measures are correlated with more nasalization. The contexts classified as "peripheral" are in black, and others are in gray; in the legend for "Following context", the top-to-bottom order of the five contexts reflects the relative A1-P0 at Timepoint 5, from highest to lowest. The exact A1-P0 values are not important here; what matters are the relative differences in A1-P0 between conditions at each timepoint.

Figure 1: Compensated A1-P0 in Yindjibarndi vowels by following context

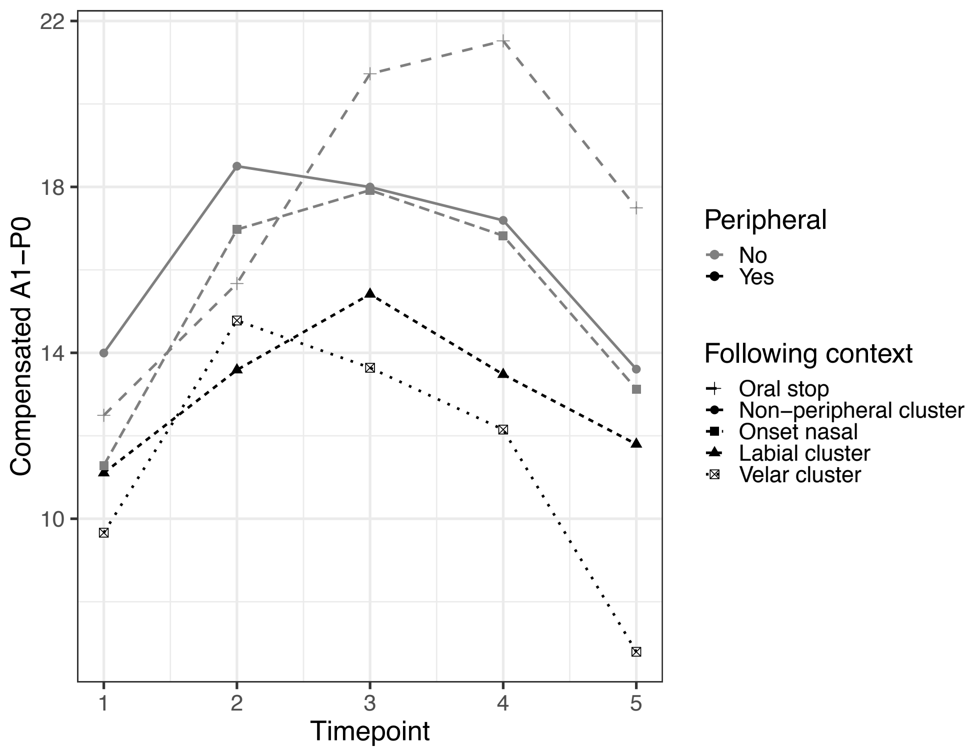


Figure 1 shows that the average A1-P0 of the vowels preceding peripheral NCs is lower at each timepoint than is the average A1-P0 of the other vowels. To determine if this difference between contexts was meaningful, a mixed effects linear regression was fit to the data. The dependent variable was compensated A1-P0; fixed effects included sum-coded predictors for the type of following context (with a comparison between peripheral NCs and the grand mean) and the timepoint (with comparisons between Timepoints 2-5 and the grand mean). A random intercept for token was also included.[11]

[10] The four failed measurements returned a "Crash-PulseBegin" error message, indicating that Praat was not able to generate needed values. (These four were [p**a**ɲi], [k**a**maji], [k**a**ɳt̪aɻa], and [p**a**caɾi] at Timepoint 1.)

[11] A series of likelihood ratio tests indicate that (i) a model including Peripheral is a better fit to the data than one that does not (χ^2 (1) = 7.54, $p < .01$), (ii) a model including Timepoint is a better fit than one that does not (χ^2 (1) = 95.42, $p < .001$), and (iii) including an interaction between Peripheral and Timepoint does not improve fit (χ^2 (1) = 2.11, $p > .1$).

(23) Results of statistical analysis for Yindjibarndi nasalization

	Factor	Coefficient	*t* value	Significant?
a.	Intercept	16.10	–	–
b.	Peripheral: Yes	-3.44	-2.84	Yes ($p < .01$)
c.	Timepoint: 2	4.42	6.52	Yes ($p < .001$)
d.	Timepoint: 3	5.67	8.36	Yes ($p < .01$)
e.	Timepoint: 4	5.00	7.37	Yes ($p < .001$)
f.	Timepoint: 5	1.41	2.07	Yes ($p < .001$)

Effects in (23c-f) indicate that A1-P0 is influenced by Timepoint; this is unsurprising given the variation in Figure 1. The result of interest is the effect of Peripheral (23b): the negative coefficient indicates that vowels followed by a peripheral NC are associated with lower A1-P0 values than average. Assuming that this speaker is representative of the larger population, these results are consistent with the hypothesis that NCD tracks acoustics of nasalization. In Yindjibarndi, the context in which NCD occurs is the context in which the post-NC_1 vowel would be most nasalized.

We can analyze the pattern in Yindjibarndi as follows. There is evidence for two ORAL$_x$ categories: one for vowels that precede a peripheral NC (ORAL$_1$), and one for vowels preceding another segment or sequence type (ORAL$_2$). By ranking MINDIST N–NC: V-ORAL$_2$ above *MERGE, we can derive the generalization that NCD occurs before peripheral NCs in Yindjibarndi (24a-b) but not elsewhere (24c-d). (The tableau below again considers four-membered candidates so that *MERGE can be evaluated; as in Bilinara, NCD here involves neutralization of the C-NC_2 contrast.)

(24) Yindjibarndi: NCD when NC_2 is peripheral (V = ORAL$_1$)

			MD N–NC: V-ORAL$_2$	*MERGE
	/muntimpa/$_i$ /muntipa/$_k$	/munimpa/$_j$ /munipa/$_l$		
a.	[munti$_1$mpa]$_i$ [munti$_2$pa]$_k$	[muni$_1$mpa]$_j$ [muni$_2$pa]$_l$	*!	
☞b.	[munti$_2$pa]$_{i,k}$	[muni$_1$mpa]$_j$ [muni$_2$pa]$_l$		*
	/kaŋkanta/$_i$ /kaŋkata/$_k$	/kaɲanta/$_j$ /kaɲata]$_l$		
☞c.	[kaŋka$_2$nta]$_i$ [kaŋka$_2$ta]$_k$	[kaɲa$_2$nta]$_j$ [kaɲa$_2$ta]$_l$		
d.	[kaŋka$_2$ta]$_{i,j}$	[kaɲa$_2$nta]$_j$ [kaɲa$_2$ta]$_l$		*!

What is necessary to confirm now is that perception of an N–NC contrast is influenced by the amount of nasalization in the following V, as measured in this way. For this see Section 4.

3 The left-hand context: generalizations and analysis

The identity of the right-hand context plays a role in determining whether or not NCD applies, but the identity of the left-hand context (NC_1, in NC_1VNC_2) can matter as well. I discuss the roles of stop voicing (Section 3.1) and place of articulation (Section 3.2), and propose an analysis under which the resulting generalizations are also linked to acoustic and perceptual factors: NCD becomes more likely as the salience of NC_1's oral release decreases (Section 3.3).

3.1 Stop voicing

A consistent generalization throughout the typology of NCD is that it rarely targets NC_1VNC_2 when NC_1 is voiceless. In fact, the only language surveyed that exhibits NCD with voiceless NC_1 is Mori Bawah (for illustrative data see (20)). (While NCs in languages like Gurindji and Yindjibarndi are often transcribed with graphemes indicating voicelessness, like <p> or <k>, voicing in these languages is non-contrastive and post-N stops are generally voiced.)

Why does NCD prefer to target voiced NC_1? Herbert (1977:365) attributes the asymmetry to the observation that "in a post-nasal environment, the voiced stops evidence the most reduction and are therefore the most susceptible to nasalization…voiceless stops and fricatives are more distinctive in this environment." Building on this observation, I hypothesize that the relevant factor here has to do with the salience of the release: the longer the release of NC_1, the less likely NCD is to occur. The idea is that a longer oral release in NC enhances the internal cues to the N–NC contrast (see Steriade 1997 on internal vs. external cues), and renders it less dependent on its external cues, like the identity of the following vowel. For experimental evidence that the duration of NC's oral component leads to increasingly accurate identification rates, see Beddor & Onsuwan (2003); for experimental evidence consistent with the present hypothesis see Section 4.

If this hypothesis is correct, the release phase of voiceless NCs must be longer than the release phase of voiced NCs in all languages where NCD targets voiced but not voiceless NCs. While this hypothesis has not been verified for all surveyed languages, the asymmetry has been documented generally (Maddieson & Ladefoged 1993 for Sukuma; Ladefoged & Maddieson 1996 for Bura; Riehl 2008 for Tamambo, Manado Malay, and Pamona; Coetzee & Pretorius 2010 for Tswana; Beguš & Nazarov 2017 for Tarma Quechua; Cho & Ladefoged 1999 on the more general asymmetry in release salience between voiced and voiceless stops; *a.o.*).

The prediction of the analysis investigated here is that if NCD occurs to avoid relatively more distinct $N–NC_1$ contrasts, it should also occur to avoid less distinct $N–NC_1$ contrasts. Therefore, if a language exhibits NCD when NC_1 is voiceless (and more easily distinguished from N), it should exhibit NCD when NC_1 is voiced (and less easily distinguished from N). As noted above, the only language in which NCD applies when NC_1 is voiceless is Mori Bawah, and in this language there are independent reasons why the prediction cannot be tested. NCD is attested most readily in Mori Bawah in forms prefixed with /moN-/, but the nasal of this prefix only surfaces when the root begins with a voiceless stop (25).[12]

(25) Effects of /moN-/ prefixation in Mori Bawah (data from Blust 2012:368)

a. Stem begins with a voiceless stop: nasal place-assimilates
   - i. /moN+paho/ → [mom-paho] 'plant'
   - ii. /moN+tunu/ → [mon-tunu] 'roast, grill'

b. Stem begins with any other segment: nasal deletes
   - i. /moN+basa/ → [mo-basa] 'read'
   - ii. /moN+dagai/ → [mo-dagai] 'guard'
   - iii. /moN+maru/ → [mo-maru] 'climb'
   - iv. /moN+lulu/ → [mo-lulu] 'chase'
   - v. /moN+aha/ → [mo-ʔaha] 'whet, sharpen'

[12] Note that Mori Bawah counterexmplifies Pater's 1999 claim that voiceless NCs are marked relative to voiced NCs.

In this context NCD is only observable when NC$_1$ is voiceless, as voiced NC$_1$ cannot be created across a morpheme boundary (2b). This means that we cannot verify the prediction that NCD with voiceless NC$_1$ implies NCD with voiced NC$_1$, as the only language where NCD occurs with voiceless NC$_1$ independently prohibits voiced NC$_1$ in the relevant position.

3.2 Place of articulation and evidence from Ngaju Dayak

If NCD is influenced by the duration of NC$_1$'s oral release, factors that influence release duration should influence NCD. One such factor is place of articulation, which is known to underlie variations in voice onset time (VOT). For example: Cho & Ladefoged (1999) find that stop VOT tends to increase as the closure moves further back into the vocal tract, though there is variation across languages (their p. 219). Given this, it is impossible to make universal predictions regarding correlations between NCD and NC$_1$'s place of articulation, but we can predict that the two should correlate similarly with release duration: the longer NC$_1$'s release, the less likely NCD should be.

Cases of NCD that track NC$_1$'s place of articulation are uncommon; the only well-documented case I am aware of comes from Ngaju Dayak. Table 1 (adapted from Blust 2012:373, with data from Hardeland 1859) summarizes the rate of NCD according to NC$_1$'s place of articulation and whether or not NCD is expected. Across categories, the difference between the rates of NCD according to NC$_1$'s following context (NC vs. C) demonstrate that NCD is conditioned by the presence of a following NC. Within the class of forms where NCD is expected, it applies most frequently when NC$_1$ is labial, less so when NC$_1$ is velar or alveolar, and least when NC$_1$ is palatal.

Table 1: NCD in Ngaju Dayak

NCD expected?	NC$_1$ PoA	NCD applies?		
		Yes	No	Variable
Yes (NC$_1$VNC$_2$)	Bilabial (mb$_1$)	93% (63/67)	3% (2/67)	3% (2/67)
No (NC$_1$VC$_2$V)		6% (9/159)	94% (150/159)	–
Yes (NC$_1$VNC$_2$)	Alveolar (nd$_1$)	29% (2/7)	29% (2/7)	43% (3/7)
No (NC$_1$VC$_2$V)		4% (3/75)	96% (72/75)	–
Yes (NC$_1$VNC$_2$)	Palatal (ɲdʒ$_1$)	15% (2/13)	85% (11/13)	–
No (NC$_1$VC$_2$V)		–	100% (89/89)	–
Yes (NC$_1$VNC$_2$)	Velar (ŋg$_1$)	64% (16/25)	36% (9/25)	–
No (NC$_1$VC$_2$V)		9% (10/114)	91% (104/114)	–

To determine which place-based differences are meaningful, a logistic regression was fit (using R's glm function) to the forms in Table 1 in which NCD is expected to apply. The dependent variable was whether or not NCD applies; the independent variable was NC$_1$'s place of articulation. Variable cases were counted as NCD undergoers and non-undergoers. Pairwise differences in (26) were assessed with Tukey's HSD post-hoc tests, using the glht function of R's multcomp package (Hothorm et al. 2008). A positive coefficient means that the second member of the comparison is associated with a higher rate of NCD, while a negative coefficient means that the first is.

(26) Pairwise comparisons for Ngaju Dayak dictionary data

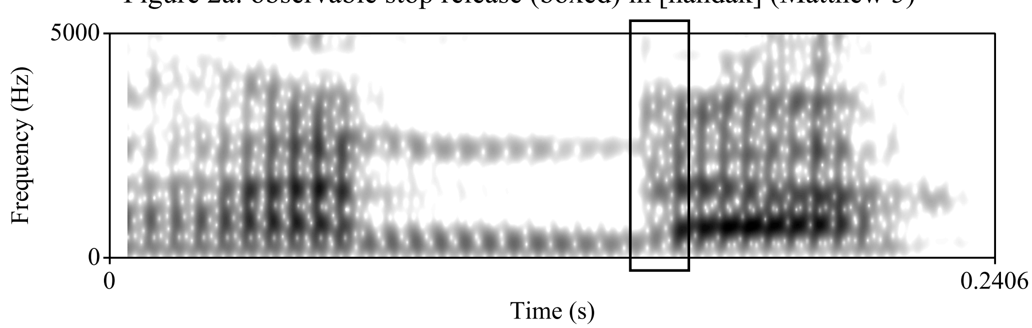
	Comparison	Coefficient	*z* value	Significant?
a.	Bilabial-Alveolar	0.44	3.75	Yes ($p < .01$)
b.	Bilabial-Palatal	0.79	7.48	Yes ($p < .001$)
c.	Bilabial-Velar	0.30	3.71	Yes ($p < .01$)
d.	Alveolar-Palatal	0.35	2.36	Trending ($p = .08$)
e.	Alveolar-Velar	-0.14	1.07	No ($p = .70$)
f.	Palatal-Velar	-0.49	4.08	Yes ($p < .001$)

The rate of application for [mb]$_1$ is lower than the rate of application for each of the other categories, and the rate of application for [ŋg]$_1$ (and likely [nd]$_1$) is lower than the rate of application for [ɲdʒ]$_1$. Taking into account the hypothesis of this section, and given these results, we can make predictions about the phonetics of Ngaju Dayak NCs: the average release duration of [mb] should be shorter than that of other categories, and the average release duration of [ŋg] (and likely [nd]) should be shorter than that of [ɲdʒ]. (The data do not allow us to make any predictions about the relationship between [nd] and [ŋg].)[13]

To test these predictions, data on the duration of oral NC releases was collected from recordings of the New Testament in Ngaju Dayak, available from Bible.is. 446 recordings of prevocalic [mb], [nd], [ɲdʒ], or [ŋg] were obtained from Matthew and John. For each cluster, the duration of the oral release was measured from the beginning of the stop burst until the onset of the vowel's periodic voicing. Speaker identity was not controlled for, though all speakers sounded male and spoke at similar rates. In 149/446 recordings there was no observable stop burst, but the available Ngaju recordings are not studio-quality and are often accompanied by background noise. Because of this, it is possible that the stop release was just obscured. Due to this complication, only the tokens with clear stop releases were measured. Spectrograms of two tokens (one with a clear and observable stop release, and one without) are in Figure 2.[14]

Figure 2: measuring oral stop releases in Ngaju Dayak

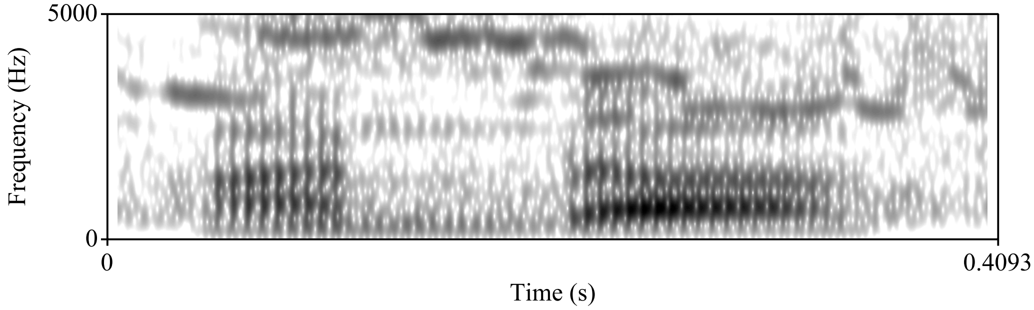
Figure 2a: observable stop release (boxed) in [handak] (Matthew 5)



[13] There are also several languages which are claimed to only exhibit NCD with [ŋg]$_1$ (see the appendix). These claims are less well-documented (typically they are made in half a sentence by Meeussen 1963, with no supporting data), but could be understood in this same way if these languages the release of [ŋg] is shorter than the release of other voiced NCs. The acoustic data necessary to test this prediction are not available.

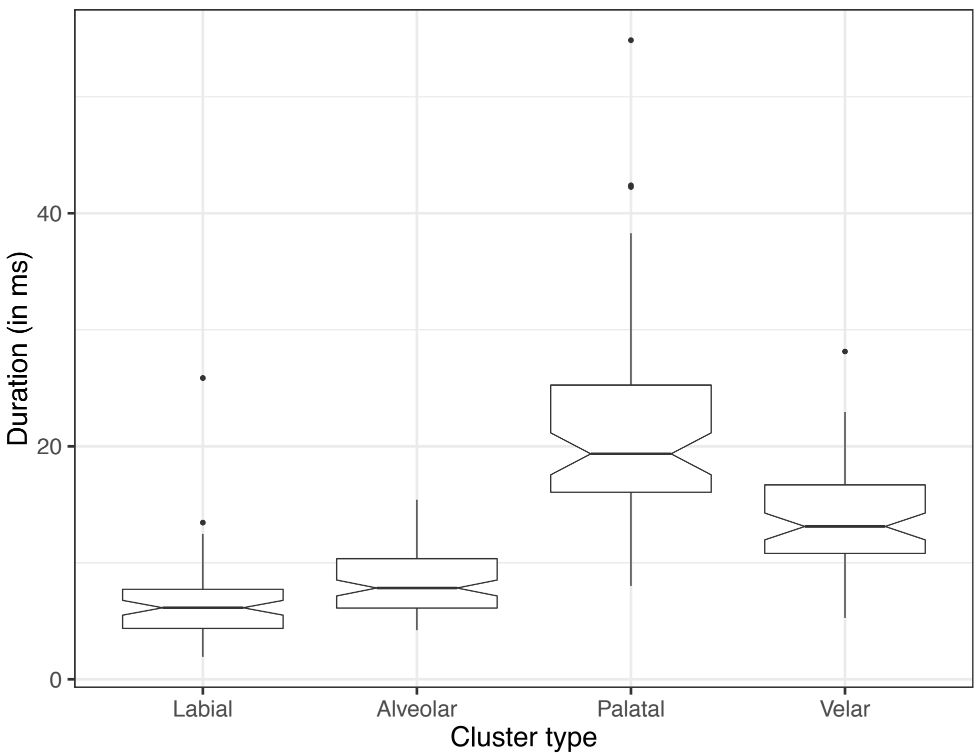
[14] Of the 149 with no observable release, there were 66 [mb]s (48.5%), 49 [nd]s (33.8%), 7 [ɲdʒ]s (9.7%), and 27 [ŋg]s (29.9%). Likelihood of non-release is negatively correlated with release duration when released (see Fig. 3); conclusions drawn from this could be that shorter releases are more likely to be obscured or that they are more likely to be absent.

Figure 2b: no observable stop release in [handak] (John 21)



In total, 70 tokens of released [mb], 96 tokens of released [nd], and 65 tokens each of released [ɲdʒ] and released [ŋg] were obtained. The resulting measurements are summarized in Figure 3.

Figure 3: oral release duration in Ngaju Dayak by place of articulation



These results confirm that asymmetries in release duration are the inverse of asymmetries in NCD frequency. [mb] has the shortest release; when NC_1 in NC_1VNC_2 is [mb], NCD is most frequent. [ɲdʒ] has the longest release; when NC_1 in NC_1VNC_2 is [ɲdʒ], NCD is least frequent. Pairwise comparisons from a linear model, obtained again with the glht function of R's multcomp package, are in (27); all comparisons except labial-alveolar are significant.

(27) Pairwise comparisons for Ngaju Dayak release data

	Comparison	Coefficient	t value	Significant?
a.	Bilabial-Alveolar	0.001	2.07	No ($p = .17$)
b.	Bilabial-Palatal	0.015	16.76	Yes ($p < .001$)
c.	Bilabial-Velar	0.007	8.16	Yes ($p < .001$)
d.	Alveolar-Palatal	0.013	15.95	Yes ($p < .001$)
e.	Alveolar-Velar	0.006	6.73	Yes ($p < .001$)
f.	Palatal-Velar	-0.008	-8.44	Yes ($p < .001$)

Discrepancies between the dictionary and acoustic data involve the alveolars: the bilabial-alveolar comparison is significant in the dictionary data (26a) but not the acoustic data (27a), and the alveolar-velar comparison is significant in the acoustic data (27e) but not the dictionary data (26e). Given the low number of alveolar tokens in the dictionary (n=7), it is likely that these discrepancies reflect limitations of the data. The results of this small study thus indicate a plausible correlation in Ngaju Dayak between the rate of NCD and the average duration of NC_1's oral release.

3.3 Analysis

The evidence in this section suggests that NC-internal properties play an independent role in NCD. I formalize this by introducing MINDIST constraints that require NC to have an oral release of at least a certain duration to be sufficiently distinct from N. Here too I assume that learners are capable of grouping NCs into separate categories (REL_x) according to the duration of their releases; the exact constitution of the categories depends on language-specific asymmetries in release duration. The fact that NCD only rarely targets NC_1VNC_2 when NC_1 is voiceless suggests that in most languages, NCs are divided into at least two categories: one for voiceless NCs (with longer releases), and another for voiced NCs (with shorter releases). In addition, the correlation between place of articulation and NCD in Ngaju Dayak suggests that these categories can be more fine-grained; it is useful in this case to assume that voiced NCs can be divided up as in (28).

(28) REL scale for Ngaju Dayak (voiceless NCs not included)

REL_x value	Ngaju Dayak referent
REL_1	[mb]
REL_2	[nd]
REL_3	[ŋg]
REL_4	[ɲdʒ]

Given this scale, we can define three MINDIST constraints along the REL dimension: MINDIST N–NC: NC-REL_2, MINDIST N–NC: NC-REL_3, and MINDIST N–NC: NC-REL_4 (29–31).

(29) MINDIST N–NC: NC-REL_2:
Assign one violation for each contrast between N and NC in which NC does not have an oral release that belongs to category of 2 or larger along the REL scale.

(30) MINDIST N–NC: NC-REL_3:
Assign one violation for each contrast between N and NC in which NC does not have an oral release that belongs to category of 3 or larger along the REL scale.

(31) MINDIST N–NC: NC-REL$_4$:
Assign one violation for each contrast between N and NC in which NC does not have an oral release that belongs to category of 4 or larger along the REL scale.

In Ngaju Dayak, the combined influences of the lefthand and righthand contexts can be modeled as additive interactions of MINDIST constraints along the REL and ORAL dimensions. Put slightly differently, the penalty assigned to a given N–NC contrast depends on two factors: the identity of the NC and the identity of the righthand context. To illustrate this explicitly, I fit a Maxent grammar to the Ngaju Dayak count data (Table 1) using five constraints: the MINDIST constraints in (29–31), *MERGE (10), and MINDIST N–NC: V-ORAL$_2$ (8); I assume that ORAL=1 for vowels preceding NC and that ORAL=2 for vowels preceding C. The weights discovered by the Maxent grammar tool (Wilson & George 2008) follow.

(32) Weights for Ngaju Dayak count data

Constraint	Weight
*MERGE	6.07
MINDIST N–NC: V-ORAL$_2$	4.24
MINDIST N–NC: NC-REL$_4$	2.92
MINDIST N–NC: NC-REL$_2$	0.82
MINDIST N–NC: NC-REL$_3$	0

These constraints interact to approximate the frequency counts. In the case of labials, for example, the combined weights of the MINDIST constraints along the ORAL and REL dimensions result in an overwhelming likelihood that, in the NC$_1$VNC$_2$ context, [m-mb] neutralizes. Numeric subscripts indicate a value along the ORAL or REL scale; alphabetical subscripts indicate correspondence.

(33) Neutralization of [m-mb] in VNC context predicted to be frequent

		weight:	6.07	4.24	2.92	0.82		
	/mV$_1$NC/$_i$	/mb$_1$V$_1$NC/$_j$	*MERGE	MINDIST N–NC: V-ORAL$_2$	MINDIST N–NC: NC-REL$_4$	MINDIST N–NC: NC-REL$_2$	Harmony	Prob.
a.	/mV$_1$NC/$_i$	/mb$_1$V$_1$NC/$_j$		*	*	*	7.98	13.0%
b.	/mV$_1$NC/$_{i,j}$		*				6.07	87.0%

In the NC$_1$VC$_2$ context, MINDIST N–NC: V-ORAL$_2$ is satisfied, so the candidate with an [m-mb] contrast has a lower harmony score. As shown below, this results in a lower (though correctly non-zero) probability that neutralization occurs in this context.

(34) Neutralization of [m-mb] in VC context predicted to be infrequent

		weight:	6.07	4.24	2.92	0.82		
	$/mV_2C/_i$	$/mb_1V_2C/_j$	*MERGE	MINDIST N–NC: NC/_V-ORAL$_2$	MINDIST N–NC: NC-REL$_4$	MINDIST N–NC: NC-REL$_2$	Harmony	Prob.
a.	$/mV_2C/_i$	$/mb_1V_2C/_j$			*	*	3.74	91.2%
b.	$/mV_2C/_{i,j}$		*				6.07	8.8%

Overall results are summarized in Table 2. The model captures the fact that NCD occurs more frequently with following NC_2 than with following C_2; the predicted frequencies of NCD, like the observed ones, are higher in in the VNC context than they are in the VC context. It also captures the fact that the rate of N–NC_1 neutralization tracks the average duration of NC_1's oral release: the predicted and observed frequencies of NCD given palatal N–NC_1, for example, are lower than the predicted and observed frequencies given labial N–NC_1.

Table 2: results of maxent analysis for Ngaju Dayak count data

Input	Outputs	Observed freq.	Predicted freq.
mVNC–mbVNC	mVNC–mbVNC	5.8% (4/69)	13.0% (9/69)
	mVNC	94.2% (65/69)	87.0% (60/69)
mVCV–mbVCV	mVCV–mbVCV	94.3% (150/159)	91.2% (145/159)
	mVCV	5.7% (9/159)	8.8% (14/159)
nVNC–ndVNC	nVNC–ndVNC	50.0% (5/10)	25.2% (3/10)
	nVNC	50.0% (5/10)	74.8% (7/10)
nVCV–ndVCV	nVCV–ndVCV	96.2% (75/78)	96.0% (75/78)
	nVCV	3.8% (3/78)	4.1% (3/78)
ɲVNC–ɲdʒVNC	ɲVNC–ɲdʒVNC	84.6% (11/13)	86.2% (11/13)
	ɲVNC	15.4% (2/13)	13.8% (2/13)
ɲVCV–ɲdʒVCV	ɲVCV–ɲdʒVCV	100.0% (89/89)	99.8% (89/89)
	ɲVCV	0.0% (0/89)	0.0% (0/89)
ŋVNC–ŋgVNC	ŋVNC–ŋgVNC	36.0% (9/25)	25.2% (6/25)
	ŋVNC	64.0% (16/25)	74.8% (19/25)
ŋVCV–ŋgVCV	ŋVCV–ŋgVCV	91.2% (104/114)	95.9% (109/114)
	ŋVCV	8.8% (10/114)	4.1% (5/114)

Decomposing MINDIST constraints on the N–NC contrast in this way predicts that NCs with longer releases should be generally preferred to those with shorter releases. While this prediction has not been investigated systematically, one potential piece of supporting evidence comes from nasal substitution in Tagalog (Zuraw 2010): among stems with initial voiced stops, substitution occurs more frequently with [N+b], less frequently with [N+d], and least frequently with [N+g]. If the phonetics of Tagalog voiced NCs mirror those of Ngaju Dayak, then Zuraw's (2010) finding is potentially explicable by the factors discussed here.

4 Experimental support

The proposed analysis for asymmetries in the NCD typology rests on two hypotheses regarding factors that make an NC more or less confusable with N, as summarized in (35).

(35) Hypothesized perceptual factors
   a. The more nasalized a vowel following NC is, the more confusable NC is with N.
   b. The shorter an NC's release, the more confusable the NC is with N.

Both of these hypotheses are consistent with what is currently known about the perception of NCs but are not supported in their specific form. Regarding (35a): Beddor & Onsuwan (2003) show that Ikalanga speakers' ability to correctly identify [mb] is negatively impacted by the presence of nasalization in a following vowel: speakers correctly identify [mb] most frequently when followed by an oral vowel, less frequently when followed by a vowel whose initial 36% is nasalized, even less frequently when followed by a vowel whose initial 68% is nasalized, and least frequently when followed by a fully nasal vowel. But showing that perception of NC depends on the duration of nasalization immediately following the release is quite different from showing that perception of NC depends on the amount of regressive coarticulatory nasalization from a following nasal consonant (which may not extend to the first NC's release), so Beddor & Onsuwan's (2003) results do not necessarily support (35a). Regarding (35b), Beddor & Onsuwan (2003) show that Ikalanga speakers' ability to correctly identify [mb] is impacted by the duration of the oral closure and release burst: averaging across following contexts, correct identification rates of [mb] were highest when [mb]'s oral closure and release burst was 27 ms, lower at 18 ms, still lower at 9 ms, and lowest when it was absent. These results support the general idea that perception of NC is dependent on the salience of its oral release, but not the specific hypothesis in (35b).

This section reports the results of an AX task designed to investigate the hypotheses as they are formulated in (35). An AX task was chosen because it allows for a direct test of the hypothesis that listeners' ability to discriminate N and NC depends on the contrast's segmental environment, and also because it is a standard task used to investigate hypotheses of this sort (e.g. Gallagher 2010). In what follows I show that the results are largely consistent with (35).

4.1 Materials

The stimuli for this experiment are trisyllabic nonce words produced by a male native speaker of Peruvian Spanish. Spanish was selected as the language for the stimuli because it is a language with different patterns of coarticulatory nasalization than are found in English. It is well-known that anticipatory nasal coarticulation in English is extensive, especially when the nasal consonant is pre-consonantal or word-final (see Cohn 1990), leading many authors to argue that nasalization in English is phonological, or "part of the programming instructions and not a function of physiological constraints of the vocal organs" (Solé 1992:30). In Spanish, by contrast, coarticulatory nasalization is less extensive, suggesting that nasalized vowels are "targeted as oral, and nasalization is the result of a physiological time constraint" (Solé 1992:38). Using productions from a Spanish speaker leads to a more conservative test of the hypothesis in (35a) than using stimuli produced by an English speaker would have been, because all else being equal we would expect that in an NC_1VNC_2 sequence there should be less nasalization in the intervening V when that NC_1VNC_2 sequence is produced by a Spanish speaker.

To facilitate analysis of the productions, a larger number of forms were recorded than were used in the task. For the recorded items, the first consonant (C_1) was /p/, /t/, or /k/; the second consonant or consonant sequence (C_2) was /m/, /mb/, /mp/, /n/, /nd/, /nt/, /ɲ/, or /ɲtʃ/; and the third consonant or consonant sequence (C_3) was d/, /n/, /nd/, or /nt/. In all cases, C_1, C_2 and C_3 were followed by /a/. Crossing these properties led to 120 forms, like *pamanta*, *kantanta*, and *tandada*. The speaker was given a list with these 120 forms, plus a filler form at either end, and asked to read the list twice at a normal speech rate. Recordings were made with a Marantz PMD-661 MKIII solid-state recorder and a Shure SM-35 microphone in a soundproof booth at New York University.

Stimuli were created from these recordings. The contrast of interest in this experiment was N–ND, so C_2 in the "same" items contained either identical nasals or identical voiced nasal-stop clusters, and C_2 in the "different" items contained one of each (see (36)). This contrast was compared across four contexts: /d/, /n/, /nd/, and /nt/ in C_3. C_1 was a filler consonant and was balanced across /p/, /t/, and /k/. For "same" items, two recordings of the same word were used where possible; for the 3 forms where there was only one fluent production (*pambanda*, *pandada*, *tandanda*), the fluent recording was duplicated. For "different" items, recordings chosen were those whose intonation matched most closely. This resulted in a set of 96 stimuli that were balanced across all conditions.

(36) Examples of "same" and "different" items

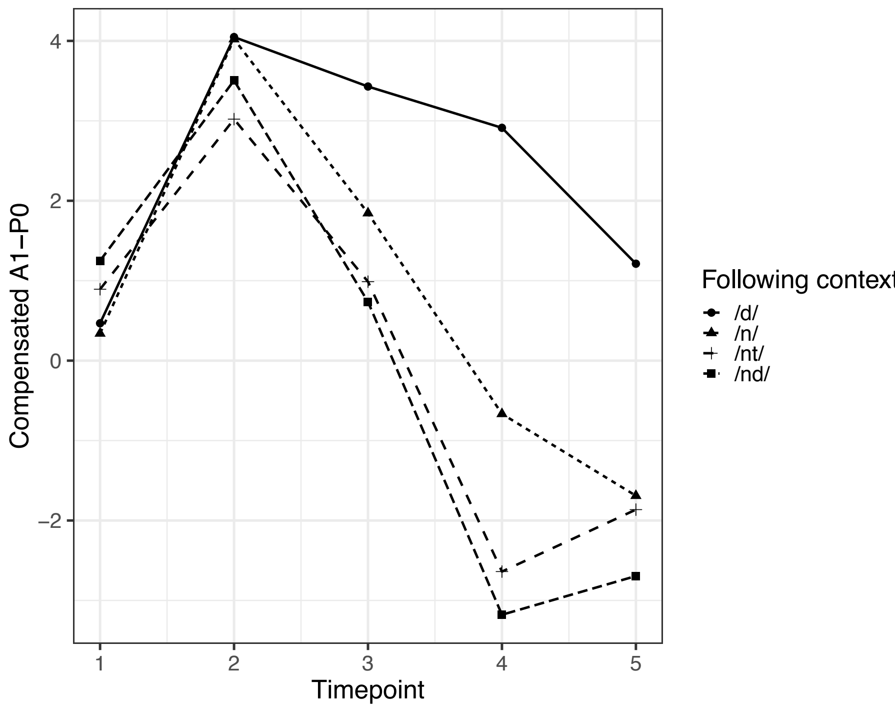
Same		Different	
Comparison	Example	Comparison	Example
m–m	*tamada-tamada*	m–mb	*tamada-tambada*
mb–mb	*tambada-tambada*	mb–m	*tambada-tamada*
n–n	*tanada-tanada*	n–nd	*tanada-tandada*
nd–nd	*tandada-tandada*	nd–n	*tandada-tanada*

An AX task with these items allows us to test the hypotheses in (35) as follows. First, varying the identity of C_3 allows us to test the hypothesis that discrimination of N and NC should depend on the amount of nasalization in the intermediate vowel. If vowels are more nasalized before /nd/ than before /d/, for example, we would expect listeners to be more sensitive to the distinction between *pamada*-*pambada* than they are to the distinction between *pamanda*-*pambanda*. Second, varying the identity of C_2 allows us to test the hypothesis that discrimination of N–NC should depend on the duration of NC's release. If releases of [nd] are longer than those of [mb], for example, then we might expect listeners to be more sensitive to the distinction between *pananda*-*pandanda* than they are to the distinction between *pamanda*-*pambanda*. As specific predictions regarding listener behavior depend on acoustic properties of the speakers' productions, I investigate those next.

4.2 Acoustic properties of productions

To quantify the amount of nasalization in vowels preceding /d/, /n/, /nd/, and /nt/, I submitted each of the 240 words recorded to the Nasality Automeasure Script Package (Styler & Scarborough 2015). The decision to use all recordings (not just those incorporated into the stimuli) was made in response to Styler & Scarborough's statement that "the best approach [to A1-P0 measurement] is to compare large groups of tokens across differing conditions". The compensated A1-P0 was measured at five equally spaced timepoints throughout the vowel between C_2 and C_3 (e.g. *pamba̲da*); timepoints 1 and 5 were offset 5 ms from the beginning and end of the vowel. Of 1200 possible measurements, the script took 1173. The *y* axis in Figure 4 is average compensated A1-P0; lower A1-P0 measures are correlated with an increased amount of nasalization. The relative ordering of the following contexts in the key represents their relative ordering at Timepoint 5. As was the case for Figure 1, the exact A1-P0 values are not important here. What matters are the relative differences in A1-P0 between conditions at each timepoint

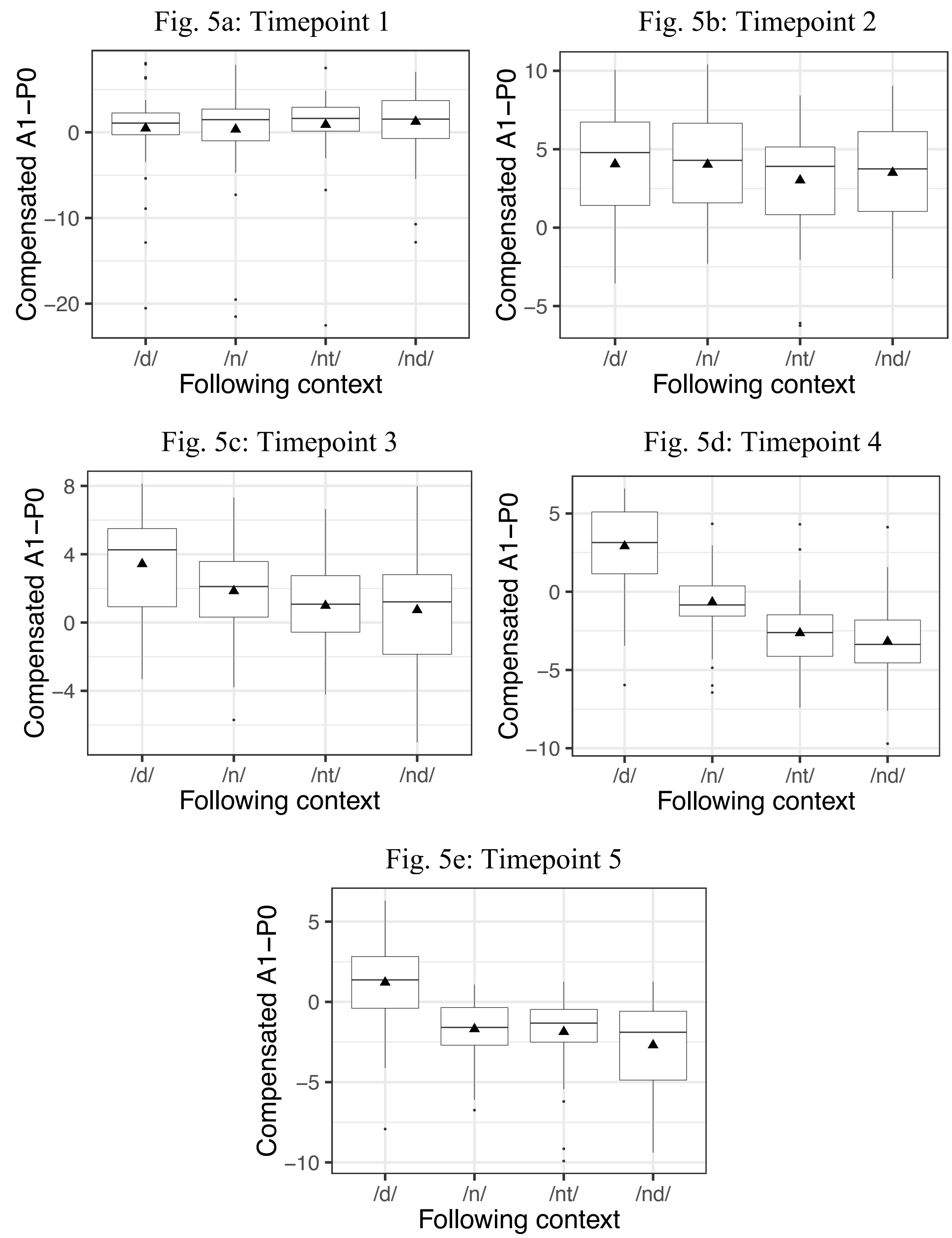
Figure 4: Compensated A1-P0 in Spanish vowels by following context



Several things are apparent. First, effects of anticipatory nasalization in this speaker's productions only extend to around the vowel's midpoint: the mean A1-P0 for vowels preceding /d/ is higher at Timepoints 3-5 than are the mean values of vowels that precede an onset or a coda nasal, but this difference is mostly neutralized at earlier timepoints. Second, the amount of anticipatory nasalization depends on the syllabic role of the nasal in C_3: starting at timepoint 2-3, vowels preceding [nd], [nt] are more nasalized than vowels preceding [n]. Finally, the relationship between [nd] and [nt] changes over the vowel's timecourse. At Timepoints 1-2, the vowel preceding [nt] is more nasalized than the vowel preceding [nd]; at Timepoints 3-5, the reverse holds.

The boxplots in Figure 5 provide a better sense of the relationship between the categories at each timepoint by plotting by-timepoint A1-P0 values according to C_3's identity.

Figure 5: compensated A1-P0 in Spanish vowels by timepoint



To determine which differences were meaningful, a linear regression was fit to each timepoint with R's lm function. The dependent variable was compensated A1-P0, and the independent variable was the identity of C_3. This predictor was helmert-coded: comparisons were between the oral and nasal contexts (/d/ vs. /n/, /nt/, /nd), the onset and coda nasal contexts (/n/ vs. /nt/, /nd/), and the voiceless and voiced NCs (/nt/ vs. /nd/). Generally speaking, the models found asymmetries in A1-P0 between the oral and nasal contexts as well as the prevocalic vs. non-prevocalic nasal contexts at the midpoint of the vowel and later. Full results are summarized in (37). A positive coefficient indicates that the first term in the comparison has a higher A1-P0 (or, is less nasal); a negative coefficient indicates that the second term's is higher. Note that in (37), the significance level is taken to be $p < .01$, to correct for multiple comparisons (with five tests, the Bonferroni correction is .05 / 5 = .01).[15]

(37) Statistical analyses of nasalization data

Following context	A1-P0 significantly different at timepoint?				
	T1	T2	T3	T4	T5
/d/ vs. /n/, /nt/, /nd/	No (t = -0.53, p = .60)	No (t = 1.09, p = .28)	Yes (t = 5.27, p < .001)	Yes (t = 14.73, p < .001)	Yes (t = 9.18, p < .001)
/n/ vs. /nt/, /nd/	No (t = -1.00, p = .32)	No (t = 1.45, p = .15)	Trending (t = 2.17, p = .03)	Yes (t = 6.12, p < .001)	No (t = 1.54, p = .12)
/nt/ vs. /nd/	No (t = -0.42, p = .68)	No (t = -0.80, p = .43)	No (t = 0.48, p = .63)	No (t = 1.26, p = .21)	Trending (t = 1.86, p = .06)

For the experiment, predictions regarding listener behavior depend on what is attended to while the listener attempts to determine if C_2 in a word like *tambanda* is an N or NC. If the listener makes the distinction using only properties of the consonantal release and the oral vs. nasal quality of the first part of the following vowel, we would not expect discrimination of N vs. NC to depend at all on the identity of C_3. If however the listener's decision process takes into account the oral vs. nasal quality of the following vowel at its midpoint or later, we might expect to find that their response patterns mirror acoustic properties of the stimuli at timepoints 3-5. In particular, listeners should be better at discriminating N-NC contrasts before [d] than before [n], [nt], or [nd]; they should also be better at discriminating N-NC contrasts before [n] than before [nt] or [nd]. As there are no significant differences in the amount of nasalization before [nt] and [nd], it is unclear what to expect for this comparison. These predictions are summarized in (38).

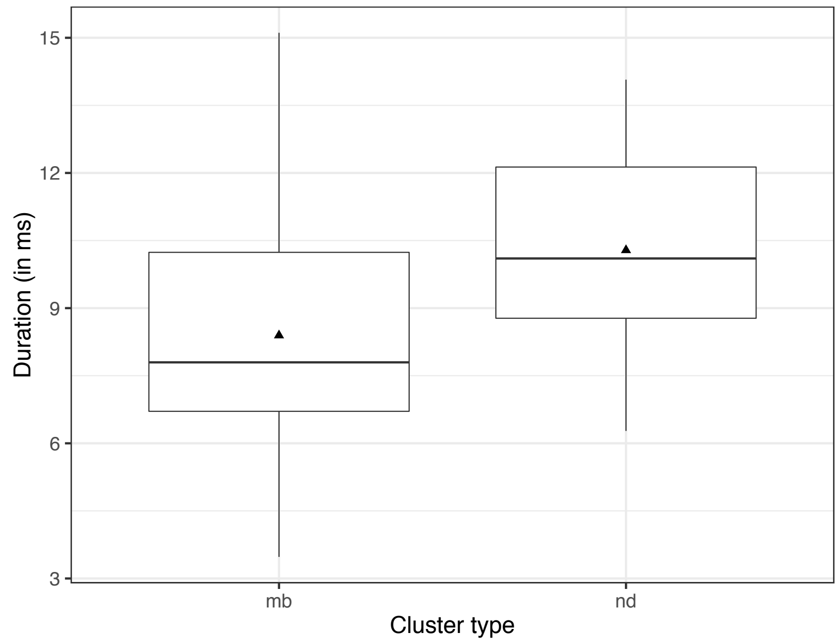
(38) Predictions given properties of vowel at timepoints 3-5

C_3 Comparison	Identity of C_3 (sample item)			
	/d/ (*tamada-tambada*)	/n/ (*tamana-tambana*)	/nt/ (*tamanta-tambanta*)	/nd/ (*tamanda-tambanda*)
/d/ vs. others	More sensitive	Less sensitive		
/n/ vs. /nt/, /nd/		More sensitive	Less sensitive	
/nt/ vs. /nd/			Unclear	

The second manipulation has to do with the identity of C_2, which was either labial (/m/ or /mb/) or alveolar (/n/ or /nd/). To know if listeners should respond differently to these two stimulus types, it is necessary to know if release duration differs by place of articulation. To determine this, I measured the duration of the release, defined here as the combined duration of burst and VOT, of each /mb/ and /nd/ recorded (49 in total, with 25 /nd/ and 24 /mb/). Figure 6 shows that the release of /nd/ is significantly longer than the release of /mb/ (t = 2.63, p < .05, linear regression).

[15] The original model fit to these data included predictors for C_3 identity and Timepoint. Such a model finds a number of significant interactions. To interpret these interactions I subsetted the data by Timepoint and looked at the comparisons only within the C_3 identity predictor. The results of this further analysis are what is reported in (37).

Figure 6: release duration of [mb] and [nd]



The prediction in this case is straightforward: listeners may be more sensitive to the distinction between /n/ and /nd/ (where the oral release is longer) than they are to the distinction between /m/ and /mb/ (where the release is shorter). Note that the difference between these two categories is small: the mean release durations for [mb] and [nd] are 8 ms and 10 ms, respectively. Probing this distinction was an intentionally conservative choice. If listeners are more sensitive to the /m/ vs. /mb/ distinction than they are to /n/ vs. /nd/, one can reasonably expect that listeners will also be sensitive to greater differences in release duration (like that between /mb/ vs. /ndʒ/ or /mp/).

4.3 Procedure

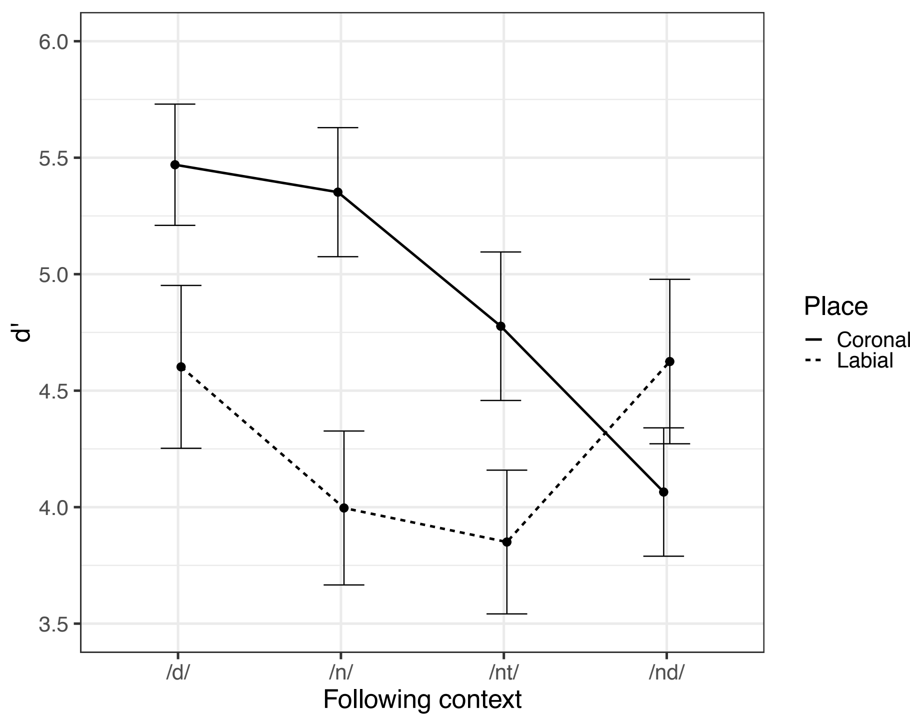
39 participants, all native English speakers, were recruited from a combination of flyers, the NYU Facebook community, and Craigslist. The experiment was conducted with OpenSesame (Mathôt et al. 2012) on a laptop computer. Participants completed the experiment in a quiet room wearing Audio Technica ATH-ANC9 headphones and were compensated for their time.

During the experiment, participants were presented with 8 trial items: 4 "same" (*kananta, tanyana, tantada, panchana*) and 4 "different", which did not contain comparisons repeated in the test items (*kanyanta-tampada, tanyanta-pampana, kananta-kantanta, padanta-panata*). The block of 96 test items followed. While a sound file played, a black dot appeared on the screen; participants were directed to decide during this period if they were hearing two different recordings of the same word or two recordings of different words. After the recording finished, a new screen appeared, with "Same (1)" at the left edge and "Different (0)" at the right. Participants were instructed to press 1 if they thought the two recordings were of the same word, and 0 if they thought the two recordings were of different words. They were asked to indicate their responses as soon as possible after the black dot disappeared (but not beforehand), and warned that if they did not respond quickly the experiment would move on to the next set of recordings. For all stimuli the ISI was 250 ms and the maximum response time was 1500 ms.[16]

4.4 Results

Accuracy was above chance for both types of item; the hit rate (a correct "different" answer for a "different" item) was 81% and the false alarm rate (an incorrect "different" answer for a "same" item) was 12%. Results are plotted by C_3 context in Figure 9, with the two series representing the by-participant d's for labial and coronal C_2 (dots indicate the mean value; error bars mark the standard error).[17] These d' values were obtained from MacMillan & Creelman (2005:A5.4) and assume the differencing model, as is appropriate for an AX task with a roving design. The lower the d', the less sensitive participants were to whether items in that group were "same" or "different". The lines in Figure 7 are included as an aid to interpretation and do not represent change over time.

Figure 7: averaged d' across participants by C_2 and C_3 identity



[16] A reviewer worries about the short ISI, on the grounds that participants could have used any acoustic difference to discriminate between A and X, instead of using categories. There are several reasons to believe this is not a valid worry. First, if listeners chose "different" on the basis of any acoustic difference, the overall rate of "different" choices would be high, as almost all stimuli contained two different recordings. Yet 88.1% of the "same" items received a "same" response, suggesting that participants likely ignored non-contrastive differences between A and X . Second, the stimuli were long, meaning that more than 250 ms elapsed before a decision could be made: on average, 956 ms elapsed between the offset of A's C_2 (e.g. *m* in *pamanta*) and the offset of X's C_2 (e.g. *mb* in *pambanta*). Third, the crucial comparisons participants made were between-category comparisons of consonants. Work by Pisoni (1973) indicates that, for such comparisons, participants likely rely on phonemic categorization at all ISIs. Finally, even if participants were relying on auditory short-term memory, it is not clear how this would affect the interpretation of the results.

[17] In addition to being a standard way of analyzing responses to an AX task, d' was useful for these data because response strategies appeared to vary substantially across conditions. For example, the false alarm rate for items where C_3 = /d/ (7.2%) was about half the false alarm rate for items where C_3 = /nt/ (14.1%).

The d' values are largely, but not entirely, consistent with the predictions in (35). Focusing on the coronals: the average d' value for [n–nd] lowers across C_3 contexts (from /d/ to /n/ to /nd/ to /nt/). These results are consistent with the predictions in (38), though the difference in d' between the /nd/ and /nt/ contexts is perhaps unexpected. Focusing on the labials: the average d' for [m-mb] contrasts lowers across most C_3 contexts (from /d/ to /n/ to /nd/). This much is consistent with the predictions in (38). The average d' for [m-mb] with /nd/ as C_3 is however higher than all of the other labial d' values, which is not expected: given the average amount of nasalization in the /nd/ context, its d' was predicted to be lower than those of the /d/ and /n/ contexts.

A mixed linear regression was fit to the d' values using the lmer function of R's lme4 package (Bates et al. 2015). The response variable was d'; independent variables included the identity of C_3 (helmert-coded, with comparisons between /d/ vs. all others, /n/ vs. /nt/, /nd/, and /nt/ vs. /nd/), C_2's place of articulation (sum-coded, with a comparison between Coronal and the grand mean), and an interaction. By-participant random slopes for C_3's identity and C_2's place of articulation were also included. *p* values were calculated with R's lmerTest package (Kuznetsova et al. 2017).[18]

(39) Summary of full statistical model

	Factor	Coefficient	*t* value	Significant?
a.	Intercept	4.56	–	–
b.	C_3: /d/ vs. all others	0.59	3.64	Yes ($p < .001$)
c.	C_3: /n/ vs. /nt/, /nd/	0.39	1.86	Trending ($p = .07$)
d.	C_3: /nt/ vs. /nd/	-0.04	-0.18	No ($p > .1$)
e.	C_2: Coronal	0.34	4.25	Yes ($p < .001$)
f.	C_3: /d/ vs. all others * C_2: Coronal	0.16	1.02	No ($p > .1$)
g.	C_3: /n/ vs. /nt/, /nd/ * C_2: Coronal	0.56	3.42	Yes ($p < .001$)
h.	C_3: /nt/ vs. /nd/ * C_2: Coronal	0.71	3.69	Yes ($p < .001$)

The main effect in (39b) confirms that N–ND is more distinct when C_3 is /d/ than when it is /n/, /nt/, or /nd/ (so Δ *pamada-pambada* > Δ *pamana-pambana, pamanda-pambanda, pamanta-pambanta*). The main effect in (39e) confirms that, across contexts, the N–ND distinction is more perceptible for coronals than it is on average; since coronals and labials are the only places of articulation considered, it must the case that N–ND is more perceptible for coronals than it is for labials (so Δ *panada-pandada* > Δ *pamada-pambada*). These results parallel the acoustic data: the release of [mb] is shorter than that of [nd], and vowels preceding /d/ are, from their midpoint on, the most oral.[19] (This latter correlation also suggests that listeners' discrimination of N–ND is at least partially dependent on information later in the vowel.)

The interactions in (39g–h) indicate that the further comparisons across C_3 contexts are dependent on C_2's identity. To investigate these effects more directly, separate models were fit to the labial and coronal data. The independent variable was C_3's identity (helmert-coded, with all comparisons

[18] Including an interaction results in an improved fit relative to a model with no interaction (χ (3) = 25.11, $p < .001$).
[19] A reviewer raises a concern that the durational difference between [mb] and [nd], 2 ms, is below the just noticeable difference for duration (estimated by Fujisaki et al. 1973 to be around 10 ms). But there is a possible scenario under which a difference in release of 2 ms might affect perception of the N-NC contrast. Perhaps it is the case that, in order for an N–NC contrast to be easy to perceive, NC's release must be 9 ms or longer. In this scenario, many labial N–NC contrasts would be below this threshold (as the average NC release is 8 ms) and many coronal N–NC contrasts would be above it (as the average NC release is 10 ms). While this scenario is perhaps simplistic, and 2 ms is a very small average difference, it is not clear to me what else could underlie the [m-mb] vs. [n-nd] distinction observed here.

included above), and a random intercept was included for participant. These models are summarized in (40–41); note that the significance level is taken to be $p < .025$, to correct for multiple comparisons (with two tests, the Bonferroni correction is .05 / 2 = .025).

(40) Summary of statistical model for coronals

	Factor	Coefficient	*t* value	Significant?
a.	Intercept	4.90	–	–
b.	C_3: /n/ vs. /nt/, /nd/	0.96	4.09	Yes ($p < .001$)
c.	C_3: /nt/ vs. /nd/	0.65	-2.38	Yes ($p < .025$)

(41) Summary of statistical model for labials

	Factor	Coefficient	*t* value	Significant?
a.	Intercept	2.88	–	–
b.	C_3: /n/ vs. /nt/, /nd/	-0.19	-0.70	No ($p > .1$)
c.	C_3: /nt/ vs. /nd/	-0.79	2.41	Yes ($p < .025$)

For the coronals, (40b) indicates that [n–nd] is more perceptible when C_3 is /n/ than when it is /nt/ or /nd/ (so Δ *panana-pandana* > Δ *pananda-pandanda, pananta-pandanta*). This comparison across contexts was not significant for the labials (41b), indicating that the trending main effect in (39) was driven by the coronals. The comparison between C_3 = /nt/ and C_3 = /nd/ was significant for both places of articulation, though in opposite directions. For the coronals, discrimination was better before /nt/ (so Δ *pananta-pandanta* > Δ *pananda-pandanda*, (40c)); for the labials, discrimination was better before /nd/ (so Δ *pamanda-pambanda* > Δ *pamanta-pambanta* (41c)).

4.5 Summary

The experiment discussed here tested two hypotheses, which arose from a consideration of both typological and language-specific restrictions on NCD. These hypotheses are summarized in (42).

(42) Hypothesized perceptual factors
  a. The more nasalized a vowel following NC is, the more confusable NC is with N.
  b. The shorter an NC's release, the more confusable the NC is with N.

The results are largely consistent with (42a-b): participants discriminate N–NC more reliably when it is in an oral context than when it is in a nasal context, and when NC's release is longer.[20] Beyond this point, the results differed by place of articulation. The coronal response data are consistent with the further hypothesis that discrimination of N–NC before /n/ should be more reliable than before /nd/ and /nt/, but the labial response data are not. In addition, neither of the significant comparisons between C_3 = /nd/ and C_3 = /nt/ were predicted given the acoustic data. Given that the most reliable distinction in the acoustic data was that between the oral and nasal contexts, however, the lack of consistent effects for these last comparisons is perhaps not surprising.

[20] A reviewer proposes an alternative interpretation of this result, namely that discrimination of the N–NC contrast is impacted entirely by the identity of C_3 (and not the amount of regressive nasalization it does or does not induce). This is possible, but until a concrete rationale for this alternative interpretation can be provided, I continue to hypothesize that the relevant factor here is the nasalization of the intervening vowel.

A reviewer and the associate editor raise a concern that the labial response data are not consistent with the hypothesis in (42a). First, as shown above, this is not entirely true: as predicted, the average d' for the labial context was higher when C_3 was /d/ than when C_3 was /n/ or /nt/.[21] And while it is true that the high d' given /nd/ as C_3 runs contrary to the predictions in (42), I do not believe that this result presents a significant problem for the proposed analysis of NCD.[22] It is unrealistic to expect that one iteration of a single experimental task would find evidence consistent with all stated predictions. Further iterations of this task would be necessary to determine which aspects of the results replicate and, by extension, which aspects of the results continue to support or contradict the hypotheses in (42).

5 Further links between NCṼ and NCD

Anticipatory nasalization of the intermediate vowel in $NC_1VN(C)_2$ is only one of the ways that an NC can come to precede a nasal(ized) vowel. Many languages also license contrasts in vocalic nasality, and in these languages NCṼ sequences (where Ṽ is a phonemically nasal vowel) are in principle possible. All else being equal, we would expect that languages that prioritize maximally distinct N–NC contrasts should disprefer NCṼ and $NC_1VN(C)_2$.

There are however differences in the amount of nasalization exhibited by contrastive and non-contrastively nasalized vowels. In the cases I am aware of, contrastively nasalized vowels are more nasalized than coarticulatorily nasalized vowels in both the extent and intensity of acoustic nasality (e.g. Cohn 1990 on French). We might expect NC to be more distinct from N before VN(C), a context of generally lesser nasality, than it is before Ṽ, a context of generally greater nasality. If this asymmetry holds cross-linguistically, the predictions in (43) follow.

(43) Predictions regarding NCṼ and NCVN(C)
- a. If a language allows NCṼ, it should also allow $NC_1VN(C)_2$.
- b. If a language bans $NC_1VN(C)_2$, it should also ban NCṼ.

As is true for all of the generalizations discussed in this article, (43a-b) follow from the way that MINDIST constraints are defined: if N–NC is penalized in a context where it is more distinct, it must also be penalized in all contexts where it is equally or less distinct. I show next that these predictions hold.

---

[21] A reviewer asks which differences among the C_3 contexts are significant. For the labial condition, Tukey's HSD post-hoc tests (done with the glht function of R's multcomp package, Hothorm et al. 2008) show that the differences between /d/ and /nt/ and /nd/ and /nt/ are trending ($p < .1$), but no others approach significance. For the coronal condition, all comparisons except the one between /n/ and /d/ are either trending or significant ($p < .05$ for /d/ vs. /nt/, /d/ vs. /nd/, and /n/ vs. /nd/; $p < .1$ for /n/ vs. /nt/ and /nd/ vs. /nt/).

[22] A reviewer asks why the labial data are not entirely consistent with the predictions. I have not been able to find a satisfying answer to this question. One possibility is that the speaker, when producing the stimuli, actively enhanced the [m-mb] contrast in a context where it is expected to be relatively compromised (pre-/nd/). This hypothesis, however, is not consistent with the acoustic data. One way to enhance an N–NC contrast would be to minimize nasalization following [mb]. But the average A1-P0 values at the vowel's midpoint, for the labial stimuli, suggest that the speaker did not employ this strategy (1.95 for vowels preceding /d/, 0.04 preceding /n/, -0.06 preceding /nt/, and -0.05 preceding /nd/). Another way to enhance an N–NC contrast would be to lengthen [mb]'s burst, but this was not clearly the case in these stimuli: the stimuli with [mb] as C_2 and [nd] as C_3 had an average burst duration of 8 ms (identical to the overall average for labials). Impressionistic listening to all stimuli yielded no further clues. Given that it is not clear what the source of this result is, the most promising direction for future work in this area would likely be to determine if the results replicate.

5.1 Prediction 1: NCṼ implies NC_1VN_2

To test the prediction that NCṼ in a given language should imply $NC_1VN(C)_2$, I searched for languages that allow NCs and a vocalic nasality contrast. Languages were identified from reference grammars at MIT's Hayden Library and online periodicals. An important criterion for inclusion was that an N–NC contrast exist: languages like Apinayé and Siriono, though identified by Maddieson (1984) as allowing NCs and a vocalic nasality contrast, do not qualify. In these and other South American languages, Ns and NCs are allophones conditioned by the quality of the neighboring vowels (e.g. Herbert 1986, Stanton 2018a). As the focus here is on the effects of vocalic nasality on N–NC, these languages are not directly relevant for the discussion that follows.

Altogether, 23 relevant languages were identified (see the appendix for a full list). Of these 23, 12 allow NCṼ sequences; the fact that 11 do not speaks to the more general claim that NCṼ sequences are dispreferred. As predicted, all languages that allow NCṼ allow $NC_1VN(C)_2$. These results are in Table 3; where applicable, gloss translations are mine. For each language, I provide minimal or near-minimal pairs to support the claim that a contrast in vocalic nasality is licensed following NCs, as well as forms supporting the claim that these languages also allow $NC_1VN(C)_2$. (Note that for Lua and Mbum, only NC_1VN_2 forms are provided because NCs are prohibited outside of initial position. See Stanton 2016a:1108-10 for discussion of the distribution of NCs in these languages.)

Table 3: Languages that allow NCṼ also allow NCVN(C)

Language (Source)	NCV–NCṼ	NCVN(C)
Day (Nougayrol 1979)	ndéé 'people' (p. 61) ndẽ́ 'little' (p. 61)	mbòmbórò 'jawbone' (p. 35) ndēèm 'to suffice' (p. 61)
Kabba (Moser 2004)	mbī 'ear' (p. 36) mbĩ̀ 'nausea' (p. 36)	ngə̀m 'lie' (p. 20) mbámbá 'soldier' (p. 20)
Lua (Boyeldieu 1985)	mbàrì 'to flatten' (p. 43) mbã́ː 'regularly' (p. 43)	ndōŋ 'it's too wide, narrow' (p. 49) ndwāàm 'Ndam of Ndam' (p. 52)
Mbay (Keegan 1996)	mbòj 'in a panic' (p. 293) mbõ̀j 'pleasantly' (p. 294)	ngōn 'son, daughter' (p. 355) mbíndíng 'very heavy' (p. 290)
Mbum (Hagège 1970)	nzáù 'spark' (p. 41) nzã́ 'balafon' (p. 59)	mbàm 'rain' (p. 30) ndàm 'poison' (p. 32)
Ngambay (Vandame 1963)	ndà 'to be white' (p. 197) ndã̀ 'to pick' (p. 15)	ndàng 'to be crazy' (p. 9) mbūnā 'interval' (p. 197)
Ngbaka (Thomas 1963)	zàlānzè 'orange' (p. 46) nzẽ̄ 'blood' (p. 30)	mbàngà 'river sand' (p. 28) mbānā 'wing' (p. 50)
Nizaa (Endresen 1991)	mbɛɛ 'to judge' (p. 42) mbɛ̃ɛ̃ 'to limp' (p. 42)	mbèmbèm 'wind instrument' (p. 48) ndaŋnì 'disobedience' (p. 48)
Tinrin (Osumi 1995)	ɳɖḭ 'leaf, be humid' (p. 17) ɳɖṵ̃ 'hawk' (p. 15)	n̪d̪an̪d̪ɔ̃ɽɔ̃ 'to hurt the foot...' (p. 5) ɳɖḭnawa 'coconut leaves' (p. 290)
Vouté (Guarisma 1978)	ngór 'thinness' (p. 45) ngɔ̃́ɔ̃ 'grass *sp.*' (p. 45)	ngʉ́ŋ 'stick' (p. 45) ngə́nbé 'paddle' (p. 24)
Xârâcùù (Lynch 2002)	baːru 'two' (p. 768) mbʷã 'distant and invisible (p. 768)	ndɔmbʷa 'thing' (p. 775) mbanĩː 'how many?' (p. 775)
Yakoma (Boyeldieu 1975)	pɛndá 'back' (p. 126) ndẽ́ 'different(ly)' (p. 100)	ngúni 'the water falls...' (p. 22) ngàmbìí 'youngest' (p. 39)

5.2 Prediction 2: *$NC_1VN(C)_2$ implies *NCṼ

To test the prediction that *$NC_1VN(C)_2$ implies *NCṼ, I attempted to find information about the vocalic inventories of each language included in the survey of NCD. Of the languages surveyed, I was able to find this information for 43. Of these 43, only Sango (Samarin 1967), Saramaccan (McWhorter & Good 2012), and Zande (Gore 1931) license a contrast in vocalic nasality (44–46).

(44) Vowel nasality contrast in Sango (Samarin 1967:38)

a.	fú	'to sew'	*vs.*	fṹ	'to smell'
b.	kɛ	'to be'	*vs.*	kɛ̃	'to refuse'

(45) Vowel nasality contrast in Saramaccan (McWhorter & Good 2012:19)

a.	péti	'puddle'	*vs.*	pẽ́ti	'comb'
b.	hási	'horse'	*vs.*	hã́si	'ant'

(46) Vowel nasality contrast in Zande (Gore 1931:2,19)

a.	we	'fire'	*vs.*	wẽ	'thus'
b.	bau	'plentifully'	*vs.*	baũ	'lion'

In none of these languages does it appear that NCṼ sequences are robustly attested. In the case of Saramaccan, McWhorter & Good (2012:26) note their rarity explicitly: the only NCṼ sequence in Saramaccan occurs in the ideophone gíngí/gingĩ́ 'suck fast', and even in this case there is variation between NCV and NCṼ. In the cases of Sango and Zande, these restrictions are not discussed explicitly but are inferred through the lack of NCṼ-containing forms in the cited sources.

The predictions outlined in (43), then, are verified.

6 Discussion and conclusions

This article has argued that typological, acoustic, and perceptual evidence are consistent with an analysis in which NCD is driven by constraints on the distinctiveness of the contrast between NC_1 and a plain nasal, N. Sections 6.1 and 6.2 discuss two possible alternative analyses, and Section 6.3 discusses some implications and concludes.

6.1 Alternative 1: a diachronic analysis

The proposed analysis claims that considerations of perceptual distinctiveness are an integral part of speakers' phonological competence (Flemming 2002, *a.o.*). But we should also consider the viability of a diachronic alternative (à la Ohala 1981, Blevins 2004, Moreton 2008): is it possible that considerations of N–NC contrast distinctiveness correlate with NCD not because they are part of the grammar, but because NCD reflects the fact that insufficiently distinct N–NC contrasts are more likely to be misapprehended and neutralized over time?

The primary difficulty for this alternative is that the kinds of alternations instantiating NCD are diverse and not all of them can be viewed as the result of diachronic neutralization. Given an illicit

NC_1VNC_2 sequence, languages in the survey generally display one of three possible responses: deletion of C_1 (47), N_1 (48), or N_2 (49) (see also Jones 2000).[23]

(47) Deletion of C_1: Ngaju Dayak (Blust 2012:372)

a.	/maN+bando/	→	[ma-mando]	'turn against'
	/maN+bagi/	→	*[mam-bagi]*	*'divide'*
b.	/maN+gundu/	→	[ma-ŋundul]	'wrap up'
	/maN+gila/	→	*[maŋ-gila]*	*'drive crazy'*

(48) Deletion of N_2: Gurindji (McConvell 1988:138)

a.	/kaɲɟu+mpal/	→	[kaɲɟu-pal]	'across below'
	/kajiɾa+mpal/	→	*[kajiɾa-mpal]*	*'across the north'*
b.	/kanka+mpa/	→	[kanka-pa]	'upstream'
	/kani+mpa/	→	*[kani-mpa]*	*'downstream'*

(49) Deletion of N_1: Timugon Murut (Blust 2012:367)

a.	/maN+tumbuk/	→	[ma-tumbuk]	'thump'
	/man+tutu/	→	*[man-tutu]*	*'pound'*
b.	/saN+goŋgom/	→	[sa-goŋgom]	'one fistful'
	/son+dopo/	→	*[son-dopo]*	*'one fathom'*

The alternations in (47) instantiate N–NC_1 neutralization as a response to an insufficiently distinct N–NC contrast, but the alternations in (48–49) cannot be characterized in this way. N_2 deletion (48) is a type of enhancement: by removing the source of coarticulatory nasalization, N–NC_1 is rendered more distinct. N_1 deletion (49) could also be conceived of as a type of enhancement: the contrast between C_1 and nothing could also be enhanced by removing the lefthand N. Contrast enhancement is generally harder to account for in a framework in which the role of phonetic information in phonology is relegated to diachrony: in order to render an insufficiently distinct contrast more distinct, the speaker must be aware that it is insufficiently distinct in the first place (though cf. Blevins 2004:285-289). Thus the existence of enhancement phenomena here and elsewhere suggests that contrast is a primitive of the synchronic grammar.

A reviewer notes that it is perhaps possible to account for the apparent enhancement phenomena in (48–49) by appealing to perceptual hypocorrection. While this is of course a possibility, it is not obvious to me what form such an analysis would take, nor am I aware of any existing concrete proposal along these lines. The point is only that, given the current analytical options on the table, I believe that analyses treating contrast as a primitive fare better in accounting for the relationship between neutralization and enhancement (see also Stanton 2018a on this point).

[23] In several cases (most notably the Eastern Ngumpin languages) the attested alternation is either N_2 deletion or N_2 denasalization, depending on whether NC_2 is homorganic or heterorganic (McConvell 1988:138). In addition, there is a potential case of C_2 nasalization in the western dialects of Gurindji (McConvell 1988:150, e.g. /ŋumpin+ku/ → [ŋumpin-ŋu] n.g.) though it is not clear to what extent this can be dissociated from a more general tendency in these dialects for NC to be realized as NN. This exhausts the attested responses to *NC_1VNC_2 that I am aware of. It is not clear to me why these repairs are attested while others, e.g. lengthening of V, devoicing of C_1 in NC_1VNC_2, or insertion of a consonant between NC_1 and V are unattested. Given the small size of the survey (relative to the number of languages that have NCs) and its focus on C_1 deletion, it is entirely possible that such languages have not been discovered yet.

6.2 Alternative 2: a co-occurrence constraint

A second alternative, due to Alderete (1997), Blust (2012), and others, is that NCD arises due to the activity of a co-occurrence constraint (*NC...NC) that penalizes words containing sequences of NCs. One of the stronger pieces of evidence against this analysis comes from generalizations discussed in Section 5: languages that allow NCṼ allow NC_1VNC_2, and languages that ban NC_1VNC_2 ban NCṼ. These generalizations would not be expected in a theory where NCD is motivated by a co-occurrence constraint. Such a theory would not predict a link between the NCVNC and NCṼ, as the constraint penalizing NCVNC (*NC...NC) would not penalize NCṼ. The absence of systems that allow NCṼ but not NCVNC, for example, suggests that there is no constraint penalizing NCVNC to the exclusion of NCṼ. Put differently, the observed link between the NCṼ and the NCVN(C) typologies suggests that the desire to avoid indistinct N–NC_1 contrasts is not just one possible motivation for NCD, but that it is the only possible motivation.

Beyond this, some aspects of the results discussed here are difficult for a co-occurrence-based analysis. I discuss first typological generalizations with no obvious explanation under this analysis; second, I discuss links between the generalizations and the extant acoustic and perceptual data.

In Section 2, it was shown that two broad generalizations characterize the typology of NCD: repair of NC_1VNC_2 implies repair of NC_1VN_2V, and repair of one of NC_1VNC_2 or NC_1VN_2 implies repair of the other. The second of these generalizations could be captured by proposing that the relevant constraint is actually one on co-occurring coda nasals ($*N]_\sigma...N]_\sigma$), but the first is more difficult for a co-occurrence-based account. While the ban on NC_1VNC_2 and NC_1VN_2 can be straightforwardly captured by $*N]_\sigma...N]_\sigma$, this constraint does not penalize NC_1VN_2V. It would be difficult to explain under this alternative analysis why repair of NC_1VN_2V implies satisfaction of $*N]_\sigma...N]_\sigma$. Furthermore, even if a co-occurrence constraint existed that was capable of penalizing NC_1VNC_2, NC_1VN_2, and NC_1VN_2V, without further amendment this constraint would not make predictions about directionality: it would penalize NC_1VN_2 and N_1VNC_2 equally. This is not the empirical result we want. Within the surveyed languages, restrictions on NC_1VN_2V are common but restrictions on N_1VNC_2 are unattested. This directional asymmetry is, however, predicted by the current contrast-based account. In N_1VNC_2V, all else being equal, NC_2 will be followed by an oral vowel, rendering it maximally distinct along the ORAL dimension. Put differently, the problem for NC_1VN_2V – that anticipatory nasalization from N_2 compromises cues to N–NC_1 – does not exist for N_1VNC_2V. Turning to the generalizations discussed in Section 3, it is not obvious under a co-occurrence-based account why the identity of NC_1, independent of the identity of NC_2, should affect the likelihood of NCD. In Ngaju Dayak, for example, a co-occurrence-based theory has no reason to expect that NCD should be more frequent when NC_1 is [mb] than it is when NC_1 is [ɲdʒ].[24]

Finally, the links established in this article between NCD, acoustics, and perception would not be explicable under a co-occurrence-based theory of NCD. First, consider the relationship between the Yindjibarndi data discussed in Section 2 and one aspect of the perceptual data in Section 4. With respect to Yindjibarndi, it was shown that the context in which NCD occurs (when NC_2 is a

[24] A reviewer asks if languages exhibiting long-distance NCD have constraints on what can intervene. Such effects are potentially unexpected under a co-occurrence-based account, but expected under the present account, to the extent that intervening segments that block NCD also block nasalization and segments that are transparent to NCD perpetuate nasalization. Space prevents me from further discussion, but see Stanton (2018b) on blocking in existing long-distance NCD cases and why these patterns are difficult to account for under a co-occurrence-based analysis.

labial or velar cluster) is the context in which the intermediate vowel carries the most coarticulatory nasalization. This finding is consistent with the perceptual data, where listeners generally became less sensitive to the contrast between N and a voiced NC as the amount of coarticulatory nasalization in the following vowel increased. Second, consider the relationship between the Ngaju Dayak data discussed in Section 3 and the other aspect of the perceptual data in Section 4. With respect to Ngaju Dayak, it was shown that increased rates of NCD are correlated with shorter stop releases. This finding is also consistent with the perceptual data, where listeners were less sensitive to the distinction between N and voiced NC when the release of NC was shorter. This article has thus established that there are links between NCD, acoustics, and perception; these links are directly captured by the contrast-based analysis proposed throughout. A co-occurrence-based analysis of these same facts would be forced to treat the links established in this article as coincidences.

6.3 Implications for a theory of dissimilation

The overall conclusion is that NCD is motivated by constraints on contrast, not by co-occurrence constraints. This conclusion leads to a new understanding of the entities targeted by co-occurrence constraints and connects to prior work that investigates perceptual bases for co-occurrence restrictions (e.g. Ohala 1981, Hall 2007, Gallagher 2010). These points are discussed in turn.

NCD does not fit comfortably within the larger typology of dissimilation. Dissimilatory processes tend to target segments that share one or more features (e.g. [+labial] or [+spread glottis]). Nasal-stop sequences can be (but are not necessarily) treated as single segments by the language's phonology; regardless of its language-specific behavior, however, an NC can only be characterized using a sequence of features (see esp. Anderson 1976 on the difficulties of using a single feature matrix). And in Bennett's (2015) comprehensive survey of long-distance dissimilatory processes, the only processes that target sequences of features involve NCs ((50); see Bennett for references).

(50) Summary of Bennett's (2015) survey

Description	Involved features	No.	Example language
C Place	[+lab], [+cor], [+dors]	42	Akkadian
Nasal	[+nasal]	2	Takelma
Laryngeal features	[+const. glottis], etc.	29	Aymara
Continuancy	[+continuant]	5	Chaha
Liquids/Rhotics	[±lateral]	22	Latin
Sibilants	[+strident]	4	Nkore-Kiga
Voicing	[-voice]	29	Kinyarwanda
NC sequences	[+nasal][-nasal]	21	Gurindji

If we adopt the proposal that NCD can only be motivated by a constraint on contrast, it is possible to characterize the remaining restrictions in (50) by stating that co-occurrence constraints can target only a single feature or a feature bundle whose members are realized simultaneously. Possible co-occurrence constraints take the form $*[\alpha,\beta]...[\alpha,\beta]$ (where $[\alpha]$ and $[\beta]$ are realized simultaneously); I assume that co-occurrence constraints of the form $*[\alpha][\beta]...[\alpha][\beta]$ (where $[\alpha]$ and $[\beta]$ are realized sequentially) are not part of CON. Thus in addition to its ability to account for generalizations present in the typology of NCD, the contrast-based analysis proposed in this article allows us to formulate a more restrictive theory of co-occurrence constraints.

This discussion leads to a larger question regarding the nature of the remaining co-occurrence restrictions in (50): are dissimilatory effects really due to the activity of some constraint with the form *[α]...[α], or can they ultimately be attributed to other factors? The proposal that constraints on contrast drive NCD has precedent in work arguing that certain other types of dissimilation are perceptually motivated. Hall (2007), for example, argues that /r/-dissimilation in English is due to perceptual hypercorrection: /r/ is most likely to disappear in contexts where its presence is masked by another /r/ (e.g. in coda position; *p[ɚ]ticular̲* vs. *p[ə]ticular̲*). Gallagher (2010) argues on the basis of typological and experimental evidence that laryngeal co-occurrence restrictions are due to a constraint on contrast distinctiveness: words with multiple laryngeally marked segments (e.g. [k'ap'i]) are confusable with words that have only one (e.g. [k'api]).

Whether or not all of the dissimilatory processes in (50) can be attributed to phonetically-grounded constraints, as hypothesized by Ohala (1981), remains to be seen (though see Hall et al. 2017 for some critical discussion). But the current proposal that NCD is driven by constraints on contrast advances the discussion in two ways. First, the results discussed here strengthen the claim that at least some types of dissimilation are motivated not by co-occurrence constraints but by constraints that disprefer the perceptual consequences of co-occurrence. Second, it suggests that the targets of co-occurrence constraints must be restricted to single or simultaneously-implemented features.

References

2007. The UCLA Phonetics Lab Archive. Los Angeles, CA: UCLA Department of Linguistics.

2013. Today's Dayak Ngaju Version. http://listen.bible.is.

Alderete, John. 1997. Dissimilation as local conjunction. In Kiyomi Kusumoto (ed.), *Proceedings of the North East Linguistics Society*, vol. 27, 17-32. GLSA.

Anderson, Stephen F. 1976. Nasal Consonants and the Internal Structure of Segments. *Language* 52. 326-344.

Bates, Douglas, Martin Mächler, Ben Bolker & Steve Walker. 2015. Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software* 67. 1-48.

Beddor, Patrice S. 2009. A Coarticulatory Path to Sound Change. *Language* 85. 785-821.

Beddor, Patrice S. & Chutamanee Onsuwan. 2003. Perception of prenasalized stops. In M.J. Solé, D. Recasens & J. Romero (eds.), *Proceedings of the 15th International Congress of Phonetic Sciences*, 407-410. Bellaterra: Universitat Autònoma de Barcelona.

Beguš, Gašper & Aleksei Nazarov. 2017. Lexicon against Naturalness: Unnatural Gradient Phonotactic Restrictions and Their Origins. Ms., Harvard University & University of Huddersfield.

Bennett, Wm. G. 2015. *The Phonology of Consonants: Harmony, Dissimilation, and Correspon dence*. Cambridge: Cambridge University Press.

Boersma, Paul & David Weenink. 2017. Praat: doing phonetics by computer [computer program]. version 6.0.31. http://www.praat.org.

Blevins, Juliette. 2004. *Evolutionary phonology: The emergence of sound patterns*. Cambridge: Cambridge University Press.

Blust, Robert. 2012. One mark per word? Some patterns of dissimilation in Austronesian and Australian languages. *Phonology* 29. 355-381.

Boyeldieu, Pascal. 1975. *Études yakoma: langue du groupe Oubangien (R.C.A.) ; morphologie – synthématique ; notes linguistiques*. Paris: SELAF.

Boyeldieu, Pascal. 1985. *La langue lua ('niellim')*. Cambridge: Cambridge University Press.

Chen, Marilyn Y. 1995. Acoustic parameters of nasalized vowels in hearing-impaired and normal-hearing speakers. *Journal of the Acoustical Society of America* 98. 2443-2453.

Chen, Marilyn Y. 1997. Acoustic correlates of English and French nasalized vowels. *Journal of the Acoustical Society of America* 102. 2360-2370

Cho, Taehong & Peter Ladefoged. 1999. Variation and universals in VOT: evidence from 18 languages. *Journal of Phonetics* 27. 207-229.

Coetzee, Andriew W. & Joe Pater. 2008. Weighted constraints and gradient restrictions on place co-occurrence in Muna and Arabic. *Natural Language & Linguistic Theory* 26. 289-337.

Coetzee, Andries W. & Rigardt Pretorius. 2010. Phonetically grounded phonology and sound change: The case of Tswana labial plosives. *Journal of Phonetics* 38. 404-421.

Cohn, Abigail C. 1990. Phonetic and Phonological Rules of Nasalization. In *UCLA Working Papers in Phonetics* 76, UCLA: Phonetics Laboratory, Department of Linguistics.

Endresen, Rolf Thiel. 1991. Diachronic aspects of the phonology of Nizaa. *Journal of African languages and linguistics* 12. 171-194.

Essono, Jean-J. Marie. 2000. *L'Ewondo: langue bantu du Cameroun*. Yaoundé: Presses de l'Université Catholique d'Afrique Centrale.b

Flemming, Edward. 2002. *Auditory representations in phonology*. New York: Routledge.

Fujisaki, Hiroya, Kimie Nakamura & Toshiaki Imoto. 1975. Auditory perception of duration of speech and non-speech stimuli. *Auditory analysis and perception of speech*, 197-219.

Gallagher, Gillian. 2010. Perceptual distinctness and long-distance laryngeal restrictions. *Phonology* 27. 435-480.

Gore, E. C. 1931. *A Zande grammar.* London: Sheldon Press.

Guarisma, Gladys. 1978. *Études vouté: langue bantoïde du Cameroun: phonologie et alphabet pratique, synthématique, lexique vouté-français.* Paris: SELAF.

Hagège, Claude. 1970. *La langue mbum de Nganha (Cameroun): phonologie, grammaire.* Paris: SELAF.

Hall, Nancy. 2007. Perceptual errors or deliberate avoidance? Types of English /r/-dissimilation. *Proceedings of the 37th Annual Meeting of the Berkeley Linguistic Society* 33. 133-44.

Hall, Nancy, Nancy Vasquez, Francisco Aguirre, Muhammad Damanhuri & Connor Tree. 2017. Long-distance Liquid Coarticulation in American English. In Karen Jesney et al. (eds.), *Proceedings of AMP 2016*. Washington, DC: Linguistic Society of America.

Hardeland, August. 1859. *Dajacksch-Deutsches Wörterbuch.* Amsterdam: Frederik Muller.

Herbert, Robert K. 1977. Phonetic analysis in phonological description: prenasalized consonants and Meinhof's Rule. *Lingua* 43. 339-373.

Herbert, Robert K. 1986. *Languages Universals, Markedness Theory, and Natural Phonetic Processes*. Berlin: Mouton de Gruyter.

Hulstaert, Gustaaf. 1957. *Dictionnaire lomongo-français*. Tervuren: Musée royal du Congo belge.

Jeong, Sunwoo. 2012. Directional asymmetry in nasalization: a perceptual account. *Studies in Phonetics, Phonology and Morphology* 18. 437-469.

Jones, Caroline. 2000. Licit vs. illicit responses in Meinhof's Rule phenomena. In *MIT Working Papers in Linguistics*, vol. 37, 95-103. Cambridge, MA: MITWPL.

Keegan, John M. 1996. *Dictionary of Mbay.* München/Newcastle: Lincom Europa.

Krakow, Rena A. 1993. Nonsegmental influences on velum movement patterns: Syllables, sentences, stress, and speaking rate. In Marie K. Huffman & Rena A. Krakow (eds.), *Nasals, Nasalization, and the Velum*, 87–116. New York: Academic Press.

Kuznetsova, Alexandra, Per B. Brokhoff & Rune H. B. Christensen. 2017. *Journal of Statistical Software* 82. 1-26.

Ladefoged, Peter & Ian Maddieson. 1996. *The Sounds of the World's Languages*. Oxford/Cambridge, MA: Blackwell.

Lynch, John. 2002. Xârâcùù. In John Lynch et al. (eds.), *The Oceanic Languages*, 765-775. Richmond: Curzon Press.

MacMillan, Neil A. & C. Douglas Creelman. 2005. *Detection Theory: A User's Guide*. London: Psychology Press.

Maddieson, Ian. 1984. *Patterns of sounds.* Cambridge: Cambridge University Press.

Maddieson, Ian & Peter Ladefoged. 1993. Partially nasal consonants. In Marie Huffman & Rena Krakow (eds.), *Nasals, nasalization, and the velum*, 251–301. San Diego, CA: Academic Press.

Mamet, M. 1960. Le Langage des Bolia (Lac Léopold ii). Tervuren: Musée royal du Congo belge.

McConvell, Patrick. 1988. Nasal cluster dissimilation and constraints on phonological variables in Gurundji and related languages. *Aboriginal linguistics* 1. 135–165.

McGregor, William. 1990. *A functional grammar of Gooniyandi.* Amsterdam: John Benjamins.

McWhorter, John & Jeff Good. 2012. *A grammar of Saramaccan Creole*. Berlin: Walter de Gruyter.

Mathôt, S., D. Schreij & J. Theeuwes. 2012. OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavior Research Methods*, 44. 314-324.

Meeussen, Achille E. 1963. Meinhof's Rule in Bantu. *African Language Studies* 3. 25–29.

Moreton, Elliott. 2008. Analytic bias and phonological typology. *Phonology* 25. 83–127.

Moser, Rosmarie. 2004. *Kabba: A Nilo-Saharan Language of the Central African Republic*. München: Lincom Europa.

Nougayrol, Pierre. 1979. *Le day de Bouna (Tchad)*. Paris: SELAF.

Ohala, John J. 1981. The listener as a source of sound change. In C. S. Masek et al. (eds.), *Papers from the Parasession on Language and Behavior*, 178–203. Chicago: Chicago Linguistic Society.

Osumi, Midori. 1995. *Tinrin Grammar*. Honolulu: University of Hawai'i Press.

Padgett, Jaye. 2003. Contrast and post-velar fronting in Russian. *Natural Language & Linguistic Theory* 21. 39-87.

Pater, Joe. 1999. Austronesian nasal substitution and other NÇ̥ effects. In René Kager et al. (eds.), *The prosody-morphology interface*, 310–343. Cambridge: Cambridge University Press.

Pater, Joe. 2009. Morpheme-Specific Phonology: Constraint Indexation and Inconsistency Resolution. In Steve Parker (ed.), *Phonological Argumentation: Essays on Evidence and Motivation*, 1-33. London: Equinox.

Pisoni, David B. 1973. Auditory and phonetic memory codes in the discrimination of consonants and vowels. *Perception & Psychophysics* 13. 253-260.

Riehl, Anastasia K. 2008. The phonology and phonetics of nasal obstruent sequences. Ithaca, NY: Cornell University dissertation.

Samarin, William J. 1967. *A Grammar of Sango*. Paris: Mouton & Co.

Schourup, Lawrence C. 1973. A Cross-Language Study of Vowel Nasalization. In *Working Papers in Linguistics* 15, 190–221. Columbus, OH: OSU Department of Linguistics.

Solé, Maria-Josep. 1992. Phonetic and phonological processes: The case of nasalization. *Nasalization and Speech* 35. 29-43.

Stanton, Juliet. 2016a. Effects of allophonic nasalization on NC clusters: a contrast-based analysis. In Christopher Hammerly and Brandon Prickett (eds.), *NELS 46: Proceedings of the 46th Meeting of the North East Linguistic Society*, 193-206. Amherst, MA: GLSA.

Stanton, Juliet. 2016b. Predicting distributional restrictions on prenasalized stops. *Natural Language & Linguistic Theory* 34. 1089–1133.

Stanton, Juliet. 2018a. Environmental shielding is contrast preservation. *Phonology* 35. 39-78.

Stanton, Juliet. 2018b. Gurindji nasal cluster dissimilation as trigger deletion. *Journal of Linguistics*, https://doi.org/10.1017/S0022226718000506.

Steriade, Donca. 1997. Phonetics in Phonology: The Case of Laryngeal Neutralization. Ms., UCLA.

Styler, Will & Rebecca Scarborough. 2015. Nasality Automeasure Script Package. Available at https://github.com/stylerw/styler_praat_scripts/tree/master/nasality_automeasure

Thomas, Jacqueline. 1963. *Le parler ngbaka de Bokanga*. Paris: Mouton.

van den Berg, Rene. 1989. A grammar of the Muna language. Dordrecht: Foris.

Vandame, Charles. 1963. *Le Ngambay-Moundou: phonologie, grammaire et textes*. Dakar: IFAN.

Wilson, Colin & Benjamin George. 2008. Maxent grammar tool. Software package. Los Angeles: UCLA. http://linguistics.ucla.edu/people/hayes/MaxentGrammarTool/

Wickham, Hadley. 2009. *ggplot2: Elegant Graphics for Data Analysis*. New York: Springer-Velag.

Wordick, Frank. 1982. *The Yindjibarndi Language*. Canberra: Australian National University.

Zuraw, Kie. 2010. A model of lexical variation and the grammar with application to Tagalog nasal substitution. *Natural Language & Linguistic Theory* 28. 417-442.