Constraints on contrast motivate nasal cluster dissimilation*

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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 paper 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 provide acoustic and behavioral data in support of this claim and propose an analysis that appeals to auditory factors.

1 Introduction

In a number of languages, the distribution of nasal-stop sequences (NCs) is restricted. The focus of this paper 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) oral component and deletion of the second NC (NC_2)'s nasal component; other strategies are discussed briefly in Section 5.3. 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 (e.g. Jones 2000, to some extent Herbert 1986) argue that NCD is perceptually motivated: in NC_1VNC_2, the first NC (NC_1) may be confusable with a nasal consonant, as its oral portion is both preceded and followed by a nasal consonant, the latter of which likely

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[1] I use IPA transcriptions throughout the paper; in several cases, including Gurindji, this means that the transcriptions in the cited sources have been adapted. Note also that in Gurindji and several other cases, limited non-local application of NCD is possible. For space reasons I do not discuss this complication here, but see Stanton 2017.

induces some amount of anticipatory nasalization in the preceding vowel (so, [$NC_1\tilde{V}NC_2$] is difficult to tell apart 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 paper 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, formulate two hypotheses regarding perceptual factors that are potentially responsible for the generalizations, and present two case studies supplemented by acoustic data. Section 4 discusses results of a perceptual experiment that support the hypotheses. Section 5 proposes a Dispersion Theoretic (Flemming 2002 *et seq.*) analysis of NCD, and Section 6 addresses a larger 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 $NC\tilde{V}$, languages that exhibit NCD should ban $NC\tilde{V}$ across the board (regardless of the source of the vowel's nasality) and languages that allow $NC\tilde{V}$ should not exhibit NCD.

The results described in this paper provide further support for the claim that constraints on the distribution of nasal-stop sequences are constraints on contrast (Stanton 2016b, 2018), and by extension for the claim that constraints on contrast are a necessary component of the synchronic grammar (e.g. Flemming 2002, Gallagher 2010). Broader implications of this work for our understanding of the larger typology of dissimilatory processes are discussed at the end.

2 Typological generalizations and the right-hand context

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 a collection of reference grammars and previous literature (e.g. Meeussen 1963, Herbert 1977, McConvell 1988); for more details and references for each language, see the appendix. This section focuses on generalizations regarding the right-hand context (e.g. NC_2, in NC_1VNC_2), and hypothesizes that these generalizations can be linked to acoustic and perceptual factors: NCD becomes more likely as the amount of nasalization in the post-NC_1 vowel increases.

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 forbid nasal-stop clusters from preceding onset nasals (see also Herbert 1986, McConvell 1987, *a.o.*; for discussion of coda nasals see Section 2.2). 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 nature of the restrictions they impose. The 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'
b.	$*NC_1VN_2V$:	/n+limi/	→ [nːimi], *[ndimi]	'tongues'

[2] I do not consider languages where bans on co-occurring Ns and/or NCs occur as part of a much larger network of consonantal co-occurrence restrictions, as it is possible that in these cases, general considerations of identity or similarity avoidance are in play. For an examples of such a languages 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 in this language comes from "only a few cases of the type -boman-", and a footnote that lists other relevant roots (-bamana, -samana, -tsinana, -umana, -unana). Meeussen does not provide evidence of alternations and the cited dictionary (Hulstaert 1957) does not explicitly 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) is explicit: he 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 occur before [i]. Finally, it is not clear that Sango actually exhibits any form of NCD. Meeussen's discussion provides one cryptic example ([imono] 'castor oil', cl. 12 [akavono]), but a reference grammar (Samarin 1967) provides many examples of words with co-occurring Ns and NCs (e.g. p. 35-6: [ngunzá] 'manioc leaves', [ndóndó] 'brain', [mbéní] 'some'). Placing these three languages in the "NC_1VN_2V only" category was a conservative decision, and further investigation might find that they do not belong to this category after all. These possible counterexamples aside, the generalization above is that a ban on NC_1VN_2V asymmetrically implies a ban on NC_1VNC_2.

The hypothesis pursued here is that this implicational generalization reflects acoustic 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 a greater amount of regressive nasal coarticulation than do onset (or prevocalic) nasals.[3] A survey of nasalization patterns compiled 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 typological 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. Let us hypothesize that an NC followed by an acoustically nasalized vowel is more confusable with a N than is an NC followed by an oral vowel. Furthermore, let us hypothesize that the greater the amount of acoustic nasalization, the more confusable NC and N are. If these assumptions are correct, we should expect two asymmetries to hold. First, the acoustic distance between N–NC when preceding an oral consonant (C, (6a)) should be greater than the acoustic distance between N–NC when preceding any kind of N (6b-c). Second, the acoustic

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

distance between N–NC when preceding an onset nasal (6b) should be greater than the acoustic distance between N–NC when preceding a coda nasal (6c). (Experimental evidence in line with these hypotheses is in Section 4.)

(6) Hypothesized perceptual asymmetries

<table>
<tr><th></th><th>Comparison</th><th colspan="2">Relative acoustic distance</th></tr>
<tr><td>a.</td><td>Δ NC$_1$VC$_2$V–N$_1$VC$_2$V</td><td>Greater</td><td></td></tr>
<tr><td>b.</td><td>Δ NC$_1$VN$_2$V–N$_1$VN$_2$V</td><td rowspan="2">Lesser</td><td>Greater</td></tr>
<tr><td>c.</td><td>Δ NC$_1$VNC$_2$V–N$_1$VNC$_2$V</td><td>Lesser</td></tr>
</table>

From here, the generalization in (3–5) follows from Steriade's (1997) hypothesis of Licensing by Cue: 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). Thus the generalization that NC$_1$VNC$_2$ asymmetrically implies NC$_1$VN$_2$V is derived. (Note that this hypothesis 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.)

2.2 Preconsonantal vs. word-final nasals

If the difference between the amounts of coarticulation induced by onset and coda nasals is responsible for the generalization in (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$_2$, where 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$_2$, and 4 allow it (7–8).

(7) 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'

(8) 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+ŋarra/ → [kantu-ŋarra], *[kantu-karra] 'low-lying cloud…

There are potentially independent factors in play for each of the languages in (8). 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 the existence of words like [ndàmbà] 'rubber (p. 48), [ndama] 'to be wide open (p. 45), and [mboŋ] 'palm flower' (p. 29) in Essono's (2000) reference grammar suggests that this restriction is not fully general. The most straightforward interpretation of the discrepancies between descriptions is that NCD only applies 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 applies in forms suffixed by the ergative postposition [-ŋga] (e.g. /go:ɳbo:+ŋga/ →

[goːɳboː-ga] 'by the woman', McGregor p. 98), but generally not in monomorphemic words (e.g. [liɲbaɳɖi] 'a type of edible leaf') or across other morphological boundaries.[4] It is possible then to explain forms like [biɲbiɲ] 'crimson chat' (p. 61) by appealing to the morphologically specific nature of NCD. 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 2.3). 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 then expect NC_1VN_2 to be forbidden when N_2 is labial or velar, 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, and the result is deletion of the second nasal (/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 happens in Bilinara clusters) can be attributed to two factors. First, NCD never results in denasalization, which is consistent with the claim that IO-IDENT[nasal] (9) >> $*NCVN]_\sigma$ (10) in Bilinara. Second, assuming that in a homorganic nasal-stop sequence the place feature is shared between N and C, deletion of /ŋ/ from an input like /ɲunu+ɲ+pa+ŋku+lu/ would not result in the loss of the consonant's place feature, because that place feature would still be linked to the sufacing [k]. By contrast, the /n/ of /ŋumpin/ has no following consonant to share its place feature with, so deletion of that /n/ would result in the loss of its place feature as well. We can account for the failure of the final [n] in [ŋumpin] to delete by claiming that MAX[place] (11) dominates $*NCVN]_\sigma$ (and that place features in Bilinara cannot float or dock to other segments).

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

(10) $*NCVN]_\sigma$:
Assign one * for each $NCVN]_\sigma$ output sequence, where $]_\sigma$ denotes a syllable boundary. (See Section 5 for a reformulation of this constraint that appeals to auditory factors.)

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

As shown in (12-13), the ranking IO-IDENT[nasal], MAX[place] >> $*NCVN]_\sigma$ predicts that NCD should occur in NC_1VNC_2 but not NC_1VN_2. I assume that deletion of N_2 violates MAX-SEG (= a * for each input segment that lacks an output correspondent), but it would also be possible in (13) to view the loss of /ŋ/ as a consequence of fusion with /k/, which would violate UNIFORMITY (see Pater 1999). The identity of this constraint is not crucial. Furthermore, I do not consider candidates like *[…ɲ-a-ŋku…] (12) or *[ŋumin] (13), where violation of $*NCVN]_\sigma$ is avoided through deletion of some other segment; for brief discussion of repair strategies see Section 5.3.

[4] In Gooniyandi, homorganic and non-homorganic nasal-stop clusters cannot co-occur within morphemes, but this restriction is part of a larger ban on similar elements: stop-stop clusters, nasal-nasal clusters, and liquid-initial clusters are also not allowed to co-occur within a morpheme. For more information on the role of homorganicity in conditioning NCD and for possible explanations for these patterns along the general lines discussed here, see Stanton 2016a.

(12) Bilinara: N_2 is deleted in NC_1VNC_2

/…ɲ+pa+ŋku…/ [vel]	IO-IDENT[nasal]	MAX[place]	*NCVN]$_{\sigma}$	MAX-SEG
a. […ɲ-pa-ŋku…] [vel]			*!	
b. […ɲ-pa-kku…] [vel]	*!			
☞ c. […ɲ+pa+ku…] [vel]				*

(13) Bilinara: N_2 remains in NC_1VN_2

/ŋumpin/ [cor]	IO-IDENT[nasal]	MAX[place]	*NCVN]$_{\sigma}$	MAX-SEG
☞ a. [ŋumpin] [cor]			*	
b. [ŋumpit] [cor]	*!			
c. [ŋumpi]		*!		*

The larger point of this discussion is that, as predicted, *NC_1VNC_2 implies * NC_1VN_2. All potential counterexamples have plausible reanalyses.

In sum, the hypothesis developed here is that NCD is a response to an insufficiently distinct N–NC contrast. The implicational generalizations summarized in (14) are explicable given cross-linguistically typical patterns of nasal coarticulation and a further hypothesis that the greater the amount of nasalization in the vowel following NC_1, the harder it is to tell NC_1 apart from N.

(14) Summary of implicational generalizations
  a. A ban on NC_1VN_2V implies a ban on NC_1VNC_2.
  b. A ban on one of NC_1VN_2 or NC_1VNC_2 implies a ban on the other.

For this hypothesis to be correct, it must be the case that all languages exhibiting NCD also exhibit patterns of nasal coarticulation that are in line with the cross-linguistically common patterns described above. More specifically, it must be the case that in languages that ban NC_1VNC_2 but not NC_1VN_2V, the intermediate vowel in NC_1VNC_2 is more nasalized than that of NC_1VN_2V. This larger point has not been established and doing so is left for future work. But for fragmented evidence that some of the surveyed languages exhibit regressive nasal coarticulation, see: Whitehead 1964:5 for Bobangi, Wambui 2014 for Gikuyu, Ennever 2014:97 for Gurindji, Herbert 1977:114 for Luganda (though cf. Maddieson & Ladefoged 1993:277-8), Essono 2000:30 for Yaunde; for a more detailed case study, see below on Yindjibarndi.

2.3 Further asymmetries and evidence from Yindjibarndi

The hypothesis above has the potential to help us understand further language-specific restrictions on NCD. In Mori Bawah, for example, NCD applies when NC_2 is voiceless (15). In Yindjibarndi, NCD applies when NC_2 is labial or velar (16).

(15) 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'

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

- a. Applies when NC_2 is labial or velar
  - 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+karra/ → [kaŋkan-karra] '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 labial and velar NCs (or "peripheral" NCs, to use Australianist terminology) than preceding non-peripheral NCs or onset nasals. Below I verify that the prediction regarding Yindjibarndi is correct (I leave further investigation of Mori Bawah to future work).

To quantify patterns of nasal coarticulation, I selected 72 words from the UCLA Phonetics Archive in which the primary-stressed (initial) vowel is followed by an oral stop, an onset N, an NC (peripheral or non-peripheral), or a nasal-nasal cluster (in all cases, the first nasal is non-peripheral). Each word was repeated several times, which yielded a total of 213 tokens. Tokens are divided in (17) into four categories: those with a following oral stop (e.g. *thurdu*), a following onset nasal (e.g. *kamayi*), a following peripheral cluster (e.g. *thambi*), or a following non-peripheral cluster (e.g. *janda, kurnma*). The words here are limited to those in which a nasal appears only in the position of interest; words like *kuthiny* were not considered in order to avoid a potential confounding influence of long-distance nasalization. All tokens are produced by a single male speaker.

(17) Yindjibarndi tokens by following context (vowel of interest underlined)

	Following context	Number	Examples
a.	Oral stop	69	*thurdu, wijba*
b.	Onset nasal	42	*kamayi, kurni*
c.	Peripheral cluster	21	*thambi, kangkaj*
d.	Non-peripheral cluster	81	*janda, kurnma*

The compensated A1-P0 was measured at five equally-spaced timepoints throughout each token's first vowel, using Praat (Boersma & Weenink 2017) and the Nasality Automeasure Script Package

(Styler & Scarborough 2015; see Chen 1995, 1997 on A1-P0). Timepoints 1 and 5 were offset 5ms from the beginning and end of the vowel, so as to avoid undue influence from the neighboring consonants. Of 1065 possible measurements, the script took 1056. Results are in Figure 1. The *y* axis reflects the average compensated A1-P0; lower A1-P0 measures are correlated with an increased amount of nasalization. Graphs were created with R's ggplot2 package (Wickham 2009).

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

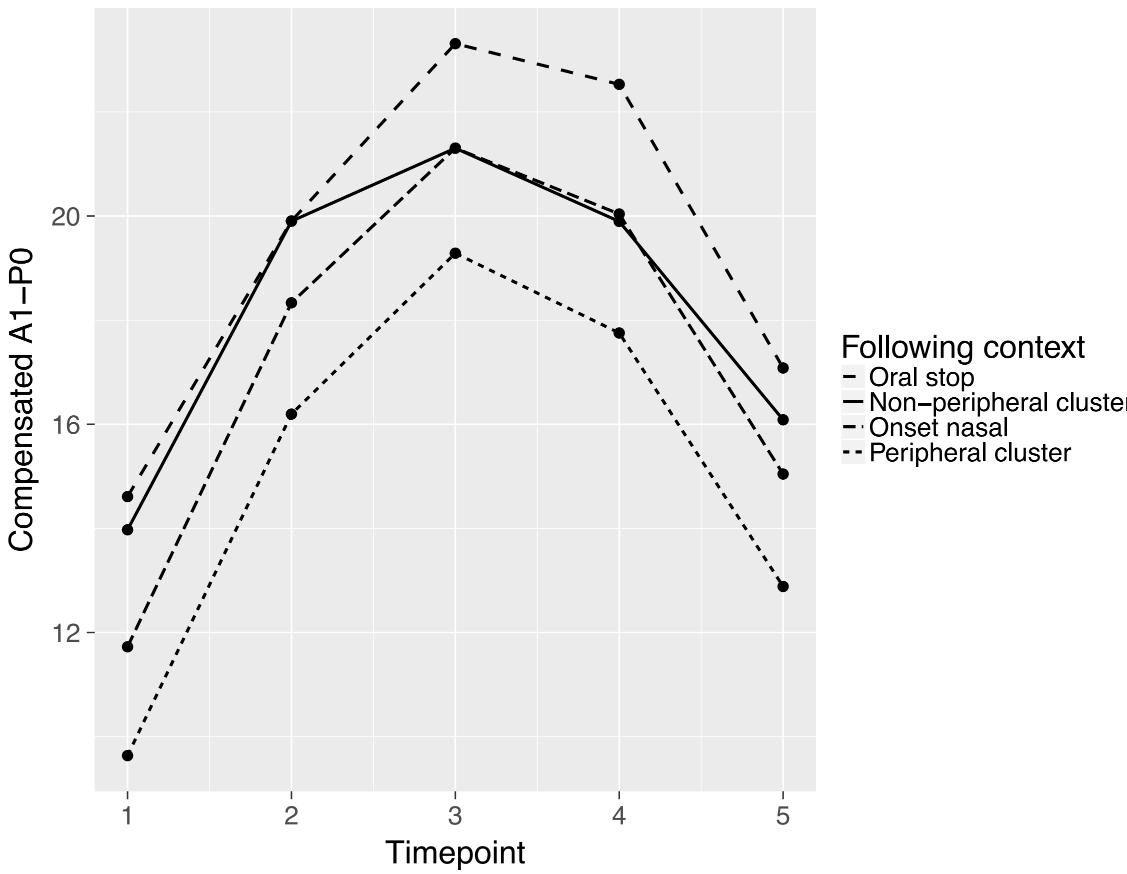


Figure 1 shows that the average A1-P0 of the vowels preceding peripheral NCs is lower at each timepoint than is the average A1-P0 of vowels in the other categories. This is exactly as predicted by the current hypothesis. The boxplots in Figure 2 zoom in to each timepoint and provide a sense of within-category variation (in each subfigure, triangles indicate the mean values).

To determine which differences were significant, a linear regression was fit to each timepoint using R's lm function. The dependent variable was compensated A1-P0 and the independent variable was the following context; the variable was dummy-coded with "peripheral cluster" treated as the baseline. The difference in A1-P0 between vowels preceding peripheral clusters vs. oral stops was significant at all timepoints at the $p < .05$ level or below; the difference between vowels preceding peripheral vs. non-peripheral clusters was significant at timepoints 1 and 2 at the $p < .05$ level and trending at timepoint 5 ($p = .052$). No other differences were significant.

Figure 2: compensated A1-P0 in Yindjibarndi vowels by timepoint
(O = “Oral stop”, NP = “Non-peripheral cluster”, N = “Onset nasal”, P = “Peripheral cluster”)

Fig. 2a: Timepoint 1

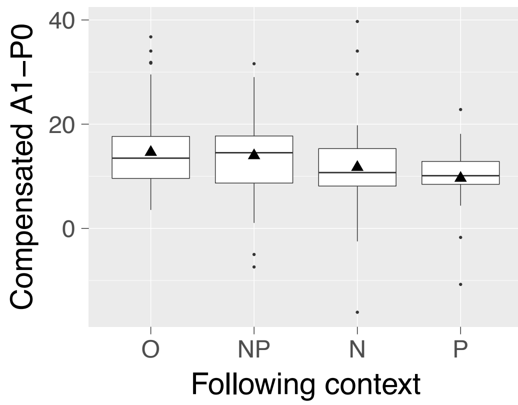


Fig. 2b: Timepoint 2

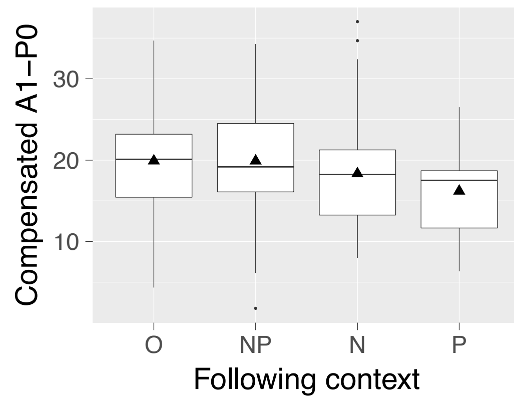


Fig. 2c: Timepoint 3

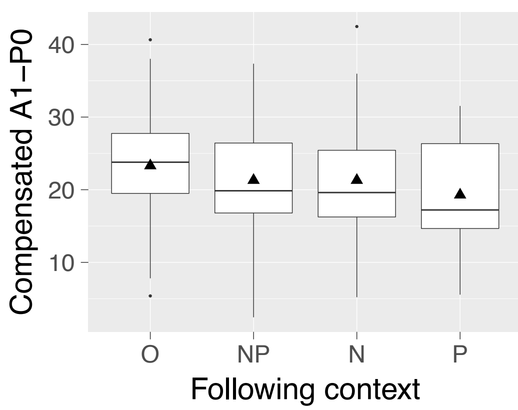


Fig. 2d: Timepoint 4

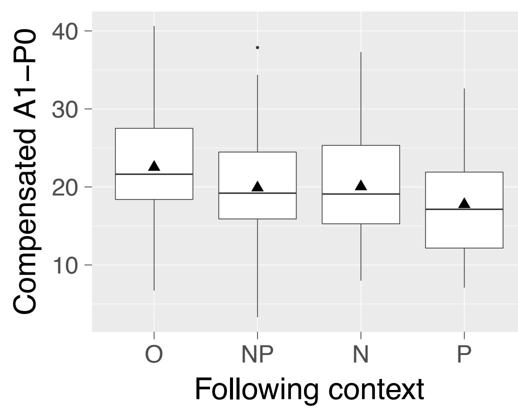
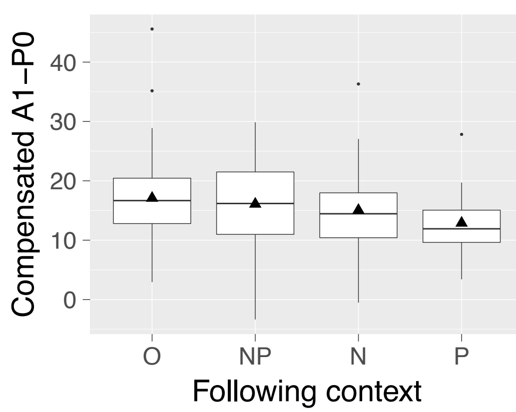


Fig. 2e: Timepoint 5



Assuming that this speaker is representative of the larger population, these results provide support for the hypothesis that NCD is linked to the acoustics of nasalization. In Yindjibarndi, the context in which NCD occurs (peripheral NC_2) is the context in which the vowel following NC_1 would be most nasalized. What is necessary to show 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 Properties of the left-hand context

The identity of the right-hand context plays a large role in determining whether or not NCD applies, but the identity of the left-hand context (e.g. NC$_1$ in NC$_1$VNC$_2$) can matter as well. I focus here on the roles of stop voicing (Section 3.1) and place of articulation (Section 3.2), and hypothesize that these generalizations are also linked to acoustic and perceptual factors: NCD becomes more likely as the salience of NC$_1$'s oral release decreases.

3.1 Stop voicing

A consistent generalization throughout the typology of NCD is that it rarely targets NC$_1$VNC$_2$ sequences with voiceless NC$_1$. In fact, the only language surveyed that exhibits NCD with voiceless NC$_1$ is Mori Bawah (illustrative data in (15)). (While NCs in languages like Gurindji and Yindjibarndi are often transcribed with graphemes indicating voicelessness, e.g. <p> or <k>, voicing in these languages is non-contrastive and post-N stops are generally voiced.)

Why might NCD prefer to target NC$_1$VNC$_2$ with 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, i.e. 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 that more directly supports 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[5], and the little available evidence suggests that it may hold of Luganda.

The Luganda recordings at the UCLA Phonetics Archive provide two near-minimal pairs that differ in the voicing of NC$_1$: [m̩bala] vs. [m̩paka] and [n̩fumba] vs. [n̩vumba]. Each word is produced once, by one speaker; oral releases were measured from the beginning of the burst until the onset of the vowel's modal voicing. The oral release of [m̩p] (11 ms.) is longer than that of [m̩b] (8 ms.), and the duration of frication for [n̩f] (181 ms.) is longer than that for [n̩v] (60 ms.). Spectrograms of the initial portion of these forms are in Figure 3; the oral release is annotated with its identity. Obviously, four tokens are not sufficient to establish any generalizations regarding asymmetries in stop release or frication length, so further investigation is necessary – of Luganda and of other languages where NCD applies with voiced NC$_1$. But given the generality of the voiced vs. voiceless

[5] 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.*

Figure 3: oral release durations in four Luganda forms

Figure 3a: release of [p] in [m̩paka] (11 ms.)

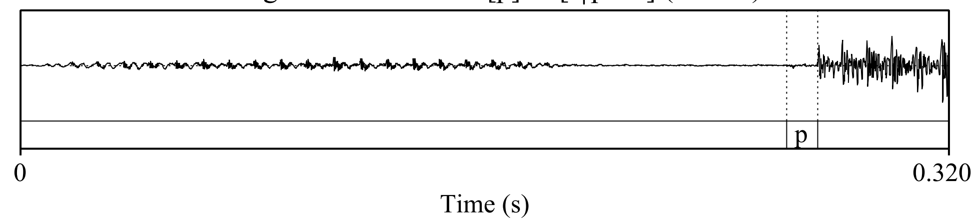


Figure 3b: release of [b] in [m̩bala] (8 ms.)

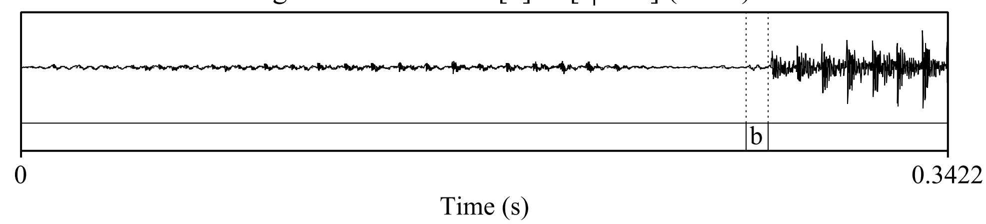


Figure 3c: frication of [f] in [n̩fumba] (181 ms.)

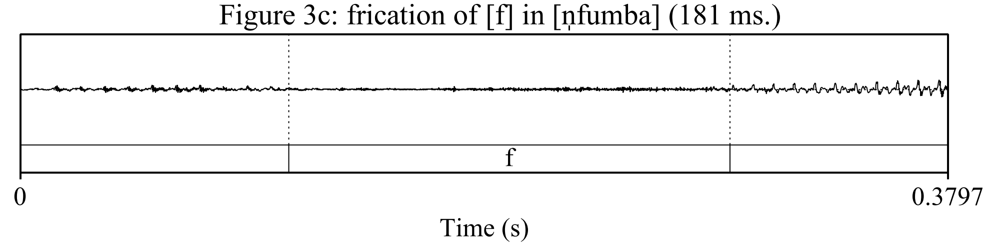
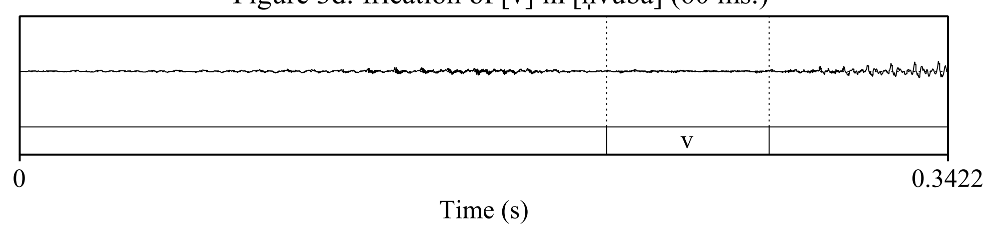


Figure 3d: frication of [v] in [n̩vuba] (60 ms.)



asymmetry in release salience, it seems reasonable to hypothesize that the cross-linguistic tolerance for NC_1VNC_2 with voiceless NC_1 can be linked to the longer release of voiceless NC.

According to the hypothesis of Licensing by Cue (Steriade 1997; Section 2.1), the hypothesis here predicts that 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 with voiceless NC_1 is Mori Bawah, and in this case there are independent reasons why the prediction is not testable. 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 (18).[6]

[6] Note that the Mori Bawah data seem to provide a counterexample to Pater's 1999 claim that voiceless NCs are universally marked relative to voiced NCs.

(18) 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'

The only context in which NCD is observable is that in which NC_1 is voiceless; these are the only kind of NC_1VNC_2 sequences that can arise in the relevant context. Thus the prediction that all NC_1VNC_2 sequences should undergo NCD regardless of NC_1's voicing has no real test cases.

3.2 Place of articulation and evidence from Ngaju Dayak

If the applicability of NCD is influenced by the length of NC_1's oral release, other factors that influence release length should also influence NCD. One such factor is place of articulation, which is well-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 substantial variation across the 18 languages studied (their p. 219). Given the existence of this variation, it is impossible to make universal predictions regarding any correlation between NCD and NC_1's place of articulation, but the hypothesis does predict that the two should correlate similarly with release length: 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, but one well-documented example comes from Ngaju Dayak. Table 1 (adapted from Blust 2012:373, whose data is from Hardeland 1859), summarizes the rate of NCD according to NC_1's place of articulation, as well as whether or not NCD is expected to occur. Across all 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 to occur, it applies most frequently when NC_1 is labial, less frequently when NC_1 is alveolar, even less frequently when NC_1 is velar, and least frequently when NC_1 is palatal.

Table 1: NCD in Ngaju Dayak

NCD expected?	NC_1 PoA	NCD applies?		
		Yes	No	Variable
Yes (NC_1VNC_2) No (NC_1VC_2V)	Bilabial (mb_1)	93% (63/67) 6% (9/159)	3% (2/67) 94% (150/159)	3% (2/67) –
Yes (NC_1VNC_2) No (NC_1VC_2V)	Alveolar (nd_1)	29% (2/7) 4% (3/75)	29% (2/7) 96% (72/75)	43% (3/7) –
Yes (NC_1VNC_2) No (NC_1VC_2V)	Palatal (ɲdʒ$_1$)	15% (2/13) –	85% (11/13) 100% (89/89)	– –
Yes (NC_1VNC_2) No (NC_1VC_2V)	Velar (ŋg$_1$)	64% (16/25) 9% (10/114)	36% (9/25) 91% (104/114)	– –

To assess which 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 (i.e. the counts for NC$_1$VNC$_2$). The dependent variable was whether or not NCD applies. The independent variable was NC$_1$'s place of articulation; the variable was helmert-coded, with comparisons between [mb]$_1$ vs. all others; [nd]$_1$ vs. [ɲdʒ]$_1$, [ŋg]$_1$; and [ɲdʒ]$_1$ vs. [ŋg]$_1$. Variable cases were counted as both NCD undergoers and non-undergoers. The results confirm that the rate of application for [mb]$_1$ is lower than the mean rate of application for the other categories ($z = 5.04$, $p < .001$), and that the rate of application for [ŋg]$_1$ is lower than the rate of application for [ɲdʒ]$_1$ ($z = 2.61$, $p < .01$). Unsurprisingly given the small number of forms with alveolar NC$_1$, the comparison between that category vs. palatal and velar NC$_1$ was not significant ($z = 0.73$, $p = .46$). Taking into account the hypothesis of this section, and given these results, we can make predictions about the phonetics of Ngaju Dayak voiced NCs: the average release length of [mb] should be shorter than the average release length of other categories, and the average release length of [ɲdʒ] should be shorter than [ɲdʒ].[7]

To test this prediction, data on the length of oral NC releases was collected from recordings of the New Testament in Ngaju Dayak, available from Bible.is.[8] 446 recordings of words containing prevocalic [mb], [nd], [ɲdʒ], or [ŋg] were obtained from Matthew and John. For each cluster, the length 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 approximately the same rate. 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. Waveforms of two tokens (one with a clear and observable stop release, and one without) are in Figure 4.

Figure 4: measuring oral stop releases in Ngaju Dayak

Figure 4a: observable stop release (R) in [handiai] (Matthew 1)

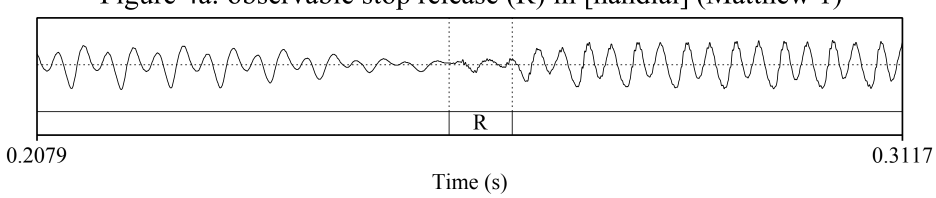
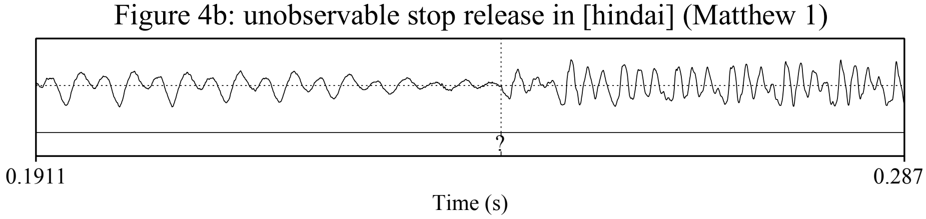


Figure 4b: unobservable stop release in [hindai] (Matthew 1)

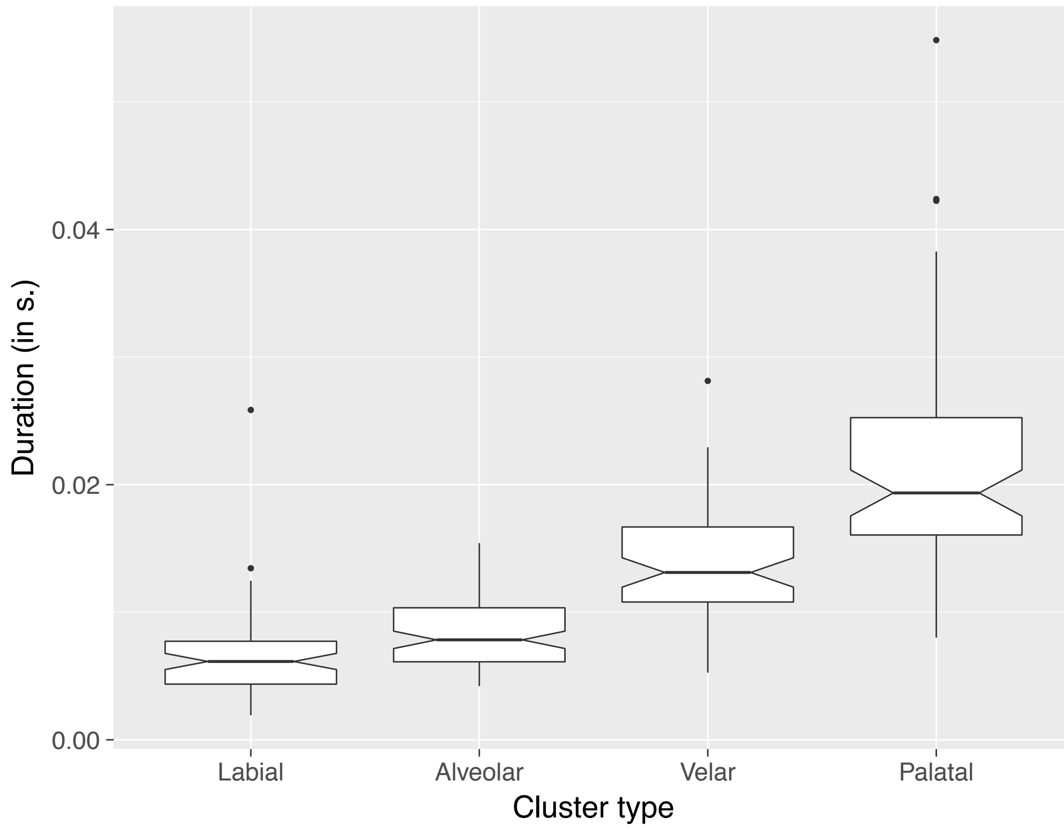


In total, 70 tokens of released [mb], 96 tokens of released [nd], and 65 tokens each of released [ɲdʒ] and released [ŋg] were obtained. The resulting measurements are summarized in Figure 5.

[7] 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 it is the case that in these languages the release of [ŋg] is shorter than the release of other voiced NC types. I have not collected the necessary acoustic data to test this prediction.

[8] I am grateful to Maddie Gilbert for her help with this portion of the project.

Figure 5: oral release length in Ngaju Dayak by place of articulation



These results confirm that asymmetries in release length are the inverse of asymmetries in NCD frequency (Table 1). [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. Results of a linear regression, fit with R's lm function, confirms that [mb] releases are shorter than the others (t = -11.21, $p < .001$); [nd] releases are shorter than [ŋg] and [ɲdʒ] releases (t = -13.53, $p < .001$); and [ŋg] releases are shorter than [ɲdʒ] releases (t = -8.44, $p < .001$).

Among the 149 recordings for which there was no observable release, there were 66 tokens of [mb], 49 tokens of [nd], 27 tokens of [ŋg], and 7 tokens of [ɲdʒ]. As shown in (19), the proportion of tokens with observable release is negatively correlated with the length of release when observable: [mb] has the highest rate of non-observable release, then [nd], then [ŋg], then [ɲdʒ].

(19) Rates of observable and non-observable release by place of articulation

	Observable release	Non-observable release	% observable
Labial [mb]	70	66	51.5%
Alveolar [nd]	96	49	66.2%
Velar [ŋg]	65	27	70.1%
Palatal [ɲdʒ]	65	7	90.3%

A logistic regression, fit with R's glm function, finds significant differences between [mb] vs. all others (t = -5.12, $p < .001$), [nd] vs. [ŋg] and [ɲdʒ] (t = -2.75, $p < .01$), and [ŋg] vs. [ɲdʒ] (t = -2.77,

$p < .01$), confirming that the rate and the length of observable release are correlated. Conclusions drawn from this could either be that shorter releases are more likely to be obscured by noise, or that they are more likely to be absent altogether. Given the quality of the recordings it is difficult to know which is correct. In any case, the results of this small study indicate that there is a plausible correlation in Ngaju Dayak between the rate at which NC_1VNC_2 sequences are repaired by NCD and the average length of NC_1's oral release.

4 Experimental support

The proposed explanation 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 (20).

(20) 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 fully supported in their specific form. Regarding (20a): Beddor & Onsuwan (2003) show that Ikalanga speakers' ability to correctly identify [mb] as such is negatively impacted by the presence of nasalization in a following vowel: speakers correctly identify [mb] most frequently when followed by a fully 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 vowel that is completely nasal. Showing that perception of NC depends on the duration of nasalization immediately following the release is however 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 NC's release), and thus Beddor & Onsuwan's (2003) results do not necessarily provide support for (20a). Regarding (20b), Beddor & Onsuwan (2003) show that Ikalanga speakers' ability to correctly identify [mb] as such is impacted by the duration of the oral closure and release burst: averaging across following vocalic contexts, correct identification rates of [mb] were highest when [mb]'s oral closure and release burst was 27 ms., lower when it was 18 ms., still lower when it was 9 ms., and lowest when it was absent. These results provide support for the general idea that perception of NC is dependent on the salience of its oral release, but not for the specific hypothesis in (20b).

This section reports the results of an AX discrimination task designed to investigate the hypotheses as they are formulated in (20). In what follows I show that both are largely borne out.

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 primarily 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 (20a) 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.

In order 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 one of /p/, /t/, or /k/; the second consonant or consonant sequence (C_2) was one of /m/, /mb/, /mp/, /n/, /nd/, /nt/, /ɲ/, or /ɲtʃ/; and the third consonant or consonant sequence (C_3) was one of /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 presented with a list containing these 120 forms, plus a filler form at either end, and was asked to read through 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 (21)). 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.

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

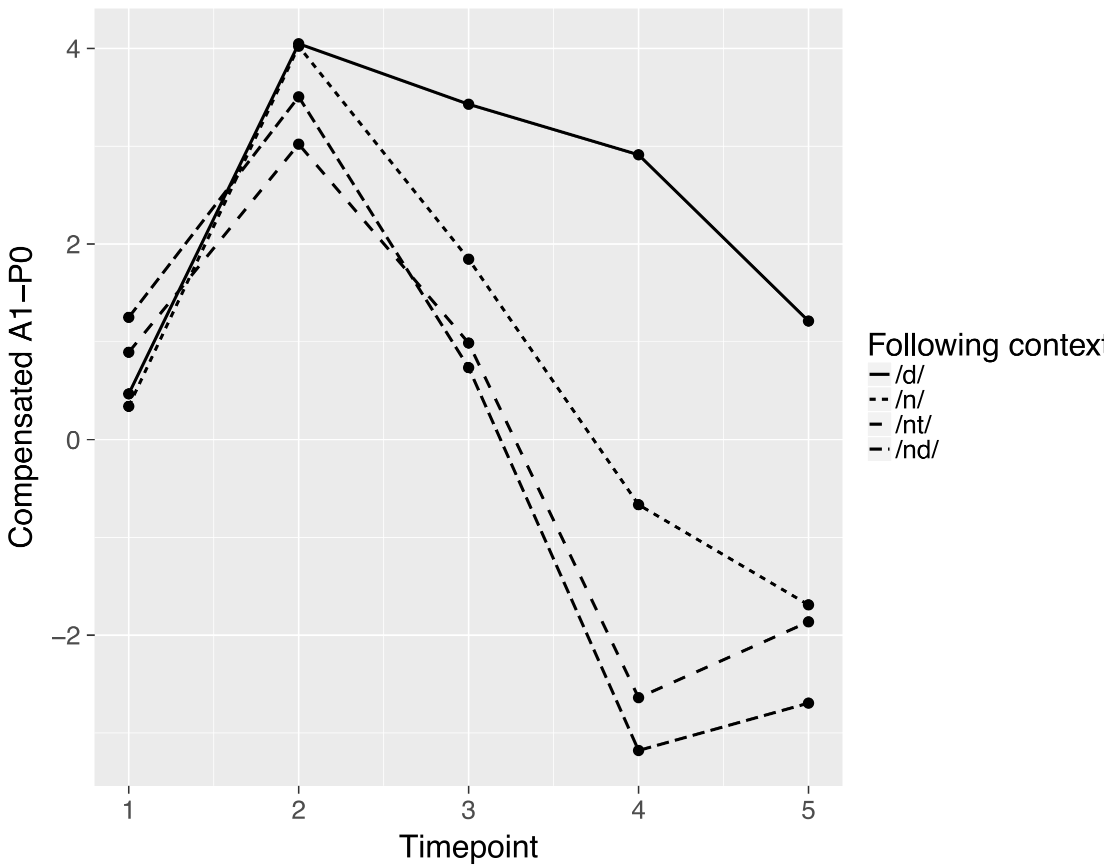
Same		Different	
Comparison	Example	Comparison	Example
m–m	*tamada-tamada*	m–mb	*tamada-tambada*
mb–mb	*tambada-tambada*	mb–m	*tambada-tamada*
n–n	*tanada-tanada*	n–nd	*tanada-tandada*
nd–nd	*tandada-tandada*	nd–n	*tandada-tanada*

An AX task with these items allows us to test the hypotheses in (20) as follows. First, varying the identity of C_3 allow 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 allow us to test the hypothesis that discrimination of N–NC should depend on the length of NC's oral release. If releases of [nd] are longer than those of [mb], for example, then we would 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 (and not just those incorporated into the stimuli) was made to heighten statistical power by increasing the number of tokens in each comparison group (see Styler & Scarborough 2015 on why this is the recommended approach to A1-P0 measurement). The compensated A1-P0 was measured at five equally spaced timepoints throughout the vowel between C_2 and C_3 (e.g. *pambada*); timepoints 1 and 5 were offset 5 ms. from the beginning and end of the vowel. Of 1200 possible measurements, the script was able to take 1173. Results are in Figure 6. As before, the *y* axis reflects the average compensated A1-P0; lower A1-P0 measures are correlated with an increased amount of nasalization.

Figure 6: 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 the vowel's midpoint: the mean A1-P0 for vowels preceding /d/ is considerably higher at timepoints 3-5 than are the mean values of vowels that precede a nasal, but this difference is effectively neutralized at earlier timepoints. Second, the amount of anticipatory nasalization depends on the prevocalic vs. non-prevocalic status 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 7 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 7: compensated A1-P0 in Spanish vowels by timepoint

Fig. 7a: Timepoint 1

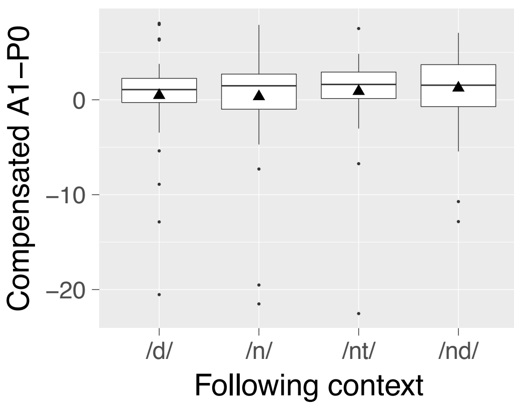


Fig. 7b: Timepoint 2

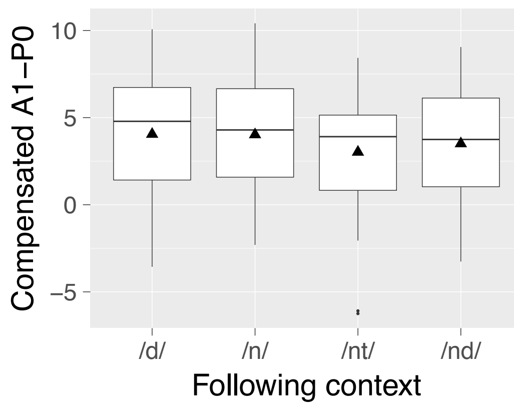


Fig. 7c: Timepoint 3

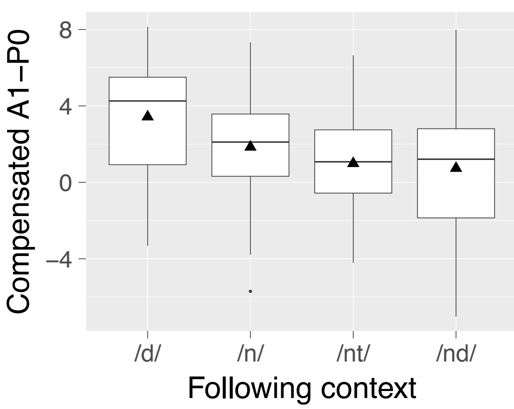


Fig. 7d: Timepoint 4

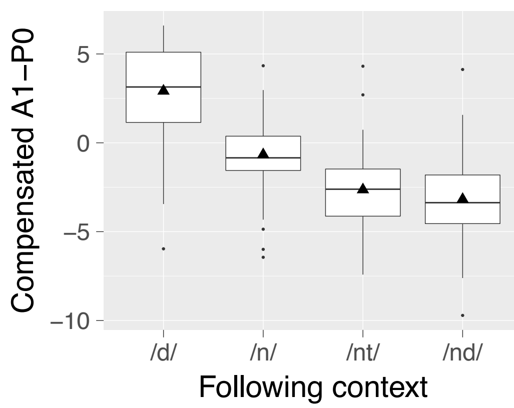
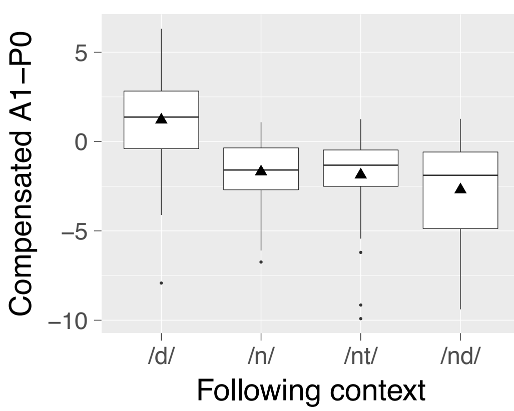


Fig. 7e: Timepoint 5



To determine which differences were meaningful, a linear regression was fit to the data at each timepoint with R's lm function. The dependent variable was compensated A1-P0; the independent variable was the identity of C_3. This variable was helmert-coded: comparisons were between the oral and nasal contexts (/d/ vs. /n/, /nt/, /nd), the prevocalic and non-prevocalic nasal contexts (/n/

vs. /nt/, /nd/), and the voiceless and voiced NCs (/nt/ vs. /nd/). Generally speaking, the models found significant asymmetries in A1-P0 between the oral and nasal context2s as well as the prevocalic vs. non-prevocalic nasal contexts at the midpoint of the vowel and later. The full results are summarized in (22). A positive coefficient indicates that the first term in the comparison has a higher A1-P0 (i.e. is less nasal); a negative coefficient indicates that the second term's is higher.

(22) 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 = -0.52, 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)	Yes (t = 2.17, p < .05)	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 attempting 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. These predictions are in (23).

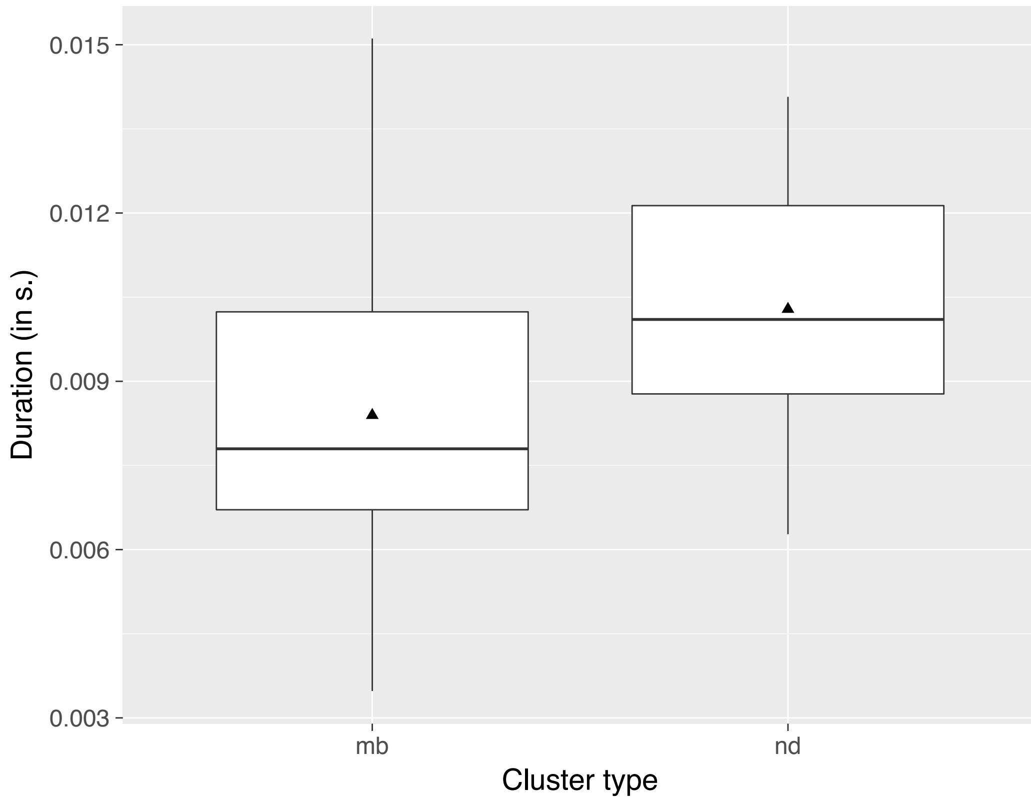
(23) Predictions given properties of vowel at timepoints 3-5

<table>
<tr><td>C_3</td><td>Sample item</td><td>/d/ vs. others</td><td>/n/ vs. /nd/, /nt/</td><td>/nd/ vs. /nt/</td></tr>
<tr><td>/d/</td><td>tamada-tambada</td><td>More sensitive</td><td></td><td rowspan="2"></td></tr>
<tr><td>/n/</td><td>tamana-tambana</td><td rowspan="3">Less sensitive</td><td>More sensitive</td></tr>
<tr><td>/nt/</td><td>tamanda-tambanda</td><td rowspan="2">Less sensitive</td><td rowspan="2">No difference</td></tr>
<tr><td>/nd/</td><td>tamanta-tambanta</td></tr>
</table>

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 length differs by place of articulation. To quantify this, I measured the length 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 8 shows that the release of /nd/ is longer than the releases of /mb/ (t = 2.63, p < .05, linear regression).

The prediction in this case is straightforward: listeners should 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 lengths 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.

Figure 8: release length of [mb] and [nd]



/mb/ distinction than they are to /n/ vs. /nd/, it is reasonable to expect that listeners would also be sensitive to greater differences in release length (like that between /mb/ vs. /ndʒ/ or /mp/).[9]

4.3 Procedure

39 participants, all native English speakers, were recruited from a combination of flyers, the NYU Facebook community, and Craigslist. All participants completed the experiment wearing Audio Technica ATH-ANC9 headphones in a quiet room 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

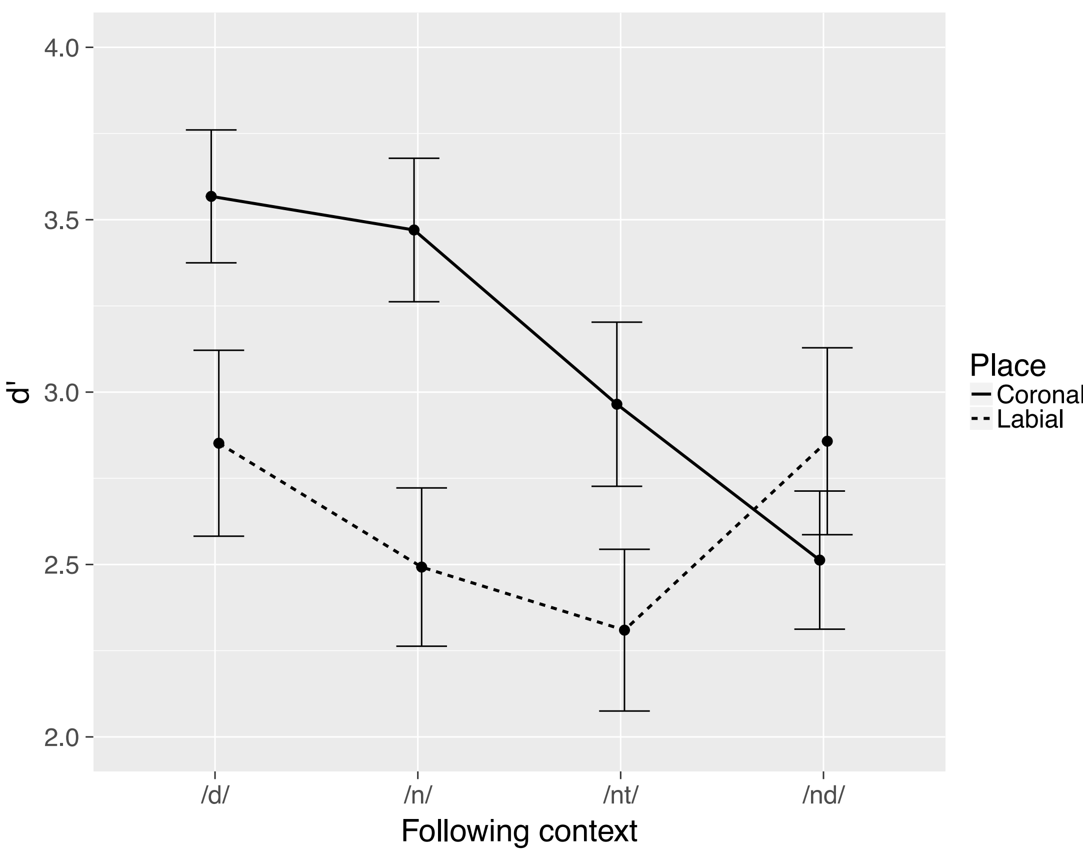
[9] It is also possible that listeners will respond to other differences between the labial and coronal series, for example aspects of their overall duration. The mean durations for the relevant N–NC pairs are: /m/ (106 ms.), /n/ (117 ms.), /mb/ (160 ms.) and /nd/ (156 ms.). A linear regression finds a significant interaction of consonant type and place, such that the N–NC durational difference is magnified in the labial series; $t = 2.00$, $p < .05$). If listeners' decisions about whether two recordings are "same" or "different" depend on the N–NC durational difference, we might expect them to be more sensitive to the distinction between /m/ and /mb/ than they are to the distinction between /n/ and /nd/, as a function of the labial series' greater durational difference. The fact that listeners did not behave this way (see Section 4.4) indicates that they pay attention to differences in the length of the release, not to overall durational properties of the consonants.

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.

4.4 Results and discussion

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).[10] These d' values were obtained in Excel using the formula NORMINV(h,0,1)-NORMINV(f,0,1), where h = hit rate and f = false alarm rate. The lower the d', the less sensitive participants were to whether items in that particular group were "same" or "different".

Figure 9: averaged d' across participants by C_2 and C_3 identity



[10] 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%).

A mixed linear regression was fit to these d' values using the lmer function of R's lme4 package (Bates et al. 2015). The response variable was d'; dependent 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 labial as the reference level), and an interaction between the two. By-participant random slopes for C_3's identity and C_2's place of articulation were also included. *p* values in (24) were calculated with R's lmerTest package (Kuznetsova et al. 2017).[11]

(24) Summary of full statistical model

	Factor	Coefficient	*t* value	Significant?
a.	Intercept	2.88	–	–
b.	C_3: /d/ vs. all others	0.44	3.69	Yes ($p < .001$)
c.	C_3: /n/ vs. /nt/, /nd/	0.32	2.15	Yes ($p < .05$)
d.	C_3: /nt/ vs. /nd/	0.05	0.29	No ($p > .1$)
e.	C_2: Coronal	0.25	4.21	Yes ($p < .001$)
f.	C_3: /d/ vs. all others * C_2: Coronal	0.14	1.22	No ($p > .1$)
g.	C_3: /n/ vs. /nt/, /nd/ * C_2: Coronal	0.41	3.31	Yes ($p < .01$)
h.	C_3: /nt/ vs. /nd/ * C_2: Coronal	0.50	3.48	Yes ($p < .001$)

The main effect in (24b) confirms that N–ND is more perceptible when C_3 is /d/ than when it is /n/, /nt/, or /nd/ (e.g. Δ *pamada-pambada* > Δ *pamana-pambana, pamanda-pambanda, pamanta-pambanta*). The main effect in (27e) confirms that, across contexts, the N–ND distinction is more perceptible for coronals than it is for labials (e.g. 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. (This latter correlation also confirms that listeners' discrimination of N–ND is at least partially dependent on information later in the vowel.)

The interactions in (27g-h) indicate that the further comparisons across C_3 contexts were dependent on C_2's identity. To investigate these effects more directly, separate models were fit to the labial and coronal data, including only those d' values where C_3 = /n/, /nt/, or /nd/. The dependent variable was the identity of C_3 (helmert-coded, with comparisons between /n/ vs. /nt/, /nd/ and /nt/ vs. /nd/), and a random intercept was included for participant.[12] These models are summarized in (25-26).

(25) Summary of statistical model for coronals

	Factor	Coefficient	*t* value	Significant?
a.	Intercept	2.98	–	–
b.	C_3: /n/ vs. /nt/, /nd/	0.73	4.20	Yes ($p < .001$)
c.	C_3: /nt/ vs. /nd/	0.45	2.25	Yes ($p < .05$)

(26) Summary of statistical model for labials

	Factor	Coefficient	*t* value	Significant?
a.	Intercept	2.88	–	–
b.	C_3: /n/ vs. /nt/, /nd/	-0.09	-0.44	No ($p > .1$)
c.	C_3: /nt/ vs. /nd/	-0.54	2.30	Yes ($p < .05$)

[11] The call was lmer(d'~C_3*C_2+(1+C_3+C_2|Subject)). Including an interaction results in an improved fit relative to an otherwise identical model with no interaction (χ (3) = 23.67, $p < .001$). Due to the low number of observations, including an interaction in the random effects structure was not possible.

[12] Calls were lmer(d'~C_3+(1|Subject)). Due to the low number of observations, a random slope for C_3 was not included.

For the coronals, (25b) indicates that [n–nd] is more perceptible when C_3 is /n/ than when it is /nt/ or /nd/ (e.g. ∆ *panana-pandana* > ∆ *pananda-pandanda, pananta-pandanta*). This comparison across contexts was not significant for the labials, indicating that the corresponding main effect in (24) 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/ (e.g. ∆ *pananta-pandanta* > ∆ *pananda-pandanda*); for the labials discrimination was better before /nd/ (e.g. ∆ *pamanda-pambanda* > ∆ *pamanta-pambanta*).

The coronal response data support the hypothesis, based on the acoustic data summarized in Figures 6, 7, and (22), that the acoustic distance between N and ND before /n/ should be greater than before /nd/, /nt/. The labial response data do not support this hypothesis. Furthermore, neither of the significant comparisons between C_3 = /nd/ and C_3 = /nt/ were predicted given the acoustic data. Subsetting the nasalization data by C_2's place of articulation reveals no obvious difference in acoustics that could explain the observed differences in response, and thus further work is needed to determine to which of these unexpected interactions are replicable and what their explanation is.

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 (27).

(27) 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 largely support (27a-b) and allow us to reformulate (27a) in a more specific way: the more nasalized at its midpoint a vowel following NC is, the more confusable N–NC is. Narrowly, these results provide evidence for the crucial hypotheses of the perceptually-based account of NCD developed in Sections 2-3; more broadly, they provide the first indication I am aware of that A1-P0 is a useful perceptual measure (cf. Styler 2015) and they add to the body of evidence that perception of consonantal contrasts can be affected by non-local information (e.g. Gallagher 2010).

5 Analysis of NCD

The acoustic and behavioral results discussed above support the hypothesis that NCD is motivated by constraints on the N–NC contrast: NCD occurs when the two categories are not sufficiently distinct. Building on the experimental results, we can specify two conditions that must be satisfied for the N–NC contrast to be maximally distinct. First, NC must be followed by a vowel that is sufficiently oral at its midpoint. Second, NC must have a sufficiently long oral release. While these are likely not the only conditions that must be satisfied for N–NC to be sufficiently distinct (Beddor & Onsuwan's 2003 results suggest, for example, that N must also be followed by a vowel that is sufficiently nasal) they were the two conditions investigated in this study and their formalization is sufficient to provide an analysis of the patterns of interest.

The proposed analysis is framed in Dispersion Theory (Flemming 2002), as Dispersion Theory's MINDIST constraints allows the grammar to reference the perceptibility of a contrast in different contexts. The reasons for assuming a synchronic analysis are discussed briefly in Section 5.3.

5.1 Influence of the righthand context

The requirement that an NC be followed by a vowel of sufficient orality can be encoded as a set of MINDIST constraints that stringently penalize N–NC contrasts in which NC is followed by a vowel with increasing amounts of nasality. Let us assume that language learners can divide vowels into a finite number of categories, according to the average amount of coarticulatory nasalization they exhibit at their midpoint; I will refer to these categories as ORAL$_x$, where x is the category number.

The number and referent of these categories is assumed to be language-specific. We might imagine, for example, that differences in nasalization patterns of Spanish and Yindjibarndi (as documented in Sections 2 and 4) might cause the categories established by a learner to vary commensurably. In Spanish, there is evidence for roughly three categories: ORAL$_1$ (V/_ND, NT), ORAL$_2$ (V/_NV), and ORAL$_3$ (V/_C). In Yindjibarndi, there is also evidence for roughly three categories: ORAL$_1$ (V/_PC, peripheral cluster), ORAL$_2$ (V/_NPC, non-peripheral cluster; V/_NV), and ORAL$_3$ (V/_C) (28). What is universal here is the existence of the categories; their content is language-specific.

(28) Differing ORAL$_x$ values for Spanish and Yindjibarndi

ORAL$_x$ value	Spanish referents	Yindjibarndi referents
1	V/_NC (e.g. *pamanda*)	V/_PC (e.g. *yumbu* 'sharp')
2	V/_NV (e.g. *pamana*)	V/_NPC (e.g. *banda* 'shallow') V/_NV (e.g. *kumirn* 'mosquito')
3	V/_C (e.g. *pamada*)	V/_C (e.g. *wubu* 'box')

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$_2$ (29-30).[13]

(29) 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 larger along the ORAL scale.

(30) 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 larger along the ORAL scale.

The contrasts that satisfy and violate (29-30) will differ on a language-specific basis. In Spanish, *pamana-pambana* (ORAL$_2$) and *pamada-pambada* (ORAL$_3$) satisfy MINDIST N–NC: V-ORAL$_2$; *pamanta-pambanta* (ORAL$_1$) violates it. In Yindjibarndi, hypothetical *amanda-ambanda*, *amana-ambanda* (ORAL$_2$) and *amada-ambada* (ORAL$_3$) satisfy MINDIST N–NC: V-ORAL$_2$; *amamba-ambamba* (ORAL$_1$) violates it. I assume that cross-linguistic differences in the lefthand 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.

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

[13] The MINDIST constraints in (29-30) make the implicit assumption that only N–NC contrasts are affected by the amount of nasalization in a following vowel. While it is possible that the perceptibility of the N–C or other C–CC contrasts is similarly affected, I am not aware of any typological or experimental evidence along these lines.

The input-output mapping /pamanda$_i$, pambanda$_j$/–[pamanda$_i$, pambanda$_j$] satisfies *MERGE; the mapping /pamanda$_i$, pambanda$_j$/–[pamanda$_{i,j}$], with neutralization of N–NC, violates it. A factorial typology of (30-32) predicts three possible types of system. If *MERGE >> MINDIST N–NC: V-ORAL$_2$, MINDIST N–NC: V-ORAL$_3$, NCD will not occur in any environment. This is the case in Spanish, for example, where contrasts like *amanta-ambanta* are licit, even though *mb* is followed by a vowel whose ORAL category is 1 (32). I indicate ORAL values with numeric subscripts following the relevant segment, and correspondence indices with alphabetic subscripts.

(32) Spanish: *MERGE undominated, no NCD

	/pamanta/$_i$	/pambanta/$_j$	*MERGE	MD N–NC: V-ORAL$_2$	MD N–NC: V-ORAL$_3$
☞a.	[pama$_1$nta]$_i$	[pamba$_1$nta]$_j$		*	*
b.	[pama$_1$nta]$_{i,j}$		*!		

In the second type of system, where *MERGE is ranked between the two MINDIST constraints, NCD occurs in only those environments where the N–NC contrast is least perceptible. This is the case in Yindjibarndi, where NC$_1$VNC$_2$ is only repaired given a peripheral (labial or velar) NC$_2$ (33). In other contexts, NC$_1$VNC$_2$ is licit (34). (The tableaux below consider four-membered candidates so that *MERGE can be evaluated; the repair to insufficiently distinct N–NC$_1$ in Yindjibarndi involves removal of the nasalization in the intervening vowel through neutralization of the C-NC$_2$ contrast. See Section 5.3 for brief discussion of repair strategies.)

(33) Yindjibarndi: NCD when NC$_2$ is peripheral (V = ORAL$_1$)

	/muntimpa/$_i$ /muntipa/$_k$	/munimpa/$_j$ /munipa/$_l$	MD N–NC: V-ORAL$_2$	*MERGE	MD N–NC: V-ORAL$_3$
a.	[munti$_1$mpa]$_i$ [munti$_3$pa]$_k$	[muni$_1$mpa]$_j$ [muni$_3$pa]$_l$	*!		*
☞b.	[munti$_3$pa]$_{i,k}$	[muni$_1$mpa]$_j$ [muni$_3$pa]$_l$		*	

(34) Yindjibarndi: no NCD when NC$_2$ is non-peripheral (V = ORAL$_2$)

	/kaŋkanta/$_i$	/kaŋanta /$_j$	MD N–NC: V-ORAL$_2$	*MERGE	MD N–NC: V-ORAL$_3$
☞a.	[kaŋka$_2$nta]$_i$ [kaŋka$_3$ta]$_k$	[kaŋa$_2$nta]$_j$ [kaŋa$_3$ta]$_l$			*
b.	[kaŋka$_3$ta]$_{i,j}$	[kaŋa$_2$nta]$_j$ [kaŋa$_3$ta]$_l$		*!	

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

Before moving on, it is worth addressing how the major generalization in Section 2 – that repair of NC$_1$VN$_2$V in a given language implies repair of NC$_1$VNC$_2$ – can be captured under this analysis. If Schourup (1973) and others are correct in claiming that NC universally induces more regressive nasal coarticulation than does NV, we might expect all language learners to place vowels preceding NC in some category ORAL$_x$, vowels preceding NV in some category ORAL$_{x+1}$, and vowels preceding oral consonants in some category $Oral_{x+2}$. If this holds, the implicational generalization follows directly from the activity of MINDIST constraints along the ORAL scale: MINDIST N–NC: V-$ORAL_{x+1}$ penalize both $N_1V_xNC_2$–$NC_1V_xNC_2$ and $N_1V_{x+1}N_2V$–$NC_1V_{x+1}N_2V$, while MINDIST N–NC: V-$ORAL_y$ penalizes only $N_1V_{x+2}NC_2$–$NC_1V_{x+2}NC_2$ (35).

(35) Assessment of N–NC given varying righthand contexts

			MD N–NC: V-$ORAL_{x+1}$	MD N–NC: V-$ORAL_{x+2}$
a.	$N_1V_xNC_2$	$NC_1V_xNC_2$	*	*
b.	$N_1V_{x+1}N_2V$	$NC_1V_{x+1}N_2V$		*
c.	$N_1V_{x+2}C_2$	$NC_1V_{x+2}C_2$		

The point is that no MINDIST constraint can penalize a more distinct contrast to the exclusion of a less distinct one. In this case, there is no possible MINDIST N–NC: NC/_V-$ORAL_x$ constraint that can penalize (35c) to the exclusion of (35a,b), or (35b) to the exclusion of (35a). Given this, the implication that repair of NC_1VNC_2 implies repair of NC_1VN_2V is derived. What remains to be shown, as noted in Section 2, is that the surveyed languages that differentiate between NC_1VNC_2 and NC_1VN_2V in this way do in fact exhibit more nasal coarticulation before NC.

5.2 Influence of the lefthand context

The evidence presented in this paper suggests that internal properties of the NC play an independent role in the perception of N–NC. First, Section 4 discusses evidence that listeners are significantly less sensitive to the contrast between [m-mb] (where the oral release was shorter) than they were to the contrast between [n-nd] (where the oral release was longer) across following contexts. Second, contrasts between N–NC are occasionally neutralized even when the following vowel is presumably oral. The count data from Ngaju Dayak (Table 1), for example, shows that while N–NC neutralization preceding VC is less common than neutralization preceding VNC, it still occurs (e.g. /maN+bili/ → [mamili] 'buy', /maN+buat/ → [mamuat] 'load cargo'; Blust 2012:375).

I formalize this with MINDIST constraints along the release (REL) dimension. These constraints require NC to have an oral release of at least a certain length to be sufficiently distinct from N. Here too I assume that learners are capable of grouping NCs into separate categories, depending on the length of their releases; the exact constitution of the categories depends on language-specific asymmetries in release length. The fact that NCD only rarely targets NC_1VNC_2 when NC_1 is voiceless suggest 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 Ngaju Dayak data suggests that these categories can be more fine-grained; it is useful in this case to assume that voiced NCs can be broken into categories as well (36).

(36) 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 (37-39).

(37) 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.

(38) 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.

(39) 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 a language like 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, as well as 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 along the REL dimension in (37-39), *MERGE (31), and MINDIST N–NC: V-ORAL_2 (29); 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 in (40).

(40) 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_1VNC_2 context, [m-mb] neutralizes. Numeric subscripts indicate a value along the ORAL or REL scale; alphabetical subscripts indicate correspondence.

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

		weight:	6.07	4.24	2.92	0.82		
	$/mV_1NC/_i$	$/mb_1V_1NC/_j$	*MERGE	MINDIST N–NC: V-ORAL_2	MINDIST N–NC: NC-REL_4	MINDIST N–NC: NC-REL_2	Harmony	Prob.
a.	$/mV_1NC/_i$	$/mb_1V_1NC/_j$		*	*	*	7.98	13.0%
b.	$/mV_1NC/_{i,j}$		*				6.07	87.0%

In the NC_1VC_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 in (42), this results in a lower (though correctly non-zero) probability that neutralization occurs in this context.

(42) 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 below. The model captures the preference for N–NC_1 neutralization in the VNC context as compared to the VC context. It also captures the fact that the rate of N–NC_1 neutralization is to some extent dependent on the average length of the NC's oral release: palatal contrasts, for example, are overall less likely to undergo neutralization than are labial contrasts.

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

Input	Outputs	Observed freq.	Predicted freq.	**Difference**
mVNC–mbVNC	mVNC–mbVNC	5.8% (4/69)	13.0% (9/69)	**+7.2% (5)**
	mVNC	94.2% (65/69)	87.0% (60/69)	**-7.2% (5)**
mVCV–mbVCV	mVCV–mbVCV	94.3% (150/159)	91.2% (145/159)	**-3.1% (5)**
	mVCV	5.7% (9/159)	8.8% (14/159)	**+3.1% (5)**
nVNC–ndVNC	nVNC–ndVNC	50.0% (5/10)	25.2% (3/10)	**-24.8% (2)**
	nVNC	50.0% (5/10)	74.8% (7/10)	**+24.8% (2)**
nVCV–ndVCV	nVCV–ndVCV	96.2% (75/78)	96.0% (75/78)	**-0.2% (0)**
	nVCV	3.8% (3/78)	4.1% (3/78)	**+0.2% (0)**
ɲVNC–ɲdʒVNC	ɲVNC–ɲdʒVNC	84.6% (11/13)	86.2% (11/13)	**+1.6% (0)**
	ɲVNC	15.4% (2/13)	13.8% (2/13)	**-1.6% (0)**
ɲVCV–ɲdʒVCV	ɲVCV–ɲdʒVCV	100.0% (89/89)	99.8% (89/89)	**-0.2% (0)**
	ɲVCV	0.0% (0/89)	0.0% (0/89)	**+0.2% (0)**
ŋVNC–ŋgVNC	ŋVNC–ŋgVNC	36.0% (9/25)	25.2% (6/25)	**-10.8% (3)**
	ŋVNC	64.0% (16/25)	74.8% (19/25)	**+10.8% (3)**
ŋVCV–ŋgVCV	ŋVCV–ŋgVCV	91.2% (104/114)	95.9% (109/114)	**+4.7% (5)**
	ŋVCV	8.8% (10/114)	4.1% (5/114)	**-4.7% (5)**

Note that 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 for this prediction 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 appealing to the factors discussed here.

5.3 Typology of repairs and evidence for synchronic activity

To summarize, the claim is that NCD is governed by three types of constraints: MINDIST constraints that require NC to be followed by a sufficiently oral vowel; MINDIST constraints that require NC to have a sufficiently long release; and *MERGE, which disprefers contrast neutralization. If this analysis is correct, it lends support to the more general hypothesis that considerations of perceptual distinctiveness are an integral part of speakers' phonological competence (Flemming 2002, *a.o.*). But it is worth considering 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 approach 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 (43), N_1 (44), or N_2 (45) (see also Jones 2000).[14]

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

a.	/maN+bando/	→	[mamando]	'turn against'
	/maN+bagi/	→	*[mambagi]*	*'divide'*
b.	/maN+gundu/	→	[maŋundul]	'wrap up'
	/maN+gila/	→	*[maŋgila]*	*'drive crazy'*

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

a.	/kaɲɟu+mpal/	→	[kaɲɟupal]	'across below'
	/kajiɾa+mpal/	→	*[kajiɾampal]*	*'across the north'*
b.	/kanka+mpa/	→	[kankapa]	'upstream'
	/kani+mpa/	→	*[kanimpa]*	*'downstream'*

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

a.	/maN+tumbuk/	→	[matumbuk]	'thump'
	/man+tutu/	→	*[mantutu]*	*'pound'*
b.	/saN+goŋgom/	→	[sagoŋgom]	'one fistful'
	/son+dopo/	→	*[sondopo]*	*'one fathom'*

The alternations in (43) instantiate N–NC_1 neutralization as a response to an insufficiently distinct N–NC contrast, but the alternations in (44-45) cannot be characterized in this way. N_2 deletion (44) is a type of enhancement: by removing the source of coarticulatory nasalization, N–NC_1 is rendered more distinct. N_1 deletion (45) could also be conceived of as a type of enhancement: the contrast between C_1 and nothing is enhanced by removing the lefthand N (though this is yet to be verified experimentally). Contrast enhancement is generally harder to account for in a framework

[14] 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 or devoicing of C_1 in NC_1VNC_2 are unattested; I assume that these issues are part of the larger 'too-many-solutions' problem (Steriade 2001).

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 has to 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.

6 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 both 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 for NC to be more distinct from N when preceding VN(C), a context of generally lesser nasality, than it is preceding Ṽ, a context of generally greater nasality. If this asymmetry holds cross-linguistically, the predictions in (46) follow.

(46) 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 paper, (46a-b) follow straightforwardly from the hypothesis of licensing by cue (Steriade 1997). I show next that they hold.

6.1 Prediction 1: NCṼ implies NC_1VN_2

To test the prediction that NCṼ in a given language should imply $NC_1VN(C)_2$, I conducted a survey to find languages that allow NCs and a contrast in vocalic nasality. This survey was drawn from a large collection of reference grammars at MIT's Hayden Library and assorted online periodicals (e.g. UCLA's Working Papers in Phonetics). An important criterion for inclusion was that an N–NC contrast exist: this means that languages such as Apinayé and Siriono, although identified by Maddieson (1984) as allowing both NCs and a contrast in vocalic nasality, do not qualify. In Apinayé and Sirono, as well as many other South American languages, Ns and NCs are allophonic variants conditioned by the quality of the neighboring vowels (see e.g. Herbert 1986, Stanton 2018). As the focus here is on the effects of vocalic nasality on the N–NC contrast, these languages are not directly relevant for the discussion that follows.

Altogether, 23 languages that have an N–NC contrast as well as a contrast in vocalic nasality were identified (see the appendix for a full list of languages). Of these 23, 12 allow NCṼ sequences; the fact that 11 do not speaks to the more general claim that NCṼ sequences, regardless of their genesis, 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	ndéé 'people' (p. 61)	mbòmbórò 'jawbone' (p. 35)
(Nougayrol 1979)	ndẽ́ 'little' (p. 61)	ndēèm 'to suffice' (p. 61)
Kabba	mbī 'ear' (p. 36)	ngə̀m 'lie' (p. 20)
(Moser 2004)	mbĩ̀ 'nausea' (p. 36)	mbámbá 'soldier' (p. 20)
Lua	mbàrì 'to flatten' (p. 43)	ndōŋ 'it's too wide, narrow' (p. 49)
(Boyeldieu 1985)	mbã́ː 'regularly' (p. 43)	ndwāàm 'Ndam of Ndam' (p. 52)
Mbay	mbòj 'in a panic' (p. 293)	ngōn 'son, daughter' (p. 355)
(Keegan 1996)	mbõ̀j 'pleasantly' (p. 294)	mbíndíng 'very heavy' (p. 290)
Mbum	nzáù 'spark' (p. 41)	mbàm 'rain' (p. 30)
(Hagège 1970)	nzã́ 'balafon' (p. 59)	ndàm 'poison' (p. 32)
Ngambay	ndà 'to be white' (p. 197)	ndàng 'to be crazy' (p. 9)
(Vandame 1963)	ndã̀ 'to pick' (p. 15)	mbūnā 'interval' (p. 197)
Ngbaka	zàlānzè 'orange' (p. 46)	mbàngà 'river sand' (p. 28)
(Thomas 1963)	nzẽ̄ 'blood' (p. 30)	mbānā 'wing' (p. 50)
Nizaa	mbɛɛ 'to judge' (p. 42)	mbèmbèm 'wind instrument' (p. 48)
(Endresen 1991)	mbɛ̃ɛ̃ 'to limp' (p. 42)	ndaŋnì 'disobedience' (p. 48)
Tinrin	ɳɖi̤ 'leaf, be humid' (p. 17)	n̪d̪an̪d̪ɔ̃ɽɔ̃ 'to hurt the foot...' (p. 5)
(Osumi 1995)	ɳɖṳ̃ 'hawk' (p. 15)	ɳɖi̤nawa 'coconut leaves' (p. 290)
Vouté	ngór 'thinness' (p. 45)	ngɯ́ŋ 'stick' (p. 45)
(Guarisma 1978)	ngɔ̃́ɔ̃̄ 'grass *sp.*' (p. 45)	ngə́nbé 'paddle' (p. 24)
Xârâcùù	baːru 'two' (p. 768)	ndɔmbʷa 'thing' (p. 775)
(Lynch 2002)	mbʷã 'distant and invisible (p. 768)	mbanĩː 'how many?' (p. 775)
Yakoma	pɛndá 'back' (p. 126)	ngúni 'the water falls...' (p. 22)
(Boyeldieu 1975)	ndẽ́ 'different(ly)' (p. 100)	ngàmbìí 'youngest' (p. 39)

6.2 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 (47-49).

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

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

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

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

(49) 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 (46), then, are verified.

7 Discussion and conclusions

This paper has argued on the basis of typological, acoustic, and behavioral evidence that NCD is driven by constraints on the distinctiveness of the contrast between NC_1 and a plain nasal, N. It is now necessary to consider the alternative, argued for by Alderete (1997), Blust (2012), and others: NCD arises due to the activity of a co-occurrence constraint, *NC...NC, which penalizes words that contain sequences of NCs. Section 7.1 provides several reasons why the current proposal is preferable and Section 7.2 discusses implications of this conclusion.

7.1 Against an OCP-based alternative

One of the stronger pieces of evidence against an OCP-based analysis of NCD comes from the generalizations discussed in Section 6: 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 any sort of link between the NCVNC and NCṼ, as the co-occurrence constraint penalizing NCVNC (*NC...NC) would not penalize NCṼ. The absence of such systems suggests that there is no constraint penalizing one of these sequences to the exclusion of the other. 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, there are various aspects of the results discussed here that a co-occurrence-based analysis would have a difficult time accounting for. I discuss first typological generalizations that do not have an obvious explanation under this alternative; second, I discuss the link between the typological generalizations and the extant acoustic and behavioral 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].

Finally, the links established in this paper 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 behavioral data in Section 4. With respect to Yindjibarndi, it was shown that the context in which NCD occurs (when NC_2 is a labial or velar cluster) is the context in which the intermediate vowel carries the most coarticulatory nasalization. With respect to the behavioral data, it was shown that listeners generally become less sensitive to the contrast between N and a voiced NC as the amount of coarticulatory nasalization in the following vowel increases. Second, consider the relationship between the Ngaju Dayak data discussed in Section 3 and the other aspect of the behavioral data in Section 4. With respect to Ngaju Dayak, it was shown that increased rates of NCD are correlated with shorter stop releases. With respect to the behavioral data, it was shown that listeners are less sensitive to the distinction between N and voiced NC when the release of NC is shorter. This paper has thus established that there are links between NCD, acoustics, and perception, and these links are directly captured by the contrast-based analysis proposed in Section 5. A co-occurrence-based analysis of these same facts would be forced to treat the links established in this paper as coincidences.

7.2 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 *[α,β]...[α,β] (where [α] and [β] are realized simultaneously); I assume that co-occurrence constraints of the form *[α][β]...[α][β] (where [α] and [β] are realized sequentially) are not part of CON.[15] Thus in addition to its ability to account for generalizations present in the typology of NCD, the contrast-based analysis proposed in this paper 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]ticular* vs. *p[ə]ticular*). 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.

[15] Note also that constraints of this form (including *[+nasal][-nasal]...[+nasal][-nasal]) would be quadrugrams and are worthy of suspicion for that reason alone. Thanks to Gillian Gallagher for pointing this out to me.

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Appendix for "Constraints on contrast motivate nasal cluster dissimilation"

Juliet Stanton

Part A: Summary of NCD survey

This part of the appendix provides more information about the survey of NCD discussed in Sections 2 and 3. Here, each of the surveyed languages is annotated with details about NCD, its genetic affiliation, and available references.

For each of the columns under "Restrictions", there are three possible values, which mean the following:

- Black cell: the restriction in this column is active.
- Gray cell: the restriction in this column is not active.
- Question mark: the status of this restriction cannot be assessed, due to language-specific phonotactic restrictions.

For the column labeled "Repair", there are five possible values, which mean the following. (Where several are listed, this often means that the attested repair varies according to a word's morphology. For more information see the cited sources.)

- NC_1 nasalization: $NC_1VN(C)_2 \rightarrow (N)N_1VN(C)_2$
- NC_1 oralization: $NC_1VN(C)_2 \rightarrow (C)C_1VN(C)_2$
- NC_2 nasalization: $NC_1VNC_2 \rightarrow NC_1VN(N)_2$
- NC_2 oralization: $NC_1VN(C)_2 \rightarrow NC_1V(C)C_2$
- Static restriction: no evidence from alternations

Language (Family)	Source(s)	Restrictions				Repair	Comments
		*NCVNC?	*NCVNV?	*NCVN#?	*NCṼ		
1. Arabana (Pama-Nyungan)	Hercus 1994			?	?	NC_2 oralization	Applies only across a stem-suffix boundary; there is no NCD within roots, across compounds, or between suffixes.
2. Bangubangu (Niger-Congo)	Meeussen 1963			?	?	NC_1 nasalization	Meeussen mentions that Bangubangu is a language where application of the rule is restricted to velar NC_1.
3. Bemba (Niger-Congo)	Kim 1999 Meeussen 1963			?	?	NC_1 nasalization	Meussen writes that "the rule only applies if there is a nasal compound in second position", but this is contradicted by Kim's data.
4. Bilinara (Pama-Nyungan)	McConvell 1988				?	NC_2 oralization	Only homorganic NC_2 is the target of NCD. See Section 2.2 for further discussion of this case.
5. Bobangi (Niger-Congo)	Meeussen 1963 Whitehead 1964			?	?	NC_1 nasalization	Meeussen writes that the existence of NCD in Bobangi is a "mere possibility" and may affect or have affected only one word.
6. Bokote (Niger-Congo)	Hulstaert 1957 Meeussen 1963			?	?	NC_1 nasalization	See Section 2.1 for discussion of this case.
7. Bolia (Niger-Congo)	Mamet 1960 Meeussen 1963			?	?	NC_1 nasalization	Only palatal NC_1 is the target of NCD. See Section 2.1 for further discussion of this case.

Language (Family)	Source(s)	Restrictions				Repair	Comments
		*NCVNC?	*NCVNV?	*NCVN#?	*NCṼ		
8. Budya (Niger-Congo)	Meeussen 1963			?	?	NC_1 nasalization	Meeussen mentions that Budya is a language where application of the rule is restricted to velar NC_1.
9. Buyu (Niger-Congo)	Meeussen 1963			?	?	NC_1 nasalization	Meeussen mentions that Buyu is a language where application of the rule is restricted to velar NC_1.
10. Caga (Niger-Congo)	Meeussen 1963			?	?	NC_1 nasalization	Meeussen mentions that Caga is a language where application of the rule is restricted to velar NC_1.
11. Dayak (Austronesian)	Herbert 1977			?	?	NC_1 nasalization	Herbert 1977 cites Dempwolff 1922 for these facts.
12. Djaru (Pama-Nyungan)	Tsunoda 1981 McConvell 1988			?	?	NC_2 oralization	NCD targets at least alveolar, retroflex, and velar NC_2; unclear if this is the full set or if other places of articulation participate as well.
13. Luganda (Niger-Congo)	Meeussen 1963 Kamoga & Stevick 1968			?	?	NC_1 nasalization	Not a lot of information provided by Meeussen except a basic description of the pattern.
14. Gikuyu (Niger-Congo)	Meeussen 1963 Armstrong 1967			?	?	NC_1 nasalization	Meeussen notes that NCD in Gikuyu is similar to NCD in Luganda.
15. Gooniyandi (Pama-Nyungan)	McConvell 1988 McGregor 1990				?	NC_2 oralization	Restrictions across morpheme boundaries are more stringent than those within morpheme boundaries. For more discussion of this case see Section 2.2 and fn. 3.
16. Gurindji (Pama-Nyungan)	McConvell 1988				?	NC_2 oralization	NCD can apply non-locally in this language; for more information see McConvell 1988.
17. Gwamba-Thonga (Niger-Congo)	Meeussen 1963			?	?	NC_1 nasalization	Meeussen mentions that Gwamba-Thonga is a language where application of the rule is restricted to velar NC_1.
18. Hemba (Niger-Congo)	Vandermeiren 1912 Meeussen 1963			?	?	NC_1 nasalization	The lack of NCD in NC_1VN_2 is noted explicitly by Meeussen. Vandermeiren's description suggests that NCD only applies when NC_1 is a voiced labial.
19. Ila (Niger-Congo)	Smith 1907 Meeussen 1963			?	?	NC_1 nasalization	Smith's description suggests that NCD only applies when NC_1 is a voiced labial or alveolar.

Language (Family)	Source(s)	Restrictions				Repair	Comments
		*NCVNC?	*NCVNV?	*NCVN#?	*NC$\tilde{V}$		
20. Kalkatungu (Pama-Nyungan)	Blake 1979 McConvell 1988				?	NC$_2$ oralization, NC$_1$ nasalization	NCD is restricted to certain suffixes, but there are no clear phonological regularities.
21. Kami (Niger-Congo)	Meeussen 1963			?	?	NC$_1$ nasalization	NCD may only apply when NC$_1$ is velar, and in one or two words where NC$_1$ is labial or coronal; this is unclear from Meeussen 1963.
22. Kaonde (Niger-Congo)	Meeussen 1963			?	?	NC$_1$ nasalization	NCD may only apply when NC$_1$ is velar, and in one or two words where NC$_1$ is labial or coronal; this is unclear from Meeussen 1963.
23. Kerebe (Niger-Congo)	Meeussen 1963			?	?	NC$_1$ nasalization	Meeussen notes that “the consonant in second position must be a nasal compound, and the relevant words are all nominals belonging to a rather fixed series.”
24. Kok-Kaper (Pama-Nyungan)	Jones 2000			?	?	NC$_1$ nasalization	Jones’s description of the pattern suggests that NCD may differentiate between onset nasals and word-final nasals, but this isn’t further discussed and the relevant examples are not provided.
25. Kikuria (Niger-Congo)	Meeussen 1963 Cammenga 2004			?	?	NC$_1$ nasalization	Extent of NCD somewhat unclear; Meeussen’s description suggests that it applies in a limited way, and Cammenga’s description contains words with co-occurring N(C)s.
26. Kwanyama (Niger-Congo)	Herbert 1977			?	?	NC$_2$ oralization	NCD applies apparently across the board, except when NC$_2$ is velar.
27. Lamba (Niger-Congo)	Meeussen 1963			?	?	NC$_1$ nasalization	Meeussen notes that “the rule only applies if there is a nasal compound in second position”, and that NC$_2$ may be voiceless.
28. Luba-Katanga (Niger-Congo)	Theuws 1954 Meeussen 1963			?	?	NC$_1$ nasalization	Meeussen notes that “the rule only applies if there is a nasal compound in second position”, and notes that in Luba-Katanga there are many exceptions.
29. Lumasaaba (Niger-Congo)	Brown 1972 Herbert 1977			?	?	NC$_1$ nasalization	Brown notes that the underlying C$_1$ must be a continuant (e.g. /β/).
30. Makonde (Niger-Congo)	Meeussen 1963 Odden 1990			?	?	NC$_1$ nasalization	Meeussen originally categorizes Makonde as a language that lacks NCD, but then claims it’s a case where one or two words with labial/coronal NC$_1$ undergo.

Language (Family)	Source(s)	Restrictions				Repair	Comments
		*NCVNC?	*NCVNV?	*NCVN#?	*NCṼ		
31. Manambu (Sepik)	Aikhenvald 2008				?	NC_1 oralization	These alternations may be restricted to palatal and velar NC_1 when it is in word-initial position.
32. Matumbi (Niger-Congo)	Meeussen 1963 Odden 1996			?	?	NC_1 nasalization	Meeussen lists this language as part of a group where NCD is attested directly or indirectly for one or two words with labial or alveolar NC_1, potentially in addition to words with velar NC_1.
33. Mori Bawah (Austronesian)	Esser & Mead 2011 Blust 2012			?	?	NC_1 oralization, NC_2 oralization	Process only applies when NC_2 is voiceless. Due to external factors NC_1 must be voiceless as well; see Section 3.1 on this point.
34. Mudbura (Pama-Nyungan)	McConvell 1988				?	NC_2 oralization, NC_1 nasalization	NC_1 nasalization occurs when N_2 is word-final; NC_2 oralization occurs elsewhere.
35. Mwanga (Niger-Congo)	Meeussen 1963			?	?	NC_1 nasalization	Meeussen mentions that Mwanga is a language where application of the rule is restricted to velar NC_1.
36. Myene (Niger-Congo)	Meeussen 1963 Rékanga 2014			?	?	NC_1 nasalization	It's not clear what the scope of NCD is; Meeussen provides three examples but also two exceptions. Rékanga's grammar does not discuss NCD and provides several words with co-occurring N(C)s.
37. Ndonga (Niger-Congo)	Herbert 1977 Fivaz 1986			?	?	NC_2 oralization	Herbert discusses Ndonga in the same context as Kwanyama; however, no examples are given, and Fivaz's grammar does not mention NCD at all.
38. Ngaju Dayak (Austronesian)	Blust 2012			?	?	NC_1 nasalization	See Sections 3.2 and 4 for discussion and analysis of this case.
39. Ngarinyman (Pama-Nyungan)	McConvell 1988 Nichols 2016				?	NC_2 oralization	NCD in Ngarinyman can apply non-locally; see Nichols 2016.
40. Ngazija (Niger-Congo)	Herbert 1977			?	?	NC_2 oralization	Herbert 1977 notes that NCD in Ngazija is "similar to the Kwanyama rule".
41. Nhanda (Pama-Nyungan)	Blevins 2001 Blust 2012			?	?	NC_2 oralization	NCD applies mostly when NC1 is homorganic and is morphologically restricted (only some suffixes trigger it). Limited non-local application is possible; see Blevins.

Language (Family)	Source(s)	Restrictions				Repair	Comments
		*NCVNC?	*NCVNV?	*NCVN#?	*NCṼ		
42. Nilamba (Niger-Congo)	Meeussen 1963 Yukawa 1989			?	?	NC_1 nasalization	Meeussen's description notes that NCD appears to only apply to labial and coronal NC_1. Forms with multiple NCs were difficult to find in Yukawa's description, though several were present.
43. Nkore (Niger-Congo)	Meeussen 1963 Taylor 1998			?	?	NC_1 nasalization	Meeussen notes that "the consonant in second position must be a nasal compound, and the relevant words are all nominals belonging to a rather fixed series."
44. Ntomba (Niger-Congo)	Mamet 1955 Meeussen 1963			?	?	NC_1 nasalization	NCD may target only alveolar NC_1. There was one example of NC…N in Mamet's description, but this example was difficult to find and not discussed explicitly.
45. Nyamwezi (Niger-Congo)	Meeussen 1963 Maganga & Schadeberg 1992			?	?	NC_1 nasalization	Maganga & Schadeberg note that NCD is no longer productive and that there are numerous counterexamples.
46. Nyiha (Niger-Congo)	Busse 1960 Meeussen 1963			?	?	NC_1 nasalization	Meeussen categorizes this as a language where NCD applies somewhat infrequently, which is echoed in Busse's description.
47. Nyoro (Niger-Congo)	Meeussen 1963 Rubongoya 1999			?	?	NC_1 nasalization	Meeussen notes that "the consonant in second position must be a nasal compound, and the relevant words are all nominals belonging to a rather fixed series." Rubongoya's description suggests that NC_1 must also be labial.
48. Ombo (Niger-Congo)	Meeussen 1952 Meeussen 1963			?	?	NC_1 nasalization	Meeussen's discussion is somewhat confusing, but the provided examples suggest restrictions on both NC_1VNC_2 and NC_1VN_2.
49. Rundi (Niger-Congo)	Meeussen 1963 Rodegem 1967			?	?	NC_1 nasalization	Meeussen notes that "the consonant in second position must be a nasal compound, and the relevant words are all nominals belonging to a rather fixed series." Rodegem's grammar doesn't discuss NCD.
50. Rwanda (Niger-Congo)	Meeussen 1963 Kimenye 2002			?	?	NC_1 nasalization	Meeussen notes that "the consonant in second position must be a nasal compound", but Kimenye suggests that NC_1VN_2V is repaired as well.
51. Sanga (Niger-Congo)	Meeussen 1963			?	?	NC_1 nasalization	Meeussen writes that NCD applies "only if there is a nasal compound in second position."

Language (Family)	Source(s)	Restrictions				Repair	Comments
		*NCVNC?	*NCVNV?	*NCVN#?	*NCṼ		
52. Sango (Ngbandi-based creole)	Meeussen 1963 Samarin 1967			?		NC_1 nasalization	Samarin's 1967 grammar does not mention NCD and additionally provides numerous examples of NC_1VNC_2 and NC_1VN_2. I've followed Meeussen's description but it's unclear what its basis is.
53. Saramaccan (English-Portuguese creole)	McWhorter & Good 2012					Static restriction	Final nasals are not common in this language, but none of the provided examples are preceded by an NC.
54. Shambala (Niger-Congo)	Meeussen 1963 Besha 1993			?	?	NC_1 nasalization	Meeussen mentions that Shambala is a language where application of the rule is restricted to velar NC_1. Words with the shape NC_1VN_2V were fairly easy to find in Besha's work, suggesting a discrepancy between the two sources, but NC_1VNC_2 words were absent.
55. Soli (Niger-Congo)	Meeussen 1963			?	?	NC_1 nasalization	Meeussen writes that NCD only applies when there is a nasal compound in second position.
56. Suthu (Niger-Congo)	Meeussen 1963 Louwrens et al. 1995			?	?	NC_1 nasalization	Meeussen mentions that Shambala is a language where application of the rule is restricted to velar NC_1. Lowrens et al.'s grammar sketch provides no NC_1VNC_2 words.
57. Swahili (Niger-Congo)	Meeussen 1963 Mpiranya 2015			?	?	NC_1 nasalization	Meeussen mentions that Shambala is a language where application of the rule is restricted to velar NC_1.
58. Tabwa (Niger-Congo)	van Acker 1907 Meeussen 1963			?	?	NC_1 nasalization	NCD may only apply when NC_1 is velar, and in one or two words where NC_1 is labial or coronal; this is unclear from Meeussen 1963.
59. Taita (Niger-Congo)	Meeussen 1963			?	?	NC_1 nasalization	NCD may only apply when NC_1 is velar, and in one or two words where NC_1 is labial or coronal; this is unclear from Meeussen 1963.
60. Tetela (Niger-Congo)	Meeussen 1963 Jacobs 1964			?	?	NC_1 nasalization	Restriction on NC_1VNC_2 applies for all parts of speech; restriction on NC_1VN_2V is only for nouns.
61. Timugon Murut (Austronesian)	Blust 2012			?	?	NC_1 oralization	NCD is restricted to voiceless NC_1, but is is because NCD only applies across morpheme boundaries and only voiceless NCs can be created across these boundaries.

Language (Family)	Source(s)	Restrictions *NCVNC?	*NCVNV?	*NCVN#?	*NCṼ	Repair	Comments
62. Vira (Niger-Congo)	Meeussen 1963			?	?	NC_1 nasalization	NCD may only apply when NC_1 is velar, and in one or two words where NC_1 is labial or coronal; this is unclear from Meeussen 1963.
63. Yao (Niger-Congo)	Hyman 2003			?	?	NC_1 nasalization	NCD only applies with coronal NC_1, but this is apparnetly because all other NCs reduce to Ns.
64. Yaunde (Niger-Congo)	Meeussen 1963 Essono 2000				?	NC_1 nasalization	Descriptions are not consistent with one another; Meeussen 1963 notes NCD across an imperative suffix boundary but this is not discussed by Essono. See Section 2.1.
65. Yindjibarndi (Pama-Nyungan)	Wordick 1982				?	NC_2 oralization	NCD only applies when NC2 is labial or velar. Limited non-local application is possible (see Wordick). For further discussion see Section 2.3.
66. Zande (Niger-Congo)	Gore 1931 Herbert 1977 Boyd 1995			?		NC_1 nasalization	Herbert writes that NC D is a "tendency" in Zande; Gore's grammar does not discuss restrictions on nasal vowels explicitly but contains no examples of NCs followed by nasal vowels.
67. Ziba (Niger-Congo)	Meeussen 1963			?	?	NC_1 nasalization	Meeussen writes that "the rule applies only if there is a nasal compound in second position."

Part II: Summary of NCṼ survey

This part of the appendix provides more information about the survey focusing on languages with NCs and a vocalic nasality contrast that was discussed in Section 6.1. The 23 languages that were included in this survey, as well as references to their descriptions, are below. For the languages that ban NCṼ, minimal pairs demonstrating the contrast and evidence that the languages also allow NCVN(C) are in Section 6.1.

Allows NCṼ (12 lgs.)	Bans NCṼ (11 lgs.)
Day (Nougayrol 1979)	Acehnese (Durie 1985)
Kabba (Moser 2004)	Apinayé (Oliveira 2005)
Lua (Boyeldieu 1985)	Gbaya Kara (Monino & Roulon 1972)
Mbay (Keegan 1996, 1997)	Gbeya (Samarin 1966)
Mbum (Hagège 1970)	Ndumbea (Gordon & Maddieson 1999)
Ngambay (Vandame 1963)	Nheengatu (Moore et al. 1993)
Ngbaka (Thomas 1963, Henrix et al. 2015)	Páez (Rojas Curieux 1998, Jung 2008)
Nizaa (Endresen 1991)	Paici (Gordon & Maddieson 2004)
Tinrin (Osumi 1995)	Sango (Samarin 1967)
Vouté (Guarisma 1978)	Saramaccan (McWhorter & Good 2012)
Xârâcùù (Lynch 2002)	Vai (Welmers 1976)
Yakoma (Boyeldieu 1975)	

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