MALAGASY /NR/-STRENGTHENING WITHIN AND ACROSS PROSODIC BOUNDARIES

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This study investigates a process of consonant strengthening reported in Merina Malagasy and models the phonological factors that are likely to trigger strengthening using a Maximum Entropy Harmonic Grammar (Hayes & Wilson, 2008). Specifically, we examine sequences of /nVr/ and show that this sequence is strengthened to a surface affricate when the vowel deletes and leaves the two consonants adjacent, a situation which must be repaired. This process is probabilistic and conditioned by prosodic position: we find that although within words and compounds strengthening occurs relatively freely, strengthening is typically blocked from crossing phonological phrase boundaries. This is evidenced by our model assigning a high weight to a markedness constraint against strengthening relativized to the phonological phrase boundary.

1. Introduction & Background

In this paper, we investigate a process of consonant strengthening that has been reported in Merina Malagasy and attempt to model the phonological factors that are most likely to trigger strengthening using a Maximum Entropy Harmonic Grammar (Hayes & Wilson 2008). Specifically, we look at whether sequences of /nr/ are likely to be strengthened within and across different prosodic boundaries, and will show that although /nr/ strengthening is probabilistic, that it is more likely to occur within, and not across, the phonological phrase boundary.

Strengthening has been described to occur to fricatives and liquids in particular morphological constructions including the genitive, as in (1), and compounds, as in (2). The phonetic realization of this strengthened variant typically resembles a prenasalized retroflex affricate [^{n}ɖ͡ʐ] or an inserted stop between the /n/ and /r/, [ndr].

(1)	/ami	-n-	raini/	→	[amin**ɖ͡ʐ**aini] (Paul, 1996: #18a)
	to	GEN	father		
	‘to his father’				

(2)	/mitsu	+	ranu/	→	[mit͡su-**ɖ͡ʐ**anu] (Martin, 2005: #10h)
	blow		water		
	‘to bless’				

While strengthening had previously only been reported in these specific morphological constructions, a more recent description of the phenomenon by Pearson (2005) mentions that this may be a property of word-internal occurrences of /nr/ more generally. Due to Malagasy’s restriction on codas and complex onsets, however, underlying examples of /nr/ are rare, leaving us will little data to test this generalization. However, certain dialects of Malagasy, including Merina, have undergone a sound change over recent decades involving vowel devoicing or deletion (Pearson 1994; Howe 2019), where unstressed high vowels /i/ and /u/ are frequently deleted. When these vowels are deleted between /n/ and /r/, it creates a surface environment in which these two consonants are now adjacent, providing additional, purely phonologically-conditioned environments where strengthening may occur.

Such a rule ordering relationship can be schematized as follows. Assuming an underlying representation in which high vowels /i/ and /u/ are present and then subsequently deleted, a word such as 'to wander' would be represented as /mirenireni/. The devoicing of the high vowel, namely the antepenultimate /i/, creates an environment in which the two consonants, originally separated by a vowel, are now immediately adjacent, a situation that must be repaired by strengthening. This is a typical phonological feeding relationship, in the terminology of Kiparsky (1968).

(3) Unstressed high vowel deletion (HVD) feeds strengthening

UR	/mirenireni/
unstressed HVD	mirenreni
strengthening	miren**ɖ͡ʐ**eni
SR	[miren**ɖ͡ʐ**eni]

In the following sections, we use data involving vowel deletion to investigate which prosodic environments are most likely to cause strengthening.

2. Background: Merina Malagasy Phonology

In order to discuss the phonology of strengthening in Merina Malagasy, we will first outline some other relevant facts about the phonology of the language.

2.1. Syllable Structure

Most dialects of Malagasy are described as having a strict (C)V syllable structure, which prohibits both codas and complex onsets (e.g., Howe 2019; O'Neill 2015). In instances where a nasal precedes a stop or affricate in Malagasy, as in the word *andry* [ˈa.ⁿɖʐi] 'pillar', they are presumed to form a single prenasalised segment.

2.2. Prosodic Structure

Aziz (2020) described the prosodic structure of Merina Malagasy as having three levels: the prosodic word, the phonological phrase (or intonational phrase, as he calls it), and the intonational phrase. He demonstrated that there is a very close mapping between syntactic and prosodic constituents; relevant to us is that phonological phrases correspond to syntactic phrases. In a simple declarative Malagasy sentence, the word order is the predicate-initial VOS, where the VP comprising the predicate predictably and consistently forms a phonological phrase, marked by a right-aligned pitch accent (H*) on the final stressed syllable of the phrase, as is the subject noun phrase.

3. Experimental methodology

3.1. Participants

This study includes data from three speakers of Merina Malagasy, from the capital city of Antananarivo in the central highlands of Madagascar. Reference to Malagasy dialects commonly occurs along ethnic lines, with a one-to-one correspondence between ethnicities and dialects (e.g., Merina, Betsileo, etc.); however, as Adelaar (2013) and Howe (2019) point out, there is linguistic variation within ethnic groups and shared features across groups. Both Adelaar and Howe consider Merina to be part of the wider Central group of dialects. So, while each of the speakers in our data set self-identified as a speaker of Merina Malagasy, we do not assume that the process of strengthening described in this paper is limited only to Merina but may appear in other dialects as well. Additionally, we recorded other Merina speakers, not included in the dataset, who did not generalize strengthening of /nr/ to contexts outside of the morphological constructions described in section 1. Thus, we assume that strengthening as a general phonological process is either a change in progress or conditioned by sociolinguistic factors that are not investigated in this paper. Regardless, strengthening of /nr/ as it is described in this paper is a feature of the phonology of some speakers of Merina Malagasy.

The three speakers were all born in Antananarivo, Madagascar, and moved to Montreal, Quebec in adulthood, where they lived at the time of recording. All speakers were between the ages of 18 and 40 and fluently bilingual in Malagasy and French. Two speakers were female, and one was male.

3.2. Data

Data for this study were collected remotely over Zoom. Each speaker was instructed to read aloud 27 Malagasy sentences, one at a time as they appeared on a screen, as if they were talking to a friend in a casual manner. Each of the 27 items included at least one instance of /nVr/, where the vowel was either an /i/ or /u/ that we expected to be deleted, leaving surface /nr/. In total, there were 30 such instances spoken by the three speakers, giving us a total of 90 tokens to include in our analysis.

Each of the items in the data set was designed to elicit instances of surface /nr/ that were within or across one of five different prosodic positions: (a) within a morpheme, (b) across the root-affix boundary, (c) across the root-root boundary within a compound, (d) across word boundaries, but within the same phonological phrase, or (e) across the phonological phrase boundary. By manipulating the prosodic environment in which surface /nr/ appeared, we could test whether strengthening of /nr/ is affected by different prosodic factors. Examples of different items used to test each prosodic environment appear in (4), with the target /nVr/ underlined.

(4) a. Within the morpheme

Ny	lehilahy	no	mire<u>nir</u>eny	lava
DET	man	FOC	wander	always

‘It is the man who always wanders’

b. Across root-affix boundary:

Ni-taraina	izy	fa	ni-resadresaka	ny	namany
PST-complained	he	COMP	PST-chat	DET	his.friends

'He complained that his friends were chatting'

c. Across root-root boundary within a compound:

Lafo	ny	tani-ravo
expensive	DET	earth-happy (=chalk)

'The chalk is expensive'

d. Across word boundaries, within the same phonological phrase:

Mahatofoka	ny	ronono ratsy	
disgusting	DET	milk	bad

'The bad milk is disgusting'

e. Across word boundaries, across phonological phrase:

Mino	Rabe	fa	mamy	ny	ro
thinks	Rabe	COMP	sweet	DET	broth

'Rabe thinks that the broth is sweet'

3.3. Phonetic Analysis

We used phonetic measures to evaluate whether strengthening occurred in each token. First, we identified all instances where /nr/ arises through deletion or an intervening vowel; as mentioned in section 1, unstressed /i/ and /u/ are frequently, but not always, deleted. We discarded any tokens where there was evidence of the vowel, including auditory-perceptual evidence and changes in the waveform and spectrogram. Then, of the tokens where the environment for strengthening was created, we looked for phonetic evidence that /nr/ had been strengthened to [^{n}ɖ͡ʐ] or [ndr], looking for a stop burst in the waveform and spectrogram. If such evidence was present, that token was tagged as strengthened.

4. MaxEnt modelling

The acoustic-phonetic experiment concluded that Merina Malagasy speakers strengthened surface instances of /nr/ often, even when not part of a particular morphological construction, such as the genitive. Additionally, the deletion of either high vowel, /i/ or /u/, could trigger strengthening. These facts together indicate that high vowel deletion can feed consonant strengthening. This process, however, is not categorical: while all speakers strengthened surface /nr/ to an extent, different speakers did so to varying degrees, and in non-overlapping environments. In a number of cases, surface [nr], which ould be an otherwise phonotactically illicit CC sequence in a language like Malagasy, was not repaired by strengthening. Additionally, a preliminary scan of the prosodic environments in which strengthening was more or less likely to occur produces a qualitative trend: the smaller the prosodic boundary, the more likely strengthening is to occur; the higher the prosodic boundary, the less likely. This is illustrated in Figure 1 below:

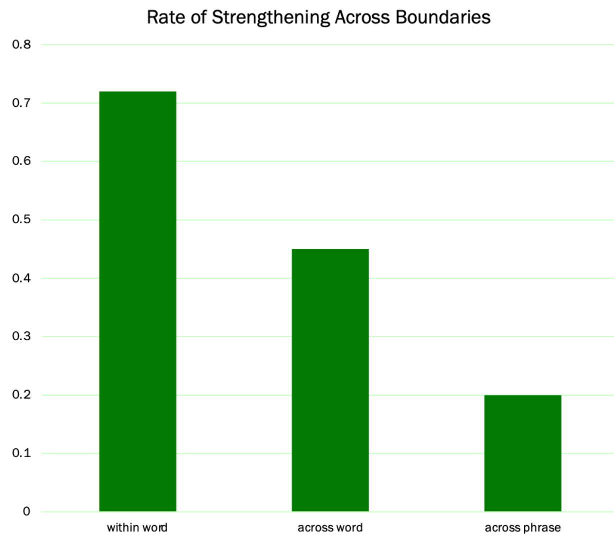

Figure 1: strengthening rates by boundary

This figure indicates that while over 70% of instances of surface [nr] sequences were repaired by strengthening when within a word boundary, the rate decreased to less than half when the sequence straddled a word boundary. When the sequence straddled both a word *and* phrase boundary, the rate was 20% strengthening.

As we found that surface CC sequences were only being gradiently repaired by speakers, and additionally that strengthening rates appear to be conditioned by prosodic factors, turned to Maximum Entropy Harmonic Grammar (Goldwater & Johnson 2003, Hayes & Wilson 2008) to model speakers' productions. Specifically, we aim to model the frequency of strengthening across speakers, and identify the factors that significantly affect strengthening rates.

4.1. Introducing MaxEnt

Maximum Entropy Harmonic Grammar (MaxEnt) is a probabilistic model of grammar that keeps many of the assumptions of standard Optimality Theory (OT, Prince & Smolensky 1993), such as the candidate set (GEN). Unlike in classical OT, however, MaxEnt is a probabilistic model, and so does not select a single winner (optimum) from among the candidate set based on that set's violation profile among the constraints (CON), but rather generates probability distributions over all candidates. As such, unlike in classical OT, constraints are not ranked, but given *weights*; constraints with higher weights are "stronger" in that incurring violations of them reduces the candidate's probability relative to other candidates. The overall probability Pr(x) for each candidate x is given in the MaxEnt formula below from Hayes and Wilson (2008):

(5) $\Pr(x) = \frac{\exp(-\Sigma_i w_i f_i(x))}{Z}$, where $Z = \Sigma_j \exp(-\Sigma_i w_i f_i(x_j))$

Above, the term $w_i f_i(x_j)$ is what is known as the "harmony score", the product of all the candidates' constraint violations (designated $f_i(x_j)$) and the weights of those constraints (designated w_i). This term is negated and raised to e for computational convenience. The sum of all candidates' harmony scores is designated Z, and so the probability that some candidate will get selected is therefore inversely proportional to the harmony scores of all its competitors.

Once the appropriate candidate set (GEN) and constraint set (CON) are selected, the second portion of the MaxEnt modelling approach is fitting the constraint's weights to match the data. Converging on best-fit constraint weights is guaranteed with a mathematical proof (Della Pietra et al. 1997); finding these best-fit weights can be streamlined and achieved with an automatic function in Excel (Solver; Fylstra et al. 1998).

Model accuracy is assessed via log likelihood, a value that the MaxEnt grammar assigns to the data. Log likelihood is calculated by multiplying the probabilities the grammar assigns to every data point to those data points' values themselves, and then taking the natural logarithm of that value. As a negative number, the closer the log likelihood to 0, the better the model fit. This value, then, can serve as a standard of model evaluation when comparing some baseline model against further developments of the model, say when another phonological constraint is added and more violations are assigned, potentially changing the candidates' probability distributions. This is called the "maximum likelihood criterion." Likelihood ratio tests (Wasserman 2004) can be performed between the two log likelihood values to assess if there was a significant decrease in log likelihood, which would indicate that the inclusion of that constraint significantly improved model fit, and that that phonological characteristic is an important feature of the language. This is methodologically analogous to diagnosing a significant effect in a logistic regression model.

4.2. GEN and CON

First, we will explain candidate set (GEN) used in the MaxEnt model. GEN consisted of every word of our test material divided into its potential strengthened and unstrengthened productions. Their actual strengthening rates were inputted based on speakers' productions, and the model's predicted strengthening rates were calculated based on the candidate's performance under the constraint set.

Next, a description of that set of constraints (CON) used in the model. To start, since we find that in general, strengthening of /nr/ occurs in Malagasy across the board, that is, even when not part of the genitive construction, we assume that Malagasy penalizes instances of surface [nr] via some baseline markedness constraint, which we will call *NR. This constraint can be conceptualized in two ways. The first is as a particular type of consonant cluster avoidance constraint (typically schematized as *CC), which is understandable, as in general Malagasy phonotactics, at least underlyingly, by and large restricts sequences of two adjacent consonants. The second way of conceptualizing *NR, pointed out by a reviewer, is as an optimal syllable contact constraint: the coda, in this case [n], must be more sonorous than the following onset [r]. As [n], a nasal, is less sonorous than [r], a liquid, surface sequences of [nr] are illicit due to ungrammatical syllable contact. To repair, strengthening of the [r] to an affricate [d͡ʐ], as is the case in Merina Malagasy (see section 1), leads to a more harmonious syllable contact, as a nasal is more sonorous than an obstruent.

This baseline markedness constraint will be in conflict with a baseline faithfulness constraint Ident[sonorant], which will be violated when the value of the feature [sonorant] for [r] changes under strengthening. As such, a strengthened candidate will violate faithfulness but not markedness, but an unstrengthen candidate will violate markedness but not faithfulness. More formal definitions of these two constraints are given below:

(6) *NR
Incur a violation for any surface sequence of [nr]

(7) Ident[sonorant]
Incur a violation for any segment whose output value for the feature [sonorant] is different from its value for the feature [sonorant] in the input

As we predict that prosodic boundary strength will also play a role in strengthening rate, we will also add a number of positional markedness constraints, which are variations of *NR but relativized to a particular boundary (Hsu & Jesney 2016). Specifically, we tested for the following four boundaries, two of which are prosodic and two of which are morphological, to see if any would have a significant effect. The following were added to the model one by one to test for significance:

(8) *NR-morpheme
Incur a violation for any surface sequence of [nr] which straddles a morpheme boundary

(9) *NR-prosodic-word
Incur a violation for any surface sequence of [nr] which straddles a prosodic word boundary

(10) *NR-compound
Incur a violation for any surface sequence of [nr] which straddles a compound boundary

(11) *NR-phonological-phrase
Incur a violation for any surface sequence of [nr] which straddles a phonological phrase boundary

An intended effect of these kinds of scaled positional markedness constraints is that, where applicable, they have the ability to form a violation hierarchy, where a violation of a markedness constraint at some higher domain automatically incurs violations of markedness constraints at lower domains, but not vice versa. For example, a surface sequence of [nr] that straddles a phonological phrase boundary also straddles a prosodic word and morpheme boundary, and so the candidate would incur all three positional markedness violations.

As a local summary thus far, our MaxEnt model includes both strengthened and unstrengthened candidates corresponding to each test item in our production study. Actual strengthening rates across speakers were compared to our model's predictions, having been based on a series of targeted phonological constraints. The maximum likelihood criterion was used as our method of evaluation. After a baseline model was achieved with just two constraints, *NR and Ident[sonorant], our baseline markedness and faithfulness constraints, respectively, additional boundary-related constraints were added to the model one by one to test for significance, which was done using likelihood ratio tests. We considered the addition of a constraint to be "significant" if it significantly increased overall log likelihood ($p \leq 0.05$), thus improving model fit.

4.3. Results

After running the baseline model and adding additional positional markedness constraints one by one and testing for their significance, we arrived at the following results. Three of the four positional markedness constraints had no significant effect on log likelihood; their weights and significance scores (*p* values) are given below:

(12)	*NR-morpheme:	$p = 0.99$	$w = 0.00$
	*NR-compound:	$p = 0.99$	$w = 0.00$
	*NR-prosodic-word:	$p = 0.96$	$w = 0.81$

The only positional markedness constraint that had any significant effect on model performance was *NR-phonological-phrase:

(13) *NR-phonological-phrase: $p = 0.04$ $w = 3.10$

While its significance is modest based on our cutoff of $p \leq 0.05$, *NR-phonological-phrase had a considerably stronger effect relative to the other positional markedness constraints in (10), as its larger weight attests to. This result demonstrates that the phonological phrase boundary is a much stronger deterrent to consonant strengthening compared to word-internal or other cross-word boundaries, as evidenced by our production study. Although strengthening is gradiently sensitive to *any* boundary–indeed, we find strengthened and unstrengthened productions of /nr/ at every location of interest in this study (see Figure 1)–there does appear to be a strong inverse relationship between boundary strength (that is, level on the prosodic hierarchy, or the number of boundaries crossed at once) and the likelihood of strengthening. Figure 2 below shows how the weight of the constraints increases with the magnitude of the boundary, indicating the increasing severity of a violation of that constraint. Note that *NR-morpheme and *NR-compound are at 0.

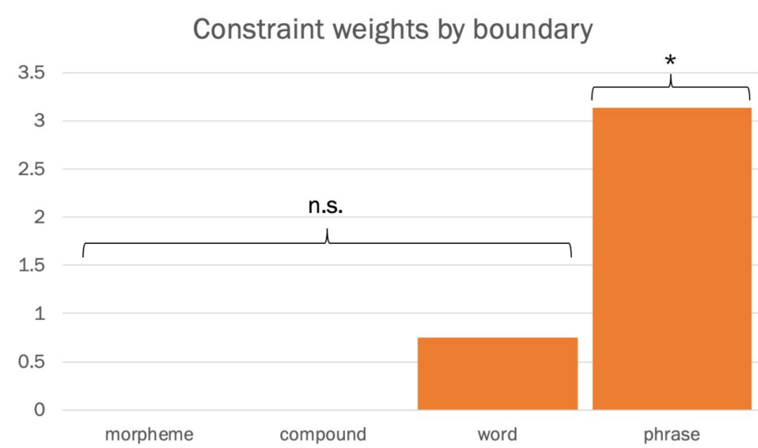

Figure 2: constraint weights by boundary

Also seen in Figure 2 above is the slight increase in weight for *NR-prosodic-word, indicating that it is slightly less preferable to strengthen across a word boundary. This was not a statistically significant effect, but this means that the model has learned of a general dispreference for strengthening across, rather than within, boundaries of any type.

5. Discussion

As explained in our review of the previous literature on the Malagasy consonant strengthening phenomenon, Pearson (2005) describes the strengthening process as being a property of word-internal sequences of surface [nr] generally, that is, even outside specific morphological constructions such as the genitive. On this account, strengthening is actually sensitive to *word* boundaries, as Pearson (2005) does not predict that strengthening should not cross word boundaries, but instead be a property of word-internal instances of surface sequences of [nr] only. Our findings in the present study, however, show instead that Malagasy /nr/ strengthening, while gradiently sensitive to all prosodic boundaries (word and phrase), is actually most sensitive to *phrase* boundaries. This sensitivity is evidenced by our MaxEnt model's assignment of significant weight to a markedness constraint against strengthening relativized to a phonological phrase boundary (which increased overall model fit via the maximum likelihood criterion), whereas that same markedness constraint relativized to a prosodic word boundary, along with other word-internal boundaries such as morpheme and compound, received low weights which did not significantly improve model fit.

Strengthening, therefore, can be considered a *phrase*-internal process of Merina Malagasy. This result is intriguing, then, because we have been able to identify a novel, uniquely non-intonational, cue to prosodic phrasing in Malagasy. As mentioned above, prosodic phrasing is clearly delimited in Malagasy by the placement of right-aligned pitch accents at the edges of phonological phrases, which match syntactic XPs (Aziz 2020). The lack of consonant strengthening, or to put it another way, faithfulness to underlying consonantal feature values, is an additional, segmental, diagnostic of prosodic phrasing.

This kind of diagnostic additionally helps situate Malagasy within a larger typology of segmental cues to prosodic phrasing, as several other languages which demonstrate similar processes have recently come to light. Tanner et al. (2017) show that greater boundary strength reduces the likelihood of coronal (t/d) deletion in a spontaneous corpus of British English. Additionally, larger prosodic boundaries have been shown to reduce rates of high vowel deletion in Tokyo Japanese (Kilbourne-Ceron & Sonderegger 2017). Like in Malagasy, these effects are probabilistic, and so a research program that continues to model the effects of increasing boundary strength on certain phonological phenomena using frameworks such as MaxEnt appears promising.

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