

Icy Targets in Karajá ATR Harmony as Contrast Preservation

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1 Introduction

Icy targets, which are segments that harmonize but then block harmony from proceeding further, are a difficult phenomenon to analyze theoretically (Jurgec 2011). Particularly problematic is a rare type of icy target found in ATR harmony in Karajá¹ (Macro-Jê; Brazil), in which the propagation of harmony depends on the underlying vowel quality. For most known cases of icy targets, the derived vowel would not trigger harmony if underlying (Jurgec 2011). This is not the case in Karajá, where the behaviour of [i, ɨ, u] in harmony depends on whether the vowel is underlyingly /i, ɨ, u/ or /ɪ, ɨ, ʊ/ (Ribeiro 2002). This distinction between underlying and derived vowels is problematic to analyze, particularly in surface-oriented frameworks.

In this paper, we argue for an extension of Contrast Preservation Theory (Lubowicz 2003) to account for this type of icy target. This theory has previously been used for derived environment effects and chain effects, but not for icy targets or harmony systems. We show that viewing the behaviour of high vowels in Karajá as a form of contrast preservation allows for an effective analysis of the Karajá data, in a way that is situated within the typology of ATR harmony. In doing so, we not only provide an account for this previously unanalyzed, puzzling pattern, but also illustrate a novel application of Contrast Preservation Theory.

This paper is organized as follows. In Section 2, we present the facts of Karajá and discuss why they are problematic to analyze. In Section 3, we propose an analysis using Contrast Preservation Theory. The remainder of the paper, Section 4, is devoted to discussion, considering the predictions and future directions of this approach.

2 Karajá

As shown in Table 1, Karajá has 16 vowels, 12 oral, and 4 nasal (Ribeiro 2002, Ribeiro 2011), which can be represented through the feature system in Table 2.

Table 1: Karajá vowel inventory (Ribeiro 2002)

Oral vowels	Nasal vowels
i ɨ u	ĩ
ɪ ɨ ʊ	
e ə o	ẽ õ
ɛ (ə) ɔ	
a	ã

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¹ This is an exonym for the language, but it is the one adopted by Ribeiro, who worked extensively with the language community, so we adopt it here too.

Table 2: Vowel Feature Chart

	HIGH	LOW	BACK	ROUND	ATR	NASAL
/i/	+	-	-	-	+	-
/ĩ/	+	-	+	-	+	-
/u/	+	-	+	+	+	-
/ɪ/	+	-	-	-	-	-
/ĩ/	+	-	+	-	-	-
/o/	+	-	+	+	-	-
/e/	-	-	-	-	+	-
/ə/	-	-	+	-	+	-
/o/	-	-	+	+	+	-
/ɛ/	-	-	-	-	-	-
/ə/	-	-	+	-	-	-
/ɔ/	-	-	+	+	-	-
/a/	-	+	+	-	-	-
/ĩ/	+	-	-	-	+	+
/ã/	-	-	+	-	-	+
/õ/	-	-	+	+	+	+
/ã/	-	+	+	-	-	+

Karajá exhibits a strictly regressive ATR-dominant harmony pattern, where [+ATR] vowels trigger harmony to preceding [-ATR] vowels, as illustrated in (1). Note that the trigger is always [+ATR] and harmony only proceeds right-to-left.

(1) Directionality of harmony in Karajá (Ribeiro 2002:479-483)

	Underlying form	Surface form	Gloss
a.	/dɔrɛ d-e/	[dorede]	‘Parrot’s wing’
b.	/r-ɔbɛrɛ-re/	[rubehere]	‘He/she went down’
c.	/d-ɛbɔ-ube/	[deboube]	‘palm of hand’
d.	/ri-dĩ/	[rĩni]	‘a type of cari (fish)’
e.	/r-ɔ-dũhɔ-rɛrɪ/	[rot[uhɔrɛrɪ]	‘He is cursing’
f.	/wa-θɛ-rikɔrɛ/	[waθɛrit[ɔrɛ]	‘My sibling’

However, unlike in other cases of ATR harmony, the high vowels /i/, /ĩ/ and /u/ are icy targets in Karajá: they harmonize to [i], [ĩ], and [u], but then block the further progress of harmony, as shown in (2). This behaviour contrasts with underlying /i/, /ĩ/ and /u/, which act as triggers, causing vowels preceding them to harmonize.

(2) Icy target behaviour in Karajá (Ribeiro 2002:480)

	Underlying form	Surface form	Gloss
a.	/kɔdɔ-dĩ/	[kɔdɔ-ni]	‘a type of turtle’
b.	/krɔbi-dĩ/	[krɔbi-ni]	‘a type of monkey’
c.	/r-a-hĩlɔ-kɔrɛ/	[rahiloikrɛ]	‘He/She will vomit’
d.	/r-ɔ-dũhɔ-rɛrɪ/	[rot[uhɔrɛrɪ]	‘He is cursing’

Karajá icy targets pose several major problems. First is a distinction between underlying and derived vowels: while underlying [+ATR] high vowels trigger harmony, [+ATR] high vowels derived through harmony do not. This distinction is a serious issue in surface-oriented frameworks, where underlying and derived vowels should behave the same way. Second is that Karajá icy targets appear to be in direct conflict with the typology of triggers of ATR-dominant harmony. Indeed, the best triggers of ATR-dominant

harmony cross-linguistically are high vowels (cf. Ozburn 2019 and references therein), yet in Karajá, these are the vowels that behave as non-triggers when derived.

3 Analysis: Contrast preservation

As noted above, standard OT cannot account for the behaviour of the icy targets. Since derived high [+ATR] vowels and underlying high [+ATR] vowels are identical in the output, markedness constraints cannot differentiate between them, resulting in the incorrect prediction that they should behave the same way in harmony. We propose to solve this paradox using Contrast Preservation, a framework of OT which views contrast as an independent principle in the grammar, one that is imperative to phonology (Lubowicz 2003). Lubowicz proposed a modification to OT, referred to as Preserve Contrast Theory (PCT), to handle cases where underlying contrast needs to be preserved. Specifically, this idea is formalized in OT as a “family of rankable and violable constraints on preserving contrast” (Lubowicz 2003:5). In PCT, inputs cannot be evaluated in isolation; instead, they need to be evaluated in the context of other inputs, in order to evaluate which contrasts need to be preserved or neutralized. This differs from Standard OT, in which input-output pairs are each evaluated independently.

The purpose of PC constraints is to ensure that inputs that differ in a particular feature will also differ in their output, although not necessarily in the same feature or in the same location. The core claim of PC theory is that opaque mappings, like chain shifts and derived environment effects, result from pressure from the grammar to preserve contrast. We argue that this pressure for contrast preservation is present in Karajá’s icy targets. Specifically, the icy target behaviour occurs as a way to satisfy both contrast preservation and a preference for high vowels to harmonize. The contrast is preserved on any preceding [-ATR] vowels, so that /ɛ...i...i/ and /e...i...i/ map to the distinct outputs [ɛ...i...i] and [e...i...i] respectively.

However, this semi-opacity is only evident in cases where at least one non-opaque [-ATR] vowel precedes a high, [-ATR] vowel. If a sequence like /i...i/ occurs, then /i/ will harmonize and the sequence will surface as [i...i], neutralizing the contrast between underlying /i...i/ and /i...i/. This shows that, while Karajá does exert a pressure to preserve ATR contrasts in the high vowels, the pressure for those high vowels to harmonize is stronger still. Our analysis, which we outline in the remainder of this section, is able to capture this aspect of Karajá icy targets.

3.1 Cluster-building algorithm

Under PCT, the input must include multiple input strings and their corresponding outputs within a single evaluation. This requirement is necessary because knowing whether contrast has been preserved is only possible when comparing many input-output pairs of the same language. These input strings, referred to as *input scenarios* or simply *scenarios*, must be generated from a base through a “cluster-building algorithm”. While it differs from the one originally proposed by Lubowicz (2003), we adopt the algorithm from Tessier (2004), which has three steps and starts with a base input form combined with a language-specific ranking of constraints. The algorithm is quoted from Tessier (2004) in (3).

- (3) The cluster-building algorithm (Tessier 2004:104)
 “To find an input cluster, given a /base/ and a ranking of constraint H_{lang} , repeat the following three steps for each markedness constraint *X:
- Step 1:** Ignoring all markedness constraints except *X, run /base/ through the grammar and find its winning output [B].
 - Step 2:** If [B] is not a fully-faithful candidate, include [B] in the cluster.
 - Step 3:** If [B] is a fully-faithful candidate, inspect the violations of *step a’s losing candidates*, and include as neighbours all the forms which:
 - (i) Violates *X exactly once and
 - (ii) are otherwise most harmonic (*I.e.*, most faithful)”

Clusters will be built by adding the winning output, if it is not faithful to the input, or the most faithful candidate that violates the markedness constraint exactly once if the winning candidate is faithful. These steps must be repeated for every markedness constraint, and all neighbours will be included in the final cluster. The resulting clusters will then be run in tableaux containing the PRESERVE constraints of PCT and all other relevant constraints.

3.2 Account of Karajá basic harmony

In order to provide an analysis of Karajá harmony within Optimality Theory, we must first be able to account for the [+ATR] dominance and for the fact that harmony is only regressive. The constraints relevant for these specific facts are given below in (4-6).

(4) IDENT-IO[+ATR]

Assign a violation for every segment that is [+ATR] in the input but whose correspondent is not [+ATR] in the output

(5) *[-ATR]C₀[+ATR]

Assign a violation to a [-ATR] segment followed by a [+ATR] segment across any number of consonants

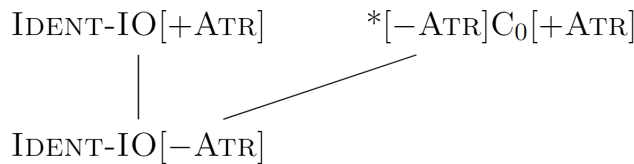
(6) IDENT-IO[-ATR]

Assign a violation for every segment that is [-ATR] in the input but whose correspondent is not [-ATR] in the output.

Harmony is induced through a general harmony constraint *[-ATR]C₀[+ATR] penalizing [-ATR] vowels from surfacing when preceding [+ATR] vowels. The separation of IDENT-IO[+ATR] into two distinct faithfulness constraints allows for an account of ATR dominance by penalizing changes from [+ATR] to [-ATR] and [-ATR] to [+ATR] separately (Gressang 2002, Sasa 2006, Ozburn 2019).

The ranking of these constraints is given in (7). The markedness constraint *[-ATR]C₀[+ATR] drives harmony, while IDENT-IO[+ATR] guarantees the retention of the [+ATR] feature. By ranking both of these constraints above IDENT-IO[-ATR], ATR-dominant harmony is induced.

(7) Constraint Ranking for Karajá basic harmony



Harmony in Karajá is exclusively regressive; even when a [+ATR] vowel is present in the middle of a word, only preceding vowels harmonize. The harmony constraint in (5) only penalizes sequences of [-ATR]...[+ATR], not the reverse, meaning that it correctly derives this directionality. A version of the harmony constraint targeting [+ATR]...[-ATR] sequences must be ranked below IDENT-IO[-ATR] to ensure that no progressive harmony occurs. We omit this constraint for space reasons; candidates that violate it will be ruled out by additional violations of IDENT-IO[-ATR].

The effect of these constraints and ranking is shown in Table 3. Candidate (a) demonstrates harmony both progressively and regressively, so is ruled out by additional violations of IDENT-IO[-ATR]. Candidate (b) shows no harmony, fatally violating the harmony constraint, while candidate (c) shows [-ATR] harmony throughout the entire word, fatally violating IDENT-IO[+ATR]. Candidate (d), on the other hand, shows regressive ATR-dominant harmony. It wins because it does not violate the higher-ranked constraints and has fewer violations of Ident-IO[-ATR] compared to candidate (a).

Table 3: Karajá basic harmony

	/r-ɔ-duhɔ-rɛrɪ/	IDENT-IO[+ATR]	*[-ATR]C ₀ [+ATR]	IDENT-IO[-ATR]
a.	a. rot <u>ɨ</u> horeri			***
b.	b. rɔt <u>ɨ</u> horeri		*!	
c.	c. rɔt <u>ɨ</u> horeri	*!		
☞ d.	d. rot <u>ɨ</u> horeri			*

Karajá also has opaque vowels, including /a/ and most of the nasal vowels. These can be straightforwardly accounted for using additional constraints (e.g. IDENT-IO[low] and *[+ATR,+low]), in exactly the same way as opacity is derived in existing work on ATR harmony. For space reasons, we do not illustrate the result here.

3.3 Account of Karajá icy targets

As noted, we adopt the PRESERVE family of constraints from Lubowicz (2003) to account for the behaviour of icy targets in Karajá. The relevant constraint is formulated in (8).

(8) PRESERVE[+ATR, +HIGH]:

If otherwise-identical inputs contrast for [ATR] in high vowels, they must map to distinct outputs.

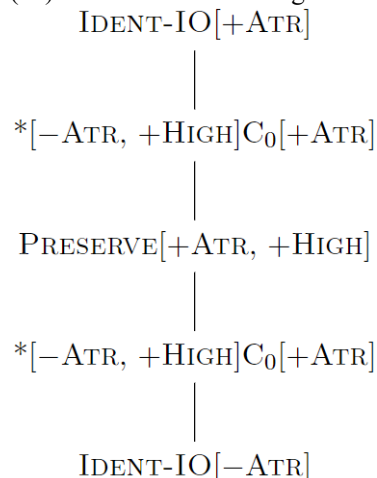
PRESERVE[+ATR,+HIGH] will compare outputs and assign a violation to candidates where an underlying contrast for ATR in high vowels was not preserved. Given that this constraint limits the spread of harmony, it must be ranked above the harmony driving constraint *[-ATR]C₀[+ATR]. However, this constraint by itself will not induce the icy target behaviour, as it would predict that high [-ATR] vowels themselves do not harmonize; instead, they would be blockers. To make sure that the high, [-ATR] vowels do harmonize, a markedness constraint banning [+HIGH, -ATR] segments from preceding [+ATR] segments is needed, as defined below in (9). This constraint is motivated in work such as Ozburn (2019).

(9) *[-ATR,+ HIGH]C₀[+ATR]:

Assign a violation to a [-ATR,+HIGH] segment followed by a [+ATR] segment across any number of consonants.

This constraint will force high, [-ATR] vowels to harmonize when preceding [+ATR] vowels, despite the lower ranking of *[-ATR]C₀[+ATR]. By ranking the markedness constraint in (9) above PRESERVE[+ATR, +HIGH], harmony occurs in the high vowels, even at the expense of neutralizing a contrast. Thus, the contrast will be preserved on preceding vowels, where possible, correctly inducing the semi-opacity exhibited by the high vowels in Karajá. A Hasse diagram of all the constraints relevant to icy targets in Karajá vowel harmony is given in (10).

(10) Constraint ranking for Karajá vowel harmony



We assume that all constraints from the PRESERVE family besides the one in (8) are too low-ranked to have any effects in Karajá. As such, it is only necessary to illustrate a full analysis in PCT for forms containing a high vowel; the use of this theory changes nothing about the basic harmony in Section 3.2. The remainder of this section is devoted to illustrating the derivation of icy targets. The starting point for generating clusters in Karajá is shown below (11).

(11) Starting point

Clusters for / $\varepsilon\dots\varepsilon\dots o\dots e$ / : / $\varepsilon\dots\varepsilon\dots o\dots e$ /_{base}

The first step of the algorithm from (3) consists of running the base through the grammar, ignoring all but one markedness constraint at a time. Given that only the harmony markedness constraints are relevant here, we repeat this step only twice, though in principle it would need to be repeated for every markedness constraint in the grammar. The interested reader is referred to Tessier (2004) for more general demonstration of the algorithm. Repeating this step further would have no effect on the analysis.

Table 4: Step 1 for markedness constraint *[-ATR]_{C₀}[+ATR]

		/ $\varepsilon\dots\varepsilon\dots o\dots e$ /	IDENT- IO[+ATR]	*[-ATR] _{C₀} [+ ATR]	IDENT- IO[-ATR]
	a.	$\varepsilon\dots\varepsilon\dots o\dots e$		*!	
	b.	$\varepsilon\dots\varepsilon\dots o\dots \varepsilon$	*!		
☞	c.	$e\dots e\dots u\dots e$			***
	d.	$e\dots\varepsilon\dots u\dots e$		*!	*
	e.	$\varepsilon\dots\varepsilon\dots u\dots e$		*!	*
	f.	$\varepsilon\dots e\dots u\dots e$		*!	**

(12) Result of Step 1 for Table 4

/ $\varepsilon\dots\varepsilon\dots o\dots e$ / → [$e\dots e\dots u\dots e$] (unfaithful)Table 5: Step 1 for markedness constraint *[-ATR,+High]_{C₀}[+ATR]

		/ $\varepsilon\dots\varepsilon\dots o\dots e$ /	IDENT-IO[+ATR]	*[-ATR,+HIGH] C ₀ [+ATR]	IDENT- IO[-ATR]
	a.	$\varepsilon\dots\varepsilon\dots o\dots e$		*!	
	b.	$\varepsilon\dots\varepsilon\dots o\dots \varepsilon$	*!		
	c.	$e\dots e\dots u\dots e$			***!
	d.	$e\dots\varepsilon\dots u\dots e$		*!	*
☞	e.	$\varepsilon\dots\varepsilon\dots u\dots e$			*
	f.	$\varepsilon\dots e\dots u\dots e$			**!

(13) Result of Step 1 for Table 5

/ $\varepsilon\dots\varepsilon\dots o\dots e$ / → [$e\dots\varepsilon\dots u\dots e$] (unfaithful)

From the tableaux in Table 4 and Table 5, we add the two neighbours from (12) and (13), resulting in the cluster in (14).

(14) After Step 2:

Cluster for / $\varepsilon\dots\varepsilon\dots o\dots e$ /:[$\varepsilon\dots\varepsilon\dots o\dots e$]_{base}[$e\dots e\dots u\dots e$]_{neighbour}[$\varepsilon\dots\varepsilon\dots u\dots e$]_{neighbour}

Using the cluster in (14) as well as the constraints already defined above, including the PRESERVE constraint, we can now fully analyze Karajá icy targets, as shown in Table 6. The constraint PRESERVE(ATR,+HIGH) is violated when two inputs differ only in the feature [ATR] on [+HIGH] vowels, but the outputs do not differ. As such, it will be violated any time / $\varepsilon\dots\varepsilon\dots o\dots e$ / and either of its neighbours map to an identical output, as in candidates (d) and (e).² The harmony constraint specific to high [-ATR] vowels ensures that high [-ATR] vowels harmonize, ruling out candidate (a). As shown, the preferred

² Note that the two neighbours themselves do not differ in [ATR] on a high vowel; they only differ in the mid vowels. As such, whether they map to the same output is irrelevant to the PRESERVE constraint.

candidate is (b), where underlying high [-ATR] vowels are icy targets, but [+ATR] high vowels trigger harmony. Remaining candidates (c) and (f) are ruled out by additional violations of [-ATR] faithfulness and the general harmony constraint respectively. Note that the harmony constraints and faithfulness constraints check the total number of violations across both inputs; where relevant, we have separated the violations for different inputs using commas for readability.

Table 6: Analysis of icy targets

		/ε...ε...o...e/	/ε...ε...u...e/	/e...e...u...e/	*[-ATR,+HIGH]C ₀ [+ATR]	PRESERVE [+ATR,+HIGH]	*[-ATR]C ₀ [+ATR]	IDENT-IO [-ATR]
	(a)	ε... ε...o...e	e... e...u...e	e...e...u...e	*!			**
☞	(b)	ε... ε...u...e	e... e...u...e	e...e...u...e			*	*,**
	(c)	ε... e...u...e	e... e...u...e	e...e...u...e			*	**,**!
	(d)	e... e...u...e	e... e...u...e	e...e...u...e		*!		***,**
	(e)	ε... ε...u...e	ε... ε...u...e	e...e...u...e		*!	*,*	*
	(f)	ε... ε...u...e	ε... e...u...e	e...e...u...e			*,*!	*,*

4 Discussion

4.1 Predictions

This account only predicts icy targets for sequences like /ε...o...e/, where a mid vowel precedes the high [-ATR] vowel. In cases with a sequence of two high, [-ATR] vowels, such as /i...o...e/, this approach predicts that the rightmost in the consecutive high vowels should not be an icy target. Indeed, the highly ranked markedness constraint *[-ATR,+HIGH]C₀[+ATR] forces high vowels to surface as [+ATR] when followed by a [+ATR] vowel. Because this constraint is ranked higher than the PRESERVE constraint, we expect high vowels to undergo harmony even if this neutralizes the contrast.

In fact, as far as we can tell, this prediction is borne out in the Karajá data. Indeed, Ribeiro (2012) gives an example /dã-d-i-wi=d-e/ ‘you brought it’, which surfaces as [dãdiwĩdẽ], with harmony to both of the high vowels. If the rightmost high vowel were an icy target, the form would be *[dãdiwĩdẽ], without harmony to the leftmost high vowel. Instead, both high vowels harmonize, even though that harmony neutralizes the contrast between /dãdiwĩdẽ/ and competing neighbours /dãdriwĩdẽ/ and /dãdiwĩdẽ/. This is precisely what our analysis predicts, as shown in Table 7.

Table 7: Sequence of high vowels

		/i...i...e/	/i...ĩ...e/	/i...ĩ...e/	*[-ATR,+HIGH]C ₀ [+ATR]	PRESERVE [+ATR,+HIGH]	*[-ATR]C ₀ [+ATR]	IDENT-IO [-ATR]
	(a)	i...i...e	i...ĩ...e	ĩ...ĩ...e	*!*		**	
	(b)	i...ĩ...e	i...ĩ...e	ĩ...ĩ...e	*!*	*	**	*
	(c)	i...ĩ...e	ĩ...ĩ...e	ĩ...ĩ...e	*!	*	*	**
	(d)	i...i...e	ĩ...ĩ...e	ĩ...ĩ...e	*!	*	*	**
☞	(e)	ĩ...ĩ...e	ĩ...ĩ...e	ĩ...ĩ...e		**		***

Ribeiro also notes that there is optionality with icy targets when the trigger is a mid vowel, meaning that this example may just reflect one of two possible outputs for such an input. However, we were unable to find any examples of sequences of three high vowels, nor of high vowels behaving as an icy target when preceded by another high vowel. As such, while it may seem problematic to predict that high vowels are not icy targets when preceded by another high vowel, there does not appear to be any evidence against this prediction.

4.2 Summary and further directions

In this paper, we proposed that icy targets in Karajá serve a purpose: they preserve an underlying contrast between [-ATR] and [+ATR] high vowels. This contrast is preserved in a different location, namely in any preceding (mid) vowels, yet there remains a distinction between underlying [-ATR] high vowels, where harmony stops, and underlying [+ATR] high vowels, where harmony proceeds. Using Lubowicz's (2003) Preserve Contrast Theory, we analyzed this pattern by adopting input sets and Preserve constraints. Specifically, the constraint PRESERVE(+ATR,+HIGH) preserves underlying ATR contrasts on [+HIGH] vowels, while a highly ranked harmony constraint affecting high vowels specifically ensures that the contrast is preserved in preceding vowels rather than on the high vowel itself.

This approach extends to correctly account for all the facts of the Karajá system, demonstrating a novel use of Preserve Contrast Theory to account for an unusual pattern. This proposal has the advantage of turning the apparently anti-typological patterning of Karajá high vowels into a behaviour that fits well within our understanding of high vowels in ATR-dominant harmony. Indeed, high vowels have been argued to be ideal targets of ATR-dominant harmony (e.g. Archangeli & Pulleyblank 1994; Ozburn 2019); Karajá fits within this typology of preferring high vowels to be ATR and preferentially targeting high vowels in ATR harmony. Moreover, difficulties in the perception of ATR contrasts on high vowels is posited to be a motivating reason for harmony (e.g. Rose 2018); harmony allows additional opportunities to hear those difficult contrasts. In Karajá, the ATR contrast on high vowels is also allotted substantial importance, such that this contrast must be preserved. The result is icy targets: high vowels harmonize, but that difficult contrast is preserved on the preceding segments.

There are future directions of this work both within and beyond Karajá. Within the language, it is important to verify the prediction that icy targets are not present with sequences of consecutive high vowels. Beyond Karajá, there are many other potential implications of viewing aspects of harmony systems as contrast preservation, including in languages with puzzling patterns such as Turkana and Esimbi. More broadly, it is possible that major issues in vowel harmony can be viewed as a choice in which contrastive information to uphold. In this way, Contrast Preservation Theory extends beyond its original uses to unify diverse patterns within the typology of vowel harmony, where other approaches cannot. It is therefore a useful avenue to pursue in future work on vowel harmony.

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