NonFinality drives epenthesis in the Moroccan Arabic broken plural*

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Abstract

We show that in Moroccan Arabic, the iambic broken plural (C.CVC) is augmented to (C.CV).CV with a final vowel, focusing on the (C.Cu).Ca pattern, e.g., old [k.tub] 'books' → new [k.tu.ba] 'books'. We argue that the added final vowel serves to prevent a final footed syllable (prevent a violation of NonFinality). This instance of prosodically-driven epenthesis fills a typological gap where such patterns were claimed to be unattested (Blumenfeld 2006, Moore-Cantwell 2016) and supports similar proposals about German plurals where NonFinality is argued to drive epenthesis (Golston & Wiese 1995, Wiese 2009). We show that NonFinality is active more broadly in the Moroccan Arabic plural system, e.g., capturing the increase in use of C.Ca.Ci in the lexicon. Our conclusions are based on a corpus and a survey of Moroccan plurals that we analyze with lexically-indexed violable constraints (Moore-Cantwell & Pater 2016).

Keywords: Moroccan Arabic, templatic morphology, broken plural, diachronic change, lexical exceptions

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1 Introduction

This paper documents and analyzes the variation in the Moroccan Arabic broken plural, with focus on plurals that have an optional final vowel, e.g., [k.tub ∼ k.tu.ba] 'books' and other C.CuC(a) plurals. We claim that the added vowel is epenthetic, inserted to prevent a violation of NonFinality (McCarthy & Prince 1993). Our observations are based on a corpus of Moroccan Arabic plurals (Nirheche 2025) which we augmented with a survey of native speakers. We show that Moroccan Arabic has a strong preference for plurals that begin with a C.CVC iamb followed by another syllable that separates the iamb from the right edge of the word, thus connecting C.Cu.Ca broken plurals to the other two trisyllabic broken plurals patterns C.Ca.Ci and C.Ca.CəC. We examine the possibility that the final [a] of C.Cu.Ca is a suffix, and reject it based on the incompatibility of the final [a] with any of the existing suffixes in the language.

Our proposal situates Moroccan Arabic as a test case for a central debate on the interaction between epenthesis and prosodic markedness. It has been argued by Blumenfeld (2006) and, later, Moore-Cantwell (2016), that there is a typological gap where epenthesis is not used to repair violations of prosodic constraints like NonFinality, despite being predicted by classical Optimality Theory (Prince & Smolensky 1993/2004). In contrast, other studies like Golston & Wiese (1995) have argued that such prosodically-driven epenthesis is possible, for instance, in the formation of German plurals. We argue that the Moroccan Arabic C.Cu.Ca plural is a case of NonFinality-driven epenthesis, supporting the latter view. This principle of prosodically-driven augmentation is also active in the formation of diminutives, which are systematically augmented via epenthesis to satisfy prosodic well-formedness constraints (Boudlal 2001).

In our grammatical model of the data, based on weighted violable constraints with MaxEnt evaluation (Goldwater & Johnson 2003, Smolensky & Legendre 2006), NonFinality competes with Dep (McCarthy & Prince 1995). Lexically-specific copies of these constraints (Pater 2000, 2007, 2010) capture the observed patterns in the lexicon, while the general constraints apply productively to novel words (Moore-Cantwell & Pater 2016).

We also examine the historical development of C.Cu.Ca plurals, noting that they are a North African innovation without a direct source in older/more eastern varieties of Arabic. A comparison with a sixty year old dictionary (Harrell et al. 1966) suggests a recent expansion of C.Cu.Ca plurals or even a change in progress,

albeit without any community awareness.

We start in §2 with a study of the C.Cu.Ca plurals in the corpus, followed in §3 by a survey of a subset of these plural with 42 speakers. We present our MaxEnt model with indexed constraints in §4. We examine and reject the possibility that the final [a] of C.Cu.Ca is a suffix in §5. We situate the C.Cu.Ca plurals more broadly in Moroccan Arabic and other dialects, which leads us to a broader generalization about the predictability of final vowels in trisyllabic broken plurals in §6, followed by further theoretical discussion in §7, and conclusions in §8.

2 Lexicon study

In Moroccan Arabic, and more generally in Arabic, plurals may be suffixal or templatic. The suffixal plurals, also called "sound plurals", are formed by adding one of three suffixes, as in (1a). Templatic plurals, known as "broken plurals", are formed via rearrangement of the singular material with some added templatic material, as in (1b). There are several different types of broken plurals, but just two of them cover 87% of the data, and those will be our focus here.

The corpus we use in this paper comes from Nirheche (2025), where the singulars come from the Darija Open Dataset (Outchakoucht & Es-Samaali 2021), and the plurals come from Nirheche's native speaker intuition. The full corpus has 1166 plurals with their corresponding singulars, in IPA. In (1) we tabulate the 891 plurals that are native or fully nativized.

(1) The two types of plurals in Moroccan Arabic: *sound* and *broken*

		SG	PL	type	n		
a.	sound	l.san	l.sa.n-at	-at	395	81%	'tongue'
		jəd.d	jəd.d-in	-in	63	13%	'hand'
		ʃi.fur	ʃi.fu.r-a	-a	28	6%	'driver'
		total sound:			486	100%	
b.	broken	kəl.b	k.lab	a-iamb	266	66%	'dog'
		qər.n	q.run	u-iamb	86	21%	'century'
				others	53	13%	
		total broken:			405	100%	

As the examples in (1b) show, the most common plural patterns start with

a syllabic consonant followed by another syllable with a full vowel, [a] or [i], creating an iamb. Inside this iamb, the difference in sonority is maximized between the unstressed dependent of the foot (a low sonority consonant) and its head (a high sonority vowel).

Regarding the prosodic structure in these examples, we assume that Moroccan Arabic has no complex onsets, and therefore initial #CC sequences are heterosyllabic. The phonetic evidence for this comes from the temporal stability patterns of these initial CC sequences, which were shown to exhibit a right-edge-to-anchor stability pattern (Shaw et al. 2009, Gafos et al. 2020). The phonetic studies corroborate the earlier phonological arguments that were based on word minimality (Al Ghadi 1990, Jebbour 1996, Boudlal 2001).

We also assume that Moroccan Arabic builds iambic feet (Al Ghadi 1990, 1994, Boudlal 2001). In our analysis, then, Moroccan Arabic words have feet and therefore stress, but we make no claim about any phonetic realization of this metrical structure, which has been a topic of controversy in the literature, with some studies reporting the existence of acoustic correlates for stress (Boudlal 2001), and others not finding any (Bruggeman 2018, Bruggeman et al. 2021).

In his description of the Moroccan broken plural, Harrell (1962) lists forty different broken plural patterns, but his taxonomy doesn't take into account many predictable aspects of pluralization. The most common pattern, an iamb headed by [a], includes the sub-types C.CaC, C.Ca.Ci, C.Ca.Ca and C.Ca.CəC, where the choice between these variants is predictable and follows phonological pressures such as the need to preserve all of the vowels and consonants of the singular. For example, the sub-type C.Ca.Ci is predictably chosen when the singular ends in the suffix [-a], as in [rək.ba ∼ r.ka.bi] 'knee(s)'; see §6.4 below.

We extracted the C.CuC(a) broken plurals from Nirheche (2025), where the corpus marked the presence of final [a] as prohibited, optional, or obligatory. The resulting sub-corpus contains 86 nouns. As shown in (2), 26% of the items are variable, and 26% always take [a].

(2) C.CuC(a) plurals in the corpus by status of [a]

	status of [a]	example		n
a.	No [a]	ʒ.durˁ	'roots'	42
b.	Optional [a]	w.ʒuh ∼ w.ʒu.ha	'faces'	22
c.	Obligatory [a]	n.mu.ra	'tigers'	22

Since this corpus represents the native speaker intuitions of just one person, we sought to collect judgments from a larger and more representative groups of speakers, a task we turn to in §3.

Further, a comparison of Harrell et al.'s (1966) dictionary to the contemporary corpus shows that final [a] is more frequent in the corpus, suggesting perhaps an ongoing historical change (we return to this point in §6.2 below). We therefore wanted to see if the [a]-less forms are perceived as characteristic of older speakers.

3 Lexical survey of C.CuC(a) plurals

To generate a more nuanced and accurate understanding of the distribution of final [a] in C.CuC(a) plurals, and to investigate the perception of any ongoing language change, we conducted a study in which 42 native speakers provided their plural preferences and the sociolinguistic perception of them for a selection of 18 nouns from the corpus.

We asked speakers whether they associate particular plural forms with older speakers and/or with women. We asked about older people with the hopes of detecting an association between plurals without [a] and older speakers. The question about gender was a distractor.

We found considerable variation between lexical items in their propensity to take a C.Cu.Ca plural. We did not find any sociolinguistic influence on the distribution of the final [a]: speakers did not judge it as correlated with age or gender. This study was reviewed by the Institutional Review Board and was granted exempt status.

3.1 Participants

Participants were recruited via word-of-mouth and on the first author's Instagram account.

We included the 42 participants who completed the entire study and self-reported an age of 18 or above, excluding all others. The included participants were 36 years old on average (range 18–62, median 33). Self-reported gender was 16 females, 24 males, and 2 not reported. As for their location in Morocco, 23 participants said they are from the central regions (Fes, Meknes, etc), 11 from the west (Rabat, Casablanca, etc), and 8 from other parts of the country. The participants volunteered their time and effort.

3.2 Materials

We chose 18 nouns that have a C.CuC(a) plural, using the three types of plurals according to the corpus: four items with no [a], ten with optional [a], and four with obligatory [a].

Each noun was paired with a frame sentence that included the noun in the singular, with a demonstrative or adjective that requires a singular, followed by another sentence with a blank for the plural, with a quantifier or an adjective that requires a plural. The frame sentences were given in the Arabic script without vowel diacritics. The frames included emojis that were evocative of the target noun, with one instance of the emoji in the singular and three instances in the plural (see Figure 1).

3.3 Procedure

The experiment was distributed online using Experigen (Becker & Levine 2015). Participants were free to use the browser of their choice (desktop or mobile phone). The entire website was in the Arabic script, in Moroccan Arabic. The first screen presented the study and included a consent form. Once consent was given, the first item appeared on the screen, as shown in Figure 1. The order of items was randomized for each participant.

Each item appeared on the screen within its frame sentence, followed by the question "which plural sounds better to you?", and two buttons, one with a C.CuC plural and one with the C.Cu.Ca plural. The order of the buttons was randomized and counter-balanced. Once one of the plurals was chosen, a statement appeared saying "old people say [first plural], not [second plural]", and participants were asked to press one of two buttons, choosing whether the statement was true or false. Once one of the buttons was pressed, a statement appeared saying "women say [first plural], not [second plural]", and participants were asked to press one of two buttons, choosing whether the statement was true or false. Once one of the buttons was pressed, the next item appeared. After the last item, participants were invited to provide demographic information anonymously.

3.4 Results

The selection of [a] was overall gradient, with items covering the entire range from 5% to 98%. Compared to the corpus, participants were less extreme (reaching

Figure 1: A black-and-white screenshot of the stimulus [qsˤər] 'palace' and its translation

neither zero nor 100%), and tended towards more [a]. The "optional [a]" items, which were expected to cluster around 50%, were in the 42–90% range. The results by item are plotted in Figure 2. Overall, however, the corpus and experiment are very well correlated, showing that the individual judgments of the corpus are strongly correlated with the judgment of the community as a whole.

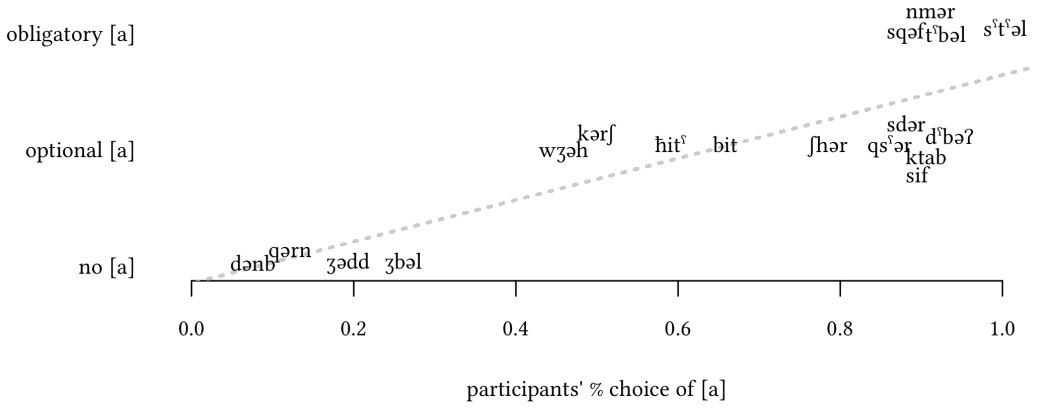

Figure 2: Preferences of 42 participants for final [a] by item. The y-axis shows the status of final [a] in the corpus with vertical jitter to remove overlap

Regarding the sociolinguistic questions, there was no indication of an age effect. Rather, participants tended to think that old people choose the same plurals as them (71%). This was true in trials where participants preferred the plural without [a] (69%) and in trials where they preferred the plural with [a] (73%).

Similarly, participants tended to think that women prefer the same plural they do (71%), both in plurals without [a] (65%) and with (75%).

To test the reliability of these effects across items and participants, we fitted a mixed-effects logistic regression model to the results using the *glmer* function in the *lme4* package (Bates et al. 2015) in R (R Core Team 2023). The dependent variable was the choice of final [a], and the predictors were corpus type (none, optional, obligatory), agreement with old people and agreement with women, with random intercepts for items and participants. Plural type came out highly significant, while the agreement with old people and women did not reach significance.

Since we have the self-reported age and gender of our participants, we also checked whether they correlate with the selection of final [a] in the plural. In a by-participant analysis, age had a very weak correlation with the selection of [a] (Pearson's correlation test, $r(40) = .04$, $t = .25$, $p > .1$). The same was true for gender (Pearson's correlation test, $r(40) = .12$, $t = .79$, $p > .1$). When entered into the regression model, neither variable made a significant improvement. We conclude that our experiment did not detect a difference in the judgment of plurals between people of different ages, nor between men and women.

3.5 Summary

We surveyed a subset of the C.Cu.Ca plurals from the corpus with 42 participants, showing considerable by-item variability. Some items are almost exclusively C.CuC, while others are almost exclusively C.Cu.Ca, with much variation in between.

We did not find evidence for sociolinguistic variables of age or gender. This null result is compatible with at least three different interpretations: the use of final [a] might not be currently increasing, or the use of final [a] is increasing without being associated with the social variables of age or gender, or the use of final [a] is increasing but our methodology was unable to detect this increase.

4 MaxEnt with lexically-specific constraints

This section presents an analysis of the Moroccan Arabic broken plural pattern C.CuC(a). Using a probabilistic model, we analyze the optionality of the final

[a] in C.CuC(a) as a competition between the constraints NonFinality and Dep. Lexically-indexed versions of these constraints are introduced to capture the propensity of individual nouns for taking [a]. The model successfully captures the observed variation in C.CuC(a) plurals.

4.1 Accounting for optional, prohibited and obligatory [a]

In this study, we use Maximum Entropy (MaxEnt) grammar (Goldwater & Johnson 2003), a probabilistic version of Harmonic Grammar (Smolensky & Legendre 2006) that captures both categorical and variable patterns in phonology. MaxEnt assigns probabilities to different output candidates by optimizing the weights of constraints. Such a probabilistic model is needed to account for the lexical items that can optionally take the final [a]. To account for the variability between existing words in the lexicon, we incorporate lexically-indexed constraints (Pater 2000, 2007, 2010).

We model our data as a competition between (C.CuC), which is parsed as an iamb, and (C.Cu).Ca, which is parsed an an initial iamb followed by a final unfooted syllable. The constraint NonFinality penalizes words that foot the word-final syllable, and therefore it penalizes (C.CuC). On the other hand, the faithfulness constraint Dep penalizes the final epenthetic vowel in (C.Cu)Ca. In addition, we use indexed versions of each of these two constraints. The *initial state*, before learning starts, is shown in (3). The constraints have no weight yet, nor are there any lexically specific constraints in the grammar at this stage, so free variation is predicted, i.e., 50% [a] for all C.CuC plurals.[1]

(3) The grammar before the beginning of learning (the initial state)

/noun + u_{PL}/		NonFinality $w = 0$	Dep $w = 0$	$\mathscr{H}$	p
/kər.ʃ/	(k.ruʃ)	-1		0	.50
	(k.ru)ʃa		-1	0	.50

Other constraints, not included in the analysis, regulate other predictable aspects of the plural, such as the quality of the final vowel, as shown in (4). The usual epenthetic vowel of the language, [ə], is not allowed in open syllables.

[1] In MaxEnt, the probability of a candidate is proportional to the exponential of its harmony, $\mathscr{H}$. The harmony is the sum of constraint violations multiplied by the weights of the constraints. When all harmonies in a tableau are equal, the probability is divided equally between the candidates.

Among the full vowels [a, i, u], OPC(high) penalizes the high vowels [i, u] after the high [u] of the iambic template, leaving [a] as the only option.

(4) Choosing [a] as the epenthetic vowel

/noun + u_{PL}/		*ə]$_\sigma$ $w = 5$	OCP(high) $w = 5$	$\mathscr{H}$	p
/kər.ʃ/	(k.ru)ʃa			0	1
	(k.ru)ʃi		−1	−5	0
	(k.ru)ʃə	−1		−5	0

Additional constraints account for the appearance of an iamb at the left edge and the choice of segments from the singular that fill this iamb. This part of the analysis is worked out in detail in Nirheche (in press). These aspects of the Moroccan Arabic plurals are uniform across all of the various iambic plural templates in the language.

4.2 Learning simulation

To simulate learning the C.CuC(a) broken plural patterns, we used the MaxEnt grammar tool of Staubs & Pater (2011) with a Shiny app that offers a user-friendly interface (Nirheche 2024). To create lexically-indexed constraints, we used a Python script that takes two inputs: a tableau with general constraints, like the one in (3), and a lexicon. The script creates candidates and indexed constraints for each lexical item, which are then handed over to the MaxEnt tool.

Training data and constraints: The training data used for the simulation contains the corpus of 86 items described in §2: 42 items with the plural template C.CuC, 22 with C.Cu.Ca, and 22 with C.CuC(a). Thus, we train the model on the speech of one individual and obtain a grammar for that individual.

In a separate simulation, we used the results of the experiment in §3.4 to model the community trends for a subset of the existing lexical items. Here we focus our report on the larger lexicon and return to the second simulation at the end.

In addition to the general constraints Dep and NonFinality, the model was given lexically-indexed versions of both constraints for each input. This means that each lexical item in the training data had its own indexed version of Dep and NonFinality, allowing the model to learn the plural patterns in an unsupervised manner.

Results: The simulation implemented the algorithm of Moore-Cantwell & Pater (2016), generating distinct results for each lexical item. The model effectively learned the grammar, optimizing weights for both the general constraints, Dep and NonFinality, and their lexically-indexed versions. The general Dep and NonFinality constraints had weights of 14.9 and 16, respectively, which was then adjusted by the lexically-indexed versions for specific lexical items. As shown in (5), the model generated optionality by assigning a small weight to the indexed versions of Dep and no weight for the indexed versions of NonFinality of these items. The noun [dərb], for instance, is expected to vary between [drub] and [druba] as possible outputs. Each candidate violates two constraints: one general and one lexically-specific. The summed penalties of the two candidates are identical, giving each candidate a probability of 50%.

(5) Modeling optionality in the existing item [dər.b] 'street'

		NonFin $w = 16$	NonFin$_{dərb}$ $w = 0$	Dep $w = 14.9$	Dep$_{dərb}$ $w = 1.1$	$\mathscr{H}$	p
/dərb/ + u_{PL}	(d.rub)	-1	-1			-16	.50
	(d.ru).ba			-1	-1	-16	.50

For words with obligatory [a], the indexed versions of NonFinality were given enough weight to overcome the effect of Dep, enforcing the obligatory C.Cu.Ca pattern, as shown in (6). The lexically specific version of Dep is not doing any work here.

(6) Modeling the obligatory [a] in [nmura] 'tigers'

		NonFin $w = 16$	NonFin$_{nmər}$ $w = 6.9$	Dep $w = 14.9$	Dep$_{nmər}$ $w = 0$	$\mathscr{H}$	p
/nmər/ + u_{PL}	(n.mur)	-1	-1			-22.9	.01
	(n.mu).ra			-1	-1	-14.9	.99

Finally, for words where the [a] is prohibited, the model gave a higher weight of 9 for the indexed versions of Dep. The tableau in (7) shows the model's prediction for this type of word. Overall, we conclude that the model's predictions aligned with the observed data for all the three patterns: C.CuC, C.Cu.Ca and C.CuC(a).

(7) Modeling the prohibited [a] in [q.run] 'centuries'

		NonFin $w = 16$	NonFin$_{qərn}$ $w = 0$	Dep $w = 14.9$	Dep$_{qərn}$ $w = 9$	$\mathscr{H}$	p
/qərn/ + u_{PL}	(q.run)	-1	-1			-16	.99
	(q.ru).na			-1	-1	-23.9	.01

As for the predictions for nonce words, we assume that nonce words are not lexically indexed, following Moore-Cantwell & Pater (2016). Since the weight of general NonFinality is higher than general Dep, the model predicts a variable outcome for nonce words that prefers C.CuC (76%) plurals over C.Cu.Ca (24%), replicating the statistical tendency towards C.CuC that is in the lexicon. The tableau in (8) shows the derivation of the broken plural of the nonce word [bən.ʃ].

(8) Derivation of nonce [bən.ʃ]: epenthesis predicted at 24%

		NonFin $w = 14.9$	Dep $w = 16$	$\mathscr{H}$	p
/bənʃ/ + u_{PL}	(b.nuʃ)	-1		-14.9	.76
	(b.nu).ʃa		-1	-16	.24

As shown (8), having no indexed constraints for the nonce word [bən.ʃ], its expected plural is variable. The model follows the numerical trend in the lexicon, where the probability of epenthesis is 40%. Rather than doing exact frequency matching, the model pulls the prediction towards the extremes, so 40% is brought closer to zero, a behavior that has been observed in similar previous studies (Hughto et al. 2019). More accurate frequency matching can be obtained by biasing the model if desired.

This completes our simulation of the corpus, which represents the grammar of one representative individual for 67 lexical items. We also ran a similar simulation using the 18 lexical items from the experiment in §3.4, which better represent the community for a subset of the items. The results for this community-based simulation similarly captured the frequency of [a] for individual items, e.g., [k.tu.ba] 'books' was entered into the model with 88% [a], and the model matched this frequency exactly thanks to the lexically-specific copy of NonFinality. The prediction for nonce words was 64% [a], closely matching the experiment average of 63%; here the close match is due to the smaller number of existing lexical items in the model.

In addition to the simulations above, which make copies of the constraints for every lexical item as in Moore-Cantwell & Pater (2016), and end up with a large number of constraints, we also ran a simulation using the software of Nazarov & Smith (2023). This learner creates lexically-specific copies of constraints only when such copies improve the grammar by an analyst-specified amount. When we ran this model, it captured the data well, creating 2–4 indexed constraints,

depending on the level of accuracy we specified. This model is able to maintain a small number of constraints due to its sophisticated indexation algorithm.

To summarize, we implemented two models that use indexed constraints to capture lexical variation, and that have an available computational implementation: Moore-Cantwell & Pater (2016), which has an attractively simple indexation method ("index everything!") but ends up with a large grammar, and Nazarov & Smith (2023), which has a highly sophisticated indexation method, and ends up with a much smaller grammar. Both models are successful, as both capture categorical and gradient behaviors of existing lexical items, and both models project a gradient prediction for novel items. The difference lies in the locus of complexity: in the resulting grammar, or in the algorithm that creates the grammar.

4.3 Conclusion

In this section, we have shown that the variation in the insertion of the final [a] in Moroccan Arabic C.CuC(a) plurals can be effectively modeled using a MaxEnt grammar with lexically-specific constraints. The analysis shows that the competition between NonFinality and Dep, as well as their lexically-indexed versions, accounts for the optional, prohibited, and obligatory presence of [a] across different nouns. The prediction for novel words approximately matches the frequency of final [a] in the lexicon. The approach we use creates grammars with dozens or even hundreds of constraints to capture the behavior of individual lexical items. This proliferation of constraints has neither practical nor theoretical drawbacks, as the model assigns weights to the general constraints and thus makes good predictions for novel items.

5 Final [a] is not morphemic

In this section, we argue that the final [a] in C.Cu.Ca plurals is not a morphemic element. We show that the final [a] does not pattern like any of the other similar suffixes of the language, specifically the feminine singular [-a] or either of the sound plural suffixes [-a] or [-at]. These arguments will support our analysis of the final [a] in C.Cu.Ca plurals as an epenthetic vowel that serves to prevent final footing and avoiding a violation of NonFinality.

5.1 Final [a] is not the feminine singular

In Moroccan Arabic, nouns are categorically assigned to one of two genders, masculine or feminine (Harrell 1962), including nouns that are not inherently associated with biological gender. Masculine nouns are unmarked, while feminine nouns are often identified by the suffix [-a]. There are exceptions to these general patterns. A minority of masculine nouns take the suffix [-i]. Similarly, some feminine nouns lack the feminine suffix [-a]. Examples of each of these are shown in (9).

(9) Classification of Moroccan Arabic nouns by gender

		singular	
Masculine	unsuffixed	raʒəl	'man'
	suffixed	dərr-i	'boy'
Feminine	unsuffixed	ʃəmʃ	'sun'
	suffixed	rəkb-a	'knee'

We examined the gender of the 44 nouns that have a C.Cu.Ca plural with a final [a], either optionally or obligatorily. The gender of each noun was tested by syntactic agreement with adjectives, and it was found that all of the plurals are masculine. Even the one noun with a feminine singular (10a) has a masculine plural (10b). This shows that the final [a] of the plural cannot be a feminine suffix.

(10) C.Cu.Ca plurals take masculine agreement

a.	l-kərʃ	ʕamr-a (*ʕamər)	
	DEF-stomach	full-F (*full.M)	'the stomach is full'
b.	l-kruʃa	ʕamr-in (*ʕamr-at)	
	DEF-stomach.PL	full-M.PL (*full-F.PL)	'the stomachs are full'

A second piece of evidence against the interpretation of [a] as a feminine suffix can be found in possessive constructions, shown in (11). In possessives, the final [a] of the feminine suffix deletes and a [t] appears on the surface. In the case of C.Cu.Ca plurals, however, the final [a] does not delete when forming possessive constructions. Again, the final [a] of C.Cu.Ca plurals does not pattern like the feminine suffix.

(11) C.Cu.Ca plurals differ from the feminine singular in possessives

		isolation	1SG possessive [-i]	
a.	feminine singular	ko.rˤ-a	korˤ.-t-i, *ko.rˤ-a.t-i	'my ball'
b.	C.Cu.Ca	k.tu.ba	k.tu.ba.-t-i, *k.tub.-t-i	'my books'

We conclude that the [a] of C.Cu.Ca matches neither the gender assignment nor the vowel deletion of the feminine suffix.

5.2 Final [a] is not the sound plural [-a]

Moroccan Arabic has a sound plural suffix [-a], which obeys two restrictions: it only attaches to nouns that denote masculine professions, and it only attaches to singulars, as exemplified in (12). Further, this suffix places no restriction on the preceding stem. In the native phonology, it attaches to CəC.CaC nouns, but it also attaches to loanwords of any shape.

(12) Sound plural suffix [-a] attaches to professions, no templatic requirement

singular	plural	
bən.naj	bən.na.j-a	'construction worker'
ʃi.fur	ʃi.fu.r-a	'driver, chauffeur'

In contrast, the final [a] of C.Cu.Ca only appears with plurals, it is limited to preceding C.CuC, and it is never observed on nouns that denote professions. The alignment of these three different properties merits an analysis in term of two different grammatical elements: a suffix on one hand vs. an epenthetic vowel on the other.

5.3 Final [a] is not the sound plural [-at]

Could the final [a] of C.Cu.Ca be the suffix [-at] without its final consonant? We say no, since C.CuC plurals co-occur with the feminine plural suffix [-at] in its full form. There are five such C.Cu.C-at plurals in the corpus, two of which are shown in (13a). The [t] is not optional in these double plurals. Beyond the C.CuC template, the two sound plural suffixes [-at] and [-in] also co-occur with the C.CaC iambic plural template, as shown in (13b).

(13) C.CVC broken plurals co-occur with sound plural suffixes

	SG	PL	
a.	sˤəh.dˤ	sˤ.hu.dˤ-at	‘heat’
	zit	z.ju.t-at	‘oil’
b.	χa.la	χ.wa.l-at	‘maternal aunts’
	dəmm	d.ma.j-at	‘blood’
	s.χun	s.χa.n-in	‘hot’
	mul	m.mʷa.l-in	‘owner of’

Diachronically, there is no evidence of loss of [t] in C.Cu.C-at plurals. We will further discuss the diachrony in §6.

5.4 Conclusion

In this section, we have shown that the final [a] in C.Cu.Ca plurals cannot be identified with any of the observed suffixes in the language: the feminine singular suffix [-a], sound plural suffix [-a], or the sound plural suffix [-at]. We conclude that the final [a] is not morphemic. Rather, its primary function is to prevent a final footed syllable, avoiding a violation of NonFinality.

6 The diachronic emergence of C.Cu.Ca

This section examines the diachronic development of the C.CuC(a) plural pattern in Moroccan Arabic, and draws connections to other varieties of Arabic and other plurals in Moroccan Arabic. First, we show that C.Cu.Ca has no corresponding MSA template (§6.1). Second, we compare historical data from Harrell et al.’s (1966) dictionary with the contemporary corpus and survey, showing the increase in use of final [a] (§6.2). We then we argue that the extension of C.Cu.Ca to new lexical items is similar to the historical extension of the C.Ca.Ci pattern (§6.3). In §6.4, we make a generalization about trisyllabic broken plurals in Moroccan Arabic, showing that their third syllable is almost completely predictable. Finally, we explore the presence of C.Cu.Ca plurals in other Arabic dialects (§6.5).

6.1 No corresponding MSA template for C.Cu.Ca

Generally in Moroccan Arabic, words that are inherited from Classical or Modern Standard Arabic are characterized by deletion of short vowels (V → ∅) and shortening of long vowels (Vː → V) (Kaye 1987, Scheer 1997). Plural forms with this correspondence are exemplified in (14).

(14) Inherited plurals via vowel shortening and deletion

MSA	Moroccan Arabic	
ki.laːb	k.lab	'dogs'
la.jaː.liː	l.ja.li	'nights'

However, no C.Cu.Ca plurals have such correspondence, as there are no CV.Cuu.Caa plurals in Classical or in Modern Standard Arabic. As shown in (15), all of the C.Cu.Ca plurals in the corpus without exception correspond to CiCaːC or CuCuːC plurals in MSA, with no final [a].

(15) No final [a] in the MSA sources of C.Cu.Ca plurals

Moroccan Arabic	MSA	
b.ħu.ra	bi.ħaːr	'seas'
ʕ.dˤu.ma	ʕi.ðˤaːm	'bones'
q.lu.ba	qu.luːb	'hearts'
n.mu.ra	nu.muːr	'tigers'

6.2 The rise of C.Cu.Ca in Moroccan Arabic

Heath (1987:104) argues that the plural form C.CuC is augmented to C.Cu.Ca, characterizing this as an innovation specific to Moroccan Arabic. This claim is further supported by the absence of corresponding templates for C.Cu.Ca in MSA, as shown in the previous subsection. To investigate the diachronic change in the usage of the [a], we examined Harrell et al.'s (1966) Moroccan–English dictionary. As seen in (16), the finding is that there is a shift in the usage of final [a]: 10 nouns that were given without [a] in the dictionary optionally have C.Cu.Ca in the corpus. Similarly, 6 words that have an optional [a] in the dictionary (e.g., [ʕ.dˤəm] ∼ [ʕ.dˤu.ma, ʕ.dˤam] 'bone') now require C.Cu.Ca obligatorily.

Both changes are in the direction of more use of [a]. Moreover, this change is in one direction only; no noun moved in the direction of having less [a]. This

unidirectionality strongly suggest a diachronic change in progress, where the use of final [a] is gradually expanding within the lexicon. Simple variation between individuals or communities wouldn't be expected to go in one direction only.

(16) Final [a] in Harrell et al. (1966) vs. contemporary usage

	contemporary corpus		
	No [a]	Optional	With [a]
Harrell et al.			
No [a]	26	10	—
Optional	—	12	6
With [a]	—	—	9

As discussed in §6.1 above, C.Cu.Ca plurals come from MSA Ci.CaaC and Cu.CuuC, which in Moroccan are C.CaC and C.CuC. Examples of C.CaC changing to C.Cu.Ca are seen in the comparison of the two sources of data we have are given in (17). Again, the change is unidirectional, moving towards final [a].

(17) Change from C.CaC directly to C.Cu.Ca to satisfy NonFinality

singular	Harrell et al.	contemporary plural	
r.bəʕ	r.baʕ ∼ r.bu.ʕa	r.bu.ʕa	'quarter'
dˤ.bəʕ	dˤ.baʕ ∼ dˤ.bu.ʕa	dˤ.bu.ʕa	'hyena'
ʕ.dˤəm	ʕ.dˤam ∼ ʕ.dˤu.ma	ʕ.dˤu.ma	'bone'
tˤərˤ.f	tˤ.rˤaf	tˤ.rˤu.fa	'fraction'
ʒbəl	ʒ.bal	ʒ.bal ∼ ʒ.bu.la	'mountain'

In our analysis, the move to C.Cu.Ca is motivated by the reduction in markedness, where the final [a] serves to avoid a violation of NonFinality, which compensates for the loss of faithfulness. For example, C.CaC → C.Cu.Ca includes two violations of faithfulness: Ident(high) caused by the change of [a] to [u], and Dep caused by the final [a]. Both of these are tolerated to satisfy NonFinality.

This analysis also explains why we never observe the change from C.CaC → C.CuC: this change is unfaithful to vowel height without any improvement in markedness. Finally, why is C.CaC not changed to C.Ca.Ci? We answer this question in §6.3 below, where we show that the final vowel of C.Ca.Ci is not epenthetic but rather corresponds to a final vowel in the singular.

6.3 Support from C.Ca.Ci for NonFinality

We have shown that C.CuC plurals in Moroccan Arabic are being augmented to C.Cu.Ca. This innovation is particularly evident in cases where the C.Cu.Ca pattern is being extended to nouns that historically followed the C.CaC plural pattern, such as [ʒ.bəl] 'mountain', which now alternates between two possible plural patterns: [ʒ.bal] and [ʒ.bu.la]. We argue that C.Cu.Ca may have joined the C.Ca.Ci plurals (18), which were originally derived from MSA (18a) but have since been extended to cover new lexical items (18b).

(18) C.Ca.Ci plurals with and without MSA sources

	singular	Moroccan plural	MSA plural	
a.	dər.ri	d.ra.ri	ða.ra:.ri:	'boy'
	li.la	l.ja.li	la.ja:.li:	'night'
b.	rək.ba	r.ka.bi	ru.kab	'knee'
	fər.qa	f.ra.qi	fi.raq	'team'

The C.Ca.Ci plurals in (18a) were derived from MSA through regular sound changes, i.e., the deletion of short vowels and the loss of vowel length. However, in the corpus, only 6 out of 26 (23%) C.Ca.Ci plurals have a direct MSA source. The majority of C.Ca.Ci plurals, like those in (18b), have different plural patterns in MSA, indicating that the C.Ca.Ci template has been extended to cover new lexical items. This extension mirrors the behavior of C.Cu.Ca, which is also being applied to nouns that historically followed other plural patterns. The key difference, however, is that C.Cu.Ca has no corresponding pattern with a final [a] in MSA, making it a complete innovation of Moroccan Arabic. The expansion of the C.Ca.Ci pattern, which, like C.Cu.Ca, is characterized by a final vowel, further supports our proposal that the final vowel in these iambic plurals serves to prevent the initial iamb from footing the final syllable and therefore avoiding a violation of NonFinality.

6.4 The predictability of final vowels in plurals

Regarding the quality of the final vowel in both C.Cu.Ca and C.Ca.Ci, we see the activity of OCP(high) in both: it prefers the high [u] followed by a low [a] in C.Cu.Ca and the the low [a] followed by a high vowel [i] in C.Ca.Ci. Surveying the corpus more broadly, we find that in plurals that are composed of an initial iamb

with a following syllable (19), the vowel in the final syllable is almost completely predictable. The vowel is [ə] in a closed syllable (19a), and [a] after [u] (19b).

(19) Predictability of final V in broken plurals with an initial iamb + third syllable

	template	n	SG	PL		predictability
a.	C.Ca.CəC	78	məs.kin	m.sa.kən	'pauper'	100%
b.	C.Cu.Ca	38	k.tab	k.tu.ba	'book'	100%
c.	C.Ca.Ci	26	rək.ba	r.ka.bi	'knee'	25/26 = 96%
d.	C.Ca.Ca	6	ħəw.li	ħ.wa.la	'sheep'	5/6 = 83%
	total	148				98%

After [a], both final [i] and final [a] are attested (19c-d), but here the final vowel is mostly predictable *from the singular*. Of the 26 C.Ca.Ci plurals, 25 have final [a] in the singular, and of the 6 C.Ca.Ca plurals, 5 have final [i] in the singular. This is an example of polarity between the singular and plural, where the vowel of the plural is required to disagree in height from the singular (for an overview and criticism of polarity, see de Lacy 2012). Thus, the final vowels in C.Ca.Ci and C.Ca.Ca are not epenthetic and do not violate DEP, but they do serve to prevent a violation of NONFINALITY. The final vowel of the singular is not a factor for C.Cu.Ca, since all C.Cu.Ca plurals have consonant-final singulars. In total, the final vowel in trisyllabic plurals is 98% predictable.

6.5 C.Cu.Ca in other Arabic dialects

To the best of our knowledge, the C.Cu.Ca pattern, or any pattern with a similar vocalic melody, does not exist in any Mashreqi (Middle Eastern) dialect of Arabic. However, in addition to Moroccan Arabic, two other North African dialects have been reported having as C.Cu.Ca plurals: Algerian and Tunisian Arabic. In Algerian Arabic, the existence of C.Cu.Ca plurals was documented by Mairi (1983), who gathered data from six adult language consultants. Words with both C.CuC and C.Cu.Ca plurals were identified, but there was no within-word variation except for one case (qtˤutˤ ∼ qtˤutˤa 'cats'). C.Cu.Ca plurals have also been documented by Souidi & Sediki (2024) in a survey investigating native speakers' judgments on broken plurals. Their study did not report any variation in the use of C.CuC.

The C.Cu.Ca pattern has also been documented in Tunisian Arabic (Stumme

1896, Chekili 1982, Singer 2010). Dallaji & Gabsi (2016) discussed the C.Cu.Ca pattern in their diachronic study of plurals in Tunisian, with a particular focus on overabundance, i.e., the coexistence of multiple plural forms for a single noun. Their fieldwork, involving 30 consultants, showed that certain nouns exhibit plural forms with the C.Cu.Ca pattern, alongside other variants. For example, the noun [b.ħar] 'sea' can form plurals such as [b.ħuːr], [b.ħuː.raːt], and [b.ħuː.ra]. While the forms with [-a] or [-aːt] were more frequently produced by younger speakers, the simpler C.CuC form (b.ħuːr) was attested in historical sources but not observed in the data collected during their fieldwork. This indicates a diachronic shift towards the C.Cu.Ca pattern in Tunisian Arabic similar to what we showed for Moroccan Arabic.

6.6 Local summary

We surveyed the known facts about C.Cu.Ca plurals in Moroccan Arabic and beyond, noting that they are a North African innovation. A comparison from a 60-year old dictionary suggests a recent expansion of these plurals.

We also examined the expansion of the C.Ca.Ci pattern, suggesting a broader role for NonFinality. More generally, the final vowels in all of the trisyllabic broken plural patterns are nearly 100% predictable, with their quality depending on vowel dissimilation and polarity.

7 Theoretical Implications

NonFinality-driven epenthesis: Our proposal contributes to a theoretical debate about the interaction between epenthesis and prosodic markedness, specifically whether epenthesis can be driven by NonFinality. One side of this debate argues that prosodic well-formedness can trigger epenthesis. For instance, Golston & Wiese (1995), and later Wiese (2009), propose that the final schwa in German plurals is not a suffix but an epenthetic vowel. They argue that these schwa-ending plurals are cases of zero-marking, and that the insertion of the final schwa ensures that the plural does not end in a stressed syllable. This is achieved in their analysis by having NonFinality outrank Dep, similar to our proposal. In both languages, the effect of NonFinality is limited to specific morphological contexts: In German, the plural, and in Moroccan, the plural and the diminutive.

On the other hand, Blumenfeld (2006) argues for the existence of a typological gap: patterns where epenthesis serves as a repair strategy for violations of prosodic constraints like NonFinality are unattested. Moore-Cantwell (2016) showed that this gap can be explained within a Harmonic Serialism framework. She argues that the initial step of inserting a segment is not, by itself, harmonically improving, since it is not immediately integrated into the prosodic structure. This makes the optimal epenthetic form unreachable, explaining its supposed unattestedness. As for the German plural case mentioned above, Trommer (2021) proposes an alternative, subsegmental analysis, where the schwa-ending plural forms arise from the interaction of constraints on an underspecified plural affix, rather than an epenthetic repair driven by NonFinality.

The analysis of Moroccan Arabic C.Cu.Ca broken plurals we presented provides a new case study that directly addresses this theoretical debate. We argue that the C.Cu.Ca plurals is a clear instance of the pattern claimed to be unattested in the typology. As we have shown, the final [a] in these plurals is not morphemic; it is an epenthetic vowel whose function is to resolve a violation of NonFinality. Our MaxEnt analysis shows how a grammar where NonFinality competes with Dep successfully models the C.CuC(a) variability across the lexicon. We can, therefore, conclude that the Moroccan Arabic data supports the proposal of Golston & Wiese (1995), where prosodic constraints can and do drive epenthesis. More importantly, it fills the typological gap identified by Blumenfeld (2006).

Prosodically-driven augmentation in Moroccan Arabic: The idea that plurals are augmented to satisfy prosodic well-formedness also finds strong support in other patterns of Moroccan Arabic morphology, specifically the formation of diminutives. Boudlal (2001) proposes an analysis of Moroccan Arabic diminutives, where he argues that their formation is governed by a strict prosodic requirement: the output must conform to a well-formed iambic foot: prosodically small bases (minor iambs with the template C.CVC) are systematically augmented. As shown in (20), masculine bases are augmented through the epenthesis of a default schwa syllable, while feminine bases are augmented by attaching a final feminine suffix [-a]. Note that these feminine diminutives pass both tests for the feminine suffix: they trigger feminine agreement on adjectives (e.g., [bnit-a zwin-a] 'beautiful little girl') and the [a] deletes upon addition of a possessive (e.g., [bnij-t-i] 'my little girl', *bnit-at-i). This provides a clear second case within the grammar of Moroccan Arabic that uses augmentation as a repair strategy to ensure a prosodic constraint

is met.

(20) Augmentation in diminutives (Boudlal 2001)

				base		diminutive	
Masc	C.CiC	→	C.Ci.jəC	kəl.b	→	k.li.jəb (*k.lib)	'dog'
Fem	C.CiC	→	C.Ci.Ca	bən.t	→	b.ni.t-a (*b.nit)	'girl'

Our analysis also finds grounding in the work of Ratcliffe (2002), who examined the historical evolution of the Moroccan Arabic broken plural system. He argues that the system is characterized by a dominant trend where plural forms converge on a small number of favored prosodic templates. This diachronic shift results in the augmentation of plural forms, making them fit a preferred prosodic structure. While Ratcliffe's proposal focuses on the broader diachronic shift where plurals expand to fit preferred prosodic templates, our analysis provides the synchronic constraint-based motivation that drives this augmentation for the C.Cu.Ca plurals.

8 Conclusions and future directions

This paper examined the role of NonFinality in the Moroccan broken plural, showing that plurals that begin with an iamb tend to acquire an additional vowel that serves to separate this iamb from the right edge of the word, preventing a violation of NonFinality. Our analysis identifies a clear instance of prosodically-driven epenthesis, filling a typological gap where such patterns were claimed to be unattested (Blumenfeld 2006, Moore-Cantwell 2016) and supporting similar proposals about german plurals where NonFinality drives epenthesis (Golston & Wiese 1995, Wiese 2009).

We started with a survey of the currently observed variation in C.CuC(a) plurals, e.g., [k.tub ∼ k.tu.ba] 'books', where the final [a] is a North African innovation. We examined and rejected the possibility that the final [a] of C.Cu.Ca is a suffix, concluding instead that it is epenthetic. We modeled the variation in C.CuC(a) plurals as a competition between NonFinality and Dep in a MaxEnt model with lexically-specific constraints (Moore-Cantwell & Pater 2016).

A comparison with an older source of data suggests a recent or ongoing historical change from C.CuC and C.CaC to C.Cu.Ca. We connected this variability to the historical expansion of C.Ca.Ci plurals, where the final [i] of the plural corresponds to a final [a] in the singular. Both C.Cu.Ca and C.Ca.Ci benefit from

the markedness boost that comes from eliminating a violation of NonFinality. More broadly still, we show that for any plural that has an iamb followed by another syllable, the vowel of the final syllable is almost completely predictable.

In future work, we hope to expand our model to correctly derive the complete system of plurals in Moroccan Arabic with a focus on the role of prosodic markedness constraints in it, and test the activity of these constraints in the way native speakers judge and produce nonce words (Berko 1958). A model with weighted constraints can make precise numerical predictions for the treatment of nonce words, and this will allow us to assess the quality of the model and further improve it. Ultimately, the goal of all linguists is to capture both the lexically-specific and the general, productive aspects of the language, and the type of model we used here allows us to do both.

References

Al Ghadi, Abdellatif. 1990. *Moroccan Arabic Plurals and the Organization of the Lexicon*. Faculty of Letters and Humanities, Mohammed V University.

Al Ghadi, Abdellatif. 1994. *An OT Account of Moroccan Arabic Prosody*: Delaware University and Faculty of Letters and Humanities, Mohammed V University dissertation.

Bates, Douglas, Martin Mächler, Ben Bolker & Steve Walker. 2015. Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* 67(1). 1–48. doi: 10.18637/jss.v067.i01.

Becker, Michael & Jonathan Levine. 2015. Experigen - an online experiment platform. Available at https://github.com/tlozoot/experigen.

Berko, Jean. 1958. The child's learning of English morphology. *Word* 14. 150–177.

Blumenfeld, Lev A. 2006. *Constraints on phonological interactions*: Rutgers University dissertation.

Boudlal, Abdelaziz. 2001. *The Prosody and Morphology of a Moroccan Arabic Dialect: An Optimality-Theoretic Account*. Rabat: VDM Verlag.

Bruggeman, Anna. 2018. *Lexical and postlexical prominence in tashlhiyt berber and moroccan arabic*: Universität zu Köln dissertation.

Bruggeman, Anna, Nabila Louriz, Rana Almbark & Sam Hellmuth. 2021. Acoustic correlates of lexical stress in moroccan arabic. *Journal of the International Phonetic Association* 51(3). 425–449.

Chekili, Ferid. 1982. *The morphology of the arabic dialect of tunis*: University of London dissertation.

Dallaji, Ines & Ines Gabsi. 2016. Overabundance in the arabic dialect of tunis: A diachronic study of plural formation. In George Grigore & Gabriel Bițună (eds.), *Arabic varieties: Far and wide. proceedings of the 11th international conference of aida – bucharest, 2015*, 185. Editura Universității din București.

de Lacy, Paul. 2012. Morpho-phonological polarity. In Jochen Trommer (ed.), *The phonology and morphology of exponence: The state of the art*, vol. 41, 121–159. Oxford University Press.

Gafos, Adamantios I, Jens Roeser, Stavroula Sotiropoulou, Philip Hoole & Chakir

Zeroual. 2020. Structure in mind, structure in vocal tract. *Natural language & linguistic theory* 38. 43–75.

Goldwater, Sharon & Mark Johnson. 2003. Learning OT constraint rankings using a Maximum Entropy model. In *Proceedings of the workshop on variation within optimality theory: Stockholm university*. 111–120.

Golston, Chris & Richard Wiese. 1995. Zero morphology and constraint interaction: subtraction and epenthesis in german dialects. In *Yearbook of morphology 1995*, 143–159. Springer.

Harrell, Richard. 1962. *A Short Reference Grammar of Moroccan Arabic*. Georgetown University Press.

Harrell, Richard Slade, Harvey Sobelman & Thomas Fox. 1966. *A dictionary of Moroccan Arabic: Moroccan-English*. Georgetown University Press.

Heath, Jeffrey. 1987. *Ablaut and Ambiguity: Phonology of a Moroccan Arabic dialect*. Albany: State University of New York Press.

Hughto, Coral, Andrew Lamont, Brandon Prickett & Gaja Jarosz. 2019. Learning exceptionality and variation with lexically scaled maxent. *Society for Computation in Linguistics* 2(1).

Jebbour, Adelkrim. 1996. *Morphologie et Contraintes Prosodiques en Berbère: Analyselinguistique et Traitement Automatique*: Faculty of Letters and Humanities, Mohammed V University dissertation.

Kaye, Jonathan. 1987. Government in Phonology. The Case of Moroccan Arabic. *The Linguistic Review* 6(2). doi:10.1515/tlir.1987.6.2.131.

Mairi, Lies. 1983. The number marking system of algiers arabic. *Zeitschrift für Arabische Linguistik* (11). 48–71.

McCarthy, John J. & Alan Prince. 1993. Generalized alignment. In Geert Booij & Jaap van Marle (eds.), *Yearbook of morphology*, 79–153. Dordrecht: Kluwer.

McCarthy, John J. & Alan Prince. 1995. Faithfulness and reduplicative identity. In Jill N. Beckman, Laura Walsh & Suzanne Urbanczyk (eds.), *Papers in optimality theory* (University of Massachusetts Occasional Papers 18), 249–384. University of Massachusetts Amherst: UMOP.

Moore-Cantwell, Claire. 2016. *The representation of probabilistic phonological patterns: Neurological, behavioral, and computational evidence from the English*

stress system: University of Massachusetts Amherst dissertation.

Moore-Cantwell, Claire & Joe Pater. 2016. Gradient exceptionality in Maximum Entropy grammar with lexically specific constraints. *Catalan Journal of Linguistics* 15. 53–66.

Nazarov, Aleksei & Brian Smith. 2023. Generalizing French schwa deletion: the role of indexed constraints. In *Supplemental proceedings of AMP 2022*, https://doi.org/10.3765/amp.v10i0.5455: LSA.

Nirheche, Ali. 2024. Maxent with hidden structure in r. Shiny app for studying Harmonic Grammar and Maximum Entropy grammar in R, including features for hidden structure learning. Available at: `https://alingwist.shinyapps.io/HGR_app/`. `https://alingwist.shinyapps.io/HGR_app/`.

Nirheche, Ali. 2025. Moroccan arabic plurals corpus. doi:10.5281/zenodo.14642330. `https://doi.org/10.5281/zenodo.14642330`.

Nirheche, Ali. in press. A parallel, constraint-based account of Moroccan Arabic iambic broken plurals. In Alireza Korangy & Karim Bensoukas (eds.), *The handbook of north african arabic*, Springer.

Outchakoucht, Aissam & Hamza Es-Samaali. 2021. Moroccan dialect -darija- open dataset.

Pater, Joe. 2000. Nonuniformity in English secondary stress: The role of ranked and lexically specific constraints. *Phonology* 17(2). 237–274.

Pater, Joe. 2007. The locus of exceptionality: Morpheme-specific phonology as constraint indexation. In Leah Bateman, Michael O'Keefe, Ehren Reilly & Adam Werle (eds.), *Papers in Optimality Theory III*, 259–296. Amherst, MA: GLSA.

Pater, Joe. 2010. Morpheme-specific phonology: Constraint indexation and inconsistency resolution. In Steve Parker (ed.), *Phonological argumentation: Essays on evidence and motivation*, 123–154. London: Equinox.

Prince, Alan & Paul Smolensky. 1993/2004. *Optimality Theory: Constraint interaction in generative grammar*. Oxford: Blackwell. [ROA-537].

R Core Team. 2023. R: A language and environment for statistical computing. Vienna, Austria. (http://www.r-project.org).

Ratcliffe, Robert R. 2002. The Broken Plural System of Moroccan Arabic. In *Current Issues in Linguistic Theory*, vol. 3, 87–109. Issue: 2002.

Scheer, Tobias. 1997. Vowel-zero alternations and their support for a theory of consonantal interaction 67. Publisher: Rosenberg & Sellier.

Shaw, Jason, Adamantios I Gafos, Philip Hoole & Chakir Zeroual. 2009. Syllabification in Moroccan Arabic: evidence from patterns of temporal stability in articulation. *Phonology* 26(1). 187–215.

Singer, Hans R. 2010. *Grammatik der arabischen mundart der medina von tunis*. Walter de Gruyter.

Smolensky, Paul & Géraldine Legendre. 2006. *The harmonic mind: From neural computation to optimality-theoretic grammar*. MIT Press.

Souidi, Khaldia & Zahira Sediki. 2024. *Plural nouns in algerian arabic as spoken in tiaret: A morphological analysis*: ibn khaldoun university-Tiaret dissertation.

Staubs, Robert & Joe Pater. 2011. Harmonic Grammar in R (hgR). Software package. Amherst, MA: University of Massachusetts Amherst. https://blogs.umass.edu/hgr/.

Stumme, Hans. 1896. *Grammatik des tunisischen arabisch: nebst glossar*. JC Hinrichs.

Trommer, Jochen. 2021. The subsegmental structure of german plural allomorphy. *Natural Language & Linguistic Theory* 39(2). 601–656.

Wiese, Richard. 2009. The grammar and typology of plural noun inflection in varieties of german. *The Journal of Comparative Germanic Linguistics* 12(2). 137–173.