Modeling Distance-Based Variable Sibilant Harmony in Moroccan Arabic with a MaxEnt Grammar

Abstract

The aim of this study is to examine the variable patterns of regressive sibilant harmony in Moroccan Arabic. This process is triggered by the palatal fricative [ʒ], and targets the alveolar fricative [z] and [s], changing them to [ʒ] and [ʃ] respectively (Harrell, 1962; Heath, 1987, 2002). This paper examines how factors such as the distance between harmonizing segments, voicing of the target segment, and morphological complexity influence the likelihood of harmonization. The findings from an experimental study reveal that the distance between the two harmonizing sibilants significantly influences harmonization, with a shorter distance indicating a higher likelihood of harmonization. Moreover, while voicing of the target sound appears to affect harmonization, a closer examination of the experimental results attributes this effect to the exceptional behavior of some words whose harmonizing sound happens to be [s]. The study uses Maximum Entropy grammar (Goldwater and Johnson, 2003) to predict the variability in applying harmonization. The analysis incorporates Agreement-by-Correspondence constraints (Rose and Walker, 2000, 2004) to account for the observed distance effects and lexically-indexed constraints (Pater, 2000, 2009) to capture the exceptional behavior of certain lexical items that do not follow the general trends.
Keywords: Moroccan Arabic, Sibilant Harmony, Variability, Exceptionality, Agreement-by-Correspondence, Optimality Theory, Maximum Entropy, Lexically-indexed Constraints, Experimental Phonology, Morphological Complexity

1 Introduction

In Moroccan Arabic (henceforth MA), an optional regressive sibilant harmony process occurs at the lexical level (Harrell, 1962; Heath, 1987, 2002). This process is initiated by the presence of the palatal fricative [ʒ], affecting the voiced alveolar fricative [z] and its voiceless counterpart [s]. These sibilants assimilate to [ʒ] in place of articulation, as shown in (1)[1].

(1)

	Non-harmonized	harmonized	Gloss
a.	zaʒ	ʒaʒ	'glass'
	zəlliʒ	ʒəlliʒ	'tiles'
	zənʒlan	ʒənʒlan	'Sesame seeds'
b.	sərʒəm	ʃərʒəm	'window'
	sfənʒ	ʃfənʒ	'doughnut'
	sətranʒ	ʃətranʒ	'chess'
c.	z-zwaʒ	ʒ-ʒwaʒ	'(the) marriage'
	s-sərʒəm	ʃ-ʃərʒəm	'(the) window'

It can be seen in (1) that sibilant harmony in MA is unbounded; that is, it occurs irrespective of the number of intervening segments between the involved sibilants. Additionally, sibilant harmony can target segments across morphological boundaries as seen in (1c). Here, harmony applies to the definite article prefix that is realized through gemination[2]. It should be noted that sibilant harmony does not extend across word-boundaries (Weissman, 2007) as shown in (2).

(2)

	Non-harmonized	Harmonized	Gloss
a.	ras r-raʒəl	*raʃ r-raʒəl	'the head of the man'
	nas ʒdad	*naʃ ʒdad	'new people'
b.	dak ʃʃi sxun	*dak ʃʃi ʃxun	'that thing is hot'

Sibilant harmony is a unique feature of North African (or Maghrebi) dialects of Arabic, distinguishing them from Modern Standard Arabic (henceforth MSA) and Middle-eastern (or Mashreqi) dialects of Arabic (Gębski, 2023). It likely emerged as a result of contact with Berber (Gębski, 2023; Zellou, 2010)[3]. Contrasting with the categorical nature of similar harmony processes in Berber languages, MA displays within-word variation, with speakers using harmonized and non-harmonized forms interchangeably (Weissman, 2007).

[1]Some of the words in (1) are taken from Zellou (2010), who claims that most of the data in her paper are from the Rabat-Sale (Coastal East, Central, Urban) dialect region; she doesn't specify the data collection methodology. Other words in (1), as well as additional examples used throughout this paper, are based on my knowledge as a native speaker.

[2]It should be noted that the definite article is the only affix in MA that occurs in the necessary environment to trigger sibilant harmony.

[3]In Tashlhiyt berber, the causative prefix /s-/ harmonizes with the sibilants in the verb stem in terms of voicing and anteriority (Elmedlaoui, 1992; Dell and Elmedlaoui, 2002; Bensoukas, 2004).

In this paper, I present the results of an experiment aimed at identifying the factors influencing harmonization. The findings of the experiment suggest that the distance between the relevant sibilants -whether they are separated by less or more than two sounds, excluding the schwa- impacts harmonization rates. Additionally, while initial observations indicate that harmonization is affected by the voicing of the target sound, a more detailed examination of the experimental results reveal that the differences in harmonization rates between [s] and [z] words are attributed to the exceptional behavior of some [s] words.

While previous studies have examined the origins of sibilant harmony in MA (Zellou, 2010) and other Maghrebi dialects (Gębski, 2023), a formal analysis of this phenomenon has been lacking. To this end, this paper proposes an analysis of sibilant harmony patterns observed in the experiment using Maximum Entropy (henceforth MaxEnt) grammar (Goldwater and Johnson, 2003), incorporating Agreement-by-Correspondence (Rose and Walker, 2000, 2004, henceforth ABC) as well as lexically-indexed constraints (Pater, 2000, 2009). MaxEnt is a framework that allows for modeling variable phonological patterns, which makes it an appropriate choice for capturing the variation observed in the MA sibilant harmony patterns. Long-distance assimilation is accounted for using ABC constraints, an approach widely used for modeling harmony systems, and which uses correspondence constraints (e.g. CORR-CC) along with particular identity markedness constraints (e.g. IDENT[F]-CC). While ABC models the long-distance assimilation between sibilants by enforcing correspondence relations, MaxEnt introduces a probabilistic component to the constraint rankings, which is needed to handle the observed variation in harmonization. Lexically-indexed constraints are used to account for the exceptional behavior of some lexical items as observed in the results of the experiment.

The paper is divided into five sections. Section 2 discusses the typology of variable harmony systems as well as the potential factors that may affect the application of harmonization and that will be tested in the experiment, presented in Section 3. Section 4 presents an analysis together with learning simulations of the sibilant harmony patterns observed in the experiment. Section 5 discusses some of the issues that can be looked into further in future research.

2 Variable harmony systems and proposed factors impacting harmonization

Variable phonotactic generalizations have been a subject of growing interest (Greenberg & Jenkins 1964; Ohala & Ohala 1986; Luce & Pisoni 1998; Frisch et al. 2000; 2001; Hammond 2004). Recent work has extensively focused on documenting and medeling these gradient/variable phonotactic patterns (Luce & Pisoni, 1998; Frisch et al., 2000, 2001; Hammond, 2004; Anttila, 2008; Coetzee & Pater, 2008; Hayes & Wilson, 2008; Futrell et al., 2017). This section reviews previous work on variability in harmony systems, mentions briefly the major proposed analyses of consonant harmony, and presents the main factors that could affect the harmony patterns in MA.

2.1 Variable harmony systems

While vowel harmony is often described as a categorical process, cases of variable vowel harmony have also been documented in the literature. One well-documented example is Hungarian vowel harmony, which exhibits variation in both backness and rounding harmony (Hayes and Londe, 2006). In the case of the dative suffix alternation, for instance, certain stems allow multiple variants: the word "hotel" can take either the front suffix variant *-nek* or the back variant *-nak* (*hotel-nek* and *hotel-nak* are both possible). Hayes and Londe (2006) showed, by conducting a corpus study, that this variation is influenced by two main factors: the height of the rightmost vowel and the number of neutral vowels the stem contains. They also confirmed native speakers' sensitivity to these factors through a wug test, where speakers mirrored the probabilistic patterns observed in the corpus. They modeled these variation patterns using Stochastic Optimality Theory (Boersma, 1997; Boersma and Hayes, 2001). Similar variable vowel harmony patterns have been documented in Bantu languages (Archangeli et al., 2012), in Croatian (Walter, 2010), and recently in Brazilian Portuguese (Guzzo and Garcia, 2021).

In contrast to vowel harmony, variable consonant harmony patterns are less commonly observed and studied. There are, however, attested cases of variable consonant harmony reported in the literature (Rose & Walker, 2004; Hansson, 2010; Rose & Walker, 2011). Examples include laryngeal harmony in Amharic (Rose & King, 2007), coronal harmony in Komi-Permyak (Kochetov, 2007), and dorsal and laryngeal harmony in Gitksan (Brown, 2008; Brown & Hansson, 2008). It should be noted that more attention has been paid to studying cases of consonant co-occurrence restrictions (Leben, 1973; McCarthy, 1986). These patterns has also been shown to exhibit variability. The most well-known case is Arabic (Frisch et al., 2004), where co-occurrence is gradiently restricted based on similarity: the more natural classes shared between a pair of consonants, the less likely they are to co-occur within the same root.

Sibilant harmony is a well-attested feature in several Western (or North African) dialects of Arabic including dialects spoken in Libya, Tunisia, Algeria, and Morocco. These dialects vary in the nature of harmony (synchronic or diachronic) and trigger of harmonization (palatals or alveolars). In MA, as mentioned above, sibilant harmony is triggered by [ʒ] and targets the alveolar sibilants [z] and [s]. The language exhibits within-word variability in the application of hatmony and the process itself is synchronically productive. Sibilant harmony is different in the other North African Arabic dialects, which show evidence of harmonization when compared to MSA forms (Gębski, 2023). In Libyan Arabic, for instance, the general trend is toward alveolar sibilants being the triggers of harmonization of palatal sibilants (e.g., MSA [ʒazzaar] $\rightarrow$ [zuzzar] 'butcher'). Some varieties of Tunisian Arabic are similar to Libyan Arabic in that alveolar sibilants trigger assimilation (e.g., MSA [zawʒ] $\rightarrow$ [zuz] 'two'), while other varieties of Tunisian Arabic, as well as Algerian Arabic, show more resistance to harmonization (e.g., MSA [ʒins] $\rightarrow$ [zənš] 'species'). Unlike MA, there is no evidence for the harmony patterns of these varieties being variable.

2.2 Analyses of consonant harmony systems

While there are various cases of variable vowel and consonant harmony systems that are documented in the typology, previous theoretical analyses have mostly focused on harmony systems that are categorical. The variable harmony systems discussed above haven't been addressed formally, except for Hungarian vowel harmony. Setting aside variability, harmony systems have traditionally been analyzed using autosegmental phonology (Goldsmith, 1976). Harmony, according to this theory, results from features spreading across a sequence of vowels. However, recent advances in the analysis of consonant harmony systems show that autosegmental spreading is inadequate as a model of consonant harmony mainly because of the differences between consonant and vowel harmony (Hansson, 2001a; Rose and Walker, 2004; Hansson, 2010). The lack of blocking effects is one of the features unique to consonant harmony systems. For example, in Bantu languages like Yaka, intervening vowels do not block or get affected by nasal consonant harmony. In vowel harmony systems, however, nasal harmony targets vowels with no apparent blocking effects. Second, unlike vowel harmony, consonant harmony is not sensitive to prosody (Hansson, 2001b, 2010); consonant harmony also often exhibits regressive directionality (Hansson, 2001a,b), which is not a dominant pattern in vowel harmony systems. Finally, in consonant harmony systems, there is a high degree of similarity between harmonizing segments, showing that similarity-based analyses are more suited to model consonant harmony.

Hansson (2010) and Rose and Walker (2004) propose that consonant harmony is better analyzed using ABC, a correspondence-based model in which harmonizing consonants are in a correspondence relationship, enforced by a family of *CORR-C↔C* constraints. Agreement between those consonants is then established via other constraints, resulting in the observed harmony. For instance, in cases of sibilant harmony, the relevant sibilants are forced to be in a correspondence relationship, which then makes them eligible for certain agreement constraints, requiring them to match in place of articulation. Unlike the feature spreading approach, the correspondence-based approach is applicable to a wider range of consonant harmony systems (Hansson, 2010). First, it allows consonant harmony to apply non-locally, with intervening segments being transparent (no blocking effects) due to their dissimilarity from the sibilants involved in the harmony. Second, blocking effects can also be captured by this ABC approach through the use of different variations of correspondence constraints. Distance-based blocking effects, for instance, can be accounted for by adopting *CORR-C↔C* constraints that target different distances between the harmonizing consonants. This approach is particularly useful for handling the sibilant harmony patterns in MA as will be shown in Section 4.

2.3 Examined factors affecting harmonization

Based on observed patterns in the typology of consonant harmony systems and my intuition as a native speaker of MA, I propose three factors that could influence the likelihood of harmonization in the words shown in (1). One significant factor in such long-distance processes is the presence of intervening elements between the two sibilant sounds. Findings from previous typological work has shown that the more elements there are between both segments, the less likely for harmonization to occur (Odden, 1994; Piggott, 1996; Suzuki, 1998; Walker, 2000; Rose and Walker, 2004; Hansson, 2010). In many cases, harmonization is blocked by a specific intervening sound or class of sounds or by having a particular trigger segment (Hansson, 2010). In the Berber Tashlhiyt variety spoken in

Morocco, for instance, voicing harmony is blocked by an intervening voiceless obstruent (Elmedlaoui, 1995).

In MA, however, sibilant harmony is not blocked word-internally (Weissman, 2007). Nevertheless, it is possible that forms with one segment between the triggering and targeted sounds (3a) may harmonize more frequently than those with multiple intervening segments (3b). Notably, the schwa in MA is not considered an intervening segment since it is an epenthetic vowel (Benhallam, 1980; Al Ghadi, 1990; Boudlal, 2001; among others). This assumption is based on the fact that schwa epenshesis occurs at a later stage after the phonological processes (e.g. sibilant harmony) have already taken place. As a result, I assume that the schwa does not participate in or affect the harmonization process.[4]

(3)		**Non-harmonized**	**Harmonized**	**Gloss**
	a.	zaʒ	ʒaʒ	‘glass’
		sərʒəm	ʃərʒəm	‘window’
	b.	sfənʒ	ʃfənʒ	‘doughnut’
		sətranʒ	ʃətranʒ	‘chess’

In addition to the intervening elements (or distance) factor, the voicing feature of the harmonizing sound may also influence the likelihood of harmonization. In other words, harmonization may occur more frequently in the cases in (1b), where the harmonizing sound is the voiceless alveolar fricative [s], than those in (1a), where the harmonizing sound is the voiced alveolar fricative [z], or vice versa. The third factor that may influence the likelihood of harmonization is morphological complexity. Previous literature suggests that harmony in morphologically complex forms, like those in (1c), must apply cyclically across every larger domain (i.e. root, root + affix1, root + affix1 + affix2; and so forth) (Bakovic, 2000).[5] Based on this proposal, morphologically complex forms may resist harmonization more than morphologically simple ones, as harmonization may occur multiple times in complex forms, such as those in (4b).

[4]In contrast, Hall (2013) proposes that, in Lebanese Arabic, epenthetic vowels are considered “intervening” and can influence phonological processes, whereas intrusive vowels do not intervene. Under Hall’s distinction, the MA schwa would likely be classified as intrusive in this context.

[5]Bakovic’s claim about cyclic application of harmony may be specific to certain languages, such as Maasai and Turkana, where harmony applies across domains like stem-affix boundaries.

(4)		Non-harmonized	Harmonized	Gloss
	a.	zwaʒ	ʒwaʒ	‘marriage’
		sərʒəm	ʃərʒəm	‘window’
	b.	z-zwaʒ	ʒ-ʒwaʒ	‘(the) marriage’
		s-sərʒəm	ʃ-ʃərʒəm	‘(the) window’

As can be seen, three factors are hypothesized to influence the likelihood of harmonization: the number of intervening segments, voicing of the target sibilant, and morphological complexity. In the following section, I present the results of an experiment designed to investigate whether these factors influence the likelihood of harmonization.

3 Experiment

I conducted an experiment that aimed to test the extent to which the factors proposed in Section 2.3 influence the choice between harmonized and non-harmonized forms of words exhibiting variable sibilant harmony in MA. The experiment was conducted as an online survey where participants were asked to translate sentences containing the target words from English and French into MA. The findings show that the distance between sibilants is the only factor that significantly influences harmonization rates: words with one or no intervening segments are more likely to harmonize than those with two or more intervening segments.

3.1 Participants

I recruited 48 adult MA speakers (31 females and 17 males), aged between 18 and 60 years. Some of them were friends of the author, while others were recruited through word-of-mouth. All participants spoke MA as their first language, and were proficient in French and/or English, which was crucial since the sentences were presented in these two languages. I excluded minors to ensure all participants were at a similar stage of language acquisition and that they possessed the necessary background in French/English.

3.2 Materials

The stimuli consisted of 19 words, as shown in Table 1. To test the distance factor, the words were divided into two categories: 8 words with less than two intervening segments (< 2) and 11 with two or more intervening segments (> = 2). For the voicing factor, 9 words had the voiced alveolar fricative [z] as the target of harmonization, while 10 words had the voiceless alveolar fricative [s]. To examine morphological complexity, 9 words were in a simple form, and 10 were in a complex form. However, it should be noted that the only context of morphological complexity tested was the prefixation of the definite article since it is the only affix in which sibilant harmony can be triggered in MA.

While the target words could involve more than one factor, the statistical model focused on the independent effects of each factor without testing for interactions between them, as interactions were found not to be significant. The unequal numbers in each category (distance, voicing and morphological complexity) were due to the limited availability of words where sibilant harmony could be applied, an issue that was addressed in the statistical analysis. Each of the words listed in Table 1 was presented within a sentence frame.

Distance	Morph. Complexity	Items (with glosses)
< = 1	Simple	zaʒa ('glass'), zənʒlan ('sesame seeds'), sərʒəm ('window'), səʒʒada ('prayer mat')
	Complex	z-zaʒ ('the glass'), z-zənʒlan ('the sesame seeds'), s-sərʒəm ('the window'), s-səʒʒada ('the prayer mat')
> 1	Simple	zwaʒ ('marriage'), zəlliʒa ('tiles'), sfənʒa ('doughnut'), sfərʒla ('ferret'), sətranʒ ('chess')
	Complex	z-zwaʒ ('the marriage'), mzəwwʒin ('married'), z-zəlliʒ ('the tiles'), s-sfənʒ ('the doughnut'), s-sfərʒəl ('the ferret'), s-sətranʒ ('the chess')

Table 1: Target items elicited from participants via English/French prompts

3.3 Procedure

The experiment was conducted using Google Forms. Participants first reviewed and signed a consent form before beginning the survey. They were then provided with 40 sentences to translate into MA: 19 sentences contained the target words, and 24 served as fillers. At the top of the form, the participants received instructions about the goal of the survey, the task they would be presented with, and what they were required to do. Each sentence was presented in both English and French, and participants were asked to write the MA version. To avoid biasing participants towards non-harmonized forms, sentences were not presented in MSA since the latter does not exhibit sibilant harmony. The sentences were randomized to prevent any potential order effects. An example of how a sentence was presented to participants is shown in Figure 1.

Figure 1: An example screen of how a sentence is presented to participants

3.4 Participant responses

Of the 48 participants, 11 used the Latin alphabet (or Arabizi), while the remaining 37 used Arabic script. In analyzing the responses, several issues arose including gemination marking and the use of alternative lexical items instead of the target words. In Arabic script, gemination is indicated by the diacritic [ـّ] (shadda). However, participants did not generally use this diacritic, as gemination is understood from context. For example, in words with a definite article, such as ‘marriage’, gemination is automatic regardless of whether harmonization occurs or not. Thus, participants used الجواج for the harmonized form [ʒʒwaʒ] (‘the marriage’) and الزواج for the non-harmonized form [zzwaʒ] (note that [lzwaʒ] or [lʒwaʒ] are ungrammatical), with gemination inferred from the context. For participants using Latin alphabet, gemination was sometimes represented by doubling the consonant, as shown in (5)[6].

[6]The following glossing conventions are used throughout the paper: **1SG**: first person singular; **3SG**: third person singular; **M**: masculine; **N**: neutral; **ACC**: accusative; **PST**: past tense; **PRES**: present tense;

(5) 3ziz el-ya s-sfenj
dear to-1SG.ACC DEF-doughnut.PL
'I like doughnuts'

In other cases, participants did not mark gemination explicitly (6), but it was understood from the context.

(6) ø-zwaj fi-h ms2oliya
DEF-marriage in-3SG.N.ACC responsibility
'Marriage has responsibility.'

In this instance, the word [zzwaʒ] in (6) must begin with a geminate since the sentence would be ungrammatical without [zwaʒ] being a definite noun (realized through total assimilation to the initial sound). Despite the lack of explicit gemination marking, the sentence remains unambiguous. Although there were no ambiguous cases resulting from misrepresenting gemination, a few participants used words whose meaning is different from that of the target words. For instance, (7) shows a response that was recorded for the target word [sfənʒ] ('doughnut').

(7) Kay-3jb-ooni lf9as
PRES-like-1SG DEF-cookie.PL
'I like cookies.'

Cases like (7), where participants used a different word from the target, occurred 68 times. There were also 8 cases where participants did not answer the prompt at all (wroting something like 'I don't know', leaving the target word position blank, or using placeholders such as "___"). As a result, the total number of responses collected was 836 (912 total items - 76 missing or mismatched responses). These 836 responses were used in the analysis.

3.5 Results

The results of the experiment show that, overall, the harmonization rate was 34%. As shown in Table 2, words with only one intervening segment between the target and trigger harmonized 46% of the time, whereas words with more than one intervening segment

DEF: definite article; **PL**: plural.

harmonized 26% of the time. For voicing, voiceless sibilants harmonized 44% of the time, while voiced sibilants harmonized 25% of the time. Regarding Morphological complexity, morphologically simple words harmonized 36% of the time, and morphologically complex words harmonized 33% of the time.

		Voiceless		**Voiced**	
		Simple	Complex	Simple	Complex
Distance	One segment	48/90 (53%)	43/88 (49%)	32/88 (36%)	31/92 (34%)
	Two or more segments	52/130 (40%)	45/128 (35%)	13/88 (15%)	18/132 (14%)

Table 2: Counts and harmonization percentages based on the three factors

An initial look at the results show that voicing influences harmonization. Harmonization is more likely when the target is the voiceless alveolar fricative [s] (44%) compared to the voiced alveolar fricative [z] (25%). However, a closer examination of the results shows that the higher harmonization rates for [s] are due to certain words being derived from MSA forms that are already harmonized. For instance, the MA word [sətranʒ] is derived from the MSA word [ʃatˤaranʒ] not from a non-harmonized form *[satˤaranʒ]. In total, four items from the 19 target words —two words, each appearing in both simple and complex forms— were derived from harmonized MSA words. When such cases are excluded from the analysis, voicing no longer seems to have an effect on harmonization, with comparable rates for [s] (26%) and [z] (24%) as can be seen in Table 3. Therefore, in the analysis provided in section 4, cases like [sətranʒ] will be treated as exceptions.

		Voiceless		**Voiced**	
		Simple	Complex	Simple	Complex
Distance	One segment	16/45 (36%)	13/45 (29%)	32/88 (36%)	31/92 (34%)
	Two or more segments	18/84 (21%)	16/87 (18%)	13/88 (15%)	18/132 (14%)

Table 3: Counts and harmonization percentages when exceptional items are included

3.6 Logistic Regression Analysis

To assess the factors influencing sibilant harmony, a logistic regression analysis was conducted with harmonization as the dependent variable. I fit two logistic regression models: one where all data is included and one where exceptional items were excluded. Three main predictors were tested: *distance* (whether the number of intervening segments is more than one or not), *voicing* (whether the target sibilant is voiced or voiceless), and *morphological complexity* (whether the word is morphologically complex or simple).

It was shown before that the experimental stimuli included an unequal number of words across the different categories (distance, voicing, and morphological complexity). To ensure that this imbalance did not compromise the reliability of the results, random effects were incorporated for both speaker and item. Interactions between variables were also examined to test whether the imbalance affected the relationships among the three predictors. In both models, with and without exceptional items, none of the interaction terms reached significance (p $>$ 0.1 for all). The simpler models (without interaction terms) were a better fit (AIC = 964.1 vs. 969.7 for the model including all data, and AIC = 716.8 vs. 719.9 for the model excluding exceptional items). Therefore, interaction terms were removed to simplify the final models, which included only the main effects of the three predictors, along with random intercepts for participants and words.

As shown in (8), the analysis was conducted using the `glmer()` function from the `lme4` package in R (R Core Team, 2024), with random intercepts for both participant and word.

(8)
```
model <- glmer(harmonized ~ morphological_complexity
+ voicing + distance + (1 | participant) + (1 | word),
data = data, family = binomial)
```

Model with exceptional items included: as shown in Table 4, the results for the model with exceptional items included indicate that voicing was a significant predictor influencing harmonization ($p = 0.0402$), with voiceless sibilants being more likely to harmonize compared to voiced sibilants. Both distance and morphological complexity did not have a significant effect on harmonization.

Fixed Effect	**Estimate**	**p-value**
Intercept	-0.7526	0.1260
Morphological Complexity	-0.3126	0.5069
Voicing	0.9470	0.0402*
Distance	-0.6904	0.1416

Table 4: Summary of logistic regression results (all data, no interactions). Significant predictors at *p $<$ 0.05.

Model with exceptional items excluded: The results of the model with exceptional items excluded are shown in Table 5. Unlike the initial model, where voicing was a significant predictor, the results of the second model show that distance becomes the only significant factor ($p = 0.0108$). Words with more than one intervening segment are significantly less likely to harmonize than those with one or no intervening segments. Morphological complexity and voicing did not show significant effects in this model, indicating that when the exceptional words are removed, the influence of voicing on harmonization is no longer present.

Fixed Effect	**Estimate**	**p-value**
Intercept	-0.9232	1.88e-05***
Morphological Complexity	0.1468	0.5216
Voicing	-0.0928	0.6870
Distance	-0.5843	0.0108*

Table 5: Summary of logistic regression results (excluding exceptional words, no interactions). Significant predictors at $^*p < 0.05$, $^{***}p < 0.001$.

These findings suggest that the influence of voicing on harmonization that was observed across the full dataset is a result of including the exceptional items. Once these are removed from the analysis, the only significant predictor of harmonization becomes the distance between sibilants. In the next section, I will provide an analysis of the observed sibilant harmony patterns using MaxEnt grammar with ABC and lexically-indexed constraints.

4 Modeling the sibilant harmony patters

In this section, I propose an analysis of the sibilant harmony patterns observed in the experiment using MaxEnt with ABC and lexically-indexed constraints. ABC constraints provide a mechanism for accounting for the harmony effects, while MaxEnt allows for modeling the variation in harmonization rates. Lexically-indexed constraints are used to account for the exceptional behavior of some lexical items. I ran a learning simulation using Harmonic Grammar in R (Staubs, 2011, HGR), an implementation of MaxEnt, to learn the sibilant harmony patterns by finding the optimal weights for the constraints.

4.1 MaxEnt and learning algorithm

MaxEnt grammar (Goldwater and Johnson, 2003) is a probabilistic model that captures both categorical and variable patterns in phonology by assigning probabilities to different output candidates based on weighted constraints. Weights serve as the equivalent of rankings in classical OT: a higher weight is equivalent to a higher ranking. In MaxEnt, the probability of an input/output pair (x_i, y_{ij}) is determined by calculating its harmony, denoted as $\mathscr{H}_{ij}$, as shown in (9). Harmony is the sum of constraint violations $f_c(x_i, y_{ij})$ each multiplied by the weights of the constraints w_c. The probability of a particular output $p(y_{ij}|x_i)$ is proportional to the exponential of its harmony. The normalizing constant Z_i ensures that the probabilities sum to one by summing the exponentials of the harmonies of all possible output candidates. MaxEnt can predict variability by allowing subtle differences between constraint weights, leading to small differences in $\mathscr{H}_{ij}$ values which, in turn, result in $p(y_{ij}|x_i)$ values that are not close to 100%. Such gradient/variable effects cannot be predicted by classical OT constraint rankings.

(9)

$$\mathscr{H}_{ij} = \sum_c w_c f_c(x_i, y_{ij})$$

$$p(y_{ij}|x_i) = \frac{1}{Z_i} e^{-\mathscr{H}_{ij}}$$

$$Z_i = \sum_j e^{-\mathscr{H}_{ij'}}$$

In MaxEnt grammars, the goal is to find the set of constraint weights that best fits the observed data by minimizing the difference between the observed probabilities, $p(obs)$, and the predicted probabilities, $p(exp)$. In a MaxEnt tableau, each row represents a candidate, and the corresponding columns show the violations for each constraint. The product of these violations and the weights of the constraints gives the harmony ($\mathscr{H}$) for each candidate. By applying the exponential function and normalizing, we obtain the predicted probability $p(exp)$, which can then be compared to the observed probability $p(obs)$ from the experimental results.

4.2 ABC constraints and long distance effects

To account for long-distance assimilation, I use ABC constraints (Rose and Walker, 2000, 2004; Hansson, 2010). This approach accounts for harmonization by (i) establishing a correspondence between the harmonizing segments and (ii) ensuring that those segments agree in a particular feature. The relevant constraints are CORR-CC and IDENT[place]-CC:

(10) a. **CORR-CC**: Let S be an output string of segments and let C_i, C_j be segments that share a specified set of features F. If C_i, $C_j \in$ S, then C_i is in a relation

with C_j; that is, C_i and C_j are correspondents of one another.

b. **IDENT [place] -CC**: Let C_i be a consonant in the output and C_j be any correspondent of C_i in the output. If C_i is [αplace], then C_j is [αplace].

(10a) ensures that if two consonant in an output form share certain features (e.g. sibilants), they must be in a corresponding relationship to each other. (10b), on the other hand, requires that, if those two consonants are linked by the CORR-CC constraint, they must share the same place of articulation (i.e. the sibilants must harmonize).

Although we do not observe any blocking of harmonization in MA, the experimental results show that harmonization rates decrease when there are two or more intervening segments between harmonizing sibilants. To account for blocking of harmonization based on these distance effects, two approaches have been proposed in the literature. The first approach suggests that distance effects should be considered in terms of intervening syllables (Odden, 1994; Rose and Walker, 2004). In other words, for harmonization to be applied, the harmonizing segments must be in adjacent syllables. Rose and Walker (2004) propose the constraint PROXIMITY to achieve this effect. Hansson (2010), however, shows that the syllable adjacency approach has several issues and limitations when examining the typology of harmony systems. This is evident when considering the distance effects in the sibilant harmony patterns of MA. For example, in both [zaʒa] (syllabified as [za.ʒa]) and [zwaʒ] (syllabified as [z.waʒ][7]) the harmonizing sounds occur in adjacent syllables, but harmonization is more frequent in the former (37%) than in the latter (15%).

The second approach that accounts for distance effects posits that intervening sounds, rather than syllables, block harmonization (Hansson, 2010). In other words, as the number of intervening segments between harmonizing sounds increases, the likelihood of harmonization decreases. Hansson proposed a hierarchy of possible sequences of CORR-CC constraints to achieve these distance effects: CORR-$[F]_{CC}$ » CORR-$[F]_{C\text{-}v\text{-}C}$ » CORR-$[F]_{C\text{-}\infty\text{-}C}$. The highest-ranked constraint, CORR-$[F]_{CC}$, requires correspondence between consonants that are directly adjacent. The second constraint in the hierarchy, CORR-$[F]_{C\text{-}v\text{-}C}$, requires correspondence between consonants that are directly adjacent as well as those separated by a vowel (either on the same syllable, <u>C</u>V<u>C</u>, or across adjacent syllables, ...<u>C</u>V.<u>C</u>V...). The lowest-ranked constraint, CORR-$[F]_{C\text{-}\infty\text{-}C}$, requires correspondence between consonants regardless of their proximity in the output form.

[7]In MA, the first member of an initial consonant sequence forms a degenerate syllable, i.e. should be assigned moraic structure (Al Ghadi, 1990, 1994; Jebbour, 1996; Boudlal, 2001) in order to satisfy the bimoraicity requirement of minimal words in the language. This degenerate syllable representation is also supported by phonetic evidence from temporal stability patterns (Shaw et al., 2009).

Hansson's (2010) approach to distance effects seems more suitable for explaining the harmony patterns observed in MA. compared to the syllable adjacency approach. For instance, [zaʒa] has a higher harmonization rate because there is only one intervening segment between [z] and [ʒ], while [zwaʒ] has a lower harmonization rate due to having two intervening segments.

4.3 Applying MaxEnt and ABC to MA harmony patterns

To adopt Hansson's approach to distance effects to the MA harmony patterns, a slight modification to his proposed hierarchy is necessary. The reasoning behind Hansson's use of the two constraints CORR-$[F]_{CC}$ and CORR-$[F]_{C\text{-}v\text{-}C}$ is the fact that harmony systems (e.g. some Bantu languages) sometimes differentiate between the harmonizing consonants being adjacent and having a vowel between them. In such systems, harmony may be blocked if there is one vowel between the consonants, but allowed when the consonants are adjacent. However, in the MA harmony patterns, as observed in the experimental results, there seems to be no distinction between having the sibilants adjacent, separated by one consonant, or separated by one vowel. All three environments behave similarly in terms of harmonization. Evidence for this comes from the comparable harmonization rates between the three items shown in Table (6). Note that the schwa is not considered an intervening segment affecting the likelihood of harmonization.

Item	Intervening Segments	Harmonization Rate (%)
səʒʒada ('prayer mat')	none	36%
ʒənʒlan ('sesame seeds')	1 consonant	35%
ʒaʒa ('glass')	1 vowel	37%

Table 6: Harmony rates for different intervening segments

Therefore, I adopt a modified hierarchy that does not distinguish between adjacency and separation by a single segment. Instead, the hierarchy focuses on whether the number of intervening segments exceeds one: CORR-$[\text{place}]_{C\text{-}x\text{-}C}$ » CORR-$[\text{place}]_{C\text{-}\infty\text{-}C}$. CORR-$[\text{place}]_{C\text{-}x\text{-}C}$ targets cases where sibilants are adjacent or separated by one intervening segment, while CORR-$[\text{place}]_{C\text{-}\infty\text{-}C}$ targets cases where sibilants are separated by more than one segment. Formally, CORR-$[\text{place}]_{C\text{-}x\text{-}C}$ requires correspondence between a consonant pair that differ at most in the place feature and have no more than one intervening segment. CORR-$[\text{place}]_{C\text{-}\infty\text{-}C}$, on the other hand, requires correspondence between a consonant pair regardless of the distance between them in the output.

The tableau in (11) shows how these two constraints interact with IDENT[place]-CC and IDENTIO(place) to account for the variable harmonization pattern observed in the form /zaʒa/ ('glass'). The constraint weights, shown underneath the constraints on the top row, in (11) and the subsequent tableaux are generated through the learning simulation presented in Section 4.5. The weights were calculated based on the harmonization rates observed in the experiment. For example, the weight of CORR-[place]$_{\text{C-x-C}}$ ($w = 1$) was slightly higher than that of CORR-[place]$_{\text{C-}\infty\text{-C}}$ ($w = 0.1$) to reflect the fact that the likelihood of harmonization is slightly reduced when there are more than one intervening segment between sibilants, which explains why having correspondence between sibilants is tolerated more in this context. The subscripts i and j, shown in the candidates in (11), represent the segments that are potentially in correspondence. When two segments share the same subscript, it indicates that they are in a correspondence relationship and must agree in the relevant feature (in this case [place]). If the subscripts differ, the segments are not correspondents, meaning that no harmony is enforced between them.

(11)

/zaʒa/	$p(obs)$	CORR-[place]$_{\text{C-x-C}}$ $w = 1$	CORR-[place]$_{\text{C-}\infty\text{-C}}$ $w = 0.1$	IDENT[place]-CC $w = 13.5$	IDENTIO(place) $w = 1.7$	$\mathscr{H}$	$p(exp)$
a. ☞ $z_i a ʒ_j a$	.63	−1	−1			−1.1	≈.64
b. ☞ $ʒ_i a ʒ_i a$	.37				−1	−1.7	≈.36
c. $z_i a ʒ_i a$	0			−1		−13.5	≈0

It can be seen in (11) that MaxEnt is able to predict probabilistic outcomes that closely match the observed probabilities (experimental results). Candidate (11a) does not have a correspondence relation between [z] and [ʒ], while candidates (11b) and (11c) do. Candidate (11c) is disfavored because it has the corresponding relation but the two sounds do not harmonize, violating the highly weighted constraint IDENT[place]-CC. Candidates (11a) and (11b) both have some probabilities that match the observed probability. They both have close harmony values since the constraints they each violate have close weight values. By applying harmonization, candidate (11b) violates IDENTIO(place), resulting in a harmony value of -1.7. Candidate (11a), on the other hand, violates both CORR-[place]$_{\text{C-x-C}}$ and CORR-[place]$_{\text{C-}\infty\text{-C}}$ because it does not form a corresponding relation between [z] and [ʒ], resulting in a harmony value of -1.1.

(12) show how the proposed weights account for the lower harmonization rates observed in forms like */zwaʒ/* ('marriage') that has a larger distance between the two sibilants.

(12)

/zwaʒ/	$p(obs)$	CORR-[place]$_{\text{C-x-C}}$ $w=1$	CORR-[place]$_{\text{C-}\infty\text{-C}}$ $w=0.1$	IDENT[place]-CC $w=13.5$	IDENTIO(place) $w=1.7$	$\mathscr{H}$	$p(exp)$
a. ☞ $\text{z}_i\text{waʒ}_j$	.83		-1			-0.1	$\approx$.83
b. ☞ $\text{ʒ}_i\text{waʒ}_i$	.17				-1	-1.7	$\approx$.17
c. $\text{z}_i\text{waʒ}_i$	0			-1		-13.5	$\approx$0

The main difference between (11) and (12) lies in how CORR-[place]$_{\text{C-x-C}}$ and CORR-[place]$_{\text{C-}\infty\text{-C}}$ interact with the candidates. In (12), the non-harmonizing candidate (12a) does not violate CORR-[place]$_{\text{C-x-C}}$ because the distance between [z] and [ʒ] is more than one segment. As a result, it only incurs a violation of CORR-[place]$_{\text{C-}\infty\text{-C}}$, with a weight of 0.1, and has a harmony value of -0.1, which is much higher than the harmony value in (11a). The harmonizing candidate (12b) does form a correspondence relation and satisfies both CORR constraints but incurs a violation of IDENTIO(place) by changing the place feature of [z] in the output. This results in (12b) having a lower harmony value of -1.7. Finally, candidate (12c) is penalized by IDENT[place]-CC for having a correspondence relation without harmonizing the sibilants, which gives it a harmony value of -13.5.

As can be seen, the distance effects observed in the experimental results are accounted for using a combination of ABC constraints whose weights were generated by a MaxEnt learning algorithm. The next subsection proposes the use of lexically-indexed constraints to handle the behavior of the exceptional lexical items with high harmonization rates.

4.4 Handling the exceptional cases

Based on the experimental results, there were four [s] items that exceptionally had high harmonization rates: [sərʒəm], [s-sərʒəm], [sətranʒ], and [s-sətranʒ]. In order to account for their behavior, I use lexically-indexed constraints (Pater, 2000, 2009). Indexed constraints account for the exceptional behavior of the lexical items that behave differently from the general phonological rules of a particular language by allowing constraints to be lexically-specific to those lexical items or morphemes, not across the grammar. To apply this to the MA harmony patterns, two indexed constraint are proposed for each of the items [sərʒəm] and [sətranʒ]. The definite versions of these, [s-sərʒəm] and [s-sətranʒ], are derived from the same inputs /srʒm/ and /stranʒ/, respectively. Therefore, [s-sərʒəm] and [s-sətranʒ] do not have indexed constraints specific to them. In other words, the same indexed constraints for [sərʒəm] and [sətranʒ] will be applied to [s-sərʒəm] and [s-sətranʒ].

As shown in Table (7), both the definite and non-definite versions of each of the two forms /srʒm/ and /stranʒ/ had very similar harmonization rates in the experiment. Therefore, the average harmonization rates will be used as observed probabilities for each definite/non-definite pair.

Item	Gloss	Harmonization (%)	Avg Harmonization (%)
sərʒəm	'window'	77%	76%
s-sərʒəm	'the window'	75%	
sətranʒ	'chess'	80%	81%
s-sətranʒ	'the chess'	81%	

Table 7: Harmony rates for exceptional items

Let's consider the word [sətranʒ], which had a high harmonization rate (81%) although it has more than one intervening segment. According to our current grammar, the input /stranʒ/ is expected to have a harmonization rate of only 17%, which is the value predicted for words with more than one intervening segment. The derivation tableau of [sətranʒ] under our current grammar is shown in (13).

(13)

/stranʒ/	$p(obs)$	CORR-[place]$_{\text{C-}\infty\text{-C}}$ $w = 0.1$	IDENT[place]-CC $w = 13.5$	IDENTIO(place) $w = 1.7$	$\mathscr{H}$	$p(exp)$
a. ☞ s_iətran$ʒ_j$	.19	−1			−0.1	≈.83
b. ☞ $ʃ_i$ətran$ʒ_i$	.81			−1	−1.7	≈.17
c. s_iətran$ʒ_i$	0		−1		−14.5	≈0

As seen in (13), the generated probabilities do not match the observed probabilities. Specifically, the word [sətranʒ] is expected to resist harmonization 83% of the time, which is contrary to our experimental results, where the input /stranʒ/ is expected to harmonize 81% of the time. To account for this mismatch, a lexically-indexed version of CORR-[place]$_{\text{C-}\infty\text{-C}}$ is proposed. This constraint, defined in (14), requires correspondence between a consonant pair specifically when the input in /stranʒ/.

(14) **CORR-[place]$_{\text{C-}\infty\text{-C}_{\text{stranʒ}}}$**: Let S be an output string of segments derived from the input /stranʒ/, and let C_i, C_j be segments that share the specified feature [place].

If C_i, $C_j \in S$, then C_i must be in a correspondence relation with C_j; that is, C_i and C_j are correspondents of one another.

The tableau in (15) shows the derivation of the exceptional word /stranʒ/ when adding the lexically-indexed constraint CORR-[place]$_{\text{C-}\infty\text{-C}_{\text{stranʒ}}}$.

(15)

/stranʒ/	$p(obs)$	CORR-[place]$_{\text{C-}\infty\text{-C}}$ $w = 0.1$	IDENT[place]-CC $w = 13.5$	IDENTIO(place) $w = 1.7$	CORR-[place]$_{\text{C-}\infty\text{-C}_{\text{stranʒ}}}$ $w = 3$	$\mathscr{H}$	$p(exp)$
a. ☞ s_iətranʒ_j	.19	−1			−1	−3.1	≈.19
b. ☞ ʃ_iətranʒ_i	.81			−1		−1.7	≈.81
c. s_iətranʒ_i	0		−1			−14.5	≈0

As shown in (15), assigning a weight value of 3 to CORR-[place]$_{\text{C-}\infty\text{-C}_{\text{stranʒ}}}$ decreases the harmony value of the non-harmonizing candidate (15a) to -3.1 because it violates both the general constraint CORR-[place]$_{\text{C-}\infty\text{-C}}$ and its indexed version CORR-[place]$_{\text{C-}\infty\text{-C}_{\text{stranʒ}}}$. As a result, the harmony value of the harmonizing candidate (15b) becomes the highest (-1.7) among the three candidates, making the $p(exp)$ of candidate (15b) match its exceptionally high observed probability of 81%.

4.5 Learning Simulation

Manually predicting constraint weights that would predict probabilities that closely match the observed probabilities is a challenging task. Therefore, an algorithmic computation of weights is necessary. The learning simulation was conducted using HGR[8] (Staubs, 2011), an algorithm designed to perform computations in Harmonic Grammar (Legendre et al., 1990a,b; Legendre and Smolensky, 2006; Boersma and Pater, 2016) using R. HGR uses Gradient Descent, an optimization algorithm that gradually adjusts the weights of constraints to minimize prediction errors.

Training data: The model was trained on the 19 experimental items. The input to the model is a TXT file containing a tableau, which contains both the observed probabilities of output candidates and the constraint violations (indicated by 1). Each row in the Tableau represents a potential output candidate for a given input form, along with

[8]The full documentation and relevant files for the HGR model can be accessed at: `https://websites.umass.edu/hgr/`.

the associated violation marks for the constraints. The constraint set includes general constraints (e.g., CORR-[place]$_{\text{C-x-C}}$, IDENTIO(place)) as well as the two lexically-indexed constraints (CORR-[place]$_{\text{C-}\infty\text{-C}_{\text{stranʒ}}}$ and CORR-[place]$_{\text{C-x-C}_{\text{srʒm}}}$). These constraints were designed to capture both the general harmony patterns and the behavior of the exceptional items. An example of an input-output pair from the input file is shown in Table 8.

Input	Output	Probability	IDENTIO(place)	CORR-[place] $_{\text{C-x-C}}$	CORR-[place] $_{\text{C-}\infty\text{-C}}$	IDENT [place] -CC	CORR-[place] $_{\text{C-}\infty\text{-C}_{\text{stranʒ}}}$	CORR-[place] $_{\text{C-x-C}_{\text{srʒm}}}$
/zaʒa/	$\text{z}_i\text{aʒ}_j\text{a}$	0.63	0	1	1	0	0	0
	$\text{ʒ}_i\text{aʒ}_i\text{a}$	0.37	1	0	0	0	0	0
	$\text{z}_i\text{aʒ}_i\text{a}$	0	0	0	0	1	0	0

Table 8: An input-output pair from the input file to HGR

Simulation: the HGR model optimizes the weights of the constraints using the L-BFGS-B optimization algorithm, which minimizes the error between the observed and predicted probabilities. Using a `solve_maxent()` function, the model learns the constraint weights iteratively based on the violation marks in the input tableau. During each iteration, the model computes the harmony for each candidate. The harmony values are then converted into expected probabilities. The model iteratively adjusts the weights until the expected probabilities closely match the observed probabilities in the input tableau.

Results: after running the learning simulation, the model generated the learned weights for each constraint, allowing it to predict the harmonization patterns observed in the experiment. Table 9 shows the learned weights for the constraints, and Table 10 compares the observed probabilities with the probabilities predicted by the model for each candidate of the input form /zaʒa/ (‘glass’) and the exceptional input /stranʒ/ (‘chess’).

Constraint	Weight
CORR-[place]$_{C\text{-}x\text{-}C}$	1
CORR-[place]$_{C\text{-}\infty\text{-}C}$	0.1
IDENT[place]-CC	13.5
IDENTIO(place)	1.7
CORR-[place]$_{C\text{-}\infty\text{-}C_{stranʒ}}$	3
CORR-[place]$_{C\text{-}x\text{-}C_{srʒm}}$	1.6

Table 9: weights of the constraints as generated by HGR

		% of harmonization	
input	**output**	**experiment**	**MaxEnt model**
/zaʒa/	z$_i$aʒ$_j$a	63%	61%
	ʒ$_i$aʒ$_i$a	37%	39%
	z$_i$aʒ$_i$a	0%	0%
/stranʒ/	s$_i$ətranʒ$_j$	19%	19%
	ʃ$_i$ətranʒ$_i$	81%	81%
	s$_i$ətranʒ$_i$	0%	0%

Table 10: Comparison of predicted probability of harmonization for two items between the experiment and the MaxEnt model

4.6 Conclusion

The analysis proposed in this section demonstrates that MaxEnt grammar, combined with ABC constrains, accounts for the variable sibilant harmony patterns in MA. By incorporating lexically-indexed constraints, the model predicts the exceptional behavior in harmonization rates of some words. In the following discussion section, the implications of these findings and potential areas for future research will be discussed.

5 Disscussion

The main finding of this paper is that the distance between the two harmonizing sounds is the primary factor determining the likelihood of harmonization, while morphological complexity and voicing of the target sibilant had no significant effect. Additionally, this study has shown that MaxEnt grammar, together with ABC and lexically-indexed constraints, can account for the distance effects, variability and exceptionality observed in the sibilant harmony patterns of MA. Therefore, by combining these three approaches, this study presents a novel theoretical and methodological approach to account for variable harmony systems. This approach can be extended to examine similar variable harmony systems, such as those mentioned in 2.1. This study also presented the first experimental and formal account of sibilant harmony in an Arabic variety.

Several issues remain that could serve as starting points for future research. First, one factor that may have influenced the overall harmonization rates observed in the experiment is the origin of the examined words. The words in (16a), for instance, are used by MA speakers when they speak or write in MSA. Since MSA does not exhibit sibilant harmony, MA speakers' knowledge of MSA may affect the application of harmony when producing these words, which explains their low harmonization rates compared to the words treated as exceptional (16b), whose MSA origin is already harmonized[9]. An unanswered question in this regard is why MA speakers use the non-harmonized form [sətranʒ], even though its origin in MSA is the harmonized form [ʃataranʒ].

(16)		**MA form**	**MSA form**	**Gloss**
	a.	zwaʒ	ʒawaaʒ	'marriage'
		sfənʒ	ʔisfanʒ	'doughnut'
	b.	sərʒəm	ʃarʒab	'window'
		sətranʒ	ʃətaranʒ	'chess'

Another issue that seems problematic is the limited number of words available for each condition I tested. The number of words to which this process applies is indeed very limited. For instance, there are only four words with fewer than two segments between the harmonizing sounds (excluding the schwa). In addition, some words not included in the experiment (e.g. səʒna "cage") are no longer used by most MA speakers. Therefore, with such a limited dataset, it is unclear how well the experimental results generalize to other items.

The observed frequencies may be influenced by other factors not considered in the experiment. One such factor is the nature of the preceding word. If the preceding word contains [ʒ], harmonization may apply more frequently in the following word to avoid a sequence of [ʒ..z..ʒ] at the consonantal tier. This situation is shown in the sentence in

[9]It should be pointed out that the MSA version of [sərʒəm] is not commonly known to MA speakers as it is an old Arabic word no longer used in MSA.

(17). The presence of [ʒ] in [ʒuʒ], which precedes the noun [zaʒat], may trigger harmonization in the latter to prevent the sequence of [ʒ..z..ʒ]. Presumably, harmonization would occur in cases like (17) more frequently than cases where [ʒ] is absent from the preceding word. This factor was controlled for in the experiment by avoiding preceding words containing [ʒ].

(17) Omar ʒab ʒuʒ zaʒ-at
Omar bring.3SG.M.PST two glass-PL
'Omar brought two pieces of glass'

Another factor that could affect the choice of harmonization is the frequency of use. The hypothesis is that frequently used words are more likely to undergo harmonization than infrequent ones. Evidence for this proposal comes from the frequently used word [ʒuʒ] ('two'), which originated from [zuʒ] and where harmonization applies categorically in many dialects of MA. The experimental results might also be influenced by social factors, which were not tested or controlled for in the experiment. Since sibilant harmony emerged in MA relatively recently (Zellou, 2010), it is expected that age may affect harmonization rates. Specifically, younger MA speakers are likely to harmonize more frequently than old speakers. In addition to age, factors such as gender and education level could also be examined in future studies.

References

Al Ghadi, A. (1990). Moroccan Arabic Plurals and the Organization of the Lexicon. Faculty of Letters and Humanities, Mohammed V University.

Al Ghadi, A. (1994). An OT Account of Moroccan Arabic Prosody. PhD thesis, Delaware University and Faculty of Letters and Humanities, Mohammed V University.

Bakovic, E. (2000). Harmony, dominance and control. Ph.D., Rutgers The State University of New Jersey, School of Graduate Studies, United States – New Jersey. ISBN: 9780599623217.

Benhallam, A. (1980). Syllable Structure and Rule Types in Arabic. PhD thesis, University of Florida.

Bensoukas, K. (2004). Markedness, faithfulness and consonant place in tashlhiyt roots and affixes. Langues et Littératures, 18:115–153.

Boersma, P. (1997). How we learn variation, optionality, and probability. In Proceedings of the Institute of Phonetic Sciences of the University of Amsterdam, volume 21, pages 43–58. Amsterdam.

Boersma, P. and Hayes, B. (2001). Empirical tests of the gradual learning algorithm. Linguistic inquiry, 32(1):45–86.

Boersma, P. and Pater, J. (2016). Convergence properties of a gradual learning algorithm for harmonic grammar. Harmonic grammar and harmonic serialism, pages 389–434.

Boudlal, A. (2001). The Prosody and Morphology of a Moroccan Arabic Dialect: An Optimality-Theoretic Account. VDM Verlag, Rabat. Issue: March.

Dell, F. and Elmedlaoui, M. (2002). Syllables in Tashlhiyt Berber and in Moroccan Arabic, volume 2 of Kluwer International Handbooks in Linguistics. Kluwer Academic Publishers.

Elmedlaoui, M. (1992). Aspects des représentations phonologiques dans certaines langues chamito-sémitiques. Doctorat d'État thesis, University Mohammed V, Rabat.

Elmedlaoui, M. (1995). Aspects de representations phonologiques dans certains langues chamito-semitiques. Faculté des Lettres et des Sciences Humaines.

Gębski, W. (2023). The development of sibilant harmony in maghrebi arabic from the perspective of language contact in pre-islamic africa. Mediterranean Language Review, 30(1):155–180.

Goldsmith, J. (1976). Autosegmental Phonology. PhD thesis, MIT.

Goldwater, S. and Johnson, M. (2003). Learning OT constraint rankings using a maximum entropy model. In Proceedings of the Workshop on Variation Within Optimality Theory, pages 111–120, Stockholm University.

Guzzo, N. B. and Garcia, G. D. (2021). Gradience in prosodic representation: vowel reduction and neoclassical elements in brazilian portuguese.

Hall, N. (2013). Acoustic differences between lexical and epenthetic vowels in lebanese arabic. Journal of Phonetics, 41(2):133–143.

Hansson, G. (2001a). The phonologization of production constraints: Evidence from consonant harmony. In Andronis, M., Ball, C., Elston, H., and Neuvel, S., editors, Papers from the 37th Annual Meeting of the Chicago Linguistic Society, volume 1, pages 187–200, Chicago, IL.

Hansson, G. (2001b). Theoretical and Typological Issues in Consonant Harmony. Ph.d. dissertation, University of California, Berkeley.

Hansson, G. Ó. (2010). Consonant harmony: Long-distance interactions in phonology, volume 145. Univ of California Press.

Harrell, R. (1962). A Short Reference Grammar of Moroccan Arabic. Georgetown University Press.

Hayes, B. and Londe, Z. C. (2006). Stochastic Phonological Knowledge: The Case of Hungarian Vowel Harmony. Phonology, 23(1):59–104. Publisher: Cambridge University Press.

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

Heath, J. (2002). Jewish and Muslim Dialects of Moroccan Arabic. Psychology Press.

Jebbour, A. (1996). Morphologie et Contraintes Prosodiques en Berbère: Analyselinguistique et Traitement Automatique. PhD thesis, Faculty of Letters and Humanities, Mohammed V University.

Legendre, G., Miyata, Y., and Smolensky, P. (1990a). Harmonic grammar – a formal multi-level connectionist theory of linguistic well-formedness: An application. In 12th Annual Conference of the Cognitive Science Society. Psychology Press.

Legendre, G., Miyata, Y., and Smolensky, P. (1990b). Harmonic grammar – a formal multi-level connectionist theory of linguistic well-formedness: Theoretical foundations. In Proceedings of the 12th Meeting of the Cognitive Science Society.

Legendre, G. and Smolensky, P. (2006). The harmonic mind : from neural computation to optimality-theoretic grammar. MIT Press.

Odden, D. (1994). Adjacency Parameters in Phonology. Language, 10.2:289–330.

Pater, J. (2000). Non-uniformity in English secondary stress: the role of ranked and lexically specific constraints. Phonology, 17(2):237–274. Publisher: Cambridge University Press.

Pater, J. (2009). Morpheme-Specific Phonology: Constraint Indexation and Inconsistency

Resolution. Publisher: Equinox Publishing Ltd.

Piggott, G. (1996). Implications of Consonant Nasalization for a Theory of Harmony. Canadian Journal of Linguistics, 41.2:141–174.

R Core Team (2024). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Rose, S. and Walker, R. (2000). Consonant agreement at a distance. In Paper presented at NELS 31. Georgetown University.

Rose, S. and Walker, R. (2004). A typology of consonant agreement as correspondence. Language, pages 475–531.

Shaw, J., Gafos, A. I., Hoole, P., and Zeroual, C. (2009). Syllabification in moroccan arabic: evidence from patterns of temporal stability in articulation. Phonology, 26(1):187–215.

Staubs, R. (2011). Harmonic Grammar in R. Software package for studying Harmonic Grammar and Maximum Entropy Grammar in R, including features for hidden structure learning. Available at: `https://websites.umass.edu/hgr/`.

Suzuki, K. (1998). A Typological Investigation of Dissimilation. PhD thesis, University of Arizona.

Walker, R. (2000). Yaka nasal harmony: Spreading or segmental correspondence? In Annual meeting of the berkeley linguistics society, pages 321–332.

Weissman, G. (2007). Moroccan Arabic Consonant Harmony. New York.

Zellou, G. (2010). Moroccan Arabic Consonant Harmony: A Multiple Causation Hypothesis. Toronto Working Papers in Linguistics, 33.