

On the status of non-iterativity in feature spreading

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Abstract:

In many cases, feature spreading is iterative, applying to all licit targets within a given domain. Early work within rule-based theories of phonology developed explicit mechanisms to induce both iterative and non-iterative patterns (e.g., Howard 1973; Anderson 1974). The issue of (non)iterativity has not received as much attention in more recent work, with the notable exception of Kaplan (2008), who argues that both iterativity and non-iterativity are emergent concepts, and are always derivable from other forces at work in the grammar. In this paper, we examine the status of non-iterativity, drawing on production data from Crimean Tatar. We argue that, in line with previous descriptions of the language, rounding harmony is truly non-iterative in the Central dialect, and not derivable from other, independent patterns in the language. We also briefly discuss data from several other languages that exhibit non-iterative spreading. We contend that the presence of these patterns demands a formal account, and we discuss the analysis of non-iterativity in both rule- and constraint-based theories, discussing their different predictions for the typology of feature spreading.

Keywords: phonology, iterativity, phonological domains, acoustics

Word count: 12,885

1 Introduction

In cases, feature spreading is iterative, applying to all licit targets within a given domain. In serial, rule-based formalisms, accounting for iterative rule application requires additional stipulations, like parenthesis-star notation, assigning rules a [\pm iterative] feature, or stipulating the direction of evaluation (Chomsky & Halle 1968; Howard 1973; Jensen & Stong-Jensen 1973; Anderson 1974; Kenstowicz & Kisseberth 1977:ch.5). The addition of these parameters all, to varying degrees, assigns an ontological status to both iterativity and non-iterativity. On the other hand, as discussed in Kisseberth (2007) and Kaplan (2008), iterativity and non-iterativity are regarded quite differently in Optimality Theory (OT; Prince & Smolensky 2004). In OT, iterativity and non-iterativity fall out indirectly from global optimization over interacting constraints. For instance, an AGREE constraint (Lombardi 1999; Baković 2000) delimiting the

syntagmatic realization of [F] operating over some phonological domain, in conjunction with some set of relatively vanilla constraints will result in iterative agreement for [F] throughout the entire domain. Thus, iterativity falls out indirectly from constraint interaction in OT, while in derivational frameworks the analysis of iterativity demands additional stipulations.

Though this might seem to be a feather in OT's cap, analyzing non-iterative patterns reveals a more complex formal situation. With some formal device, like a [\pm iterative] rule feature, a derivational account has no trouble with non-iterative spreading since both iterative and non-iterative patterns are given a relatively clear status in the theory. However, non-iterativity is a more challenging issue for OT. Discussing Yip's (2002) analysis of local tone shift, a pattern where a high tone appears to relocate to the next tone-bearing unit, Kisseberth (2007) notes the central issue for OT – the structure of basic markedness and faithfulness constraints is largely incapable of formalizing non-iterative patterns. Yip's LOCAL constraint, defined as “spread only to the adjacent element” (2002:84), is, in practice, untenable. Yip's constraint needs to determine both the underlying location of the high tone as well as the extent of spreading on the surface. Since markedness constraints evaluate surface structures only, and faithfulness constraints typically reference input-output pairs, the analysis of non-iterative patterns is not clear-cut in OT.

Kaplan (2008) responds to Kisseberth's critique by arguing that non-iterativity is always epiphenomenal, being derivable from independent forces in a given language. Concerning OT, Kaplan writes, “[w]hen a process applies (non)iteratively, it does so because that happens to be the best way to satisfy some output desideratum, not because the process is specifically required to be (non)iterative” (2008:2). Thus, although iterativity may be derivable from a simple set of OT constraints, neither iterativity nor non-iterativity possess any real formal status in the theory. Each is the byproduct of other, independent structural features of the language in question. To support this claim, Kaplan (2008) devotes much time to demonstrating that attested cases of apparently non-iterative feature spreading are actually byproducts of other factors, some phonetic, some phonological.

This paper examines the status of non-iterativity with data from Crimean Tatar (Sevortjan 1966; Kavitskaya 2010). In the Southern dialect, [+round] spreads from to all following [+high] vowels. However, in the Central dialect, [+round] spreads only once, leaving all subsequent vowels to surface faithfully. If Kaplan's claim is correct, then the extent of harmony in the Southern dialect is not really due to iterativity. Likewise, under his analysis, the extent of harmony in the Central dialect does not derive from any direct reference to non-iterativity, but rather something else. Using a production study, we examine both the empirical facts of harmony in these two dialects, as well as the formal status of non-iterativity.

The paper is structured as follows. In Section 2, we discuss the issue of iterativity in phonological theory. In Section 3, we describe the basic harmony pattern in Crimean Tatar, and in Section 4 we present an acoustic study on rounding harmony in the language to determine at a more basic level how far rounding extends in the word. Section 5 presents crucial data from suffixal triggers, and Section 6 evaluates the case of non-iterative spreading in Central Crimean Tatar. Section 7 briefly describes several other non-iterative spreading patterns, and Section 8 discusses the formal analysis of non-iterative patterns in rule- and constraint-based theories. In Section 9 we conclude the paper.

2 Iterativity and non-iterativity

From the advent of the Generative program, phonologists have wrestled with how a rule applies to an input. In Chomsky & Halle (1968:344), rule application is simultaneous, meaning that when the structural description of some rule is met, that rule applies simultaneously to all licit targets. As a consequence, no rule can feed or bleed itself, and Chomsky & Halle introduce parenthesis-star notation to generate patterns of unbounded feature spreading. Howard (1973) and Anderson (1974) discuss cases of self-feeding and self-bleeding rules, arguing for iterativity and directionality as necessary primitives within a serial, rule-based formalism (see also Kenstowicz & Kisseberth 1977: ch.5). Although some later work, e.g., Archangeli & Pulleyblank (1994) and Nevins (2010) adopt similar parametric theories of rule application, more recent discussion of iterativity is limited.

The most far-reaching theory of iterativity and non-iterativity in recent work comes from Kaplan (2008). As indicated above, Kaplan (2008) contends that all semblances of iterativity and non-iterativity are emergent, and thus not formally real. He calls his claim the *Emergent non-iterativity hypothesis*, in (1).

- (1) Emergent non-iterativity hypothesis: No formal entity in phonological grammars may require non-iterativity (Kaplan 2008:2).

Kaplan goes on to exemplify his claim by discussing a number of putatively non-iterative patterns. Specifically, he argues that the domain of spreading in the relevant cases falls out from word-internal domains, non-intersection of potential triggers and targets, prominence-targeting spreading, or phonetic implementation. These four types of emergent non-iterativity are discussed and exemplified below. We will contrast these four types of emergent non-iterativity to the true non-iterativity exemplified in Central Crimean Tatar in later sections.

2.1 Word-internal domains

Perhaps the simplest form of emergent non-iterativity is due to sub-word domains. If some spreading pattern operates within a given domain, and that domain ranges over two syllables only, then the extent of harmony can be derived from the size of the domain without reference to non-iterativity. The most well-known two-syllable domain is the metrical foot, and Pearce (2006; 2007) argues that the extent of fronting harmony in Kera is definable precisely in these terms. Kera builds iambic feet from left to right, and allows the following foot types: (CV.CV:), (CV.CVC), (CV:), (VC), and (CVC). In disyllabic feet, the head controls the frontness of the preceding non-head (2). When the imperfective suffix attaches to a root with a back vowel it triggers fronting of the root if the two can be syllabified into a single foot (2a-c). In cases where the two cannot, the underlying backness of the root vowel is maintained (2d-f).¹

(2) Foot-bounded frontness spreading in Kera

a.	/bàl-é/	(bè.lè:)		‘love-IMPF’
b.	/bìŋ-é/	(bì.ŋì:)		‘open-IMPF’
c.	/ís-é/	(í.sí:)		‘sit.down-IMPF’
d.	/bà:d-é/	(bà:)dè	*(bè:)dè	‘wash-IMPF’
e.	/vì:g-é	(vì:)gì	*(vì:)gi	‘empty-IMPF’
f.	/ísk-é/	(ís)kí	*(ís)kí	‘hear-IMPF’

Regressive frontness harmony in Kera is thus foot-bounded, and is supported by a range of other data marshalled in Pearce (2006; 2007). A number of other languages have metrical systems that can be leveraged to account for the extent of feature spreading (cf. Piggott's (1996) 'harmony foot'). For instance, frontness harmony in Veps applies to the second-syllable only, which aligns with the right edge of the word-initial trochee in the language (Zaiceva 1981). Additionally, Wang & Lin (2017) propose that the foot delimits the domain of tone sandhi in Tianjin Chinese.

2.2 Non-intersection of triggers and targets

In some cases, the extent of feature spreading is defined by the featural makeup of triggers and targets. Specifically, if the set of triggers does not intersect with the set of outputs, then the pattern cannot possibly feed itself. Consider the case of Bengali in (3). ATR harmony in the

¹ There is also progressive height harmony from the root that forces /ɛ/ to raise to [i] if the root is [+high], as in (2b,c,e,f). This separate harmony pattern is orthogonal to foot-bounded fronting harmony.

language operates from right to left, and is triggered by [+high] vowels only. Harmony targets mid vowels, triggering assimilation of /ε ɔ/ to [e o]. However, since the outputs of harmony are mid and not high, they cannot further propagate [+ATR] spreading.

(3) Trigger-target non-intersection in Bengali (Mahanta 2008:152-153)

	Unaffixed	Gloss	Suffixes	Gloss
a.	pɔt ^h	way	pot ^h ik	traveler
b.	pɔd	position	pɔdobi	position.holder
c.	ɔʃɔt	dishonest	ɔʃoti	dishonest.F

Similar patterns are found in Mayak (Andersen 1999), Icelandic (Anderson 1974; Jurgec 2011), and Sanskrit (Whitney 1879; Allen 1951; Ryan 2017). In patterns like these, iterativity is simply precluded by the conditions on triggers and targets (Jurgec 2011; Chandlee 2021).

2.3 Prominence-targeting spreading

In many instances, feature spreading is initiated by some prominent position in the word, like a morphological root, a stressed syllable, or a word edge. However, Walker (2005; 2011) and Kaplan (2008; 2015) suggest that a number of spreading patterns involve weak triggers. In these cases, spreading is initiated by a weak element and targets a strong element.

In the Romance dialect of Grado, [+high] word-final vowels trigger raising of some preceding vowels (Walker 2005). In (4a-c), word-final high vowels target a single preceding mid vowel, raising it to high. In (4d), though, the word-final high vowel assimilates two preceding mid vowels to high. Note that the difference in these is definable in terms of stress and not syllable number. Metaphonic raising extends leftward to the stressed syllable, and thus may extend to one or sometimes two syllables in order to reach its target.

(4) Stress-targeting metaphony in Grado (Walker 2005: 924-925)

	Post-tonic vowel is [-high]		Post-tonic vowel is [+high]	
a.	mét-o	put-1.sg	mít-i	put-2.sg
b.	rénd-e	return-3.sg	rínd-i	return-2.sg
c.	odorós-o	odorous-m.sg	odorús-i	odorous-m.pl
d.	ʃóven-e	young.man-m.sg	ʃúvin-i	young.man-m.pl

Walker's (2005) analysis requires that the [+high] feature be affiliated with a strong position, and in order to satisfy the licensing requirement, the language spreads [+high] to overwrite the height feature of the stressed syllable (see also Kaplan 2015).

Kaplan (2008) argues that this same sort of licensing is found in ATR harmony in Lango, where suffix-initiated ATR harmony terminates after assimilating a single root vowel due to a licensing constraint demanding that ATR be affiliated with the root. While iterative spreading throughout the root would also satisfy this requirement, doing so would incur gratuitous violations of faithfulness.

2.4 Phonetic implementation

Thus far, discussion has centered primarily on segmental patterns. Bantu tonal patterns typically involve spreading or shifting. Spreading is usually rightward, and may either extend to one adjacent syllable, or throughout a larger word or phrasal domain. Tone shifting on the other hand involves the displacement of an underlying tone, typically one syllable to the right (see Kisseberth & Odden 2003; Hyman 2011 for overviews).

An interesting case of tone shifting comes from Kikuyu (Clements 1984). In (5a,b), observe that all morphemes are underlyingly toneless (or alternatively, low toned). However, in (5c) the object prefix /má-/ is underlyingly high toned, but that tone surfaces on the following vowel, the underlyingly toneless root /rɔr/. In (5d), the underlyingly high-toned root /tóm/ surfaces with its high tone one syllable to the right, on the toneless suffix /-ay/. Finally, in (5e), both the object prefix and the root bear high tones, and both of these shift one syllable to the right.²

(5) Tone shifting in Kikuyu

a.	/to-rɔr-ay-a/	[to-rɔr-ay-a]	“we look at”
b.	/to-mo-rɔr-ay-a/	[to-mo-rɔr-ay-a]	“we look at him/her”
c.	/to-má-rɔr-ay-a/	[to-ma-rór-ay-a]	“we look at them”
d.	/to-tóm-ay-a/	[to-tom-áy-a]	“we send”
e.	/to-má-tóm-ay-a/	[to-ma-tóm-áy-a]	“we send them”

In cases like this, there is no obvious domain or target that determines the nature of the shift. High tones from roots or prefixes undergo shifting in (5). Further, there is no obvious target for shifting, since shifting may result in a high-toned root or suffix. Kaplan's analysis builds on

² In some cases, H shifts left to the initial-syllable, but these are not germane for the topic at hand.

insights from Myers (1999; 2003), which reports that high tones may be realized late within their target syllable or even in the following syllable, a phenomenon called peak delay. If the realization of a high tone requires more time than other tones, then non-iterative rightward tone shift, as well as tone spreading, is very plausibly a phonetic fact. Peak delay has been used to account for tonal patterns in Chichewa, Kinyarwanda, as well as Mandarin (Myers 1999; 2003; Xu 2001). If non-iterativity in tonal processes is phonetic in nature, understood as the gestural lag necessary to realize a high tone, then these relatively common tonal processes are not truly challenges to Kaplan's hypothesis (cf. Key & Bickmore 2014).

2.5 Summary of types of epiphenomenal non-iterativity

In the preceding subsections we outlined four types of patterns that result in apparent non-iterativity. In all of these, Kaplan contends that non-iterativity is not formally necessary since independent phonological, morphological, or phonetic factors determine the extent of spreading. In the first type, a word-internal domain delimits the extent of spreading (e.g. the foot). In the second type, spreading appears to be non-iterative only because the set of triggers and potential targets do not share the relevant features. In the third type, feature spreading derives from weak triggers targeting strong positions to satisfy a licensing requirement. Fourth, apparent non-iterative spreading may also be due to the phonetic implementation of the relevant phonological feature. When the phonetic realization of the phonological feature requires a relatively large amount of time, e.g., high tone, this may result in apparent non-iterativity.

These facts provide a framework through which to view reported patterns of non-iterativity to determine whether or not the extent of spreading is formally derivable from independent facts about the language, or if iterativity and non-iterativity are more fundamental parts of the phonological grammar. Previewing our claim, the rounding harmony pattern in Central Crimean Tatar does not conform to any of Kaplan's proposed categories, presenting the clearest evidence to-date that non-iterative feature spreading is not always a byproduct of other factors in the language.

3 Crimean Tatar

3.1 The general pattern

Crimean Tatar (iso: crh) is a Turkic language spoken primarily on the Crimean Peninsula, and by diaspora speakers in Central Asia, Turkey, Eastern Europe, and North America. Southern Crimean Tatar has an inventory of eight contrastive vowels, /i y e ø a o u u/, while Central and Northern dialects possess an additional vowel /i/ (Berta 1998; Kavitskaya 2010; 2013).

The eight vowels that are common to all three dialects are describable in terms of three binary oppositions [\pm back], [\pm round], and [\pm high], in (6).

(6) Crimean Tatar vowel features

	[-back]		[+back]	
	[-round]	[+round]	[-round]	[+round]
[+high]	i	y	ɯ	u
[-high]	e	ø	a	o

In all three dialects, backness harmony operates extensively. As for rounding harmony, in the Northern dialect rounding harmony is absent, and even initial-syllable /y u/ may be unrounded. Consequently, we focus on the Southern and Central dialects. In the Southern dialect, [+round] spreads rightward, typically from the initial syllable, to all following high vowels. However, in the Central dialect [+round] spreads only once, as demonstrated in (7). Since the initial-syllable vowel is [-round] in (7a-d) the second-syllable vowels are both [-round], too. In (7e-h) though, the same nominalizing and possessive suffixes are rounded to [y] and [u] due to the presence of a round vowel in the initial syllable. In (7i,j), the two dialects diverge, with harmony in the Southern dialect applying to third-syllable vowels, while in the Central dialect harmony applies to second-syllable vowels only, leaving the possessive suffix unassimilated. Note that the third-person possessive suffix alternates for harmony when it immediately follows an underlyingly [+round] vowel (7b,d,f,h); thus, the incomplete round spreading in the Central dialect in (7i,j) is not due to some morpheme-specific fact about the possessive suffix.

(7) Rounding harmony in Crimean Tatar

	Southern	Central	Gloss
a.	tez-lik	tez-lik	‘speed-NMLZR’
b.	tez-i	tez-i	‘speed-POSS.3’
c.	qıwz-lıwq	qıwz-lıwq	‘girl-NMLZR’
d.	qıwz-ıw	qıwz-ıw	‘girl-POSS.3’
e.	køz-lyk	køz-lyk	‘eye-NMLZR’
f.	køz-y	køz-y	‘eye-POSS.3’

g.	tuz-luq	tuz-luq	‘salt-NMLZR’
h.	tuz-u	tuz-u	‘salt-POSS.3’
i.	køz-lyg-y	køz-lyg-i	‘eye-NMLZR-POSS.3’
j.	tuz-lug-u	tuz-luy-u	‘salt-NMLZR-POSS.3’

4 Production study

Recent work has shown that experimental studies are useful follow-ups to impressionistic transcriptions of phonological phenomena. In some cases, experimental results have shown that previous claims were (to varying degrees) incomplete or inaccurate (e.g., Van Zanten, Goedemans & Pacilly 2003; de Lacy 2014; Shih 2018; Bowers 2019). In the domain of suprasegmental patterns, in particular word-level stress, such experimental results have been crucial to recent scholarship because the cues to stress are often subtle, and are difficult for non-native linguists to accurately perceive. Similarly, phonetic examination of harmony patterns has been used to determine whether a particular spreading pattern is phonetic or phonological in nature. As an example, Hess (1992) and Casali (2012) examine the degree of assimilation of certain Akan vowels across word boundaries to determine if phrasal [+ATR] spreading is phonological, or if it only represents a lower-level coarticulatory effect. Like stress and the particular ATR-related effects in Akan, the acoustic effects of lip rounding are relatively subtle (Kaun 1995: Ch. 5). Therefore, a production study aimed at determining the extent of phonological rounding, especially when coarticulatory (phonetic) rounding is also present, is a plausible means of evaluating existing descriptions of Crimean Tatar, which allows for a more confident assessment of the theoretical significance of the pattern.

4.1 Methods

4.1.1 Speakers

Through existing relational networks, we recruited four speakers of the Southern dialect (2 females, average age: 59 yrs, age range: 51-67 yrs) and five speakers of the Central dialect (5 females, average age: 64.6 yrs, age range: 60-77 yrs) to participate in the study.

4.1.2 Stimuli

Speakers were presented a wordlist (n = 368 words) consisting of minimal and near-minimal pairs for each of the eight shared vowel contrasts in the two dialects. The lexical roots in the

wordlist are shown in (8). Both mono- and disyllabic roots were elicited because existing descriptions of the Central dialect (e.g., Kavitskaya 2013) report that disyllabic roots do not spread rounding onto a suffix, e.g., [jyzym-i] ‘grape-POSS.3s’. This suggests that the second syllable of such roots behaves like a suffix, rather than having its own underlying [+round] feature. Speakers produced target words up to four syllables in length. Due to the relative sparsity of measurements from fourth-syllable vowels, the analysis only evaluates data from syllables one to three in the forms shown in (9l-n). See Figure 1 for a spectrogram of a four-syllable word elicited from a speaker of the Southern dialect.

(8) Roots elicited

	Vowel	Roots
a.	a	al ‘take’, tal ‘willow’, qaz ‘goose’, aruq ‘ditch’
b.	o	ol ‘be’, qol ‘arm/hand’, soluq ‘breath’, qofu ‘horse race’, qoruv ‘security’, qozu ‘lamb’
c.	e	kel ‘come’, el ‘nation’, kez ‘meet’, tefik ‘hole’, kerik ‘dilated’
d.	ø	øl ‘die’, køl~gøl ‘lake’, øz ‘self’ søz ‘word’, køz~gøz ‘eye’
e.	u	qul ‘hair’, quuz ‘girl’
f.	u	qul ‘slave’, qur ‘build’, tuz ‘salt’
g.	i	il ‘hang’, til ‘language’, tiz ‘knee’, is ‘smell’, tif ‘tooth’
h.	y	kyl ‘laugh’, kyl ‘ash’, gyl ‘flower’, kyz ‘autumn’ jyz ‘face’, tyj ‘dream’, jyzym ‘grape’, symyk ‘snot’

The wordlist contained a range of suffixes appended to each root. Two example series of inflected forms are shown in (9), one for nominal roots and one for verbal roots. Words were represented in Cyrillic. In the standard orthography, which is based on the Central dialect, rounding harmony is represented on second-syllable high vowels. Words were produced in the carrier sentence in (10).

(9) Sample inflected forms

	/tuz/	‘salt’		/qur/	‘build’
a.	tuz-um	POSS.1S	o.	qur-maq	INF
b.	tuz-uŋ	POSS.2S	p.	qur-dum	PST.1S
c.	tuz-u	POSS.3	q.	qur-duŋ	PST.2S
d.	tuz-umwz	POSS.1P	r.	qur-du	PST.3S
e.	tuz-uŋwz	POSS.2P	s.	qur-duq	PST.1P
f.	tuz-lar-ı	PL-POSS.3	t.	qur-duŋwz	PST.2P
g.	tuz-lu	ADJ	u.	qur-du-lar	PST.3P
h.	tuz-suz	PRIV			
i.	tuz-luq	NMLZR			
j.	tuz-luŋ-um	NMLZR-POSS.1S			
k.	tuz-luŋ-ı	NMLZR-POSS.3			
l.	tuz-luŋ-umwz	NMLZR-POSS.1P			
m.	tuz-luŋ-uŋwz	NMLZR-POSS.2P			
n.	tuz-luq-lar-ı	NMLZR-PL-POSS.3			

(10) Carrier sentence

Тилимизде ____ сѣзю бар.

Til-imiz-de ____ söz-y bar

language-POSS.1P-LOC ____ word-POSS.3S exist

“In our language, the word ____ exists.”

4.1.3 Recording and measurements

All sessions were conducted in a quiet room, and audio data were recorded to a Zoom H6 at a sampling rate of 44.1 kHz with a Shure unidirectional microphone. All sound files were segmented in Praat (Boersma & Weenink 2015). The beginning and end of each vowel was aligned to the onset and offset of the second formant. In cases where the second formant persisted across flanking consonants (sonorants), abrupt shifts in the amount and distribution

of spectral energy were used to indicate vowel onset and offset. Sample waveforms with formant tracks are shown in Figure 1.

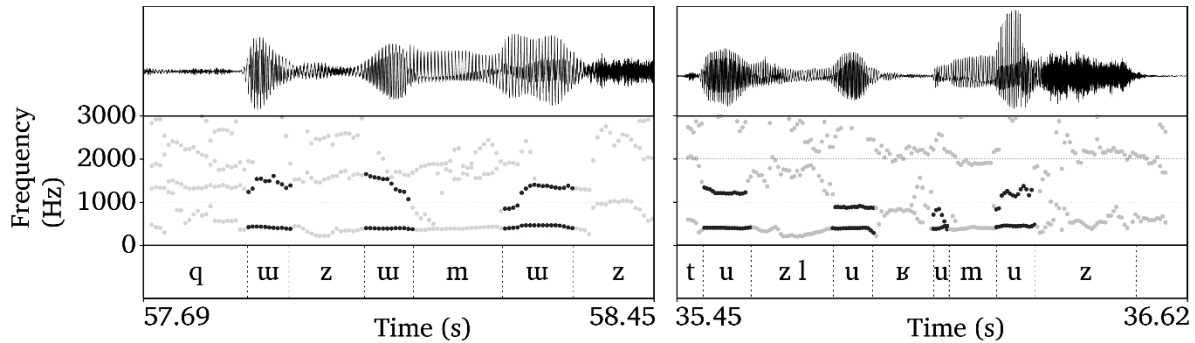


Figure 1: Sample waveforms and formant tracks (black for vowel F1 and F2; gray otherwise) for [quz-umuz] ‘girl-POSS.1P’ and [tuz-luy-umuz] ‘salt-NMLZR-POSS.1P’ produced by Speaker 9 (southern, female, 62 years old)

After segmentation, the first three formants (F1, F2, and F3, in Hz) at vowel midpoint were measured, in addition to duration (ms), mean intensity (dB), mean f0 (Hz), maximum intensity (dB), and maximum f0 (Hz). Since formant structure is significantly affected by flanking consonants, we measured formants at vowel midpoint to minimize effects from flanking consonant place of articulation.

Formant values were z-score normalized (Lobanov 1971) to facilitate more meaningful between-speaker comparisons. The data for normalization consisted of eight tokens of each vowel and were taken from monosyllabic words. If eight tokens of a given vowel were not present in monosyllables, then the remaining tokens were taken from the initial syllable of disyllabic words. The data were manually inspected for outliers; 129 data points were removed from the 3,188 tokens recorded from speakers of the Southern dialect, and 113 data points were removed from the 3,122 tokens recorded from speakers of the Central dialect (approximately 4% from each dialect). The majority of these outliers were due to formant tracking errors.

4.1.4 Analysis

The goal of the statistical analysis was to determine if third-syllable high vowels undergo phonological [+round] spreading or not. Stated differently, we are interested in whether the effect of initial-syllable rounding is phonological or perhaps phonetic in syllable three. In order to determine whether third-syllable effects are phonological or not, an independent threshold for coarticulatory effects is necessary. We operationalized this threshold as the difference in F2

and F3 of /e/ after [\pm round] vowels (e.g., second-syllable [e] in [køl-de] ‘lake-LOC’ versus [el-de] ‘nation-LOC’). Although using /a/ and /o/ for such a threshold is possible, the difference in both F1 and F2 make determining the coarticulatory effect of rounding less straightforward. As we discuss briefly below, F3 was not a reliable predictor of lip rounding, and was not included in any of the analyses below.

In order to determine the actual coarticulatory threshold, as well as $\Delta F2$ values for the high vowels, we constructed a mixed-effects regression using the lme4 package in R (Bates et al. 2015; R Core Team 2017). We predicted $F2(z)$ based on harmonic pairing, rounding, and syllable number, plus random intercepts for speaker, preceding context, and following context. Context differentiated six different environments (word edge, bilabial, dental, liquid, (alveo-)palatal, and dorsal). The model failed to converge with more elaborate random effect structures. Pairwise comparisons were conducted using the emmeans package (Lenth et al. 2018). The upper confidence limit around the mean of $\Delta F2_{/e/}$ in syllable 2 was then used as the null hypothesis for a series of one-tailed one sample t-tests to determine if $\Delta F2$ for some pairing in some position is greater than the coarticulatory threshold. Our analytical method follows other work in assuming that a categorical effect is likely to result in full neutralization of phonetic contrast, in contrast to a gradient, phonetic effect, which will result in an intermediate vowel quality (e.g., Hess 1992). By operationalizing the magnitude of the assimilation as $\Delta F2$, and embedding this in a mixed-effects model, we attempt to analyze the extent of phonological spreading.

4.2 Predictions

Since [+ round] spreading is iterative in the Southern dialect, $\Delta F2$ of second- and third-syllable high vowels should be significantly greater than the coarticulatory threshold (i.e., second-syllable $\Delta F2$ for /e/). In contrast, if harmony is non-iterative in the Central dialect, then only $\Delta F2$ of second-syllable high vowels should exceed the threshold. Consider the two plots in Figure 2. In each, $\Delta F2$ of each pairing is plotted for syllables one through three. In each, the realization of /e/ after [\pm round] vowels (red) serves as the point of comparison for phonological harmony and phonetic coarticulation. If harmony applies, $\Delta F2$ should be greater than the coarticulatory threshold; if harmony does not apply, $\Delta F2$ should not be significantly greater than the threshold.

In the Southern dialect, all else being equal, we predict that $\Delta F2$ for both /i-y/ and /u-u/ should be equivalent across all three syllables (right panel). In contrast, we predict that $\Delta F2$ for /i-y/ and /u-u/ in the Central dialect should be equivalent in the first two syllables, but decrease to below the coarticulatory threshold in the third syllable (left panel).

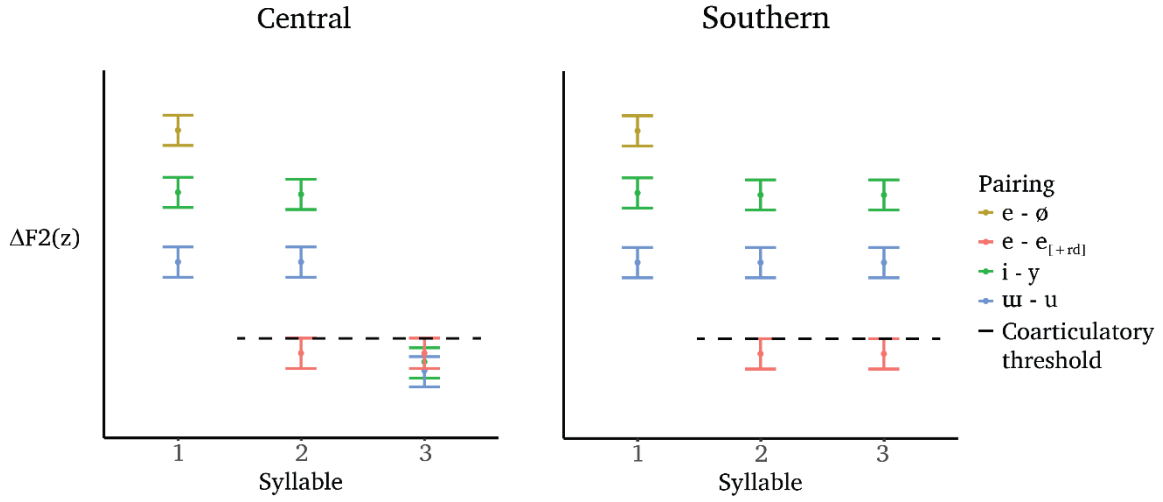


Figure 2: Predicted $\Delta F2(z)$, with 95% confidence intervals) for each vowel pairing and syllable compared to the coarticulatory threshold in Central and Southern Crimean Tatar

4.3 Results

4.3.1 General observations

Combined vowel plots for each dialect are presented in Figure 3 and Figure 4. In each figure, vowels are plotted by syllable. Since mid rounded vowels [ø o] do not occur in second or third syllables, the vowel inventory is effectively reduced to six vowels in non-initial syllables. This is evident in the center and rightmost panels of each figure, where the ellipses for /e/-/e/[_{+rd}] and /a/-/a/[_{+rd}] overlap almost entirely. Observe also in both dialects that /y/ varies greatly between an acoustically front and back vowel, particularly in initial syllables. Kavitskaya (2010:14-17) reports backing of initial-syllable /y ø/ to [u o] before some consonants in the Central dialect. Throughout our data, the realization of initial-syllable /y ø/ was dependent on preceding consonantal place; phonetically front round vowels were produced after coronals, while phonetically back round vowels were produced elsewhere. We return to this issue below.

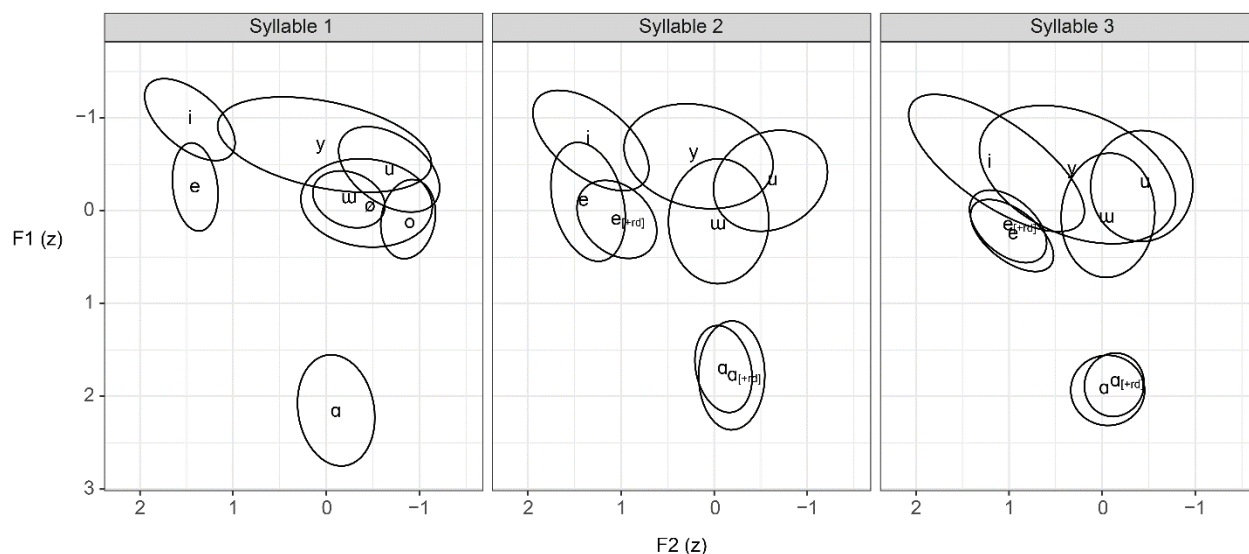


Figure 3: By-syllable F1-F2 (z) vowel plots for speakers of the Southern dialect. Non-high vowels that followed [+round] triggers are marked with a [+rd] subscript.

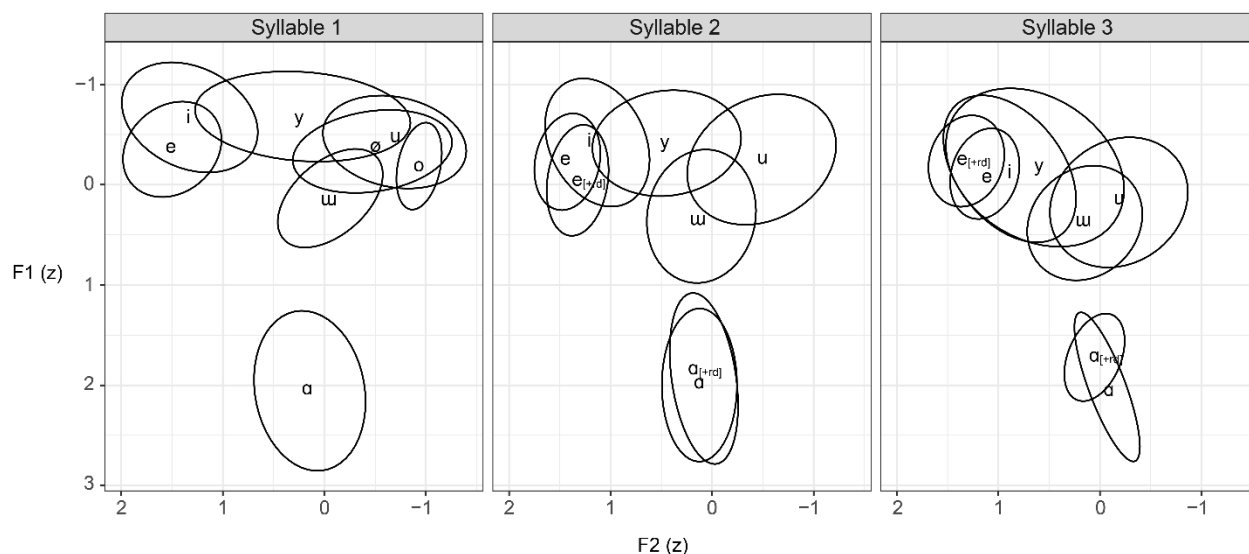


Figure 4: By-syllable F1-F2 (z) vowel plots for speakers of the Central dialect. Non-high vowels that followed [+round] triggers are marked with a [+rd] subscript.

Relative F2 of each vowel is also evident in Figure 5, which shows the distribution of F2 for each vowel quality pooled across all contexts. Unrounded vowels have relatively high F2 while rounded vowels have relatively low F2.

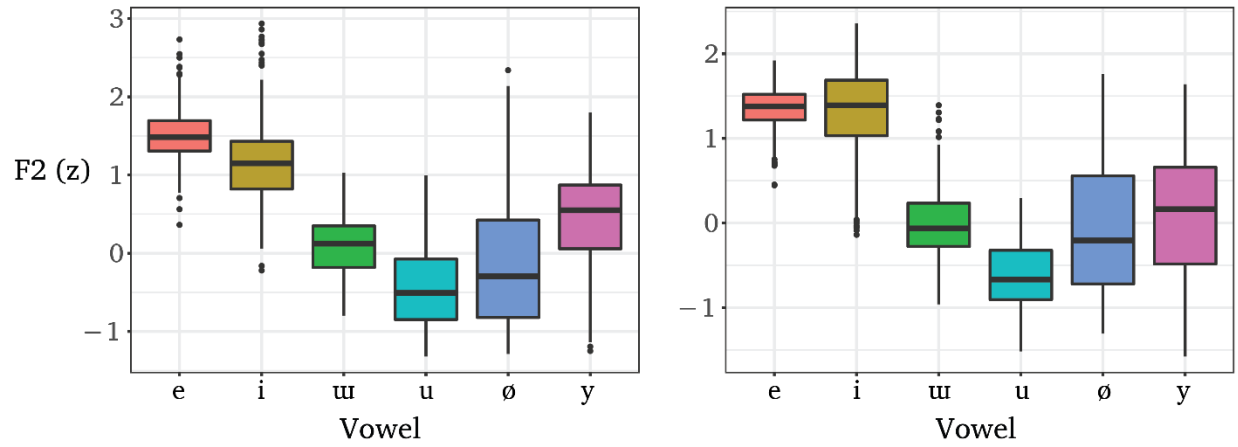


Figure 5: F2(z) for each vowel pooled across all contexts in Central (left panel) and Southern (right panel) Crimean Tatar

F3 for each vowel is shown in Figure 6. Note that in this figure, the differences in F3 for round and unrounded vowels are small and inconsistent. McCollum (2015) and Lionnet (2017) report that F3 is not a reliable correlate of lip rounding in Kazakh and Laal, and this appears to hold for Crimean Tatar, too. As a result, we consider only the effect of rounding on F2 throughout.

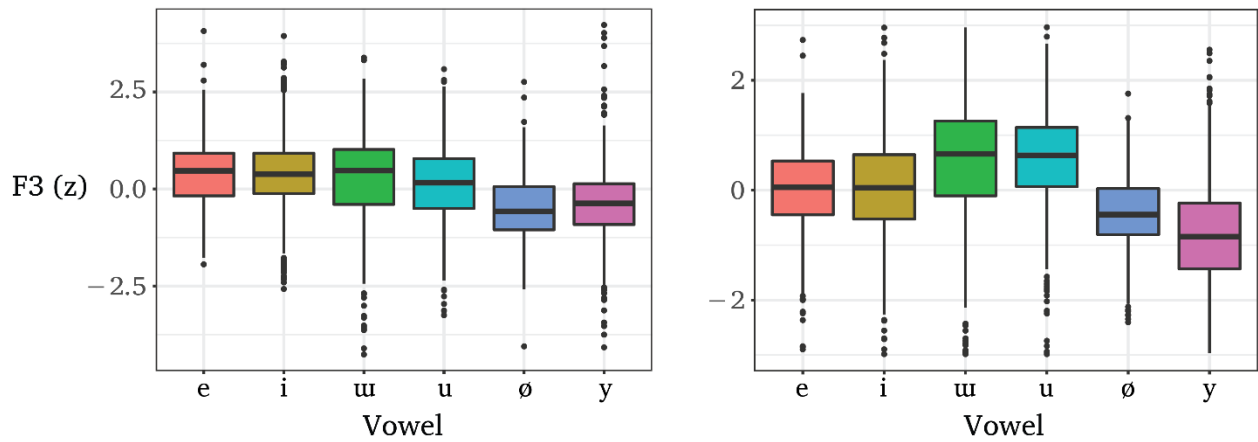


Figure 6: F3 (z) for each vowel in Central (left panel) and Southern (right panel) Crimean Tatar

4.3.2 Southern dialect

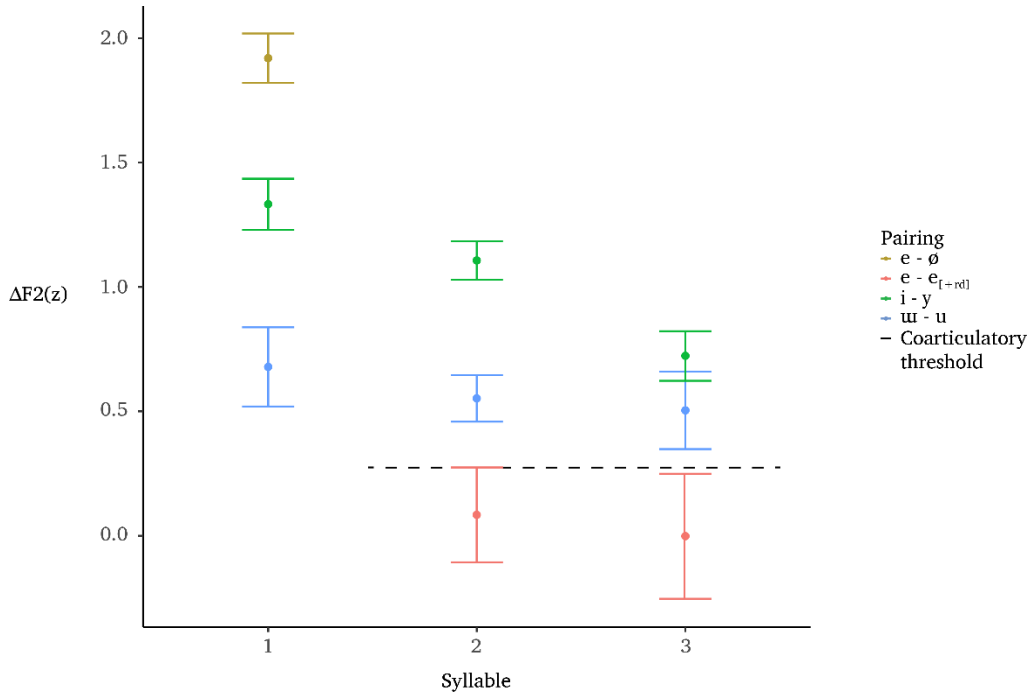


Figure 7: $\Delta F2(z)$, with 95% confidence intervals) for each vowel pairing and syllable compared to the coarticulatory threshold in Southern Crimean Tatar

The coarticulatory threshold for the Southern dialect was 0.27z, which was the highest $\Delta F2$ from the confidence interval around the mean of $\Delta F2$ for second-syllable /e/ after $[\pm\text{round}]$ vowels [$\Delta F2(119) = 0.08z$; 95% confidence interval = $[-0.11 - 0.27z]$]. This threshold is marked in Figure 7 by the dotted line extending from the upper limit of the confidence interval around $\Delta F2$ of e-e_[±rd] in syllable two. Compared to the coarticulatory threshold, $\Delta F2_{/w-u/}$ in syllable two was significantly greater [$\Delta F2_{/w-u/} - \text{threshold}$: $t(572) = 4.42$, $p < .001$]. Similarly, $\Delta F2$ of /i-y/ in syllable two was also significantly greater than the threshold [$\Delta F2_{/i-y/} - \text{threshold}$: $t(842) = 9.68$, $p < .001$]. Mean $\Delta F2$ of /w-u/ was 0.55z, with a confidence interval extending from 0.46 to 0.66z. Mean $\Delta F2$ of /i-y/ was 1.11z, with a confidence interval ranging from 1.03 to 1.18z. These findings are evident in Figure 7, in which the confidence intervals around $\Delta F2_{/w-u/}$ and $\Delta F2_{/i-y/}$ in syllable two do not overlap with the coarticulatory threshold. The significance of these acoustic differences persists in third-syllable vowel pairs, as well. Third-syllable high vowel pairs all exhibited significantly greater $\Delta F2$ than the proposed coarticulatory threshold [$\Delta F2_{/w-u/} - \text{threshold}$: $t(572) = 3.36$, $p < .001$; $\Delta F2_{/i-y/} - \text{threshold}$: $t(521) = 5.93$, $p < .001$].

The data plotted in Figure 7 differ from the predictions laid out in Figure 2 in two ways. First, in Figure 2, $\Delta F2$ of each pairing is equal in syllables one and two. While the difference between $\Delta F2$ of /u-u/ across syllables in Figure 7 is only slightly divergent, there is a notable decrease in $\Delta F2$ of /i-y/ in syllable two. As noted above, there is a pattern of /y/-backing in initial syllables, where /y/ is realized as [y] after coronals, and as [u] elsewhere, e.g., /kyz/ [kuz'] 'autumn'. Backing of initial-syllable /y/ is observable in the leftmost panel of the density plots in Figure 8.³ Observe that the distribution of /y/ (in green) includes two peaks that differ in F2, indicating bimodality. Of the 328 tokens of initial-syllable /y/, 137 were produced with a relatively back vowel, defined here as any vowel with F2 lower than 0z. As a result, $\Delta F2$ of /i-y/ in syllable one in Figure 7 is inflated because it includes many data points for which $\Delta F2$ reflects the difference between [i] and a phonetically back vowel [u].

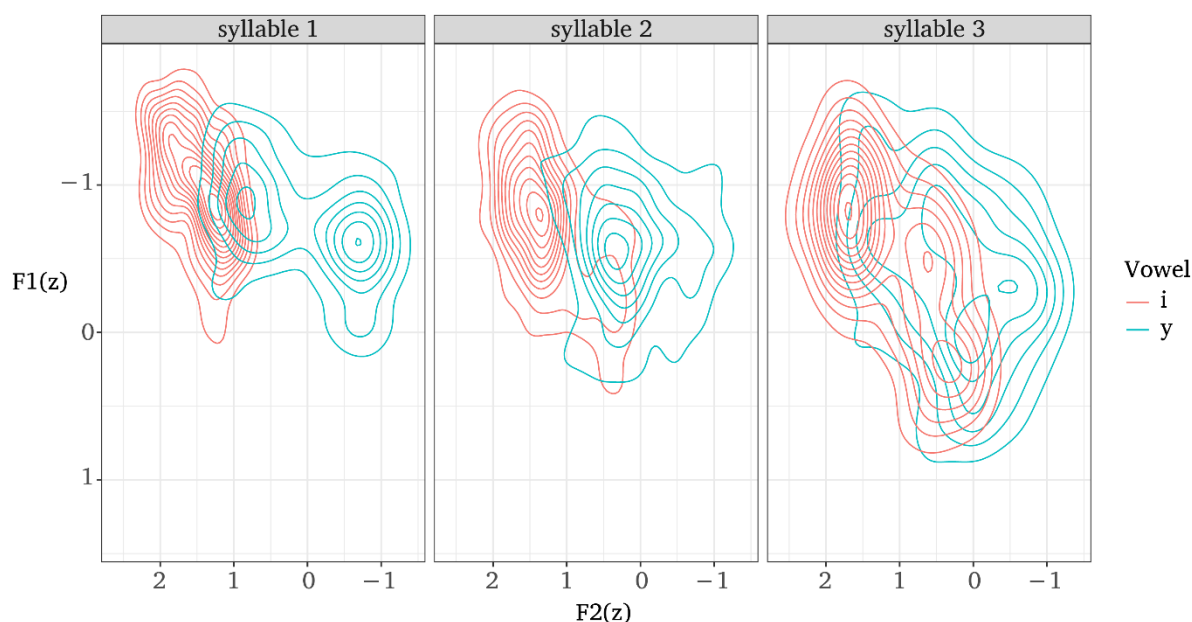


Figure 8: F1-F2(z) density plots for /i/ and /y/ in syllables 1-3 in the Southern dialect

Second, as in Figure 1, we expected $\Delta F2$ of each high vowel pairing to hold constant in syllable three. Yet, in in Figure 7 third-syllable $\Delta F2$ is less than $\Delta F2$ in both syllables one and two. Again, the trend with /u-u/ is not troubling because the differences are small, and could presumably be due to a simple contraction of the vowel space in non-initial syllables (Vayra & Fowler 1992; Tabain 2003). Thus, the issue is once again with the high front pairing, /i-y/.

³ The two-dimensional density plot in Figure 8, also called a contour plot, represents the distribution of some set of data points along two continuous dimensions, here F1 and F2. The method employed uses kernel density estimation to generate a probability distribution function.

Unlike the deviation from predictions just discussed for initial syllables, this does not fall out from any pattern of /y/ backing. Rather, the decrease in $\Delta F2$ for third-syllable /i-y/ is due to centralization of /i/ to a vowel quality much closer to [i] or [ə], as described in Kavitskaya (2010; 2013). To see this, compare the distributions for /i/ (red) in all three syllables in Figure 8. In the initial syllable, there is a single mode, with a median F2 value around 1.2z. In the second syllable, the median F2 value is similar, but also includes a number of data points with F2 between 0.8 and 0z, values notably absent from the leftmost panel of the figure. In the third syllable, the distribution is polymodal, with one mode around 1.7z, and two lesser modes around 0.6 and 0.4z. These additional modes reduce $\Delta F2$ in the third syllable of Figure 7 by including a number of comparisons between [y] and [i], which exhibit a smaller acoustic difference than [y] and [i]. Kavitskaya (2010, 2013) reports backing of historical *i to /i/ in the Northern and Central dialects, but here we see phonetic backing in the Southern dialect. This backing differs from /y/-backing discussed above because it is less context-dependent, and more speaker-dependent. Table 1 reports these facts – Speakers 5 and 9 consistently produced front [i] while Speakers 6 and 7 variably produced [i] and [i]. To reiterate, the centralization of /i/ in syllable three (and to a lesser degree, in syllable two) reduces $\Delta F2$, which contributes to the decrease in $\Delta F2$ reported in syllable three of Figure 7.

Table 1: By-speaker counts of centralization of third-syllable /i/ in the Southern dialect (n = 256).

Speaker (gender, age)	Front (F2 > 1.0z)	Central (F2 < 1.0z)	Percent centralized
5 (female, 65)	60	0	0
6 (male, 51)	56	9	13.8
7 (male, 56)	28	37	56.9
9 (female, 62)	66	0	0
Total	210	46	18.0

Using $\Delta F2$ and the coarticulatory effect of initial-syllable round vowels on second-syllable /e/ to operationalize rounding harmony in Crimean Tatar, we interpret the results from this subsection to support the case that the Southern dialect exhibits harmony on both second- and third-syllable high vowels. Previous research suggests that this result should contrast with the Central dialect, where $\Delta F2$ of [+hi] vowels should exceed the coarticulatory threshold in second syllables only.

4.3.3 Central dialect

The coarticulatory threshold established for the Central dialect was 0.25z, derived from confidence interval around mean $\Delta F2$ of the mid front vowel in [\pm round] contexts, [mean $\Delta F2(99) = 0.06z$; 95% confidence interval = [-0.14 - 0.25z]]. It is clear in Figure 9 that $\Delta F2$ for each of the two [+hi] vowel pairs in syllable two is significantly greater than the coarticulatory threshold [$\Delta F2_{/u-u/}$ - threshold: $t(461) = 6.11, p < .001$; $\Delta F2_{/i-y/}$ - threshold: $t(565) = 11.72, p < .001$]. Observe that the confidence intervals for the second-syllable high vowel pairs do not overlap with the coarticulatory threshold. Mean $\Delta F2$ of /u-u/ was 0.52z, with a confidence interval extending from 0.44 to 0.61z. Mean $\Delta F2$ of /i-y/ was 0.68z, with a confidence interval stretching from 0.61 to 0.76z. However, $\Delta F2$ for each vowel pairing in syllable three was not significantly greater than the coarticulatory threshold [$\Delta F2_{u-u}$ - threshold: $t(320) = 0.44, p = .33$; $\Delta F2_{y-i}$ - threshold: $t(381) = -0.77, p = .80$]. Visually, the fact that the coarticulatory threshold falls within each confidence interval supports the case that $\Delta F2$ in syllable three does not exceed the magnitude of a proposed phonetic effect. For /u-u/, the third-syllable mean $\Delta F2$ was 0.28z, with a confidence interval from 0.16 to 0.41z. Similarly, the third-syllable mean $\Delta F2_{/u-u/}$ was 0.23z, with a confidence interval from 0.12 to 0.31z.

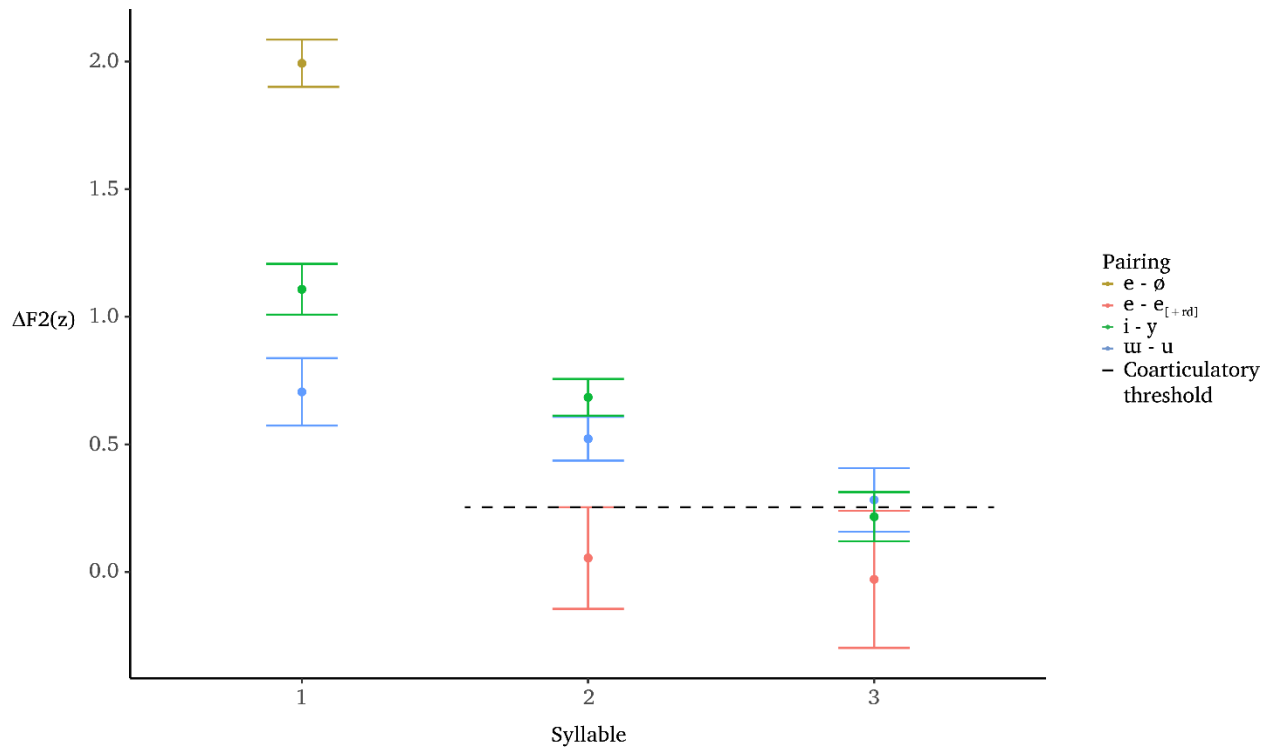


Figure 9: $\Delta F2(z)$, with 95% confidence intervals) for each vowel pairing and syllable compared to the coarticulatory threshold in Central Crimean Tatar

Like Figure 7, the plot in Figure 9 deviates from our predictions because $\Delta F2$ for the two high vowel pairings is smaller in syllable two than in syllable one. There appear to be two reasons for this. First, as discussed above, there is backing of /y/ to [u] in some initial-syllable contexts, which inflates $\Delta F2$ in syllable one. The distribution of initial-syllable /y/ and /i/ is observable in the leftmost panel in Figure 10; in particular, note the bimodal distribution for /y/. Thus, initial-syllable $\Delta F2$ of /i-y/ in Figure 9 is likely too high. In addition, these two-dimensional density plots convey information about the harmonic pairings not available in Figure 9. For instance, consider also the distribution of /u/ and /u/ shown in Figure 11. It is not entirely obvious from Figure 9 that the rounding of second-syllable /u/ is phonological while rounding of third-syllable /u/ is not. In Figure 11, we see the most consistent difference in F2 in the initial syllable, with robust but slightly diminished F2 distinctions (i.e., more overlapping distributions) in the second syllable, with almost complete overlap in F2 in the third syllable. Additionally though, we see that /u/ is typically produced with higher F1 than /u/. This observation holds in the first two syllables, where underlying and derived /u/ exhibit

lower F1 than /u/. However, in the third syllable, this difference in F1 is lost, and both high back vowels are produced with F1 that is generally consistent with /u/. Thus, third-syllable high back vowels show no distinction in F1 or F2, further supporting the case that there is a phonological difference between the effects on second- and third-syllable high vowels.

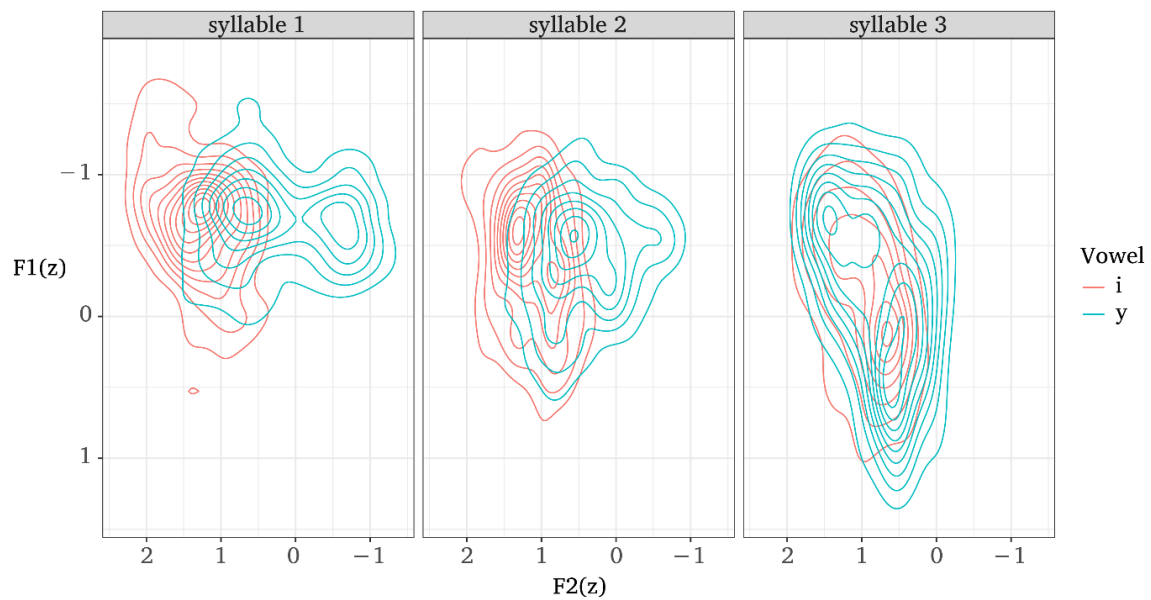


Figure 10: F1-F2(z) density plots for /i/ and /y/ in syllables 1-3 in the Central dialect

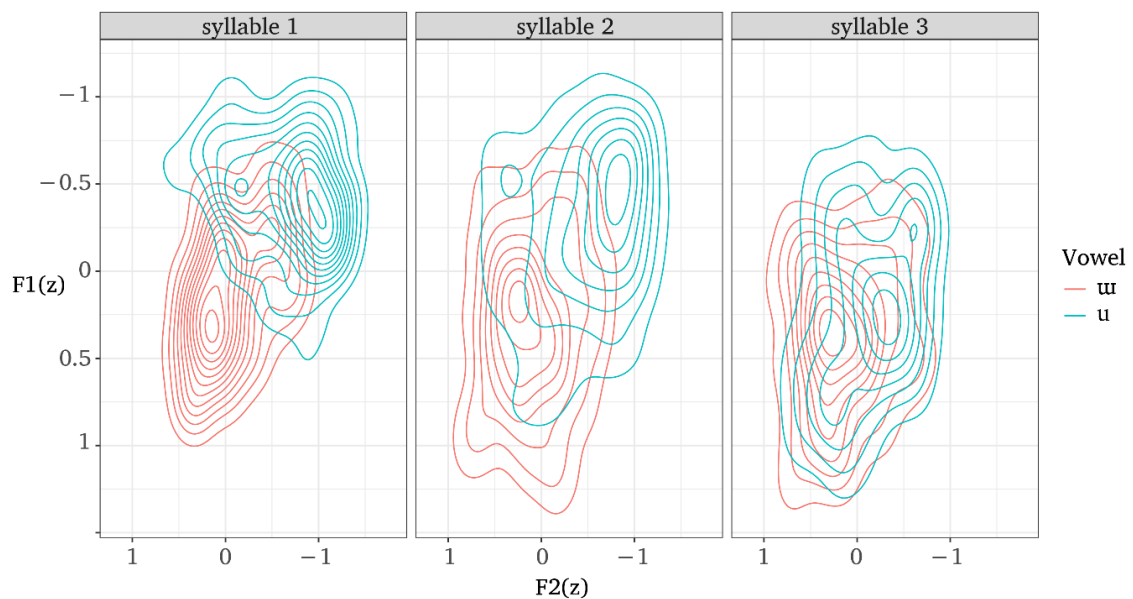


Figure 11: F1-F2(z) density plots for /u/ and /ʊ/ in syllables 1-3 in the Central dialect

Methodologically, we have presented one way to assess the presence or absence of harmony from acoustic data. $\Delta F2$ values have provided useful information to corroborate previous descriptions of rounding harmony in Southern and Central Crimean Tatar. However, the method employed here does not entirely answer the research question, as other acoustic information was necessary to determine the extent of rounding harmony in each dialect. Also, a reviewer asks whether it would be possible to identify acoustic correlates of the onset, trajectory, and offset of lip rounding as an alternative way to probe the domain of phonological versus phonetic lip rounding. This methodology is employed in work like Myers (2003) to identify f_0 turning points for tone. However, there is key difference between f_0 and $F2$ – $F2$ is affected by intervening consonants in a manner quite distinct from the small perturbations in f_0 from consonants. While such a method could help understand the shift from phonological assimilation to coarticulation and the phonology-phonetics interface, it requires kinematic data that are unavailable at present.

Concluding this section, $\Delta F2$ of each high vowel pair was significantly greater than the coarticulatory threshold in syllable two but not in syllable three. This suggests the veracity of previous descriptions of the Central dialect, which spreads rounding to a single high-vowel target only. In short, our results are generally consistent with the claim that the Southern dialect exhibits iterative harmony while the Central dialects exhibit non-iterative harmony.

5 Further evidence: invariantly round suffixes

Up to this point, the paper has focused only on spreading from an initial-syllable trigger, e.g., [tuz-luy-w] ‘salt-NMLZR-POSS.3.’ However, some suffixes in the language are always rounded, and in the Central dialect these suffixes also trigger lip rounding on a single high vowel. For instance, the gerundial and collective suffixes are always [+round], although they do alternate for backness. The gerundial suffix alternates between [yv] and [uv] while the collective suffix alternates between [jy] and [ju]. A number of examples within our corpus of fieldwork data exhibit harmony after GER and COLL, shown in (11).⁴

⁴ Based on the orthographic practice, McCollum & Kavitskaya (2018) suggest that this class of suffixes does not trigger harmony on following high vowels. Rounding harmony is orthographically represented elsewhere in the language, but not in this particular context.

(11) Rounding harmony after GER and COLL

a.	/as-uv-lu/	→	[as-uv-lu]	‘hang-GER-ADJ’
b.	/atʃ-uv-u/	→	[atʃ-uv-u]	‘open-GER-POSS.3’
c.	/atʃ-uv-u-dan/	→	[atʃ-uv-u-ndan]	‘open-GER-POSS.3-ABL’
d.	/qoj-uv-u/	→	[qoj-uv-u]	‘put-GER-POSS.3’
e.	/bir-ju-u-n/	→	[bir-jy-y-n]	‘one-COLL-POSS.3-ACC’
f.	/ek-ju-u-n/	→	[ek-jy-y-n]	‘two-COLL-POSS.3-ACC’
g.	/ytʃ-ju-u-n/	→	[ytʃ-jy-y-n]	‘three-COLL-POSS.3-ACC’

In (11a,b,e,f), we see that round vowels may occur in almost any two-syllable window within the word. Rounding need not be triggered by the initial syllable, and it certainly does not need to extend to the final syllable. Moreover, rounding may be present in three consecutive syllables if the first two round vowels derive from two different sources (11d,g). As such, it is clear that rounding is not limited to the first two syllables only. In the Central dialect, rounding spreads rightward to one high vowel from any underlyingly [+round] vowel, root-internal or suffixal.

6 Is non-iterativity in Central Crimean Tatar emergent?

We have already suggested that round spreading is non-iterative, and as such is not obviously amenable to the types of analyses put forth in Kaplan (2008). In this section we argue against possible attempts to reconcile the data from the Central dialect with Kaplan’s claim in (1).

6.1 Stress

One might attempt to explain the extent of harmony in the Central dialect by referencing stress and metrical footing. The argument goes as follows: if stress falls on the leftmost syllable, then it is possible to construct a left-aligned trochee, making rounding harmony in Central Crimean

Tatar foot-bounded. Alternatively, if stress is peninitial, then the apparent non-iterativity of harmony could derive from a metaphony-like spreading up to the stressed syllable.

Problematically for both potential stress-based analyses, previous work argues that primary stress falls on the rightmost syllable (Sevortjan 1966; Baski 1986; Kavitskaya 2010; 2013; Memetov 2012; 2013). Most of these authors also report secondary stress on the initial syllable of words of at least three syllables in length. According to Baski (1986:119), primary and secondary stressed syllables are evident by their resistance to phonetic reduction and elision. Based on our own experience with the language, however, high vowels are often reduced to the point of elision in all non-final syllables, with an even greater tendency to elide initial-syllable high vowels, consistent with Kavitskaya (2004; 2010; 2013).

Regardless of where stress falls, the data from Section 5 show that a round vowel may trigger harmony from any non-final syllable. If one attempts to align harmony to primary stress at the right edge of the word, a single, binary foot cannot coincide with rounding harmony in a word like *tuz*.(lu.ɣú) ‘salt-NMLZR-POSS.3s’. If a binary foot is constructed at the left edge of the word (iambic or trochaic) based on secondary stress, it cannot account for words like (qo.ju).vu ‘put-GER-POSS.3’. Since rounding harmony can be triggered by any non-final syllable, no metrically-oriented analysis can successfully define the domain of harmony (cf. Piggott 1996). For readers interested in acoustic data bearing on the question of stress placement in the Central dialect, the Appendix contains discussion of duration, f₀, and intensity measures from our data, which provide little evidence for any form of word-level stress.

6.2 Other possibilities

In addition to stress, work in Lexical Phonology (Mohanan 1982; Kiparsky 1985) has demonstrated that the domain of some phonological patterns is definable in terms of morphological constituency. In the realm of vowel harmony, some work has shown that lexical strata play a role in the application of some patterns (e.g., Kiparsky 1985; Lahiri 2000; McPherson & Hayes 2016). In the present case, though, no such morphological analysis is possible because the extent of harmony extends one syllable rightward from an underlying [+round] vowel regardless of its position in the word. Thus, rounding may operate within a root, [qoruv] ‘security’, from a root to a suffix, [tuz-luq] ‘salt-NMLZR’, or from a suffix to another suffix, [atʃ-uv-u] ‘open-GER-POSS.3s.’ Moreover, each suffix’s ability to participate in round spreading depends on its proximity to a [+round] trigger regardless of any particular

morphological strata. More concretely, if the third-person possessive suffix is within a stratum subject to rounding harmony, it should always alternate for harmony. Yet, in words like [tuz-luy-w] ‘salt-NMLZR-POSS.3S’ we see that the possessive suffix is not subject to harmony when separated from the original trigger by an intervening syllable. Since harmony is not definable in terms of any particular lexical strata or sub-word morphological domains, we conclude that no morphological analysis will be able to define the domain of rounding harmony in the Central dialect.

Recall from above that some work analyzes word-internal harmony as the result of prominence-targeting patterns (Walker 2005; 2011; Kaplan 2008; 2015). In these cases, harmony is initiated by a weak position, spreading the harmonic feature to some prominent position in order to satisfy some licensing requirement. In Central Crimean Tatar, though, there is no evidence that triggers or targets exhibit any particular prosodic weakness or prominence to drive spreading. Instead, non-iterative spreading obtains on high vowels in any position.

We know of no other possible sub-word domains that are coextensive with, or that could motivate non-iterative harmony in the language. For instance, we are unaware of any minimality requirements in the language, although content words are almost always CVC or longer. If this strong tendency is encoded in the grammar, however, it would lend support for the mora, but not for any syllable-based generalization to define the application of rounding harmony.

Finally, in contrast to cases of tone shifting and tone spreading (Section 2.4), there is no phonetic reason for a lip rounding gesture to require a two-syllable domain. In fact, phonetic research on lip rounding has consistently found that lip rounding is often achieved before the onset of the target segment (e.g., Bell-Berti & Harris 1982; Perkell & Matthies 1992), undermining any potential analysis predicated on sluggish articulation.

For these reasons we conclude that non-iterative rounding harmony in Central Crimean Tatar is truly grammatical, and not emergent. In the next section we discuss some other cases of irreducible non-iterativity in feature spreading.

7 Other cases of non-iterative feature spreading

Two related languages, Karakalpak (Menges 1947) and Kazakh (Balakayev 1962), display rounding harmony patterns almost identical to that in Central Crimean Tatar. In these languages, underlying [+rd] vowels, regardless of position, trigger harmony on a following high vowel, e.g., Kazakh /tʊr-mʊs-ʊ-nʊŋ/ [tʊr-mʊs-ʊ-nʊŋ] ‘live-NMLZR-POSS.3-GEN’; /ber-ʊw-ʊ [ber-yw-ɪ] ‘give-GER-POSS.3.’

Along with these genetically related languages, several varieties of Greek spoken in Asia Minor exhibit non-iterative regressive backness harmony (van Oostendorp & Revithiadou 2005). In Megisti Greek, final vowels trigger assimilation of penultimate vowels, irrespective of stress placement, e.g., /zervjá/ [zarvjá] ‘left’; /zílǵ-a/ [zúlǵa] ‘jealousy-NOM.F’; /ágir-a/ [águra] ‘anchor-NOM.F.’

A number of phrasal harmonies are also reportedly non-iterative (Downing 2018; Kaisse 2019; Obiri-Yeboah & Rose 2021; Downing & Krämer to appear). For instance, consider across-word ATR harmony in Akan in (12). Observe the serial verb constructions in (12a,b) from Ampofo & Rasin (2020), as well as the data from Kügler (2015) in (12c,d). In each case, the [+ATR] value of the following noun assimilates the final vowel of the preceding verb while all other vowels surface faithfully as [-ATR].

(12) ATR harmony in Akan constructions⁵

- | | | | | |
|----|----------------|---|-----------------|----------------------|
| a. | /tʊ fa kɔ/ | → | [tʊ fa kɔ] | “buy, take, and go” |
| b. | /tʊ fa di/ | → | [tʊ fæ di] | “buy, take, and eat” |
| c. | /ɔ-pɛ sika/ | → | [ɔ̌-pè sɪká] | ‘3s-like money’ |
| d. | /ɔ-tɕirɛ kube/ | → | [ɔ̌-tɕiré kùbé] | ‘3s-show coconut’ |

Another example of non-iterative spreading is found in tone. Cases of non-iterative high tone spreading in Bantu are well known (C. Kisseberth & Odden 2003; Key & Bickmore 2014), but we know of one case of non-iterative low tone spreading. In the Eagle dialect of Hän (Athabaskan), low tone spreads rightward to the immediately following tone-bearing unit (Manker 2014; Lehman 2018). In (13a), in the absence of any underlying low tone, all tone-

⁵ Tone is not marked in Ampofo & Rasin (2020).

bearing units surface with a default high tone. In (13b) though, the low tone associated with /žùŕ/ ‘wolf’ spreads rightward onto /łáy/ ‘dog’, and in (13c) that same low tone spreads onto the first tone-bearing unit of the verb.

(13) Low tone spreading in Hän

- | | | | | |
|----|-----------------|---|-----------------|-------------------------|
| a. | /čæ: łáy nohʔi/ | → | [čæ: łáy nóhʔi] | “The boy sees the dog” |
| b. | /žùŕ łáy nohʔi/ | → | [žùŕ łáy nóhʔi] | “The wolf sees the dog” |
| c. | /łáy žùŕ nohʔi/ | → | [łáy žùŕ nòhʔi] | “The dog sees the wolf” |

Under Kaplan’s proposal, non-iterative tone spreading should be limited to high tone spreading due to the lag typically needed to realize a high or rising tone (Myers 1999; 2003; Xu 2001). Yet, in Hän the spreading tone is low, which makes Kaplan’s analysis less tenable. In addition, there are two pieces of evidence that support the non-iterativity of low tone spreading in Hän. First, spectrographic evidence in Lehman (2018) indicates that a high tone is phonetically realized within the target syllable, removing any peak delay-based explanation of the pattern. Second, Manker (2014) and Lehman (2018) discuss properties of this pattern that further suggest the pattern is not reducible to phonetic implementation – low tone spreading is sensitive to the OCP as well as lexical stress. Low tones do not spread onto lexically stressed tone-bearing units or when a second underlying low is two tone-bearing units away.

These cases of non-iterativity in ATR harmony, backness harmony, and low tone spreading serve to demonstrate that non-iterativity is not limited to Central Crimean Tatar. We conclude that these patterns are truly phonological, and in the following section we discuss the analysis of non-iterativity in rule- and constraint-based theories.

8 Analytical implications

The data discussed in Sections 4-6 suggest that non-iterativity in Crimean Tatar is not epiphenomenal. The domain of harmony is not derivable from prosodic, morphological, or phonetic forces, but must be a phonological fact, deserving a formal account. In this section we

compare several approaches to feature spreading, discussing how non-iterativity is derived in each.

8.1 Rule-based phonology

We use the term rule-based phonology to refer to a system of ordered rules, like Chomsky and Halle (1968). We acknowledge that there are many different rule-based theories that have developed during the last half century, but for our purposes, the essential architecture debated during the late 60's and early 70's is sufficiently articulated to account for the facts at hand. In any rule-based theory that has access to the feature [\pm iterative] or may parametrically vary the direction of rule application, the Central Crimean Tatar pattern is easily derivable (Johnson 1972; Howard 1973; Jensen & Stong-Jensen 1973; Anderson 1974; Kenstowicz & Kisseberth 1979). Either the rule motivating harmony, [$+$ syllabic] \rightarrow [$+$ round] / [$+$ syllabic, $+$ round] C_0 __ is tagged as [-iterative], or the string is evaluated from right to left. If directional evaluation is used, non-iterative spreading in /tuz-luq-u/ is due to the fact that the rule evaluates /...luqu/ before it has access to the rounding feature of the initial syllable, outputting third-syllable [u]. The second-syllable /u/ is output as [u] because, at this next step in the application of the harmony rule, the rule has access to the [$+$ round] feature of the initial-syllable vowel. Non-iterativity is thus not problematic for a relatively standard rule-based formalism.

One question for such a formalism is why non-iterative patterns appear to be far less frequent than iterative ones. Given a rule feature [\pm iterative], one might predict that iterative and non-iterative patterns occur relatively freely across the world's languages, but this is not the case. During our research, we found that the vast majority of attested patterns are iterative within some domain, often the word. We do not yet have concrete numbers, but we would estimate that there are hundreds of unambiguously iterative patterns, while there are only a handful of unambiguously non-iterative patterns. This typological skew, however, is only relevant for theories that view typological asymmetries as within the purview of phonological theory (see e.g., Hale & Reiss 2008; Vaux & Myler 2017 for discussion). For other theories, these facts are immaterial, but to the extent that a theory expects the phonological grammar to interact directly with typological frequency, the typological rarity of non-iterativity deserves an explanation.

8.2 Constraint-based analysis

The impetus for Kaplan's emergent non-iterativity hypothesis in (1) is the architectural challenge of deriving non-iterativity in OT (see Kisseberth 2007; Vaux 2008 for further discussion). Consider the interaction of two constraints, \forall -HARMONY-R([+RD],V) and DEP-LINK-[+rd] (14, 15). The harmony-driving constraint, adapted from Walker (2011), in conjunction with a low-ranked DEP-LINK constraint motivates rightward harmony via autosegmental linkage.⁶

- | | | |
|------|-------------------------------|---|
| (14) | \forall -HARMONY-R([+RD],V) | given a word in which a [+round] autosegment is affiliated with some vowel $v_{[+rd]}$, assign a violation to every vowel to the right of $v_{[+rd]}$ that is not associated with some [+round] autosegment. |
| (15) | DEP-LINK[+RD] | assign a violation to every association line present in the output that is absent in the input |

If \forall -HARMONY-R outranks DEP-LINK, as in (16), iterative harmony is predicted; if the ranking is reversed, no harmony is predicted. Thus, in (16) the non-iterative candidate is collectively harmonically bounded (Samek-Lodovici & Prince 1999). There is no simple ranking of the sort of typical markedness constraints motivating harmony and faithfulness constraints to generate the particular pattern in Central Crimean Tatar, a fact which also holds for other constraint-based theories (e.g., Harmonic Grammar; Legendre et al 1990).

⁶ We assume a highly-ranked faithfulness constraint protecting the initial-syllable vowel and DEP[+RD] constraint, preventing harmony via insertion of a new [+round] autosegment.

(16)

[+ rd] /tuz-luq-u/	∀-HARMONY- R([+ RD],V)	DEP- LINK[+ RD]	
[+ rd] tuz-luy-u	*!*		<i>no spreading</i>
[+ rd] \ tuz-luy-u	*!	*	<i>non-iterative spreading</i>
[+ rd] \ \ ☞ tuz-luy-u		**	<i>iterative spreading</i>

However, this problem is not insurmountable. Gapped configurations are the subject of much discussion in autosegmental research (McCarthy 1984; Ringen 1988; Vago 1988; Archangeli & Pulleyblank 1994; Odden 1994). At its core, a well-formedness condition (or violable constraint) on gapped configurations involves several conditions. Given a tier containing the elements x , y , and z such that $x < y < z$, and some autosegment $[F]$, there are two conditions necessary to produce a gapped structure: first, linkage of a single autosegment of $[F]$ to two elements, x and z , which are not strictly adjacent; and second, no linkage between the relevant autosegment $[F]$ and y . If only the first is satisfied, long-distance linkage, without the failure to link to y , then this is well-formed, and is simply an instance of iterative feature spreading. If only the second is satisfied, but not by spreading, this is also unproblematic. For instance, the Turkish root [protesto] ‘protest’ has [+round] underlyingly linked to the first- and third-syllable vowels.

The first precondition for gapped configurations, linkage of non-adjacent elements to the same autosegment, is the key to deriving non-iterativity. We introduce a constraint, ADJACENCY, in (17) that militates against such shared linkage among non-adjacent elements. As far as we know, this particular constraint is not described in previous work, despite some similar proposals in the literature (Cassimjee & Kisseberth 1998; Topintzi & van Oostendorp 2009; Jurgec 2011; Key & Bickmore 2014). Though it is not crucial, this constraint assigns violations to each autosegment that is linked to non-adjacent vowels. It does not assign violations to the

linkages themselves. Consequently, it does not distinguish between a token of [F] linked to three elements versus [F] linked to four elements.

- (17) ADJACENCY[+ RD] given a string Y consisting of $V_1...V_n$ and a [+ round] autosegment, assign a violation to every token of [+ round] that is linked to non-adjacent vowels, e.g. V_y and V_{y+2} ; V_{y-2} and V_{y+2} ; V_{y-1} and V_{y+1} .

(18)

[+ rd] /tuz-luq-u/	ADJACENCY[+ RD]	∀-HARMONY-R ([+ RD], V)	DEP-LINK[+ RD]	
[+ rd] tuz-luy-u		**!		<i>no spreading</i>
[+ rd] ☞ \ tuz-luy-u		*	*	<i>non-iterative spreading</i>
[+ rd] \ tuz-luy-u	*!		**	<i>iterative spreading</i>

In addition to the basic pattern, where spreading is initiated by the root, our analysis is able to account for spreading from [+ round] suffixes like GER and COLL in (11). Crucially, to generating spreading from the [+ round] suffix in (19) is that /qoj/ and /uv/ are each affiliated with their own unique [+ round] autosegment. As a result, the sequence of three consecutive round vowels in [qoj-uv-u] does not violate ADJACENCY because only the last two are linked to the same token of [+ round].

(19)

$\begin{array}{c} [+rd][+rd] \\ \quad \\ /qoj-uv-u/ \end{array}$	ADJACENCY [+RD]	V-HARMONY-R ([+RD],V)	DEP-LINK- [+RD]	
$\begin{array}{c} [+rd][+rd] \\ \quad \\ qoj-uv-u \end{array}$		*!		<i>no spreading from GER</i>
$\begin{array}{c} [+rd][+rd] \\ \swarrow \quad \quad \quad \searrow \\ qoj-uv-u \end{array}$			*	<i>spreading from GER</i>

8.2.2 Typology

Returning to the issue of typology, one of OT's core assumptions is that the typology of permuted rankings should generate a reasonable fit to attested data. Some work goes beyond this, suggesting that the frequency of a pattern within and across languages can be derived from the relative number of rankings that generate that pattern (Anttila 1997; Coetzee 2004; Bane & Riggle 2008; Riggle 2010; Coetzee & Pater 2011). If this view of the grammar is adopted, then it becomes possible to evaluate not only whether an analysis can generate iterative and non-iterative spreading, but also whether the analysis can model the typological skew toward iterative spreading patterns.

We investigated the factorial typology generated by the three constraints above using OTSoft (Hayes, Tesar & Zuraw 2011). Three types of candidates were considered: no spreading, iterative spreading, and non-iterative spreading. With this set of constraints, there are six possible rankings. Three of these generate a language with no spreading (20a-c); two generate a language with iterative spreading (20e,f); and only one generates a language with non-iterative spreading (20d) – the ranking instantiated in (18) and (19). Given the relative infrequency of non-iterative harmony, these constraints should generate non-iterative harmony far less often than iterative harmony.

(20) Factorial typology

a.	DEP-LINK > > ADJACENCY > > \forall -HARMONY	<i>no spreading</i>
b.	DEP-LINK > > \forall -HARMONY > > DEP-LINK	<i>no spreading</i>
c.	ADJACENCY > > DEP-LINK > > \forall -HARMONY	<i>no spreading</i>
d.	ADJACENCY > > \forall -HARMONY > > DEP-LINK	<i>non-iterative spreading</i>
e.	\forall -HARMONY > > ADJACENCY > > DEP-LINK	<i>iterative spreading</i>
f.	\forall -HARMONY > > DEP-LINK > > ADJACENCY	<i>iterative spreading</i>

The OT account above enables the analyst to fit a model to not only a set of possible languages, but also to their relative frequencies. If the grammar is viewed as responsible for predicting typology, this OT analysis predicts higher incidence of iterative over non-iterative harmony. While we consider this to be a favorable result, there is still much to be desired. If one were to naively derive frequencies from these, they would still fail to fit the attested asymmetry. We suspect that the actual ratio of iterative to non-iterative harmony is much closer to 100:1 than 2:1, the basic ratio predicted by this analysis.

8.3 Discussion

8.3.1 Roots

The OT analysis sketched above makes predictions about the production of roots as well as polymorphemic words. As a reviewer notes, the OT analysis predicts that, because only initial-syllable faithfulness and not a more general root faithfulness constraint is active, no trisyllabic roots should exist in the Central dialect with rounding on all three syllables. We mentioned in Section 4.1.2 that disyllabic roots like [jyzym] ‘grape’ do not spreading rounding onto a suffix, e.g., [jyzym-i] ‘grape-poss.3s.’ The absence of spreading here indicates that there is only one [+round] autosegment associated with polysyllabic roots of this sort, since root-internal second syllables behave exactly like suffixal second syllables. The examples in (21) demonstrate that trisyllabic roots, in accordance with this prediction, only have rounding on the initial two

syllables in the Central dialect.⁷ These facts entail that, completely independent of a necessary initial-syllable faithfulness constraint, ADJACENCY outranks root faithfulness.

(21) Polysyllabic roots with a two-syllable domain for rounding

- a. jyzym ‘grape’
- b. kølyk ‘livestock’
- c. xusus ‘answer’
- d. tʃykyndir ‘beet’ (tʃykyndyr ~ ytʃkyndyr in the Southern dialect)
- e. ɕumxuriet ‘republic’

8.3.2 Directionality

Rule- and constraint-based analyses make substantially different predictions concerning the general interaction between iterativity and directionality. In a rule-based approach, it is possible to derive bidirectional non-iterativity by marking each rule as [-iterative].⁸ Consider the mirror-image rule in (22).

$$(22) \quad [+syll, +hi] \rightarrow [+rd] \text{ // } C_0 [+syll, +rd] C_0 ; [-iterative]$$

Given an underlying form like /iCiCyCiCi/, this rule predicts the surface form [iCyCyCyCi]. However, bidirectional non-iterative spreading cannot be generated by the analysis laid out in Section 8.2. Any three consecutive elements linked to a single token of [F] will violate ADJACENCY without respect for which element was underlyingly linked to [F]. Thus, this cannot distinguish between unidirectional iterative harmony $/[+F][-F][-F]/ \rightarrow [+F][+F][+F]$ and bidirectional non-iterative harmony $/[-F][+F][-F]/ \rightarrow [+F][+F][+F]$. This is an interesting difference between a rule-based analysis and our analysis, but we are not sure which prediction

⁷ Although (21e) is clearly a loan, (21c) is also a loan from Arabic that behaves like a native root, [xusus-uw] ‘answer-poss.3s.’

⁸ We suspect directional evaluation (Anderson 1974; Kenstowicz & Kisseberth 1979) would require the composed rules in a mirror-image rule to be evaluated separately.

is superior. We know of no attested bidirectional non-iterative patterns (see also Piggott 1996:158). That being said, it is incorrect to say that constraint-based theories are simply incapable of generating something similar. This really depends on the representational assumptions made as well as the particular constraints invoked, but under the analysis just discussed, it is impossible.

In addition to bidirectional non-iterativity, if iterativity is a feature of rules, then it is possible to generate a language with non-iterative harmony in one direction but iterative harmony in the other direction. The rule-based analysis is clear-cut; one of the two rules driving harmony is simply tagged as [-iterative]. In a constraint-based analysis, if directional asymmetries exist in the propagation of [F], then a larger inventory of constraints will play an active role in the analysis (e.g. Archangeli & Pulleyblank 2002). The closest example we know of comes from ATR harmony in Nawuri (Casali 2002; though see the Northern Palestinian Arabic data in Davis 1995). In Nawuri, ATR harmony operates regularly within words, but across word boundaries a directional asymmetry emerges. In the leftward direction, harmony may affect a number of vowels. In the rightward direction, though, harmony may only affect a single [+hi] vowel. Thus, phrasal ATR harmony in Nawuri is iterative in the leftward direction (23) and non-iterative in the rightward direction (23).⁹

(23) ATR harmony across word boundaries in Nawuri (Casali 2002)

- | | | | | | |
|----|---------------------------|-----------|------------|----------------|-----------------|
| a. | /ɪ-sɪ | ɪ-bu | ɔ̃-bu-to/ | → | [isi ibo obuto] |
| | NC-sand | INCMPL-be | NC-room-in | | |
| | “the sand is in the room” | | | | |
| | | | | | |
| b. | /gɪ-bu: | tu:-sɑ/ | → | [gibu: tu:sɑ] | |
| | NC-stone | throw-ADJ | | | |
| | “a stone for throwing” | | | | |
| | | | | | |
| c. | /ɑ-fu: fʊ:ti-sɑ/ | → | | [əfu: fu:tɪsɑ] | |
| | NC-air breathe-ADJ | | | | |
| | “air for breathing” | | | | |

⁹ Our transcriptions differ from Casali’s in several ways. One, we omit tone markings. Two, we abstract away from several other vowel patterns that interact with harmony (e.g. centralization). And three, we transcribe the [ATR] variant of the low vowel as [ə] rather than [ɔ̃].

This pattern is actually not problematic for OT – the necessity of word boundaries makes it possible to derive non-iterativity in a manner similar to Kaplan’s licensing analysis. Given a constraint like (24) iterative rightward spreading in Nawuri would incur gratuitous faithfulness violations since the constraint only demands a word-initial high vowel assimilate to [+ATR]. Independent evidence for this type of constraint comes from a similar phrasal harmonies in Vata (Kaye 1982; Kimper 2011) and Akan (Kügler 2015).

- (24) *[ATR]# #C₀[+HI] assign a violation to every word-final syllable that contains an [ATR] vowel and is followed by a word-initial syllable containing a vowel that is [+hi] and not [ATR].

The difference between Nawuri and Central Crimean Tatar is that a constraint like *[ATR]# #C₀[+HI] renders ADJACENCY is completely extraneous. The optimal candidate is selected by ranking both \forall -HARMONY-L and *[ATR]# #C₀[+HI] over DEP-LINK-[ATR]. In fact, ADJACENCY is only potentially relevant for leftward spreading, but since it is outranked by \forall -HARMONY-L, it is inactive. If a non-iterative pattern occurs alongside another pattern propagating [F] in the opposite direction, be it iterative or non-iterative, and does not refer to any particular morphosyntactic or prosodic boundaries, then modeling the pattern in OT may not be this straightforward. Again, in this circumstance the issue is with the constraint that favors local, non-iterative spreading above, ADJACENCY. Since this constraint curtails tri-syllabic sequences of [+F][+F][+F], it effectively limits harmony to being unidirectional and non-iterative. In rule-based accounts, directionality and iterativity are two independent parameters, but in constraint-based theories they are much more difficult to separate.

8.3.3 Transparency

Since our ADJACENCY constraint subsumes a constraint on gapped configurations (Itô, Mester & Padgett 1995), it is also violated by transparency in feature spreading. Consequently, this constraint predicts that, all else being equal, there should be no non-iterative patterns that involve transparency. As an example of such a pattern, if non-high vowels were skipped by

rounding harmony in Central Crimean Tatar, we could generate /qulaq-luq-u/ *[qulaq-luy-u] ‘ear-NMZLR-POSS.3’ rather than the attested [qulaq-luy-u]. A similar case is found in C’Lela, where height harmony affects a single target and exhibits transparency (Dettweiler 2000). However, the trigger is always root-internal while the target is always word-final, which makes the pattern similar to Bengali because there are restrictions such that triggers and targets form two non-intersecting classes (Chandlee 2021). While non-iterativity is completely independent of transparency in a rule-based analysis, the two are inseparable under our OT analysis.

Both rule- and constraint-based theories have formal tools that are useful for analyzing non-iterative spreading. However, they make different predictions regarding typological frequency (if one desires that from a formal analysis), the relationship between boundaries and feature spreading, and multidirectional feature spreading.

8.4 What is non-iterativity?

Asking ‘what is non-iterativity?’ at the end of a paper on the topic may seem obtuse, but comparing these two types of theories requires some analytical context, which we hope to have provided by this point. In a rule-based theory, non-iterativity means a rule can apply only once, or alternatively that it cannot feed itself. In a constraint-based theory no direct equivalent is available, because as Kaplan (2008:2) rightly notes, “[w]hen a process applies (non)iteratively, it does so because that happens to be the best way to satisfy some output desideratum, not because the process is specifically required to be (non)iterative.” Thus, there is no single intensional characterization of non-iterative feature spreading available to both theories. In this regard, we agree with Kaplan – feature spreading in Central Crimean Tatar terminates after a single application, not because the harmony driver dictates it do so, but because another constraint, ADJACENCY, militates against further spreading. We diverge from Kaplan, though, because the constraint that curtails further spreading is not independently necessary to analyze the phonology of the language, as is the case in many of the languages discussed in Kaplan (2008). Instead, the interaction between ADJACENCY and \forall -HARMONY encodes a parameter-like setting in the grammar – when ADJACENCY \gg \forall -HARMONY, feature spreading is non-iterative; when \forall -HARMONY \gg ADJACENCY, feature spreading is iterative.

In this paper we have verified impressionistic reports of vowel harmony in Crimean Tatar with a production study, finding that the extent of rounding harmony in the Central dialect is smaller than in the Southern dialect. We interpret this result to support the case that rounding harmony in Central Crimean Tatar is non-iterative. We discuss possible ways to derive non-iterativity from other facts about the language, showing that these fail, requiring the inclusion of some relatively direct encoding of non-iterativity in the grammar. After discussing some other attested cases of non-iterative feature spreading, we illustrate possible analyses of true non-iterative spreading in rule- and constraint-based theories, discussing the different predictions made by each. Looking forward, we expect that further investigation will help us understand how the predictions of these various formalisms compare with the typology of non-iterative feature spreading more generally.

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