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Russian Vowel Reduction and Dispersion Theory

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ABSTRACT Recent work on phonological vowel reduction explains some of its properties by appeal to proposed functional bases (Flemming 1995 [2002], to appear, Crosswhite 2001, to appear, Barnes 2002). This paper explores the feasibility of a Dispersion Theory (DT) account for Russian vowel reduction. No detailed analysis of a case of vowel reduction exists in DT. Also new here is an attempt to base such an analysis on a careful phonetic study, in this case a study of Russian vowel reduction due to Tabain and Padgett (2003). The account succeeds in explaining many aspects of Russian vowel reduction. However, though the phonetic data answers important questions, it also raises difficult new ones.

Keywords Russian, vowel reduction, Dispersion Theory

1. Theoretical Background

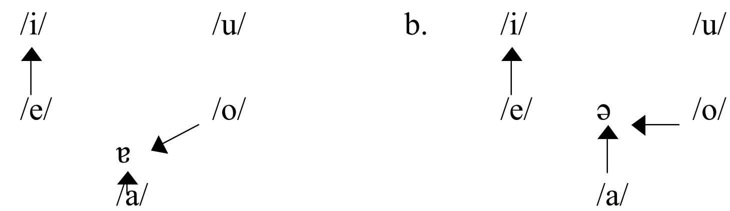
Phonological vowel reduction (understood as neutralization in weak stress environments) has been relatively poorly understood. Why does it happen? What explains its properties? Recent work seeks to explain vowel reduction by appeal to its functional phonetic underpinnings (Flemming 1995 [2002], to appear, Crosswhite 2001, to appear, Barnes 2002). This work suggests that a division of constraints into the *articulatory* and the *perceptual* can contribute to our understanding of vowel reduction. Articulatory constraints penalize "high-cost" articulations, especially those requiring *distant movements* in *little time.* Vowels like short [ĕ,ă,ŏ] especially suffer. Constraints on the perceptual distance of contrasting sounds cause neutralization in the compressed vowel space that results.

This paper tests the approach to vowel reduction taken by Dispersion Theory in particular (Flemming 1995 [2002]). No detailed analysis of a case of vowel reduction exists in Dispersion Theory. Also novel is the attempt to base such an analysis on a quantitative phonetic study of vowel reduction, in this case a study of Russian due to Padgett and Tabain (2003). Although the account succeeds in several important respects, the phonetic data raise some important questions.[1]

2. Russian Vowel Reduction: Traditional Description

Vowel reduction in Contemporary Standard Russian (CSR) is usually described as follows (Shcherba 1912, Avanesov 1956, 1972, Halle 1959, Lightner 1965, 1972, Ward 1975, Hamilton 1980, Bondarko 1998, Crosswhite 2001, to appear). The stressed vowel system [i,e,a,o,u] reduces to a 3- or 2-vowel system in unstressed syllables, depending on palatalization. After non-palatalized consonants, vowels neutralize as in (1)a in the first pretonic syllable, and as in (1)b in other unstressed syllables. (Unstressed [ɐ] also occurs before a vowel and in word-initial onsetless syllables, not discussed here.)

(1) a. b.



Barnes (2002) argues that the difference between (1)a and (1)b is a gradient phonetic one. Though his data are preliminary, the conclusion seems plausible. Hence I do not distinguish them in the phonological account below, though the difference is transcribed in this section.

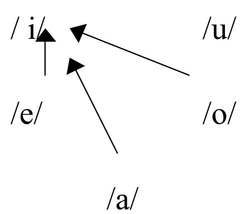
Examples of reduction are shown in (2). The stressed vowels in (2)a reduce in related forms (2)b when stress shifts. (Non-palatalized consonants are velarized before front vowels.)

(2)

a.	'dˠim	'smoke'	b.	dˠimɐ'voj	(adj.)
	'sudnə	'ship'		sudɐ'voj	(adj.)
	'tsˠex	'(factory) shop'		tsˠixɐ'voj	(adj.)
	'got	'year'		gədɐ'voj	'annual'
	'praf	'law'		prəvɐ'voj	'legal'

After palatalized consonants, reduction is said to occur as shown in (3) and (4), all vowels but /u/ surfacing as [i].

(3)



(4)

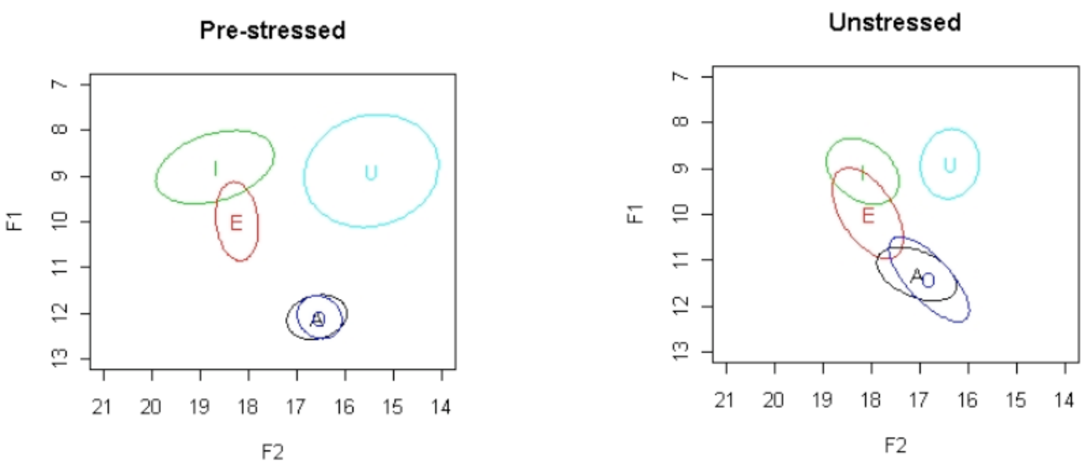
a.	vʲit	'species'	b.	vʲidɐ'voj	(adj.)
	'klʲutʃ	'key'		klʲutʃi'voj	(adj.)
	'dʲelə	'business'		dʲilɐ'voj	(adj.)
	'slʲos	'tears (gen.pl.)'		slʲizətɐ'tʃivˠij	'tear (gas) (adj.)'
	'rʲat	'row, file'		rʲidɐ'voj	'average'

3. A Phonetic Study

A quantitative study of Russian vowel reduction by Padgett and Tabain (2003) provides some relevant results. The plots in (5) show the first pretonic and (other) unstressed vowels of one fairly representative speaker (of nine, speaker AC), after non-palatalized consonants. Each vowel ellipsis represents about 15 tokens, produced in a real word in a carrier phrase. The scale employed is ERB, very similar to Bark, and providing a better picture of the perceptual space than a plot in Hertz.

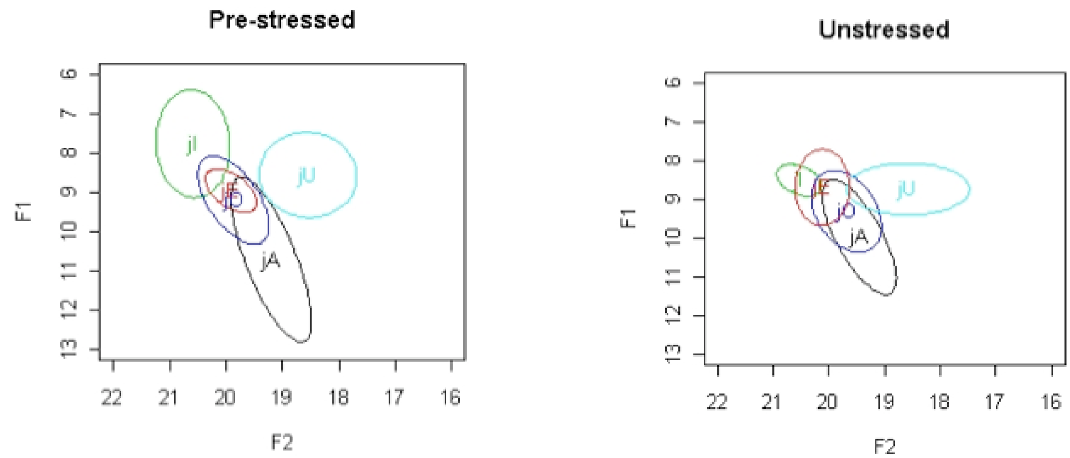
Worth noting are the following. First, /i/ and /e/ do not in fact neutralize completely in this data, a result representative of the nine subjects. (Compare these plots to (1)a,b.) This is in contrast to /a/ and /o/, which *do* neutralize categorically for all subjects. Second, compared to the stressed vowels (not shown), vowel spacing is less consistent here. For example, [i] and [u] are closer together than stressed vowels tend to be, while [u] and [ɐ] (the output of /o/ and /a/) are farther apart than stressed vowels tend to be. (See section 4.) The incomplete neutralization in particular raises some tricky questions for a phonological account. (Compare the debate regarding incomplete neutralization of final devoicing in various languages, see for example Ramer 1996 and references therein.) Though the means of /i/ and /e/ remain distinct acoustically, it is unclear whether the difference is linguistically relevant, since they differ by roughly one ERB, which represents a threshold of perceptibility under certain experimental conditions. How should a phonologist regard such a difference? We might wish to write it off as due to artificial spelling pronunciations under experimental conditions. But since /a/ and /o/ are also spelled distinctly and yet neutralized, this interpretation is hardly secure.

(5) *After non-palatalized consonants*



Vowels after palatalized consonants can be seen in (6) (same speaker). Similar issues arise even more strikingly here. Vowels are closer together than in the stressed context (not shown). And contrary to expectations (see (3)), we do not find complete neutralization of /i/, /e/, /a/, and /o/. Speakers differ somewhat in the details, but all show a tendency to retain some degree of the phonetic properties of the respective underlying vowels. (Note how /a/ has some of the lowest realizations, with /e/ and /o/ in between, for this speaker.) Again the phonological conclusion to be drawn is unclear: despite the acoustic differences, there is also great overlap among some or all of these vowels for all speakers; adjacent vowel pair means along this continuum often differ by less than one ERB (though a significant number do not); and impressionistic descriptions uniformly agree that neutralization *does* occur here.

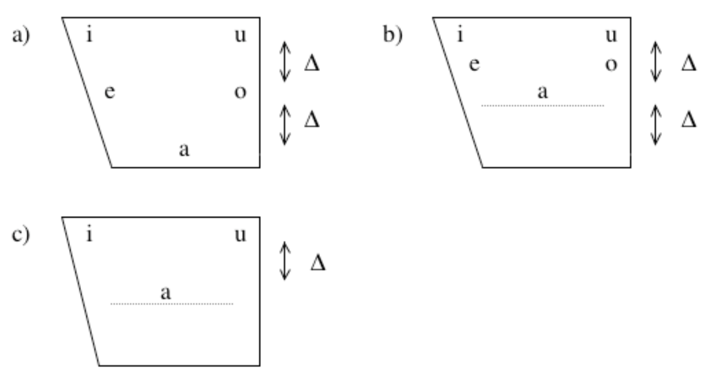
(6) *After palatalized consonants*



4. Explaining Vowel Reduction

Flemming (1995 [2002], to appear) suggests the following account of phonological vowel reduction. (See Crosswhite 2001, to appear, and Barnes 2002 for proposals similar in important respects.) First, unstressed vowels are on average significantly shorter in duration than their stressed counterparts. This makes lower vowel targets harder to reach in unstressed syllables (Lindblom 1963), leading to an overall raising of the vowel space "floor", depicted in (7)b (compared to stressed vowels, (7)a). This contraction of the overall vowel space reduces the space between vowel pairs. Assuming a minimal distance Δ must be respected, this can lead to neutralization, as shown in (7)c. Let us consider each part of the account in a bit more detail.

(7)



The claim about vowel duration holds true of Russian. The study by Padgett and Tabain (2003) found stressed vowels to average 132 ms., compared to 49 ms. for pretonic vowels, and 53 ms. for the other unstressed category, averaging over speakers and vowels, and the difference was significant within each speaker. (It is interesting that a difference between pretonic and other unstressed vowels was not well supported by the study, but see the cited work for details.)

The idea behind (7)b is that vowels are normally uttured in the context of consonants, and consonants by nature require a relatively high jaw position. This means that the lower the vowel (and presumably the lower the jaw position required), the more effort required to reach it. The difficulty is greater for short vowels, since the distance must be covered in less time. In essence, raising of the vowel space "floor" is a way of avoiding distant, fast articulations. Besides the undershoot data reported by Lindblom (1963) and other work cited by Flemming (to appear), there is typological support for the idea. According to Crosswhite's (2001) survey, phonological vowel reduction always involves avoidance of lower unstressed vowels. It is in this sense primarily a *raising* effect.

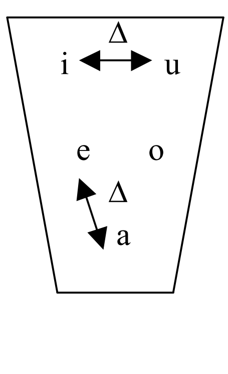
However, it is not just [+low] short vowels that are avoided. Why are [ĕ] and [ŏ] (short [e] and [o]) prohibited too, in Russian and many other languages having vowel reduction? Note that Russian has unstressed [ɐ/ə], so we cannot rule out mid(-low) vowels generally. It cannot follow from the minimal distance requirement Δ, if Δ is a matter of formant values alone: the distance between, for example, stressed (and so longer) [i] and [e] meets this requirement by hypothesis, and, therefore, so would the distance between [ĭ] and [ĕ]. A possibility worth future pursuit is that Δ is computed with reference to formant values *and* duration: [ĭ] and [ĕ] are less distinguishable precisely because they are shorter. Here I rely instead on a phonetic study of Bulgarian vowel reduction, due to Petterson and Wood (1987) and Wood and Petterson (1988), who conclude that [i,u,ə] are a natural class opposed to [e,o,a], even though [e,o,ə] are all mid. The difference is based on degree of jaw lowering, with [i,u,ə] having less. This allows us to formulate the articulatory constraint in (8), which has the effect of ruling out [ĕ,ă,ŏ].

(8) $*\breve{V}_{[+\text{low jaw}]}$ 'No short [+low jaw] vowel'

It is more challenging to flesh out Δ, even putting aside the potential contribution of duration. The reader is referred to Herrick (2003) for discussion of similar issues in a study of Catalan vowel reduction, reaching some similar conclusions. Distances between vowels discussed below are in the scale ERB, and based on the data of Padgett and Tabain (2003).

In order to generate realistic predictions about vowel inventories, phonetic models of vowel dispersion must assume that the color space (roughly F2) is "compressed" in comparison to the height space (F1), by a factor of about 1/2 (Lindblom 1986, Schwartz, et al. 1997). In other words, the vowel space is assumed to be like (9), taller and slimmer than what is usually depicted. Otherwise, [i] and [u] are predicted to be unnecessarily far apart, and [i] and [e] (for example) too close.

(9)



If this reflects psychoacoustic reality at all, then formant values alone are not in fact all there is to vowel spacing, even ignoring stressed-conditioned duration differences. There is some independent theoretical and experimental support for this view (Lindblom 1986, Schwartz, et al. 1997, Benkí 2003, and references therein). Among other possibilities, F1, which cues height distinctions, might "count more" perceptually because it is louder than F2.

Notice also that the achievable F2 space shrinks as we go down in vowel height, an uncontroversial point reflected to some degree in the shape of normal vowel charts. The overall color space available to low vowels is about half that available to high vowels; this is likely why low vowels show the fewest contrasts for color across languages.

In what follows I assume *Euclidean* distances between vowels ("as the crow flies"), as Liljencrants and Lindblom (1972) and Lindblom (1986) do, and as depicted by the arrow between [e] and [a] in (9), rather than gauging spacing in the color and height dimensions independently. This allows us to control vowel distances by means of one constraint only. Euclidean distances between stressed Russian vowels, after averaging formant values across speakers (assuming F2 "compression" as in (9)), are given below (Padgett and Tabain 2003).

(10)

	i vs. e	**e vs. a**	**a vs. o**	**o vs. u**	**i vs. u**	**e vs. o**
Non-palatalized	3.17	2.56	3.53	2.38	3.44	2.81
Palatalized	3.00	3.08	3.24	2.63	3.53	2.55

We might suggest based on this data that stressed vowels are on average about 3 ERB apart. This is obviously only roughly true, yet all vowel pairs are within about .5 ERB of this value. (The greater distance between [o] and [a], and the lesser distance between [u] and [o], are probably both related to some diphthongization in the pronunciation of [o]. The values for this vowel therefore depend more on where measurements are taken than for other vowels.) Suppose we adopt the simple assumption that 3 ERB is in fact the minimal distance required to hold between *all* Russian vowels, stressed or unstressed, as stated in (11). (For discussion of Space constraints and their formulation see Padgett 2003a,b.)

(11) Space: Potential minimal pairs differing in vowel quality differ by at least 3 ERB.

This move raises some important questions. First, it should be emphasized that the values given above are speaker *averages*. Individual speakers can show much less consistency in spacing between different vowels. Padgett and Tabain (2003) suggest that listeners, who must recognize the vowels of diverse speakers, might well be aware of cross-speaker averages. However, this does not answer the question what exactly a constraint like that in (11) regulates, or how it relates to an particular speaker's grammar, if at all.

Second, as we saw in (5) and (6), even average distances are less consistent across vowel pairs in unstressed contexts. This can be seen in table (12), which shows distance values for vowels in pretonic and (non-pretonic) unstressed syllables. It should be emphasized that these figures assume the vowel neutralizations described impressionistically, as depicted in (1) and (3), even where we found (see (5) and (6)) that they look phonetically questionable. For example, the value 3.39 in this table represents the distance between "i" and "ɐ", where "i" represents the average value of pretonic /i/ and /e/ *combined*, and "ɐ" of /a/ and /o/ combined. I return to this point momentarily. As can be seen, we might at best claim that the 3 ERB minimum is respected for pretonic vowels after non-palatalized consonants (top row). Even there, the value 2.41 seems too low, and 4.27 is unaccountably high.

(12)

		i vs. ɐ	**ɐ vs. u**	**i vs. u**
Non-palatalized	Pretonic	3.39	4.27	2.41
	Unstressed	2.07	2.82	1.88
Palatalized	Pretonic			1.56
	Unstressed			1.34

Two approaches to the problem of close distances suggest themselves. First, we might assume that the 3 ERB minimum holds of the phonological output even in pretonic and (other) unstressed syllables, and that any crowding we see there is a matter of phonetic undershoot. Second, these vowels may be more closely spaced in these contexts even in the phonological output, implying that a laxer Space constraint regulates non-stressed vowels. The first view (but not the second) predicts that vowel targets should better satisfy the 3 ERB minimum in careful or hyperarticulated speech. Since the Padgett and Tabain (2003) study did not test for effects of rate or style of speech, it is impossible to decide this question now, and for the sake of discussion I adopt the former approach. This means, for example, that [i] and [u] in the palatalized context are assumed to be 3 ERB apart in the phonological output, but closer at phonetic implementation, due largely to phonetic fronting of [u] after a palatalized consonant (see (6)). Similarly, [i] is phonetically backed after non-palatalized consonants, which are velarized before [i] (see (5)).

Also after non-palatalized consonants, undershoot of [ɐ] (the apparent phonological output of /a/ and /o/) can lead to [ə]-like pronunciations in non-pretonic syllables (Barnes 2002), and [i] and [u] are on average lower than their stressed counterparts, possibly due to undershoot of tongue body raising for these vowels (Padgett and Tabain 2003).

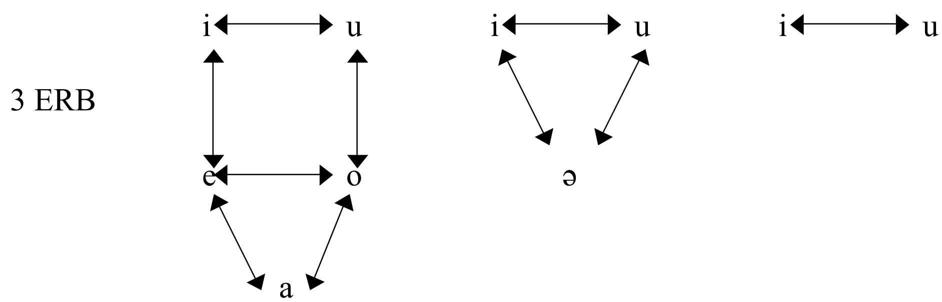
The third question raised by (12) is whether it is right to assume the neutralizations impressionistically described for Russian. As should be clear from (5) and the discussion there, were we to count /i/ and /e/ as distinct in the phonological output, for example, and likewise for other impressionistically neutralized vowels, the distance values obtained would be more wildly inconsistent than seen in (12), and often tiny. (See padgett and Tabain 2003.) Though I hold to the impressionistic descriptions for the sake of the analysis below, this is obviously a matter that requires more investigation.

5. Dispersion Theory Analysis

As should be clear from the above, providing a phonological account of Russian vowel reduction requires making difficult decisions about the interpretation of the phonetic data, and about the relationship between phonetic data and phonology. The reader should be forewarned that these questions will not be resolved in this paper. Instead, let us see what a simple Dispersion Theoretic analysis can do as a way of sharpening these questions.

The phonological output assumed, one that can be derived by simple assumptions, is depicted below. Vowels are assumed to respect a 3 ERB minimal distance in all contexts. For stressed vowels, this allows at most five vowels to contrast, roughly [i,e,a,o,u]. This follows from the size, and shape, of the overall available vowel space. As depicted in (9), in particular, the F2 space available for low vowels is about half of that available for high vowels. For non-stressed vowels, the articulatory constraint in (8) rules out [e,o,a]. Phonetic implementation is assumed to modify this phonological output: vowels can be more closely spaced in non-stressed syllables; [i] and [u] are lower than in stressed syllables; and so on.

(13) a. Stressed b. Non-stressed c. Non-stressed after C^j



The analysis begins in (14). In Dispersion Theory, the input, assuming richness of the base, consists in principle of all theoretically possible phonological forms. In practice, we idealize severely, abstracting away from irrelevant differences between words (see Padgett 2003a,b for discussion). For an analysis of Russian vowel reduction, all that matters are stress and the palatalization status of a preceding consonant. This tableau assumes stressed vowels, and [b] stands in for any preceding non-palatalized consonant. In stressed syllables, however, palatalization of the preceding consonant does not matter. The 13 vowel qualities entertained in the input are sufficiently rich to make clear how the analysis works.

Stressed vowels respect $*\forall_{[+\text{low jaw}]}$ vacuously, and so the derivation involves a contest between Space and faithfulness. Space computes a violation for every minimal pair disrespecting the 3 ERB minimum. For the high, mid-high, and mid vowels, this includes any pair of vowels adjacent in the space, whether horizontally, vertically, or diagonally. Among the mid-low and low vowels, any pairing violates Space. Again, this is because the available F2 space shrinks by one-half from high to low. As a result, Space allows at most five output vowels, and (14)b is the winner. Candidates (14)c-d neutralize more than is necessary to satisfy Space. (For now, I count one Ident violation for each underlying vowel that does not surface, and put aside which input maps to what output, but see below.)

(14) Stressed, non-palatalized, context

		*∀$_{[+\text{low jaw}]}$	Space	Ident(VPlace)
Input:	bi bɨ bu bɪ bʊ be bə bo bɛ bɔ bæ ba bɑ			
a.	bi bɨ bu bɪ bʊ be bə bo bɛ bɔ bæ ba bɑ		26!	
b. ☞	bi bu be bo ba			8
c.	bi bu ba			10!
d.	bi bʊ be bɑ			9!

The next tableau extends the analysis to unstressed vowels. (I do not attempt to analyze stress itself, since this is an entirely independent issue.) Now the articulatory constraint bans any vowels that are not either high or [ə]. Candidate (15)c is interesting, attempting to maintain a five vowel inventory by allowing vowels to get closer. Given the ranking of Space >> Ident, (15)d is more harmonic.

(15) Unstressed, non-palatalized, context

Input: bi bɨ bu bɪ bʊ be bə bo bɛ bɔ bæ ba bɑ	$*\breve{V}_{[+\text{low jaw}]}$	Space	Ident(VPlace)
a. bĭ bŭ bĕ bŏ bă	3!		8
b. bĭ bŭ bă	1!		10
c. bĭ bŭ bĕ bə bŏ	2!	2!	8
d. bĭ bŭ bɪ̆ bʊ̆ bə̆		4!	8
e. ☞ bĭ bŭ bə̆			10
f. bĭ bŭ			11!

The facts after palatalized consonants require one more constraint, shown below. Like that in (8), this constraint is motivated by the avoidance of distant, fast, articulations. They are both essentially assimilatory as well (either tongue backness or jaw height being assimilated).

(16) $C^jV_{[+hi]}$: ‘After C^j, a short vowel is [+high]’

The next tableau considers vowels in unstressed syllables after palatalized consonants. Candidates that have been eliminated by the analysis already seen above are ignored. The three vowel output in (17)a would have won in (15), but it is now ruled out by $C^jV_{[+hi]}$.

(17) Unstressed, palatalized, context

Input: bʲi bʲɨ bʲu bʲɪ bʲʊ bʲe bʲə bʲo bʲɛ bʲɔ bʲæ bʲa bʲɑ	$*\breve{V}_{[+low\ jaw]}$	$C^jV_{[+hi]}$	Space	Ident(VPlace)
a. bʲĭ bʲŭ bʲə̆		1!		10
b. ☞ bʲĭ bʲŭ				11
c. bʲĭ				12!

The analysis above focuses on outputs alone. Once we ask how input vowels get mapped to the output, things become more complicated. The mappings required for Russian were given in (1) and (3). Following Crosswhite (2001, to appear), I let particular mappings follow from language-specific faithfulness rankings. For Russian, the ranking required is Ident(bk) >> Ident(hi) >> Ident(rd). Let us assume for the moment the account of vowel reduction above. Thus, the tableaux in (18)-(20), which consider mappings after non-palatalized consonants, entertain only [i,u,ə] in the output. (Shortness diacritics are omitted.) The input vowels /e,o,u/ are considered one at a time. (Obviously /i,u/ will map to their short counterparts.) As can be seen, with faithfulness to backness paramount, /e/ must map to [i]. The inputs /o/ and /a/ might choose between [u] and [ə]. Faithfulness to height favors [ə]. As a matter of interest, some Southern Russian dialects employ the ranking Ident(hi) >> Ident(bk), as Crosswhite (2001, to appear) notes: all three inputs map to [ə].

(18)

/tsena/ 'price'	Ident(bk)	Ident(hi)	Ident(rd)
a. ☞ ts^{ɣ}i'na		*	
b. tsu'na	*!	*	*
c. tsə'na	*!		

(19)

/voda/ 'water'	Ident(bk)	Ident(hi)	Ident(rd)
a. v^{ɣ}i'da	*!	*	*
b. vu'da		*!	
c. ☞ və'da			*

(20)

/dala/ 'she gave'	Ident(bk)	Ident(hi)	Ident(rd)
a. d^{ɣ}i'la	*!	*	
b. du'la		*!	*
c. ☞ də'la			

However, the account fails for vowels after palatalized consonants, as shown below. Once again I entertain only outputs licensed by the account of reduction earlier: here, [i,u]. The problem involves the inputs /a/ and /o/. As can be seen in (21), /a/ would map correctly if Ident(round) outranked Ident(back); but this ranking fails for vowels after non-palatalized consonants (in particular /o/, see (19)). The situation in (22) is even worse: the winner harmonically bounds the desired output. It is easy to see why: if both [i] and [u] are licit outputs, there is simply no way for faithfulness to prefer the mapping /o/ → [i], no matter how Ident constraints are ranked.

(21)

/vz^{j}ala/ 'she took'	Ident(bk)	Ident(hi)	Ident(rd)
a. vz^{j}i'la	*!	*	
b. ☹ vz^{j}u'la		*	*

(22)

/v^{j}ola/ 'she led'	Ident(bk)	Ident(hi)	Ident(rd)
a. v^{j}i'la	*!	*	*
b. ☹ v^{j}u'la		*	

This problem for the account, arising for vowels in the palatalized context, meshes in an interesting way with both the phonetic findings discussed above and with the history of Russian vowel reduction. Historically speaking, the extreme reduction to [i] in this context is an independent development from reduction to schwa. More specifically, the mapping in (1) is thought to have held after *both* palatalized and non-palatalized consonants until roughly 100 years ago for Standard Russian. Raising of /a/ and /o/ (along with /e/) to [i] came later.

If it turns out that this extreme raising is a matter of phonetic implementation even today, and not of phonological neutralization, as the phonetic results might lead one to suppose, then the account of vowel reduction after non-palatalized consonants would extend in full to the palatalized context. The tableau below illustrates, now integrating the markedness and faithfulness accounts. Assuming that /a/ and /o/ map to [ə] after palatalized consonants, the constraint Ident(high) must outrank C^{j}V$_{[+hi]}$. All forms are now subscripted in order to allow the tracking of input-output mappings. (Height is treated as having five values, with one Ident(high) violation for each degree of height difference.) Many of these mappings are hypothetical, of course, but the reader can verify that the they include those that demonstrably occur in Russian.

(23) Unstressed, all consonantal contexts

Input:				*V̆$_{[+low\ jaw]}$	Space	Id(bk)	Id(hi)	Id(rd)	C^{j}V$_{[+hi]}$
	b^{j}i$_1$ b^{j}ɪ$_4$ b^{j}e$_6$ b^{j}ɛ$_9$ b^{j}æ$_{11}$	b^{j}ɨ$_2$ b^{j}ə$_7$ b^{j}a$_{12}$	b^{j}u$_3$ b^{j}ʊ$_5$ b^{j}o$_8$ b^{j}ɔ$_{10}$ b^{j}ɑ$_{13}$						
a. ☞	b^{j}ĭ$_{1,4,6,9,11}$	b^{j}ə̆$_{7,8,10,12,13}$	b^{j}ŭ$_{2,3,5}$				16	3	1
b.	b^{j}ĭ$_{1,4,6,9,11}$		b^{j}ŭ$_{2,3,5,7,8,10,12,13}$				26!	3	
c.	b^{j}ĭ$_{1\text{-}13}$					8!	26	5	

Under this view, the facts after palatalized consonants involve a kind of derivational opacity: the phonology accomplishes the mapping in (1), and further raising of [ə] to(wards) [i] is a phonetic effect. An alternative is that extreme raising to [i] is also phonologized, as impressionistic accounts of Russian assume, and that the opacity resides fully in the phonology. This approach implies that the phonetic results suggesting non-neutralization are either incorrect, or are to be interpreted in some way consistent with phonological neutralization. One approach to derivational opacity in Optimality Theory, which I adopt here for the sake of illustration, is to carry over the familiar distinction between lexical and postlexical phonology (McCarthy and Prince 1993, Kiparsky 1998, Itô and Mester 2001). Assuming this distinction, the output of the mapping above (now understood as the lexical phonology) serves as input to the postlexical phonology, shown below. At this level the constraint $C^jV_{[+hi]}$ must outrank Ident(back) and Ident(high).

(24) Hypothetical postlexical mapping. ($C^jV_{[+hi]}$ >> Ident(back), Ident(high))

Input: bʲi$_1$ bʲu$_2$ bʲə$_3$	*V̆$_{[+low\ jaw]}$	Space	$C^jV_{[+hi]}$	Id(rd)	Id(bk)	Id(hi)
a. bʲĭ$_1$ bʲŭ$_2$ bʲə̆$_3$			1!			
b. bʲĭ$_1$ bʲŭ$_{2,3}$				1!		2
c. ☞ bʲĭ$_{1,3}$ bʲŭ$_2$					1	2

Let us conclude this section by returning to some of the questions raised about the connection between the phonetic results and the phonological account. First, the Dispersion Theory account predicts that vowels are roughly equally spaced, and that the distance between any vowel pair is roughly 3 ERB regardless of the context. According to the phonetic results, however, distances are less consistent in non-stressed contexts. Many vowels are closer together, though it is unclear whether this is specified by the phonology or whether it resulted from phonetic undershoot in the experiment. In one case both the phonetic results and impressionistic data indicate a spacing *greater* than 3 ERB: in pretonic position, the output of /a/ and /o/ is not [ə] but [ɐ]. (Reduction of [ɐ] to [ə] in other unstressed syllables is taken to be a matter of phonetic undershoot, following Barnes 2002.) Here the Dispersion Theory account more clearly falls short. In order to correct the problem, it might be necessary to regulate spacing in unstressed syllables by a separate Space constraint, and perhaps treat color and height separately.

Second is the matter of neutralization. Recall that /e/ and /i/ do not seem to neutralize (at least articulatorily) in the experimental data of Padgett and Tabain (2003). The Dispersion Theory account follows traditional descriptions in deriving neutralization, but could presumably be modified in order to not to. The comparison is more interesting in the case of /a/ and /o/ in palatalized contexts. Here once again the phonetic data suggest a lack of neutralization to [i]. The mapping of /a,o/ to [i] is problematic for the phonological account as well, an issue of derivational opacity. A possible resolution of the latter problem is to split this mapping into two parts, a mapping to [ə], now assumed to hold after all consonants, and a further mapping of [ə] to [i] after palatalized consonants. Perhaps the phonetic data support such a move, suggesting that the latter mapping is phonetic (or even postlexical, if postlexical processes can be gradient, as some have suggested).

6. Conclusion

The basic Dispersion Theory account of vowel reduction here relies on only two simple markedness constraints, and on faithfulness. The markedness constraints have plausible phonetic bases: vowel reduction results from a combination of an articulatory restriction against vowels like short [ĕ,ă,ŏ], and a perceptual constraint, Space. These constraints have some typological support as well. The particular input-output mappings seen for Russian, or any language, seem to require rankings of feature-specific faithfulness.

This paper represents the first attempt to apply such thinking in a thorough way to the facts of a particular language. It is also noteworthy for its attempt to link the account to quantitative phonetic results. The quantitative are a real asset in some respects. For instance, they motivate the Space constraint's appeal to a 3 ERB minimum, at least for stressed vowels; they support the idea that vowel reduction involves raising of the vowel space "floor"; and they confirm the neutralization of /a/ and /o/ after non-palatalized consonants. (For all of this, see Padgett and Tabain 2003.) On the other hand the phonetic results raise difficult questions for this, or any, phonological analysis. This is a rich area for further research.

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Notes

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