Phonetics and Phonology in Russian Unstressed Vowel Reduction: A Study in Hyperarticulation

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(Short title: Hyperarticulating Russian Unstressed Vowels)

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Abstract:

Unstressed vowel reduction figures centrally in recent literature on the phonetics-phonology interface, in part owing to the possibility of a causal relationship between a phonetic process, duration-dependent undershoot, and the phonological neutralizations observed in systems of unstressed vocalism. Of particular interest in this light has been Russian, traditionally described as exhibiting two distinct phonological reduction patterns, differing both in degree and distribution. This study uses hyperarticulation to investigate the relationship between phonetic duration and reduction in Russian, concluding that these two reduction patterns differ not in degree, but in the level of representation at which they apply. These results are shown to have important consequences not just for theories of vowel reduction, but for other problems in the phonetics-phonology interface as well, incomplete neutralization in particular.

Introduction

Unstressed vowel reduction has been a subject of intense interest in recent debate concerning the nature of the phonetics-phonology interface. This is the case at least in part due to the existence of two seemingly analogous processes bearing this name, one typically called phonetic, and the other phonological. Phonological unstressed vowel reduction is a phenomenon whereby a given language's full vowel inventory can be realized only in lexically stressed syllables, while in unstressed syllables some number of neutralizations of contrast take place, with the result that only a subset of the inventory is realized on the surface. A representative example of such a pattern is found in many Eastern Bulgarian dialects (e.g., most of those classified as Central Balkan by Stojkov [1993: 108-111]). In these dialects, lexically stressed syllables realize a six vowel inventory /i, e, a, ə, o, u/, while lexically unstressed syllables are restricted to the three vowels /i, ə, u/.[1] Phonological unstressed vowel reduction is thus one of a number of patterns of neutralization that Trubetzkoy [1969: 235-241] called "structurally conditioned", and that Steriade [1995] has more recently termed "positional". Positional neutralization patterns are characterized by the ability of certain structural positions within the word or phrase to license greater numbers of contrasts than other positions. What is usually called phonetic vowel reduction, on the other hand, is the phenomenon, investigated perhaps most famously by Lindblom [1963], whereby in certain contexts vowels fail to achieve what would otherwise be considered their acoustic targets, suffering instead some degree of phonetic "undershoot". In his foundational work on the subject, Lindblom demonstrates a relationship between the phonetic duration allotted to the articulation of certain Swedish vowels and the degree of gestural undershoot to which those vowels are subject. Essentially, with less time available to carry out the necessary gestural routines, speakers fall short of target articulations, with the result, Lindblom argues, of greater coarticulation with neighboring consonants, and hence also formant patterns that fall short of the values typical of more favorable durational circumstances.

Noting that unstressed vowels in phonological vowel reduction languages tend to be produced with curtailed durations relative to analogous stressed vowels, many phonologists have posited a connection of one sort or another between phonological vowel reduction on the one hand and phonetic reduction or gestural undershoot on the other [e.g., Barnes, 2002, 2006; Beckman, 1998; Crosswhite, 2001, 2003; Flemming, 1995/2002, 2001, 2005; Herrick, 2003; Padgett and Tabain, 2005; Smith, 2002; Steriade, 1995]. While there is still no agreement as to the precise nature of the relationship between these two phenomena, it is clear that the resolution of problems such as these is of crucial importance for the more general clarification of the relationship between phonetics and phonology, and in particular of questions concerning the role of phonetic information in formal theories of the phonological grammar.

Among systems of phonological vowel reduction, Contemporary Standard Russian has held a position of particular prominence in the literature, in part because the system is relatively well described, but in part also because it is unusually complex as such systems go. (See Barnes [2002, 2006] and Crosswhite [2001, 2003] for typological surveys). What has made Russian interesting to phonologists in the past has been the apparent division of its reduction system into two distinct levels or degrees of reduction, one more extreme and one less so in effect. The present paper presents an experimental investigation of the facts of Russian vowel reduction, focusing in particular on the relationship between phonetic vowel durations and the

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[1] Throughout this paper, I will use the /.../ notation to indicate phonological representations, both "underlying" (Input) and "surface" (Output). I will use [...] to indicate phonetic transcription only.

implementation of reduction patterns. Following up on work reported in Barnes [2006], wherein speech rate was manipulated to obtain a range of durational values for each target word, this study seeks to improve on those earlier results by eliciting both casual and hyperarticulated or clear speech versions of target words. I argue on the basis of the results obtained here that the Russian system of vowel reduction has in fact been mischaracterized traditionally: rather than having two patterns or degrees of phonological vowel reduction, the correct analysis of Russian includes only a single pattern of phonological vowel reduction, with what has traditionally been labelled Degree 2 reduction in fact being explicable entirely in terms of duration-dependent phonetic undershoot. This new analysis of the Russian facts is further argued to have important consequences not only for our understanding of the nature of vowel reduction, but also for our understanding of hyperarticulation as a process of enhancement of phonological contrast. In particular, consequences for the analysis of putative patterns of phonetic analogy or incomplete neutralization are explored.

The remainder of this paper is structured as follows: section 2 provides background information on Russian vowel reduction and on the phonetic underpinnings of phonological vowel reduction more generally. Section 3 presents the results of the hyperarticulation experiment at the heart of the current study. Section 4 discusses these results in the broader context of vowel reduction, hyperarticulation and patterns of phonological neutralization. Section 5 sums up, drawing conclusions and pointing out several promising directions for the future.

2 Background

2.1 Vowel reduction in Contemporary Standard Russian

Contemporary Standard Russian is traditionally described as displaying two distinct patterns or degrees of vowel reduction [Avanesov, 1972; Bondarko, 1977; Halle, 1959; Jones and Ward, 1969; Lightner, 1972; Matusevič, 1976; Shcherba, 1912; Timberlake, 2004; Trubetzkoy, 1969; Ward, 1975; *inter alia*]. The first of these, henceforth Degree 1, is typically described as being less severe or extreme than the second, henceforth Degree 2. Degree 1 reduction is associated primarily (though see below for details) with the syllable immediately preceding the lexically stressed syllable, what I will call throughout the first pretonic syllable. The second degree of reduction is described as occurring in all other unstressed syllables.

From the point of view of phonological contrast in the vowel system, the picture is as follows. Russian contrasts five vowels in stressed syllables, as shown in (1). (See Padgett [2001] and a long tradition of sources therein for arguments against a contrast between /i/ and the high central vowel /ɨ/.) In unstressed syllables, the mid vowels [e] and [o] do not surface. In first pretonic syllables, the primary context for Degree 1 reduction, this results in the contraction of the vowel system to the three vowels [i, a, u] shown below, while in other unstressed syllables, Degree 2 reduction compresses this already-reduced inventory somewhat, its most apparent effect being the realization of [ə] in place of [a]. It should be noted, however, that even in Degree 1 reduction a certain amount of vertical compression of the vowel space is traditionally described as taking place, at least for some speakers: the vowel usually rendered as [a] in Western sources is in fact said to be realized somewhat higher, closer to IPA [ɐ]. (The traditional transcription in Russian sources is [ʌ], which can be somewhat misleading, given this symbol's IPA value.) Following (and particularly between) palatalized consonants, the effects of vowel reduction are more noticeable still, with the low vowel [a/ə] raising toward, and perhaps merging with [i]. (See

Padgett and Tabain [2005], however, for some evidence against the completeness of this merger).

(1) Stressed and Unstressed Vowel Inventories of Russian

STRESSED SYLLABLES				DEGREE 1 REDUCTION			DEGREE 2 REDUCTION		
i			u	i		u	i		u
	e	o						ə	
	a				a				

In so-called “hard” or palatalization-free environments at least, then, expression of phonological contrast is affected in Russian vowel reduction solely through the exclusion of the mid vowels from unstressed syllables. In both Degrees 1 and 2 of reduction, for most contemporary speakers, underlying /e/ merges with /i/ (noting again the uncertainty here contributed by Padgett and Tabain), and underlying /o/ merges with /a/. It is important to note that the transition from Degree 1 reduction to Degree 2 does not actually reduce the number of contrasts available in the system. Instead, the difference between the two degrees of reduction lies most prominently in the degree of centralization of the reduced reflex of underlying /a/ and /o/. For this reason, it will be primarily these vowels that will be of concern in this paper. I will also focus exclusively on the realizations of these vowels in palatalization-free environments, acknowledging the difficult questions that this leaves unaddressed. The realization of /a, o/ in syllables in various positions relative to lexical stress is exemplified in (2), where in each case underlying /o, a/ surface as [o, a] under stress, merge as [a] in the first pretonic syllable, and raise to schwa in the second pretonic syllable.

(2)		STRESSED		DEGREE 1 REDUCTION		DEGREE 2 REDUCTION	
	/o/	ˈm**o**lədəst^j	‘youth’	m**a**ˈlod^{j}ɪn^{j}k^{j}ɪj	‘young’ (dim.)	m**ə**laˈdoj	‘young’
		ˈb**o**l^j	‘pain’	b**a**ˈl^{j}et^j	‘to hurt’	b**ə**l^{j}ɪˈvoj	‘pain’ (adj.)
	/a/	ˈst**a**rɨj	‘old’ (adj.)	st**a**ˈr^{j}ik	‘old man’	st**ə**r^{j}ɪˈna	‘old times’
		ˈr**a**zum	‘reason’	r**a**ˈzumnə	‘wisely’ (adv.)	r**ə**zuˈm^{j}et^j	‘to understand’

2.2 Exceptional contexts

At this point it is important to note that while vowel reduction in Russian is virtually exceptionless lexically (that is, no instance of lexical /e, o/ is permitted to surface as such in unstressed syllables), there are a number of contexts that are traditionally described as exceptions to the pattern of reduction described above. These exceptional contexts all involve the apparent failure of Degree 2 reduction to apply where it otherwise should (that is, anywhere but stressed and first pretonic syllables). Thus, what ought to surface as a schwa is instead realized closer to [a], or at least [ɐ]. The first of these contexts is absolute word-initial position, as seen in (3).

(3)	a.	/odnoˈmu/	[adnaˈmu]	‘one’ (dat.sg.)	*[ədnaˈmu]
	b.	/obiˈʒajet/	[ab^{j}iˈʒajɪt]	‘insult, abuse’ (3sg.)	*[əb^{j}iˈʒajɪt]

Here lexical /o/ in absolute word-initial position fails to reduce to schwa, surfacing as [a/ɐ] instead. Note that this applies only to vowels in absolute word-initial position; /o, a/ in word-initial syllables with onset consonants reduce as expected (cf. /podoˈʃol/ 'went' (masc.sg.) ⇒ [pədaˈʃol]).

The second exceptional context involves sequences of vowels in hiatus. According to Timberlake [2004: 51-2], when underlying /a/ or /o/ is the second of (any) two vowels in sequence, or when it appears immediately before another instance of underlying /a/ or /o/, raising to schwa fails to apply (or applies less dramatically). (4) shows examples of /o, a/ in second and third pretonic syllables failing to reduce to schwa in the relevant contexts.

(4)	a.	/odnooˈbraznɨj/	[adnaaˈbraznɨj]	'monotonous'	*[adnəaˈbraznɨj]
	b.	/sootnoˈʃenije/	[saatnaˈʃenʲije]	'relationship'	*[səatnaˈʃenije]

The last exceptional context, less commonly cited in the literature than the two previous, is absolute phrase-final position. When appearing in phrase-final position, lexical /o, a/ fail to reduce to schwa, or do so only "partially" or "optionally" [Matusevič, 1976: 102; Zlatoustova, 1962: 109-139]. Full Degree 2 reduction is avoided. These exceptional contexts for Russian vowel reduction will become important in the arguments presented below.

2.3 Past Analyses

Traditional analyses of Russian vowel reduction do not draw a distinction of the sort assumed today by many phonologists between abstract, symbolic rules or processes affecting phonological representations and the phonetic implementation of those representations. In most cases, therefore, the question as to whether the two "degrees" of vowel reduction both apply at the same level of representation is simply never addressed explicitly. Degree 1 and Degree 2 reduction are nonetheless clearly portrayed as the same kinds of processes, applying simply to a greater or a lesser extent. Trubetzkoy, for example, notes the complementary distribution of Degree 2 [ə] and Degree 1 [a/ɐ], and describes them as positional variants of the phonemes /a/ and /o/, which are neutralized in favor of the low unround vowel in unstressed syllables. In the generative phonological tradition (arguably beginning in both the local and general senses with Halle [1959], and further exemplified by Lightner [1972] and Alderete [1995], among others), the traditional analysis of Degree 1 and Degree 2 reduction is continued largely intact, to the extent that in both cases phonological rewrite rules (or more recently the interaction of constraints on phonological representations) replace underlying phonological /a/ or /o/ with appropriate output forms /a/ or /ə/ as the case may warrant. Importantly, both patterns are considered to be equally "phonological" in nature. Any distinction between the two is only a matter of degree, rather than of kind.

Crosswhite [2001] represents an important break with this tradition. For Crosswhite too, both Degree 1 and Degree 2 reduction are phonological processes. Where they differ is in their functional motivations (and hence for Crosswhite also in their formal implementations). Degree 1 reduction is an example of what Crosswhite calls "contrast-enhancing" vowel reduction. The idea is that in contexts where discriminating vowel contrasts might be difficult (such as unstressed syllables), constraints against the realization of certain marked vowels have the effect of creating greater perceptual distance between the vowels that are ultimately allowed to surface. Thus, mid vowels are banished from unstressed syllables, while the high and low vowels are permitted. (This account assumes that first pretonic [a/ɐ] is in fact a low vowel.) Crosswhite singles out these Degree 1 environments as distinct from Degree 2 environments structurally by assuming, with Halle and Vergnaud [1987], that the first pretonic syllable and the tonic together constitute the head foot of the word. (Stress in Russian is lexically contrastive, culminative, and obligatory; secondary stresses are unattested in non-compound forms.) All other syllables are analyzed as unfooted, weaker both prosodically and in terms of licensing capacity for vowel contrasts. Degree 2 reduction is thus analyzed by Crosswhite as something altogether different in motivation from Degree 1 reduction, something that she calls "prominence-reducing" reduction. In this analysis, vowels outside the head foot in Russian as taken to be non-moraic, moras being assigned only to vowels located in footed syllables. There is, furthermore, a constraint against the realization of relatively more sonorous vowel qualities (i.e. /a/) in non-moraic contexts.[2] The formal implementation of this ban is less important in the present context than the simple fact that the constraints involved ultimately necessitate the substitution of the less sonorous vowel /ə/ for the /a/ that might otherwise have surfaced in these positions. While the idea of reducing the sonority of an unstressed vowel does seem related to the notion of gestural undershoot, Crosswhite is careful to distinguish phonological prominence-reduction from phonetic undershoot. While the latter is a change in vowel quality resulting from a decrease in duration, the former is a decrease in duration resulting from a change in vowel quality [Crosswhite 2001: 46].

2.4 Vowel reduction in phonetics and phonology

Crosswhite is not alone, of course, in noting the similarity between some phonological vowel reduction patterns and the kind of phonetic undershoot originally attributed to decreased vowel durations by Lindblom [1963]. Flemming [1995/2002, 2001, 2005] and Barnes [2002, 2006] both posit a causal link of some kind between duration-dependent undershoot and patterns of phonological vowel reduction. Such a link makes intuitive sense for a number of reasons: It is well-known that lower vowels have longer durations, all things being equal, than higher vowels [Lehiste, 1970]. This difference is typically attributed to the additional time it takes to reach the more open targets for the articulators of the upper vocal tract characteristic of lower vowels. It is also the case that most languages with phonological vowel reduction exhibit large differences in duration between lexically stressed and unstressed vowels, unstressed vowels undergoing severe shortening in comparison to their stressed counterparts. (Exceptions to this tendency do exist. Shimakonde [Liphola 2001], for example, removes mid vowels from unstressed syllables even when they are bimoraic. See section 4.4 below for more on patterns such as this.) Within the Slavic family, Russian (see below), Belarusian [Czekman and Smułkowa, 1988: 226], and Bulgarian [Tilkov, 1982] all have lexically contrastive stress cued in part by severe shortening of most unstressed vowels, and all three also have phonological vowel reduction; on the other hand, Polish [Jassem, 1959], Czech [Lehiste, 1970: 36-7], and Macedonian [Savitska and Spasov, 1997: 172] all have fixed stress not associated with such a degree of shortening, and they also

[2] Note that in unifying Degree 2 environments as "unfooted syllables", this analysis encounters difficulties accounting for the failure of Degree 2 reduction in the exceptional contexts discussed above, since none of those exceptional syllables are obviously "footed". Absolute initial vowels, for example, are treated with a constraint stipulating that absolute initial vowels bear a mora. Another constraint is posited banning schwa in hiatus. Absolute phrase-final vowels are not treated, but presumably could also be stipulated to bear moras along with absolute word-initial vowels.

lack phonological vowel reduction (though not phonetic vowel reduction, on which see Nowak [2006] for a detailed study of the problem in Polish). Likewise, in Serbo-Croatian, though stress is not fixed, and there are significant differences in the durations of stressed and unstressed vowels, nonetheless unstressed vowels fail to shorten to the extremes we find in languages like Russian and Bulgarian. Lehiste and Ivić [1986: 69-70] give average durations for unstressed short vowels in Ivić's speech in a variety of prosodic contexts typically falling somewhere between 70 and 100 ms., well above the mean durations we will see below for most unstressed syllables of Russian; and as predicted, Serbo-Croatian does not exhibit phonological vowel reduction.

Crosswhite [2001] and Barnes [2002] both demonstrate from broad cross-linguistic surveys that phonological vowel reduction overwhelmingly targets vowel height contrasts (rather than, say, contrasts of palatality, rounding, or ATR). Furthermore, when height contrasts are neutralized, it is invariably the low and/or mid vowels whose realizations are affected; high vowels remain effectively unaltered. Thus, the stressed and unstressed inventories shown in (5), with elimination of underlying mid and low vowels in favor of high vowels and schwa in unstressed syllables, is cross-linguistically common (e.g., Russian second pretonic syllables in non-palatalized contexts). The stressed-to-unstressed mapping in (6), on the other hand, in which high vowels are prohibited in unstressed syllables while mid and low vowels persist, is unattested. Likewise unattested is the mapping in (7), in which three levels of vowel height remain contrastive, while the front/back contrast is eliminated. There are, in other words, no vertical vowel systems that are restricted to unstressed syllables, and no vowel reduction analogues to the neutralizations of palatality contrasts found in the vowel harmony systems of many Turkic or Uralic languages.[3]

(5) STRESSED | UNSTRESSED

i		u	i		u
e		o		ə	
	a				

(6) STRESSED | UNSTRESSED

i		u			
e		o	e		o
	a			a	

(7) STRESSED | UNSTRESSED

i		u		ɨ	
e		o		ə	

[3] Though see Barnes [2006] on the reduction system of Sosva Mansi, and the possibility of reduction systems developing over time out of earlier harmony systems.

a a

Barnes and Flemming both seek to explain these patterns as the result of duration-dependent undershoot of F1 targets for mid and low vowels, resulting in a vertical compression of the vowel space. In this compressed vowel space, height contrasts would become less robust perceptually, with contrasting vowels now closer to one another than typically are their stressed analogues. Flemming [2005] presents a model deriving optimal unstressed vowel inventories using the principles of Adaptive Dispersion originally developed in Liljencrants and Lindblom [1972]. Flemming takes as his model for the effects of undershoot the output of the equations used by Lindblom [1963] to model the results of his one-speaker study of eight Swedish vowels. In this study, the relevant vowels were situated in nonsense words of the form /bVb/, /dVd/ and /gVg/. Each resulting monosyllable was embedded in four sentence frames differing in the target word's sentence position and (phrasal) accentedness, such that a relatively wide variety of vowel durations (80-300 ms) were ultimately obtained. In his analysis, Lindblom found the major predictors of formant values for any given vowel to be duration and distance from consonantal locus to vowel formant target. He takes this result to argue for a view of undershoot as coarticulation, rather than the uniform centralization that others [e.g., Tiffany, 1959] had previously assumed. For F2, of course, this means that the direction and degree of undershoot would change as a function of both consonantal context and the F2 target value for the vowel in question. For F1, however, this result means something different. Lindblom's model of F1 undershoot predicts no undershoot at all for vowels with target F1 below 375 Hz (meaning, in effect, that high vowels are unaffected). For vowels with F1 targets above 375 Hz, Lindblom models F1 undershoot as an exponential function of decreasing vowel duration with an equation similar to those used to model F2 undershoot. The general form of the F2 equations was $\alpha e^{-\beta t} + F1_{(target)}$, where t represents vowel duration, α is a constant proportional to the distance between consonant locus F2 and target F2 for each vowel, and β is a constant fixed for each consonantal context. In the F2 model, then, α could vary in both sign and magnitude as a function of F2 consonant locus relative to vowel target, meaning that F2 could either raise or lower to varying degrees as a function of undershoot. To the extent that all consonant places can be seen to have F1 loci lower than target values for any vowel, in the F1 model, all consonants affected the realization of vowels in the same fashion, proportionally to the difference between the vowel's F1 target and 375. Since only vowels with targets greater than 375 were submitted to this equation in Lindblom's model, α had the same sign for all vowels and all consonants. In other words, while the degree of undershoot a given vowel would experience might change from context to context, the direction of undershoot was always the same: mid and low vowels raise. The parallelism between this phonetic effect, identified in the realization of Swedish stressed vowels of varying durations, and the cross-linguistic typology of phonological unstressed vowel reduction, is striking indeed, and strongly suggestive of a relationship of some sort between the two phenomena.

Indeed, Flemming [2005] characterizes the undershoot obtained in Lindblom's study as causing primarily vertical compression of the vowel space, and argues that this is the ultimate source of the height bias in the cross-linguistic typology of phonological vowel reduction.[4] For Flemming,

[4] It is interesting, incidentally, that this is not how Lindblom himself summarizes his findings. In fact, Lindblom characterizes the undershoot he obtains in his study as affecting primarily F2, while "in most cases there is little

the causal connection between undershoot and phonological vowel reduction exists synchronically in the grammars of phonological vowel reduction languages. The essence of this proposal involves the interplay of duration-dependent undershoot and the principle of Adaptive Dispersion [Liljencrants and Lindblom, 1972], operationalized by Flemming in an Optimality-theoretic framework [Prince and Smolensky, 1993/2004] assuming a unified model of phonetics and phonology. The idea is that at sufficiently decreased vowel durations, there is no way for speakers to maintain adequate perceptual distance between vowels in the inventory without expending unacceptable amounts of articulatory effort (an additional factor conditioning undershoot added to the earlier Lindblom model by Moon [1991], and Moon and Lindblom [1994]). In this model, factors such as vowel duration and articulatory effort interact with constraints mandating the maintenance of phonological contrasts, with the result in this case that speakers prefer to abandon certain contrasts altogether, rather than expend the biomechanical energy necessary to maintain them. The result is fewer available vowel contrasts in unstressed positions within an optimally dispersed, albeit smaller, vowel inventory. This type of approach to phonological vowel reduction, relying as it does on shortened vowel durations and substantial, active synchronic formant undershoot for the derivation of phonological neutralization, succeeds in expressing formally the link between undershoot and neutralization, and in making robust and quantitatively explicit typological predictions about the sizes and shapes of unstressed vowel inventories. It does so, however, at the cost of making undershoot a necessary and (under certain assumptions) sufficient condition for phonological vowel reduction. The problems that arise from this move are discussed in greater detail in section 4.4 below.

By contrast, Barnes [2002, 2006] argues that the link between undershoot and phonological vowel reduction is instead a diachronic one. As in the synchronic model, compression of the vowel space along the F1 dimension due to undershoot makes vowel height contrasts less robust perceptually. Adopting the listener-oriented approach to sound change pioneered by John Ohala [*passim*], the diachronic approach holds that the increased confusability caused by substantial undershoot makes it more likely that the relevant contrasts will in fact be misperceived frequently in the course of actual language use. Consistent misperception of height contrasts in unstressed syllables leads to their ultimate collapse, as listeners/learners reinterpret the effects of undershoot as speakers' intended target realizations for the vowels in question. A sound change thus takes place whereby previously contrasting vowels that had drifted too close to one another in perceptual space merge into a single phonological category in unstressed syllables. The Bulgarian dialects mentioned in section 1 illustrate this nicely, with modern-day dialect geography recapitulating in space the historical development of the dialects through time.

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undershoot in F_{10} observable even at short durations of the vowel..." [1963: 1776]. Given this, we might wonder why F2 undershoot seemingly never results in neutralization of phonological contrasts in the way that F1 undershoot so often does. Padgett and Tabain [2005] discuss this problem in some detail, positing as one explanation the inconsistency in both direction and degree of F2 undershoot in different consonantal contexts, compared to the monolithic raising effect of F1 undershoot across contexts. Another factor that may be important to bear in mind is that Lindblom's model is based on results that included no vowels under 80 ms in duration. Unstressed vowels in vowel reduction languages are substantially shorter than this (cf. the mean durations for Russian presented in Table 3 and Table 4 of the present study, and the results of the speech rate study of Barnes [2006]). This leaves open the possibility that at the relevant durations undershoot of F1 increases more dramatically than does that of F2, in a way that would necessitate modification of Lindblom's original equations.

The Western dialects of Bulgarian (including the native dialect of the region surrounding the capital, Sofia) represent the first stage in this historical progression, reportedly lacking reduction of unstressed vowels of any kind.[5] Thus /ˈdarove/, ‘gifts’, /zeˈleno/, ‘green’ (neut.sg.), and /baʃˈta/, ‘father’, would be pronounced [ˈdarove], [zeˈleno], and [baˈʃta] respectively [Stojkov, 1993: 144]. In (most of) these dialects, then, there are six vowels /i, e, a, ə, o, u/ contrasted in both stressed and unstressed syllables. At the opposite end of the spectrum, many Eastern dialects, for example the Central Balkan dialects spoken around Loveč, Trojan, and Gabrovo, have a complete merger of /i-e/, /ə-a/, and /u-o/ in unstressed syllables [Stojkov, 1993: 109]. Thus, in contrast to the Western examples given above, here we find /daroˈve/, ‘gifts’ pronounced [dəruˈve], /zeˈleno/, ‘green’ (neut.sg.), pronounced [ziˈlenu], and /baʃˈta/, ‘father’, pronounced. [bəˈʃta]. The stressed and unstressed vowel inventories of these dialects are given in (8).

(8) Phonological vowel reduction in Central Balkan Dialects of Bulgarian

Stressed				Unstressed		
i		u		i		u
			⇒			
e	ə	o			ə	
	a					

The putative link between these two systems, one with phonological vowel reduction, and one without, are dialects in which the mid and low vowels are raised phonetically toward, but do not yet merge with, their higher counterparts in the system. Stojkov [1993: 211] identifies the Rupic dialects as displaying such a system, which he calls “half-reduction” (*polureduktsija*). (Rupic is a cover term for most of the dialects of southeastern Bulgaria, including Thrace and the Rhodopes. By no means, however, do all these dialects share the same system of vowel reduction.) In the relevant dialects, /ˈdarove/, 'gifts', /zeˈleno/, 'green' (neut.sg.), and /baʃˈta/, 'father', would be pronounced something like [ˈdaro̝ve̝], [ze̝ˈleno̝], and [ba̝ˈʃta]. The diachronic progression through these three stages of development, going from an initial state with no appreciable reduction, phonetic or phonological, to substantial phonetic reduction resulting in vertical crowding of the vowel space, and finally to collapse of those perceptually compromised contrasts, is illustrated in schematically (9) below.[6]

(9) Development of unstressed vowel inventories in Bulgarian dialects

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[5] This claim is surely too strong in its most literal sense; some formant undershoot no doubt occurs if there are even minor durational differences between stressed and unstressed vowels (which there almost certainly are, given the documented presence of such differences in Serbo-Croatian [Lehiste and Ivić, 1986] and Macedonian [Savitska and Spasov, 1997], the languages to which the various Western dialects of Bulgarian are ultimately transitional). Traditional descriptions of the mid and low vowels of these dialects, in any case, count unstressed /e, a, o/ as “not differing” from their stressed analogues [Stojkov 1993: 144], where we might take this just to mean that any existing difference is perceptually insignificant.

[6] A complete picture of this progression will be somewhat more complex. It is likely in particular, given the facts in other dialects, that the various mergers between stages II and III themselves occurred in stages, with the merger of /a/ and schwa happening first, followed by that of /o/ and /u/, and only lastly by /e/ and /i/. See also on this Scatton [1983: 55-57]. Sadly, accounts of the phonetics of vowel reduction in Bulgarian dialects are still almost exclusively impressionistic in nature.

Stage I: Non-reduction			Stage II: Phonetic Compression			Stage III. Merger		
i		u	i		u	i		u
			e̝	ə	o̝			
e	ə	o		a̝			ə	
	a							

It is not the purpose of the present study to adjudicate definitively between the diachronic and synchronic approaches to the relationship between phonetic undershoot and phonological vowel reduction. Rather, for present purposes, it is enough to recognize that in both approaches, duration-dependent undershoot is assigned a causal role in the formation of patterns of phonological vowel reduction.

2.5 Undershoot and Russian vowel reduction

Given the hypothesized link between durational impoverishment of unstressed syllables and systems of phonological vowel reduction, Barnes [2006] designed an experiment to determine the relationship between vowel quality and vowel duration in the reduction system of Modern Russian. This experiment focused in particular on first formant values for underlying /a/ and /o/ in stressed, first pretonic, and second pretonic syllables. In order to achieve a range of differing vowel durations for a given set of strings, subjects were asked to read through a list of target utterances twice, once at a comfortable, conversational tempo, and then a second time as fast as possible. Target strings were 72 real trisyllabic words of Russian, in which the relevant vowels were all located in open syllables followed by unpalatalized voiced or voiceless stops and preceded by unpalatalized voiced stops, voiceless stops, or laterals. These segment types were chosen primarily to facilitate segmentation for duration measurements. Target forms were embedded in frame sentences of the form *Mashka X skazala,* ‘Mashka said X’, and each target word appeared twice for a total of 144 sentences. Sentences were randomized and arranged in blocks of 12. Four subjects participated in the study, details concerning whom are presented below in section 3.1.1. Target word types from this study are exemplified in (10).

(10) Sample target words from the speech rate study reported in Barnes [2006]

a.	Stressed /a/:	/loˈp**a**ta/	[lɐˈp**a**tə]	‘shovel’
b.	Stressed /o/:	/poˈg**o**da/	[pɐˈg**o**də]	‘weather’
c.	First pretonic /a/:	/nap**a**ˈdatʲ/	[nəp**ɐ**ˈdatʲ]	‘attack’ (inf.)
			(cf. [naˈp**a**tkʲi]	‘attacks’ [nom.pl.])
d.	First pretonic /o/:	/gol**o**ˈdatʲ/	[gəl**ɐ**ˈdatʲ]	‘starve’ (inf.)
			(cf. [gɐˈl**o**dnɨj]	‘hungry’ [masc.sg.])
e.	Second pretonic /a/:	/t**a**koˈvoj/	[t**ə**kɐˈvoj]	‘such’ (masc.nom.sg.)
			(cf. [t**a**k]	‘thus, so’)
f.	Second pretonic /o/:	/g**o**doˈvoj/	[g**ə**dɐˈvoj]	‘annual’ (masc.nom.sg.)
			(cf. [g**o**t]	‘year’)

Major findings of this study were as follows: First, in line with all previous descriptions, the neutralization of /a/ and /o/ in unstressed syllables was found to be categorical (at least in terms of first formant and durational values, the only variables controlled in this experiment). No significant difference between underlying phonological categories was preserved in unstressed position. Mean values and standard deviations for these measures for all speakers and positions are given in Table 1 and Table 2. More surprising was the relationship between F1 values and durational measures for the three positions. The first point concerns the means. The relatively low mean durations for second pretonic /a/ and /o/ seem to line up well with the schwa-like F1 values of the relevant vowels; to the extent that reduction, and reduction to schwa in particular, is in any sense a product of duration-dependent undershoot, these values are to be expected. Problematic in this light, however, are the durational values for first pretonic and stressed /a/ and /o/: Mean duration for first pretonic /a/ and /o/ was somewhat shorter than that of stressed /a/ (69 and 70 ms vs. 82 ms respectively). However, even if we believe (and we do not) that a mean durational reduction of 12 or 13 milliseconds (15 or 16%) could in principle cause enough undershoot that an otherwise robustly distinguishable [a] and [o] might be forced unacceptably close to one another, mean F1 values show that in this study at least, this has not in fact occurred. If anything, mean F1 for first pretonic /a/ is actually slightly higher than it was for stressed /a/. In other words, whatever durational impoverishment there was here has not caused the low vowel in the system to raise at all. This result represents a serious challenge to any approach to vowel reduction that seeks to derive neutralization synchronically from facts about phonetic duration. The contrast between Russian /a/ and /o/ is neutralized in the first pretonic syllable despite the fact that little durational impoverishment, and no vowel space compression, have taken place. In Barnes [2006], I argue that this is because neutralization of /a/ and /o/ in Russian unstressed syllables is a categorical phonological process triggered by abstract structural factors, in particular presence vs. absence of lexical stress. Neutralization is thus phonetically unmotivated, not to say unnatural, in the Russian first pretonic syllable. See Barnes [2006] for potential diachronic accounts of this pattern, and see section 4.4 below for further discussion of the implications of this finding.

[Table 1 about here]

[Table 2 about here]

Looking more closely at the data summarized above yields a second important observation. The scatterplot in Figure 1 shows F1 measurements for second pretonic /a/ and /o/ for all speakers as a function of vowel duration, and it is here that the relevance of the manipulation of speech rate begins to be apparent. What we expect in second pretonic position from phonological descriptions of Russian is Degree 2 reduction (i.e. [ə]). What we in fact find is substantially more nuanced. While the mean given above suggests a schwa-like vowel, closer inspection shows a strong positive correlation ($r = .532$, $p < .0021$, $N = 357$) between F1 values and vowel duration: the longer the vowel got, the lower it was realized, and conversely, the shorter it was, the higher. In other words, Degree 2 reduction appears from this data to apply gradiently, with decreases in duration yielding more reduction and increases yielding less. As much then as the neutralization of /a/ and /o/ is oblivious to phonetics, the raising of /a/ to schwa appears not just to be phonetically-motivated in the loose sense in which this term is usually employed in phonology, but actually phonetically-driven, in the sense of direct causation in performance.

[Figure 1 about here]

The difference between categorical and gradient application of processes has been taken by many to be a defining distinction between symbolic phonological processes and quantitative phonetic processes [Barnes, 2002; Cohn, 1990; Keating, 1988, 1996; Myers, 2000; Zsiga, 1993; *inter alia*]. Assuming the validity of this distinction, Barnes [2006] concludes that so-called Degree 2 reduction in Russian is best treated as a matter of phonetic implementation. This means that, contrary to all previous reports, Russian has not two, but one phonological vowel reduction pattern: the neutralization of /a/ and /o/ in all unstressed syllables, with substitution of /a/ for underlying /o/. In positions such as stressed syllables or first pretonic syllables, positions where vowel durations tend to be longer, phonological /a/ is realized phonetically as a low vowel, [a/ɐ]. Where durations are shorter, as in most other unstressed syllables, low target articulations for /a/ are subject to undershoot, with the result that the low vowel is raised phonetically in proportion to the reduction in its duration in any given instance. There is no evidence that the phonology of Russian has any role in (or access to) this process of gradient duration-dependent raising. In terms of phonological categories, then, there is in fact no schwa in Russian; there is only /a/, which may be undershot to varying degrees as a function of duration.[7]

If this analysis is correct, then our account of Russian phonology is simplified dramatically, in a way that requires only the independently attested phenomenon of gestural undershoot as deployed in a language-specific phonetics. The payoff increases, however, when we consider the "exceptional contexts" discussed above in section 2.2, where raising to schwa fails to apply. This set of contexts, again, is absolute word-initial position, various configurations in hiatus, and absolute phrase-final position. In terms of phonological structure, this set of positions is disparate indeed, and for the phonological account of Degree 2 reduction to succeed, it is forced to posit three architecturally unrelated reasons for the failure of Degree 2 reduction in each context. If Degree 2 reduction is in fact just duration-dependent undershoot, however, a single, unified account of the exceptional contexts emerges with no elaboration of the analysis: all three exceptional positions are associated with increased phonetic segment durations; indeed, cross-linguistically all three are associated with resistance to reduction processes of precisely the type we find in Russian.

Absolute word-initial position is associated cross-linguistically with articulatory strengthening and/or durational enhancement of consonants and vowels, the details of which are the subject of an extensive experimental literature [Byrd, 2000; Byrd, Krivokapić, and Lee, 2006; Byrd and Saltzman, 2003; Cho, 2002; Cho, 2005; Cho and Jun, 2000; Cho and Keating, 1999; Cho and McQueen, 2005; Cho, McQueen, and Cox, in press; Dilley, Shattuck-Hufnagel, and Ostendorf, 1996; Fougeron and Keating, 1997; Keating, Cho, Fougeron and Hsu 1999, Oller 1973]. Other languages with sound patterns involving absolute word-initial vowels, the effects of which could be derived synchronically or diachronically from initial strengthening include Nawuri [Casali, 1995; Kirchner, 1998], Luganda [Hubbard, 1994: 161-165] and Runyambo [Larry Hyman, p.c.]. The additional segment duration and increased gestural magnitudes that have been found in absolute word-initial position in a variety of languages could easily serve to prevent the application of Russian Degree 2 reduction, since either, or more likely both together, would have the effect of preventing undershoot in the production of low vowels.

Absolute phrase-final position is also associated cross-linguistically with additional duration for vowels, a phenomenon known as domain-final lengthening [Beckman and Edwards, 1987;

[7] In Optimality-theoretic terms, what this means is that the Markedness constraint against whatever constellation of features we take to represent schwa (call it *Schwa for short) outranks all relevant Faithfulness constraints. Phonological schwa is not tolerated as a representation in any position, stressed or unstressed.

Beckman, Edwards, and Fletcher, 1991; Byrd, Krivokapić, and Lee, 2006; Byrd and Salzman, 2003; Cambier-Langeveld, 1997, 1999; Keating, Wright, and Zhang 1999; Klatt, 1975; Oller, 1973; Wightman, et al., 1992; *inter alia*]. The relationship between this increased duration and gestural magnitude is still somewhat unclear, and certain cases have been identified in which final lengthening demonstrably fails to undo the effects of undershoot in final position. (See Johnson and Martin [2001] for experimental details on Creek, and Barnes [2006: 141-151] for a crosslinguistic survey.). However, there is also abundant evidence that final syllable vowels, and especially phrase-final vowels, are resistant to a variety of reduction or assimilation processes which should otherwise target them in a wide array of languages, including Belarusian, Ukrainian dialects, Brazilian Portuguese, Eastern Mari, Uyghur, Hausa, Catalan dialects, English, Yakan, Maltese, Nawuri, Shimakonde, Bonggi, and Timugon Murut [Barnes 2006: 79-114].[8] Russian fits this pattern nicely, and to the extent that Degree 2 reduction is the result of compressed segment durations, it would be unsurprising to see it circumvented by the increased durations associated with phrase-final position.

The last exceptional context, hiatus before [a], is similarly explicable. If, again, reduction of [a] to schwa is in fact a consequence of duration-dependent undershoot, a sequence of two like vowels uninterrupted by other gestures should certainly provide adequate duration for articulators to reach their targets, effectively undoing Degree 2 reduction. The problem of exceptional contexts is discussed further in section 4.3, together with suggestions for next steps in understanding resistance to reduction in these three positions.

There was, however, a problem. The two crucial experimental findings supporting the analysis described above were the apparent irrelevance of speech rate or duration to the application of neutralization of /a/ and /o/ in unstressed syllables, and the strong correlation between extent of raising toward schwa and vowel duration. The prediction that this analysis makes is that, given sufficient segmental durations (at, for example, an extremely slow rate of speech), reduction toward schwa should fail across the board. In other words, we should find no difference between vowel qualities in second pretonic and first pretonic syllables. The speech rate study of Barnes [2006] did not, however, succeed in demonstrating this conclusively. As can be seen in Figure 2, while segment durations (and hence first formant values) did approach values recorded for the shortest first pretonic tokens of /a/ and /o/, there was almost no overlap in the realizations of the vowels in these two positions. Barnes [2006] takes this lack of overlap to reflect constraints on the durations of second and first pretonic vowels in normal speech: apparently, even in the slowest normal speech, second pretonic vowels will only lengthen a certain amount, with an upper bound somewhere around 50 to 60 milliseconds, and this turned out not to be enough to completely avert undershoot. The prediction, however, is that, had a fuller range of durational values been obtained, we would have seen not two distinct clouds of productions as in the scatterplots shown here, but rather a single curve that grew at first steeply, and then more gradually as it approached an asymptote representing target F1 for the Russian vowel [a].

[Figure 2 about here]

One other aspect of the scatterplots in Figure 2 is important to note before moving on. While it is true that second pretonic /a/ and /o/ never lengthened into the range of durational values characteristic of their first pretonic or stressed syllable analogues, it is not the case that we see no durational overlap at all between the two categories. For one speaker in particular in fact, DT,

[8] See Zhang [2001] for related facts involving the licensing of contour tones.

first pretonic vowels produced at the faster tempo did get short enough in a number of instances that we actually see substantial overlap between the shortest first pretonic /a/ and /o/ and the longest second pretonic vowels. Interestingly, however, F1 values for DT's first pretonic vowels stayed consistently above those of the second pretonic, as is immediately visible from the scatterplot. In other words, the data from this speaker would be more accurately modeled not by one curve, but by two. This is odd from the point of view of the Russian data in the present study, but nonetheless interestingly reminiscent of observations made about sources of phonetic target undershoot in languages such as English, Swedish, and Dutch [e.g., Engstrand, 1988; Kuehn and Moll, 1976; Moon and Lindblom, 1994; Nord, 1975, 1987; Van Son and Pols, 1990, 1992]. Though the details and conclusions of these studies differ greatly, they all present evidence of one sort or another suggesting duration alone is insufficient to account for patterns of target undershoot. Particularly relevant is the work of Moon and Lindblom [1994] on phonetic vowel reduction and clear speech in English. In this study of undershoot of F2 targets, Moon and Lindblom independently varied vowel duration (induced through polysyllabic shortening) and degree of hyperarticulation, a binary contrast between what they call Citation Form, or ordinary pronunciation of forms in isolation, and a level of Clear Speech obtained by instructing subjects to “overarticulate”. While duration-dependent undershoot was observed (at least for lax vowels) in both registers, in many cases duration alone was insufficient to predict degree of undershoot; specifically, for a given duration, vowels in the Clear Speech register were subject to less undershoot than vowels in the Citation Form register. In this English data, then, hyperarticulation of vowel quality seems to involve changes in some other variable in addition to increased vowel duration. This other variable, in the context of the H&H model of Lindblom [1990], is hypothesized to be articulatory effort, signalled by an increase in movement velocities, allowing a more distant target articulation to be achieved in a fixed amount of time. These increased velocities are achieved through an increase in force amplitudes for the relevant gestures, which in turn would require an increase in “biomechanical power expenditure”. Target undershoot can be avoided, in other words, either by increasing the duration allotted for the achievement of target values, or alternatively, by increasing the amount of effort expended in order to achieve those same values in a given allotment of time. Given these results, it is tempting to see DT's productions in the speech rate study of Barnes [2006] in a similar light. For DT, while increased duration in second pretonic syllables did result in less raising of phonological low vowels toward schwa, corresponding decreases in the durations of first pretonic vowels did not guarantee analogous increases in the degree of undershoot the unstressed vowel was subject to. Rather, first pretonic /a/ retained its higher F1 values even in the face of substantial reductions in duration, suggesting that for DT preservation of target F1 values in first pretonic syllables is important enough to warrant the expenditure of sufficient articulatory effort to stave off the effects of undershoot. This strategy of DT's becomes relevant again in the discussion of outliers in the hyperarticulation experiment presented in the following section.

The failure of the manipulation of speech rate to produce greater overlap in durational values for second pretonic and first pretonic syllables in this study makes it difficult to determine whether other speakers share DT's strategy for the preservation of first pretonic F1 target values. It also makes it impossible to know the full extent of the curve relating duration to F1 values in second pretonic syllables: while duration and F1 values here approach those of first pretonic syllables, it is not certain that given sufficient duration, they would come to overlap with them as well. In order to remedy this problem, a further experiment was subsequently devised, which constitutes the heart of this report.

3 The Experiment: Hyperarticulation and vowel reduction in Russian

While Barnes [2006] did show that F1 values for Degree 2 reduced /a/ and /o/ increased as a function of the increased duration they received at slower speech rates, even the slowest speech rates were insufficient to produce durational values for these vowels that would result in canonical [a]-like quality. It seems from this that Russian places an upper limit on the duration of Degree 2 vowels in normal speech that keeps them regularly somewhat shorter than phonemically analogous vowels in the first pretonic syllable. The result of this was clear in the scatterplots displayed above: effectively missing was crucial data from the area between the canonical durational values for Degree 1 and Degree 2 of reduction; a gradual transition between the two levels of reduction is suggested, but not definitively displayed, by the data collected there.

The present experiment was devised to remedy this shortcoming. If the durations of Degree 2 vowels are severely limited under normal circumstances, these limitations seem to fall away under conditions of extreme clear speech or hyperarticulation. This effect was known to me impressionistically through informal observation of Russian speakers' productions in contexts demanding hyperarticulation. A sizable literature on clear speech and hyperarticulation, albeit dealing almost exclusively with data from English, suggested that this would be the case as well. This literature is focused primarily either on the extent to which clear speech enhances intelligibility for a given population or communicative context, or on the features that are enhanced to achieve any putative added intelligibility. A number of works have documented either increased segment durations, or an expanded vowel space (or both) as characteristics of clear speech in some language [e.g., Bradlow, et al., 2003; Ferguson 2003; Liu, et al., 2004; Picheny, et al., 1986; Uchanski, et al., 1996]. Of particular interest is the work of Moon and Lindblom [1994] introduced above, demonstrating in English a mitigation of duration-dependent undershoot in clear speech too substantial to be attributed to duration alone, suggesting the activity of an additional variable, articulatory effort, in determining vowel realization. Lastly, in a much-needed extension of the study of clear speech to a language other than English, Smiljanić and Bradlow [2005] find essentially the same durational enhancement and vowel space expansion in both English and Croatian, despite substantial differences in vowel inventory size between the two languages.

All this suggests that the elicitation of clear speech or hyperarticulation would be an effective method of overcoming the problems encountered in Barnes [2006]. A situation was thus constructed in which hyperarticulated versions of a set of target words would be produced, with the aim of attaining vowels with durational values long enough in principle to license any vowel quality a speaker might wish to produce. As reported in the following sections, this approach was largely successful.

3.1 Methodology

3.1.1 Speakers

The same four native speakers of Contemporary Standard Russian participated in this study as were included in Barnes [2006]. These were three females (RR, from Ufa, TM, from Saint Petersburg, M, from Moscow) and one male (DT, from Moscow). All had been born, raised, and educated through the secondary level in a predominantly Russian-speaking environment, and all were between the ages of 18 and 35 at the time of recording. All reported continued frequent use of Russian here in the United States with family and friends. Three of the four speakers had some level of training in linguistics, though all were naive as to the purpose of the experiment.

3.1.2 Stimuli

Stimuli were 18 real trisyllabic words of Russian. All words had lexical stress on the final syllable, and the vowel [ɐ] (unstressed /a/ or /o/) in the first pretonic syllable. In the target, second pretonic syllable, 9 of the words had underlying /a/, while the other 9 had underlying /o/. All target syllables were open, and all target vowels were followed by unpalatalized voiced or voiceless stops and preceded by unpalatalized voiced stops, voiceless stops, or laterals. These limitations were chosen primarily to facilitate segmentation and formant analysis later on. Examples are shown in (11) below, where the relevant vowels are bolded in IPA transcription. The complete list is given in the Appendix. It should be noted that words were included in the "underlying /o/" category only when the relevant morpheme surfaces under stress, and hence as phonetic [o], in a morphologically related form. Many words of Russian contain vowels [ɐ] or [ə] that are spelled with orthographic 'o', but which never surface under stress in the language, such that evidence for their underlying status as /o/ is questionable. While no such words were included in the /o/ category here, several of the /a/ words tested did in fact lack morphologically related stressed [a] counterparts (e.g., *kabare,* [kəbɐˈre], 'cabaret').[9] It was felt, however, that in this instance orthographic evidence (*a*-spellings), together with [a]-like surface realizations, were sufficient to support their inclusion in the /a/ category (that is, rather than their inclusion in the /o/-category, the only other possibility, and one for which there is no evidence of any kind).

(11)	UNDERLYING /a/			UNDERLYING /o/		
	/takoˈvoj/	[təkɐˈvoj]	'such' (adj.)	/b**o**koˈvoj/	[b**ə**kɐˈvoj]	'side' (adj.)
	cf. /tak/, [tak], 'thus, so'			cf. /bok/, [bok], 'side'		

These target words were placed in frame sentences of the form *Po-moemu on X skazal,* 'It seems to me that he said X'. These sentences were presented to subjects in the form of a printed list, written in Cyrillic orthography, in pseudo-random order. To achieve hyperarticulated versions of the target words, an experimental paradigm used in, e.g., Johnson, Flemming and Wright [1993], was adapted to these circumstances. Speakers were asked to read through the list of sentences at a comfortable, conversational rate of speech. After each sentence, however, speakers were asked twice to repeat themselves by the experimenter, simulating incomprehension. (Speakers were informed before the experiment began that this would occur, though apparently advance warning did little to make the experience less irritating.) These exchanges are represented by the short dialogue in (12). Speakers' responses to the first and second interruptions were not scripted however, so that what they actually said, apart from repeating the target word itself, varied from token to token. The following is a typical exchange.

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[9] In fact, one such word was mistakenly included in the /o/ category as well: /bogatɨrʲ/, [bəgɐˈtɨrʲ], 'a hero of the Russian oral epic tradition'. Appearances notwithstanding, this word does not in fact share a root with /bog/, [bog], 'god', /bogatɨj/, [bɐˈgatɨj], 'rich', /ubogij/ [uˈbogʲij], 'wretched, destitute', and so on. Rather, it seems to be a borrowing of early Turkic *baɣatur, whence also Hungarian bátor, 'brave' [Vasmer, 1950-58]. Whether or not speakers of Modern Russian infer a connection between these forms is unclear. More appropriate for inclusion would have been, for example, bogatet' [bəgɐˈtʲetʲ], 'get rich'. This oversight did not affect results in any case.

(12) Sample dialogue

Speaker:	*Po-moemu on X skazal.*	'It seems to me he said X'
Experimenter:	*Aaa? Ne ponjal.*	'Huh? I didn't get that.'
Speaker:	*X on skazal!*	'He said X!'
Experimenter:	*Što eto on skazal??!!*	'He said what??!!'
Speaker:	*X!*	*'X!'*

Each target word thus received three repetitions, the second and third generally with substantial hyperarticulation.

3.1.3 Recording and analysis

Sessions were recorded in a sound-attenuated room at Boston University at a sampling rate of 44.1 KHz, using a Marantz CDR-300 portable CD-recorder and a Shure SM10A cardioid headworn dynamic microphone run through a Rolls MP13 Mini-Mic preamplifier. Recordings were downsampled to 22.050 KHz and saved as .wav files using Praat 4.0.2 speech analysis software [Boersma and Weenink, 2004]. Measures of duration for target vowels were taken from linked spectrogram and waveform displays. After stops, vowels were marked as beginning at the onset of reliable periodicity following the burst. (Russian voiceless stops typically have low voice onset times.) Following laterals, vowels were measured as beginning at visible spectral discontinuities associated with the lateral's release, or failing this, at the onset of significant energy in the second formant and above. In certain extreme cases, where no sufficient landmark could be detected between the lateral and the vowel, tokens were simply discarded. Measurements of the first formant, taken to be indicative of vowel height, and hence position on a potential cline of values between [a] and [ə], were made at vowels' midpoints using LPC analysis (10 poles, with downsampling of original files to 11 KHz for female subjects and 10 KHz for male, analysis window 25 ms., shortened to 10 ms. where vowel durations necessitated).

After discarding all tokens that could not be reliably measured (whether due to devoicing, overlap by neighboring consonants, or lack of sufficient landmarks to properly segment), of 216 total productions (18 words x 3 repetitions x 4 speakers), the total number of tokens analyzed was 209 (51 from RR, 53 from TM, 52 from DT, and 53 from M). Of these, 103 were instances of /a/ in Degree 2 reduction, and 106 were instances of /o/ in Degree 2 reduction.

3.2 Results

3.2.1 Neutralization

This experiment was not designed to be a definitive test of the completeness of neutralization of Russian Degree 2 reduction of /a/ and /o/. Had it been, it would have been necessary to control, for example, identity of surrounding consonants in a way that was unnecessary for present purposes. Additionally, the variance in both duration and F1 introduced by the manipulation of level of hyperarticulation in responses makes the comparison of category means for different underlying vowels difficult, in that this variability could easily mask the more subtle variation introduced by underlying vowel as a factor. As the question of phonological neutralization is central to the analysis of VR in Russian presented here, however, it must be noted that the results of this study do in fact support the conclusions of previous experimental work, particularly

Padgett and Tabain [2005], on this question. As mentioned above, Padgett and Tabain find some (rather startling) evidence that certain reduction processes traditionally described as neutralizing are in fact not, with minute differences of the type familiar from the literature on incomplete neutralization persisting between mean realizations of seemingly merged underlying categories. The neutralization of /a/ and /o/ in their data, however, was found to be complete by any measure they applied. In the present study, results come only from the comparison of /a/ and /o/ in terms of duration and F1. Measures of higher formants were taken, but because no attempt was made to control place of articulation of surrounding consonants, and because, as noted above, different consonants affect undershoot of F2 targets in crucially different ways, error in the F2 data from the present study was too great to say anything of value on the question. In Table 3 and Table 4, F1 and duration means and standard deviations are shown for both vowels from each speaker. Note that the high standard deviations here reflect the intent of the experiment to produce each word in both ordinary and hyperarticulated variants. These values are thus effectively a measure of the greater success of the hyperarticulation task in producing a range of duration and F1 values than was achieved in the speech rate study of Barnes [2006], where standard deviations (see section 2.5 above) were much lower.

[Table 3 about here]

[Table 4 about here]

Repeated measures analysis of variance performed on the data with underlying vowel as a within-subjects factor found no significant effect of underlying vowel on first formant measurements: $F(1,3) = 8.509$, $p > .05$. No main effect was found on duration either: $F(1,3) = 7.207$, $p > .05$. This is perhaps unsurprising, of course, given the low power of the test and degree of variability in the data. As a check on this result, individual univariate ANOVAs were carried out for each speaker assessing the effect of underlying vowel on both F1 and duration. Ordinarily of course, significance tests of this sort, however common they may be in the literature, are to be avoided; treating in this fashion individual trials from a single subject as independent experimental units is problematic in a variety of ways, most notably because it violates the assumption of independence of error effects, as well as massively overestimating the degrees of freedom for the error term in the analysis [Max and Onghena, 1999]. To the extent that the effect of these violations is an increased danger of Type I errors, though, swe can feel comfortable with the result that even under such circumstances, in the study at hand F1 and durational differences between /a/ and /o/ failed to reach significance for any speaker. These results are given in Table 5.

[Table 5 about here]

Still, it is interesting to note in Table 3 the tendency for each speaker's underlying /a/ to have a higher mean first formant value than that of underlying /o/, with mean F1 for /a/ across all speakers at 576 Hz, compared with that /o/ at 552. Since stressed [a] has an F1 that is significantly higher than stressed [o] (see section 2.5 above), this difference in the present study could conceivably be taken as evidence of incomplete neutralization of /a/ and /o/ in unstressed syllables, a tiny lingering vowel height difference between what otherwise appear to be identical sets of vowels. Given the lack of statistical significance of this result, along with previous results in the literature, it is unlikely that this is the case. Indeed, one possible source for the oddly consistent F1 difference in this data is the fact that while all instances of underlying /a/ in this study are located in lexical root morphemes, several of the instances of underlying /o/ were in fact contained in prefixes, specifically /do-/, /po-/ and /pod-/. (See Appendix for a complete word list.) This is relevant due to a much-cited tendency in the literature [e.g., Bybee, 2001; Fidelholtz, 1975; Hooper, 1976; Jurafsky, et al., 2001; Zipf 1929] for more frequent or predictable (more probable, in Jurafsky et al.'s terms) material to be subject to more severe reduction processes than less frequent or predictable material. Grammatical morphemes such as verbal prefixes in Slavic languages are a prime example of such material. They are extremely (type-) frequent morphemes in that most verb roots in the language can appear with one or (usually) more such prefixes, and they are highly predictable in that they are members of a small closed-class of morphemes, not all of which commonly occur with every verb root. And indeed, when the underlying /o/ data from this study is broken down further, into those forms where /o/ is contained in a root (N = 5) and those in which /o/ is contained in a prefix (N = 4), the predicted difference emerges, as seen in Table 6.

[Table 6 about here]

Root /o/ is on average both longer and (by the analysis presented here hence) lower than prefix /o/. Using only the data from root /o/, mean F1 for underlying /o/ and /a/ become substantially closer together, if not identical.

There is also one additional source of evidence for the completeness of the merger of underlying /a/ and /o/ in unstressed syllables in Russian, and that is their behavior under hyperarticulation. This issue is addressed more completely below in sections 4.5 and 4.6. For now, though, let us assume just the following: hyperarticulation is a device that serves at least in part to enhance phonological contrasts (witness the expanded vowel spaces discussed above from the literature on Clear Speech). Thus, if there is a contrast of any kind left between underlying mid and low vowels in Russian unstressed syllables, we might expect hyperarticulation to exaggerate that contrast, making it more readily observable.[10] Phonological /a/, in other words, should become more [a]-like under hyperarticulation, while phonological /o/ ought to become more [o]-like. (The debt this line of reasoning owes to Gussenhoven and Rietveld [2000] is acknowledged more explicitly below.) Figure 3 shows the positions of stressed /a/ and /o/ (mean values taken from Barnes [2006]) as landmarks in a two-dimensional F1/F2 vowel space, and then plots relative to those reference points the mean formant values for the first, second, and third repetitions of unstressed underlying /a/ and /o/ for all speakers in the hyperarticulation study. Recall that the first repetition reflects something like ordinary speech, while the second and third repetitions should have exhibited progressively increasing hyperarticulation. This seems indeed to have been the case.

[Figure 3 about here]

Figure 3 shows clearly that both underlying /a/, and more importantly also underlying /o/ get progressively lower and fronter in their realizations as hyperarticulation increases. They both become, in other words, more [a]-like, in terms of both F1 and F2. Were there a surface contrast left to enhance between /a/ and /o/ in unstressed positions in this data, we would expect hyperarticulated tokens of underlying /o/ to move instead higher and backer in their realization,

[10] There may seem to be some question-begging in the offing here concerning the proper analysis of incomplete neutralization. Competing points of view on this matter are addressed more completely in section 4.5. I would argue, however, most if not all of these seem to predict the same thing with respect to hyperarticulation, however they may differ otherwise.

the very opposite of what in fact occurred. I take this to be strong evidence for the completeness of the neutralization of unstressed /a/ and /o/ in Russian.

3.2.2 Vowel Height as a Function of Vowel Duration

The scatter plots in Figure 4 show first formant values in Hertz for underlying /a/ and /o/ for each speaker given as a function of vowel duration in milliseconds. Table 7 shows a linear regression model of the data for each speaker together with its R^2 value. The differences in R^2 values reflect the presence of a certain number of strongly influential cases in the data from some of the subjects (e.g., TM and M), on which more below. For now, it can be observed merely that extreme hyperarticulation (that is, realization of unstressed /a/ or /o/ with duration and F1 approaching values typical of stressed [a]) was relatively rare as a response, though it did occur.

[Figure 4 about here]

Furthermore, some speakers (again, TM and M) were more likely to produce responses with extreme hyperarticulation than others. This seems essentially to have been a consequence of the strategy adopted by each speaker for dealing with their interlocutor's persistent requests for repetition: Some speakers, such as TM, became (or rather, I sincerely hope, pretended to become) visibly and audibly exasperated, with each repetition increasing in duration, loudness, and pitch range. Other speakers, such as RR, took a more stoic approach, quietly repeating the target word in each case without strong overt signals of impatience or annoyance. The difference is made graphically clear in Figure 5 and Figure 6. For stoic speakers, the hyperarticulation paradigm was simply less successful in eliciting extreme values for the relevant parameters than it was for other speakers—witness the comparatively much lower durations for all responses by RR. Indeed, the fact that even for the demonstrative TM more extreme duration and F1 values appear to create unacceptable leverage in the regression model, rather than an even cline of values from less to more hyperarticulated indicates that the hyperarticulation paradigm as implemented was less successful than we might have hoped. See section 4 for further discussion. What is clear from Figure 4 in any case, though, is that for all speakers tested, vowel duration emerges as a strong predictor of vowel height for the reduced vowels produced in this study.

[Figure 5 about here]

[Figure 6 about here]

Figure 7 shows the data for all speakers pooled, 209 responses in total. Regression coefficients $\beta0$ (455.98) and $\beta1$ (2.3379) were both significant at less than .001 ($t = 50.944$ and 14.91 respectively). The overall model was significant at less than .001 ($F = 222.304$), with an R^2 value of 0.5178.

[Figure 7 about here]

While clearly an important predictor of vowel height, the real significance of vowel duration in determining the extent of Degree 2 reduction is nonetheless masked to some extent in the data above due to the difficulty in comparing formant values across speakers, and in particular, across speakers of different genders, as is the case here. To remedy this situation, standardized scores for duration and F1 were produced individually for each speaker, and then these too were analyzed using linear regression.[11] The result is shown in Figure 8. This amendment to the analysis has the effect of raising R^2 for the model to 0.6376, a very high level indeed, indicating that nearly two-thirds of the variance in the F1 scores is explained by duration alone. I take this as strong support for the hypothesis that Degree 2 vowel reduction in Russian is a phonetic process, whereby underlying /a/ and /o/ are raised gradiently in the vowel space toward schwa as a function of durational compression. In cases of extreme hyperarticulation, both underlying vowels are produced with duration and F1 values similar to those ordinarily found in Russian stressed /a/. At the other end of the scale, when both vowels are extremely short, they are produced with a schwa-like quality. This relationship is mischaracterized when Degree 2 reduction is taken to be a phonological process whereby the symbolic category labels /a/ and /o/ are replaced by a category label /ə/ in the relevant unstressed syllables. Rather, only a single non-high vowel category, /a/, is licensed in any unstressed syllable, with F1 targets for the implementation of that vowel being determined to a large extent by the duration allotted to the unstressed syllable in question.

[Figure 8 about here]

Looking more closely at the regression model presented here, though, outlier cases of two types nonetheless emerge and demand an accounting. True outliers, that is, cases that deviate from the values predicted by the regression model were relatively few here. Examining the standardized residuals from the model, we find 10 cases at more than 2 standard deviations from predicted values. This is just slightly less than 5% of the total, and thus acceptable assuming that the residuals are normally distributed. Slightly more worrisome is the number of cases exceeding 2.5 standard deviations from the model's predictions. There are 6 such cases, where a normal distribution of residuals would predict something more like 2 (i.e. approximately 1%). Interestingly, of the 10 cases falling farther than 2 standard deviations from predicted values, only one had a residual that was negative. All the rest were positive, meaning that they were instances in which F1 was higher (i.e. the vowel was less reduced) than its duration would predict. What is more, 8 out of these 9 "underreduced" vowels were produced by a single speaker, DT, in either his second or his third repetitions of a given target word. In each case, where our model would predict a lowish, schwa-like F1 (somewhere between 500 and 600), DT nonetheless realized his unstressed vowel with a relatively high, [a]-like value for F1 (700 or above). Since these are all second and third repetitions, another way of viewing these outliers is that DT, unlike the other speakers, seems able to hyperarticulate vowels by some other means than increasing their duration. This pattern is strongly reminiscent of a similar one discussed above in section 2.5 with respect to the results of the speech rate study of Barnes [2006]. Recall that there too the pattern of undershoot found in the productions of Speaker DT appeared to be difficult to explain with duration alone. Specifically, DT's first pretonic vowels at short durations appeared to be systematically less reduced than the duration-dependent undershoot hypothesis would have predicted. There it was hypothesized, after Moon and Lindblom's [1994] analysis of Clear Speech in English, that DT was avoiding undershoot at short durations by increasing his level of articulatory effort (or more concretely, his gestural velocities) in the production of the relevant syllables. While the data is admittedly sparse for drawing firm conclusions, in principle at least the same account could be extended to DT's outlier cases in the present study. In effect,

[11] Z-scores were used for standardization, calculated as $z_x = (x - m_x) / s_x$, , where m is the mean for a given set of values, and s the standard deviation.

our regression model for DT is actually missing a parameter: Rather than increasing segment durations to avoid undershoot in hyperarticulation contexts, DT is again adjusting his degree of articulatory effort instead. If this is true, and DT therefore represents a distinct subpopulation from our other speakers with respect to patterns of hyperarticulation, we might take this as justification for excluding his responses altogether from the model constructed here. Note that doing so improves the fit of the model substantially, as can be seen in Figure 9. In this new model, R^2 becomes 0.678, and when again applied to standardized duration and F1 values instead of raw scores, R^2 rises all the way to 0.707.

[Figure 9 about here]

There is, however, still the matter of the influential cases mentioned above, those cases that, though they do lie close to the line of best fit, nonetheless have values for the predictor variable extreme enough potentially to have an undue effect on the course of that line. The removal of such cases would alter both the regression coefficients and the degree of the model's fit. Whether such cases belong in the model or not (i.e. whether their influence is indeed undue) is open to interpretation. I would argue that they do indeed belong in the model, that their extreme values for duration represent simply the far end of the hyperarticulation scale, yielding extreme, [a]-like values for F1, just as the analysis here predicts they should. Their relative rarity and distance from the bulk of responses stems simply from the failure of the hyperarticulation paradigm as implemented here to produce enough sufficiently hyperarticulated forms for analysis. Speakers, in other words, were generally too reserved in their responses to bring out the full range of values that might have been observed with a more effective elicitation strategy (on which problem, see section 4).

To play devil's advocate for a moment, however, we might conclude instead that these influential cases are skewing our understanding of the relationship between duration and vowel height in Russian unstressed syllables, and therefore deserve to be excluded from our analysis. To use a common diagnostic for influential cases, we could target for exclusion any responses with leverage values greater than three times the average (i.e. $3(k+1)/n$, where k is the number of predictors, here one, and n is the number of cases included in the model). For our data set, the limit for the leverage statistic (as calculated by SPSS) would be .027. Applying this guideline, we locate 9 suspect cases. Interestingly, all but one of these are second or third repetitions of a target word by a single speaker, TM. Recall from above that TM was the most given to hyperarticulation of the four speakers, making some of her productions stand out from the general mean. Exclusion of these cases does change matters. R^2 now falls to .302 for the raw values, or .507 for the standardized scores.[12] Even so, however, the model still accounts for just over half of the variance in F1 scores, and is significant at $p < .001$. A scatter plot of the data with these cases removed is shown in Figure 10.

[Figure 10 about here]

[12] Adopting a more stringent view of what constitutes an influential case, setting the leverage statistic cutoff at just twice average (here .018), removes 13 cases, again all but one from TM's second and third repetitions. R^2 is correspondingly reduced to .27 for the raw values, and to .495 for the standardized scores.

4 Discussion

4.1 Vowel Duration in the hyperarticulation task

Since the hyperarticulation experiment reported here was originally undertaken primarily to improve on the results of the speech rate study of Barnes [2006] in terms of the range of duration and F1 values obtained for /a/ and /o/ in circumstances of Degree 2 reduction, the first question to be decided in evaluating this study is whether or not it succeeded in this goal. Comparing the results of the two studies, it is clear that it did, though perhaps not to the extent that we might have hoped.

Figure 11 illustrates the elevated duration and F1 ranges obtained in this study, as compared with those found in the speech rate study of Barnes [2006]. For all speakers, the hyperarticulation task has elicited higher values on both measures, as evidenced by the median, interquartile ranges, and overall ranges. The fact that the hyperarticulation task has not elicited duration and F1 values as low as were found in the speech rate task owes to the fact that in that study speakers were asked to read half the repetitions of each target sentence as fast as they could manage. In the hyperarticulation task, on the other hand, the lowest durations and F1 values would have occurred in the non-hyperarticulated first repetitions of each target sentence, and these would have been produced at something like a neutral, conversational rate of speech. Clear also from Figure 11 is the fact, noted already above, that one speaker, TM, produced hyperarticulated forms with more abandon than the remaining speakers. RR in particular altered her productions little as a result of the experimenter's prompts for repetition. This difference in response strategy is reminiscent of the findings of Curl [2002], to the effect that the extent to which requests for repetition will in fact elicit “clear speech” is dependent on the pragmatics of the speech situation, and more specifically, on the extent to which the speaker finds the request for repetition “justified”. In this light, RR seems to have responded as though the experimenter’s requests for repetition were in fact warranted by some aspect of her source productions, while TM responded as though the requests were unwarranted. Be this as it may, the range of responses to the task suggests that another means of eliciting clear speech might have captured a fuller range of duration and F1 values for all speakers, and thus would be preferable for future research in this direction. More hyperarticulation from the remaining three speakers, for example, would have made TM's productions seem less extreme in the pooled analysis. One common procedure that might be an improvement would be to ask speakers to read as though their listener had a hearing impairment, or less-than-fluent knowledge of the language (as in, e.g., Smiljanić and Bradlow [2005]).

[Figure 11 about here]

4.2 Implications for the analysis of Russian vowel reduction

Such minor defects notwithstanding, the results of the hyperarticulation study lend strong support to the conclusions of Barnes [2006] concerning the nature of Russian vowel reduction: for the Degree 2 reduction pattern investigated here, all speakers showed a highly significant correlation between vowel duration and vowel height as measured by F1. Contrary to all previous reports, reduction of /a, o/ to [ə] in fact applies gradiently, with significant raising in shorter vowels, and substantially less in syllables made longer through hyperarticulation; where durational values of second pretonic vowels approached or coincided with values characteristic of first pretonic or stressed vowels, F1 increased analogously. Indeed, in the most hyperarticulated tokens of second pretonic vowels, both duration and F1 were well within the range normally characteristic of /a/ bearing lexical stress.

Additionally, these hyperarticulated phonetic [a] vowels were found equally realizing underlying phonological /a/ and of underlying phonological /o/. Which is to say, while increased duration was sufficient to allow realization of an unraised phonetic [a] in a lexically unstressed syllable, no amount of lengthening was sufficient to realize phonetic [o] in that same environment. That out of 209 productions not a single speaker, under any degree of hyperarticulation, produced so much as a single unstressed phonetic [o] argues forcefully for the conclusion that the neutralization of Russian /a/ and /o/ in unstressed syllables is categorical and phonological, displaying no sensitivity at all to the phonetic context in which the vowels are produced on any given occasion. It also argues against an interpretation of the hyperarticulation task as somehow paralinguistic or unnatural. Were hyperarticulation indeed something more like spelling pronunciation, for example, we might expect to hear underlying /o/ surface intact when hyperarticulated, since Russian orthography maintains a distinction between ‘a’ and ‘o’ in spelling even where that contrast is neutralized phonologically.

Based on these findings, I argue that we must revise the traditional analysis of Russian vowel reduction as follows: there are indeed two types of vowel reduction corresponding in a loose way to what have been called Degree 1 and Degree 2 of reduction. The difference between the two patterns, however, is not one of degree, or even of functional motivation à la Crosswhite, but rather of the level of representation at which the two patterns are realized. To the extent that gradient application is a hallmark of phonetic processes, we may conclude that Russian Degree 2 reduction is a matter of phonetic implementation, the result of duration-dependent undershoot of F1 targets in durationally impoverished unstressed vowels. The best model of Russian /a, o/ → [ə] will thus be something like the decaying exponential functions used by Moon [1991] and Moon and Lindblom [1994] (after Lindblom [1963]) to model the English and Swedish data in their respective experiments, an equation of the general form $F1 = -\alpha e^{-\beta t} + F1_{target}$. (This is a simplification in some respects of the equations offered by Lindblom and Moon, whose control of consonantal context allowed them to build consonant place into their model along with vowel target and duration. It does express at least the desired shape of the function, rising toward an asymptote [the F1 target] as *t* [time] increases, and falling exponentially as *t* decreases). Such an equation should describe the realization of /a/ in any structural context in Russian, stressed or unstressed. That a schwa-like vowel surfaces in the second pretonic syllable, but does not in the first pretonic and stressed syllables, is not the result of the application of two distinct reduction processes, but rather just a consequence of the different amounts of duration normally associated with each of those syllables. As durational values change, whether due to speech rate, or to hyperarticulation, vowel height changes too.

Neutralization of /a/ and /o/, on the other hand, is a phonological process, and as such it is best modeled, for example, as the result of an Optimality-theoretic constraint banning mid vowels in unstressed syllables (or licensing them only in stressed syllables), such as the following.

(13) License (–high, –low) / σ́

This constraint makes no mention of phonetic duration, being defined solely in terms of elements of categorical phonological structure. As such, it will apply in equal measure to any string meeting its structural description, regardless of factors from phonetic context. (The interaction of this constraint with relevant Faithfulness constraints will determine what in fact surfaces in unstressed syllables that contain underlying mid vowels, i.e. whether alternations will involve raising or lowering. See Beckman [1998], Crosswhite [2001], and Zoll [1998] for various models of alternations such as these in Optimality Theory. The details of these accounts are beyond our concerns here.)

The result of accomplishing raising to schwa in the phonetics is that Russian phonology no longer needs to license a representation /ə/ in *any* position, stressed or unstressed, and hence also escapes the need to refer in any way to the unnatural class of positions in which Degree 2 reduction fails to occur. Non-reduction to schwa in first pretonic syllables, absolute word-initial position, and absolute phrase-final position are all a consequence of the additional duration accorded to the phonologically low vowels realized in these positions. Characteristic high F1 for [+low] vowels in these positions is a consequence of the output of a function like that sketched above, rather than of what are effectively exception clauses to a phonological constraint that otherwise would create schwa. This analysis simplifies Russian phonology greatly, while requiring nothing additional from the phonetics, save the capacity to realize subphonemic durational patterns related to prosodic boundaries and accent in a way that is at once in line with well-documented cross-linguistic patterns, but also capable of significant variation in a language-specific way.

4.3 Effort and undershoot: speaker- and position-specific patterns

There are, nonetheless, ways in which the analysis presented in the preceding paragraphs oversimplifies matters. What can be concluded from the above is that for all four speakers, there was a correlation between duration and F1 for second pretonic /a, o/, such that vowels with greater durations approached, and in many cases overlapped with, expected F1 values for low vowels in first pretonic and stressed syllables, strongly suggesting that reduction to schwa in Russian is a gradient process subject to reversal in the correct phonetic contexts. Certain aspects of the results, however, raised questions as to whether duration by itself is sufficient to predict degree of undershoot in Russian. In the hyperarticulation study presented above, the productions of speaker DT in particular stood out as reminscent of earlier work on hyperarticulation in English by Lindblom [1990] and Moon and Lindblom [1994]. Recall that these studies argue for the inclusion of articulatory effort as a variable in a model of F2 undershoot in English. Like the "clear speech" productions in those earlier studies, a substantial number of DT's hyperarticulated productions in this study stood out from the rest of the results as realizing surprisingly little undershoot for the amount of durational compression involved. The interpretation offered in the previous section for this is that DT is employing a strategy of increased effort, rather than (just) added duration, to avoid undershoot in his hyperarticulated speech. This type of interspeaker variation in the realization of clear speech would fall in line nicely with the results of other studies, such as Kuehn and Moll [1976], which suggest that different speakers may respond differently to durational pressure on articulation—some by yielding to undershoot, others by increasing articulator velocities to compensate. Whether DT is anomalous in this respect, or characteristic of a broader class of Russian speakers is impossible to say from a study with as small a sample of speakers as this one. Clearly though, this is an important question for future research to address.

It was also noted above that DT stood out again in the comparison of first pretonic and second pretonic syllables in the speech rate study of Barnes [2006]. While some speakers, such as TM, seemed to produce a single smooth curve of F1 values spanning both prosodic contexts, DT's results seemed different; his second pretonic /a/ and /o/ did exhibit raised F1 as predicted at greater durations, but his first pretonic vowels seemed to maintain relatively high F1 values even in the face of substantially decreased vowel durations. Thus, for a given duration, DT's first pretonic F1 values were consistently higher than those of his analogous second pretonic vowels. Recalling de Jong's [1995] analysis of the articulatory profile of English lexically stressed syllables as localized implementation of Lindblom's hyperarticulatory mode, we may wonder whether, at least for some speakers of Russian, the first pretonic syllable constitutes just such a domain of localized hyperarticulation (hereafter DLH). Whether the first pretonic syllable constitutes a distinct DLH whose level of contrast enhancement must be defined separately from that of the stressed syllable, or whether for speakers such as DT the first pretonic and the stressed syllable are better analyzed as a single, extended DLH remains to be seen. We will also want to know how these DLH’s are like or unlike the other undershoot-resisting contexts in Russian, absolute word-initial and absolute phrase-final position. In particular, how, if at all, does the enhancement of clarity differ in its implementation from DLH to DLH in Russian? Likewise, how, if at all, does the type of contrast enhancement we find in Russian differ from that documented in other languages? Differences in either instance might be quantitative, in terms of degree of additional effort, or they could be qualitative, in terms of the phonetic features selected for enhancement. This research program is already well underway in the contexts of boundary-adjacent and accentual enhancement patterns in a number of languages—see the references in section 2.5. In the Russian context though, what is most urgently needed is a follow-up study of the variables contributing to undershoot. This study would involve a larger sample of speakers than did this one, and it would restrict participants to native speakers of a single regional variant of Contemporary Standard Russian (i.e. all Moscow speakers, or all Petersburg speakers, on which see the following section). Secondly, target contexts for comparison would include not only second and first pretonic syllables, but also the other potential DLH’s discussed above, such as absolute word initial position and absolute phrase-final position. Each of these positions should be produced in a range of contexts, including extreme durational compression (fast speech), ordinary or conversational speech, and hyperarticulation. It would then be possible to determine whether a single function suffices to describe the relationship between duration and F1 in all these contexts, or whether susceptibility to undershoot differs from context to context.

4.4 On vowel reduction and causation in phonology

The results of this study also bear interestingly on debate concerning the nature of the causal connection between duration-dependent undershoot and phonological vowel reduction. Recall from section 2.4 that such a causal connection, if we accept it, could be viewed as active in at least two distinct ways: Barnes [2002, 2006] proposes a diachronic link between the two phenomena; severe duration-dependent undershoot, on this view, is the historical precursor to systems of phonological vowel reduction, which arise out of the former when perceptually compromised contrasts are lost through sound change. One crucial prediction of this approach is that once phonologized, patterns of neutralization should no longer be dependent on the facts of phonetic duration for their continued existence; the patterns become abstract, structural generalizations about the distribution of vowels in the language, rather than online adaptations to the vagaries of phonetic context. The results of the present study are consistent with this view in the following ways: raising of /a/ to schwa, as a phonetic process, is subject to variation as a response to changes in the facts of phonetic context in any given utterance. Durational changes resulting from changes in speech rate or degree of hyperarticulation will cause proportional changes in the extent of application of the raising process, and this is precisely what the present study finds.

The neutralization of /a/ and /o/ in unstressed syllables, on the other hand, is a phonological pattern. As such it is not sensitive to the phonetic characteristics of the context in which any given form is uttered; increases in duration resulting from a slower rate of speech or from hyperarticulation do nothing to counteract the neutralization of /a/ and /o/ because this neutralization depends not on the phonetic durations found in lexically unstressed syllables, but to the very unstressedness of those syllables itself, as an abstract generalization about the metrical structure of the prosodic word in Russian. No amount of additional duration can change that metrical structure, because syllables are not stressed or unstressed in Russian by virtue of the durations they bear, but rather the reverse. This prediction too is upheld by the present study; while hyperarticulation often produced formant values for unstressed underlying /a/ and /o/ well within the range typical for an /a/ bearing lexical stress ("undoing" the effects of Degree 2 reduction), no amount of hyperarticulation was able to undo the neutralization of the contrast between /a/ and /o/; nothing like an [o] ever surfaced in an unstressed syllable in this study.[13]

An opposing view of the relationship between duration-dependent undershoot and phonological vowel reduction holds the causal connection between the two phenomena to be active synchronically, a fact about the grammar of any language exhibiting phonological vowel reduction [Flemming, 1995/2002, 2001, 2006]. Phonological vowel reduction arises when the grammar of a language mandates that speakers give up certain contrasts to neutralization rather than expending the effort to realize them in circumstances that would compromise them perceptually. Significant duration-dependent undershoot is thus a necessary condition for the manifestation of phonological vowel reduction (though it is perhaps not a sufficient condition, in that the grammar of a language with undershoot but no reduction can always just be analyzed as more permissive of perceptual difficulty than a language that exhibits neutralization of contrasts under similar circumstances).

The facts of Russian challenge this view in several ways. The first problem is well-known from the literature on phonetically-driven phonology, and is exemplified by the results of the hyperarticulation study: if phonological reduction is really a consequence of duration-dependent undershoot, we might expect that the additional duration contributed to unstressed vowels under hyperarticulation would be sufficient to license the reappearance of contrasts such as that between Russian unstressed /a/ and /o/. That this does not occur is an instance of what Hayes and Steriade [2003] call *the stabilization problem*. The idea is that the phonology must somehow achieve a relatively stable form despite massive variation in phonetic realization across contexts.

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[13] It should be noted that the diachrony behind the phonologization of this pattern is a matter of dispute in the Slavist literature. See Barnes [2006: 36-37] for details.

For this to happen, some of that variation must be ignored. For speech rate and hyperarticulation to be as irrelevant as they are for the application of Russian phonological vowel reduction, any synchronic causal connection between duration-dependent undershoot and phonological neutralization must not be a direct one. Rather, it must be mediated in such a way that the phonology refers not to the actual duration of any given vowel in performance, but instead either to phonetic duration in some neutral or average performance context [Steriade, 1999], or to some average durational value computed across all possible contexts [Hayes, 1999]. Either way, the notion that sound patterns depend on "average" duration rather than duration itself makes the causality we understand to be involved here more abstract than might be supposed at first brush. Reduction to schwa in Russian, by contrast, seems to involve actual duration, and hence also actual causality.

The second problem for the synchronic causality view comes from the durational and F1 values obtained in the first pretonic syllable in the speech rate study presented in Barnes [2006] and summarized here in section 2.5. What is troublesome here is that while mean duration values for first pretonic /a/ and /o/ were somewhat lower than the stressed vowels measured (approximately 70 ms as compared with 82 and 75 ms for stressed /a/ and /o/ respectively)[14], mean F1 values for first pretonic /a/ and /o/ were not any lower than those obtained for stressed /a/ (705 and 694 Hz for first pretonic /a/ and /o/ respectively as compared with 700 Hz for stressed /a/). Interestingly, this remains true even when speakers' "fast" productions are factored out and only "normal" or "conversational" speech rate productions are considered: mean F1 for conversational productions of first pretonic /a/ and /o/ was 717 Hz, as compared to 708 Hz for stressed /a/. What this all means is that the low vowel being realized in first pretonic syllables here is not in fact undershot at all in comparison with analogous stressed vowels. To the extent that these productions are also "average" or "typical", an account of Russian phonological vowel reduction driven by synchronic duration-dependent undershoot encounters a problem here: the vowel space in first pretonic syllables is not in fact compressed, and lacking such compression, we would predict that no neutralization of contrasts would be necessary. And yet it happens anyway. It should be noted that this result is strange also in light of traditional phonetic descriptions of the realization of first pretonic /a/ and /o/ in Russian. As noted above, this vowel is usually transcribed 'ʌ', a symbol from the Slavist tradition which corresponds to something like IPA [ɐ], a vowel somewhere in between low [a] and reduced, mid schwa.

The traditional description is reflected to some extent in the instrumental results of Padgett and Tabain [2005], who document raising in first pretonic syllables to values somewhere in between those of the [a] of stressed syllables and the schwa of the second pretonic. Padgett and Tabain also note, however, that the mean amount of raising they obtained for first pretonic /a/ and /o/ seemed surprisingly small given traditional descriptions of the height of this vowel. Taking values from their Table 3 [2005: 30], the mean difference between F1 for low vowels in stressed and first pretonic positions (in non-palatalized contexts for all female speakers in their study [*N* = 8] was 1.1 ERB, or just above the 1 ERB value adopted by them as a rough estimate of the threshold of perceptibility for differences in formant values. They note that such a small

[14] That stressed vowel durations were as low as they are here is a consequence of the manipulation of speech rate in this study: recall that half of each subject's productions came as a result of an instruction to speak "as fast as possible".

difference is a potential problem for a theory of vowel reduction based on perceptual difficulties arising from duration-dependent undershoot. Could such a small degree of undershoot really compromise the distinctions between high and mid or mid and low vowels in the system? They suggest as a hypothesis, citing Crosswhite [2001] that a better measure of perceptual confusability might include some sort of weighting of formant differences for vowel duration, the idea being that the same spectral distance might be harder to distinguish on shorter vowels than on longer. Still, the fact that in both their study and that of Barnes [2006] first pretonic /a/ and /o/ showed typical durations in the vicinity of 70 to 90 milliseconds should make us wonder just how compromising such durations could realistically be of vowel contrasts, particularly in the absence of significant undershoot. Durations of this magnitude, after all, are more characteristic of the unstressed vowels of languages like Serbo-Croatian, Macedonian, Polish, or Czech (see above) that *lack* phonological vowel reduction, rather than of the much shorter unstressed (non-first pretonic) vowels of canonical phonological vowel reduction languages like Belarusian or Russian. (See above, section 2.4.) If durational values this large are truly compromising of vowel quality contrasts, then our typology of unstressed vowel reduction should look substantially different than it actually does.

But this is not the whole story, for like Barnes [2006] and the present study, Padgett and Tabain failed to obtain a sample of speakers that was homogenous with respect to region of origin in the Russian-speaking world. Specifically, of the nine speakers included in their study, only four were born and raised in Russia itself, and only two of these were natives of Moscow. Three were actually born and raised in China, the descendents of White Guardists who fled Russia in the wake of the civil war from which the Soviet Union eventually emerged. This is not necessarily a problem of course; all participants in all three studies were carefully vetted as active native speakers of Contemporary Standard Russian, devoid of any obvious regional peculiarities. Even within the bounds of what is uncontroversially CSR, however, minor regional differences exist, and could have escaped detection. Most important for our purposes are differences in the pronunciation of unstressed /a/ and /o/ in the first pretonic syllable, and here a clear regional difference is in fact well-documented. The relevant division is described as being between Muscovites and non-Muscovites. Timberlake [2004: 81] describes the so-called ‘Old Muscovite’ pronunciation (i.e. the dialect of pre-1917 Moscow), one of the characteristic features of which was a substantially lower realization of first pretonic /a/ and /o/. Timberlake gives the standard transcription [α] for this vowel. Most features of Old Muscovite pronunciation, Timberlake notes, have since been overtaken by the broader national norms of CSR. This one, however, apparently has not. Indeed, an unusually long and low first pretonic [a] is now a widely recognized sociolinguistic marker of Muscovite origins.[15]

Looking again at Padgett and Tabain's data (in particular Table A4 in their appendix), we find confirmation of this peculiarity of Muscovite pronunciation. Comparing measures of vowel height for stressed /a/ and first pretonic merged /a/ and /o/ (given as F1–F0 measured in ERB), we see that all speakers show at least some undershoot in first pretonic syllables. For seven of

[15] Purely anecdotally, ask nearly any native speaker of Russian for a characterization of a “Moscow accent”, and the result will usually be an enthusiastically cartoonish rendition of the phrase *Ja iz Moskvy*, ‘I am from Moscow’ (ordinarily [ja iz mɐskvɨ]), rendered with first pretonic [a] in the initial syllable of Moscow extremely long, unmistakably low, and bearing a significant rising pitch contour. Dialect stereotypes are of course not the greatest source for phonetic data all things being equal, but nor do they arise altogether out of thin air.

nine of speakers, these differences are 1 ERB or greater, meaning again that they are above what Padgett and Tabain use as a rough threshold of perceptual discriminability. (In fact, their speaker JD has first pretonic /a/ and /o/ .94 and .96 ERB below stressed /a/, and speaker TO has a first pretonic /o/ .93 ERB below stressed /a/. I take these differences to be close enough to the standard of 1 ERB, given the roughness of the boundary to begin with.) Two speakers in this study, however, the only two born and raised in Moscow, have first pretonic /a/ and /o/ that are significantly under this 1 ERB threshold away from stressed /a/: their speaker AC has F1–F0 for first pretonic /a/ and /o/ only .62 and .66 ERB lower than stressed /a/, while their speaker MK has first pretonic /a/ just .36 ERB below stressed /a/, while her first pretonic /o/ is actually .01 ERB above her stressed /a/. In sum, while most speakers measured by Padgett and Tabain did have some (though not much) raising of the low vowel in first pretonic position relative to its stressed syllable analogue, their two Muscovite speakers differed from the rest in showing so little raising of this vowel as to fall below the threshold of perceptibility set for vowel quality differences. If most speakers, in other words, showed surprisingly little undershoot in first pretonic syllables, the Moscow natives showed next to none.

Clearly what is necessary is a follow-up study to Barnes [2006] and/or Padgett and Tabain [2005] in which speakers' regional origins are controlled, or perhaps even set as a between-subjects factor for investigation, comparing either Moscow vs. Non-Moscow, or perhaps better Moscow vs. some second location, such as St. Petersburg. The added difficulty in finding suitable speakers would doubtless be repaid by the increased accuracy of the picture we would obtain of vowel reduction in Russian. For the time being, at least, I will conclude here that the effective lack of F1 undershoot in first pretonic syllables of Modern Muscovite Russian is a serious problem for theories of vowel reduction that rely on duration-dependent undershoot as a necessary synchronic causal factor for phonological neutralization. No undershoot, not even in "average" or "neutral" contexts, should mean no neutralization, and yet neutralization occurs nonetheless. As mentioned above, this same problem is found also in the unstressed syllables of Belarusian (especially the first pretonic) and Shimakonde. (See Barnes [2006], Chapter 2 for references and details on both.)

4.5 On the enhancement of contrasts by hyperarticulation

As reviewed briefly above, most of the work to date on clear speech or hyperarticulation has focused on (1) establishing the set of phonetic features that undergo modifications in this register in English, or (2) establishing the extent to which use of this register in English enhances intelligibility under a variety of circumstances in which communication is impeded (due either to characteristics of the listener or characteristics of the environment). As Smiljanić and Bradlow [2005] note, there has been almost no work on clear speech for the enhancement of intelligibility in languages other than English (their comparative study of English and Croatian being a notable exception). The present study thus adds to our general understanding of the nature of hyperarticulation in a small way by confirming that in Russian, as in English and Croatian, clear speech involves both extended segment durations and an expanded vowel space. (To be fair, this latter is actually somewhat more than we can say with confidence, since only low vowels were analyzed. At the very least, clear speech in Russian involves a lessening of the undershoot to which low vowels in unstressed syllables are otherwise subject.)

More significantly though, this study also adds something to our understanding of clear speech which has not been demonstrated before. This is that the contrasts that are perceptually enhanced by hyperarticulation in Russian appear to be *surface contrasts only.* Contrasts at the level of Underlying Representation (or to put it another way, category membership at the level of the morphophonemic alternation set rather than category membership at the level of the individual phonological segment string) appear inaccessible to the activity of hyperarticulation. The evidence that the present study provides for this shallowness of contrast enhancement comes from the continued complete neutralization of underlying /a/ and /o/ in unstressed syllables, even under conditions of extreme hyperarticulation. By way of clarification, recall that under the assumptions laid out above, the neutralization of /a/ and /o/ in Russian is a process of phonological category relabelling, with the result that segments that were representationally distinct in the Input to the phonology become representationally identical in its Output. Imagining now for a moment a hypothetical set of circumstances under which hyperarticulatory contrast enhancement were not shallow, but rather deep, what we would expect to find would be modifications to the ordinary phonetic realization of a string such that the acoustic signal actually came to contain useful cues under hyperarticulation to contrasts at the level of Underlying Representation. Deep contrast enhancement would then constitute at least a partial "undoing" of phonological neutralization. We can also easily imagine why such a process would be functionally desirable: deep contrast enhancement would help to resolve surface ambiguities created by phonological neutralization. In the Russian case, deep enhancement would give us perceptible differences between underlying /a/ and underlying /o/ surfacing in unstressed syllables, with /o/ moving perhaps up and back in the vowel space, and /a/ moving analogously forward and down. Obviously, this is not what we observe (recalling Figure 3). Rather, extreme hyperarticulation of underlying /o/ resulted in production of something strongly reminiscent of stressed [a], precisely the result of extreme hyperarticulation of underlying /a/. The contrast enhancement we see here is thus shallow in the sense that it moves the realization of both underlying /a/ and /o/ toward ideal targets for a phonological /a/. It is the output of the phonological process of neutralization that is thus enhanced, rather than its input.

One area in which the question of shallow rather than deep contrast enhancement becomes particularly interesting is in the context of certain recent work on incomplete neutralization. Incomplete neutralization is the phenomenon whereby underlyingly contrasting segments that appear to be neutralized on the surface (most famously final voiced and voiceless obstruents in languages such as Dutch, German, Catalan, and Polish) are nonetheless realized with subtle phonetic cues to their underlying identity [Dinnsen and Charles-Luce, 1984; Dinnsen and Garcia-Zamor, 1971; Fourakis and Iverson, 1984; Port and Crawford, 1989; Port and O'Dell, 1985; Slowiaczek and Dinnsen, 1985; Warner, et al., 2004]. In Dutch, for example, Warner et al. [2004] show that word-final underlying /t/ has a slightly longer burst duration on average than does word-final underlying /d/, and that vowels preceding word-final underlying /d/ are slightly longer on average than vowels preceding word-final underlying /t/, and all this despite that fact that word-final devoicing in Dutch is commonly held to neutralize the contrast between underlying voiced and voiceless obstruents. The problem this result potentially causes for what Pierrehumbert [2002] calls the traditional feed-forward modular view of the relationship between phonology and phonetics should be clear enough: if neutralization indeed takes place in the phonology, then it is achieved by the substitution of the phonological category label [–voice] for underlying [+voice] on obstruents in word-final position, with the result that underlying voiced and voiceless obstruents should exit the phonological module of the grammar with identical surface representations. To the extent that the input to the phonetic interpretation module is identical in both cases, the output of phonetic interpretation should on this view likewise be identical (assuming a strict view of informational encapsulation in the activity of distinct modules [Fodor 1983]). Scholars have differed wildly in their interpretations of the incomplete neutralization result over the years, with views ranging from rejection of the phenomenon as "linguistic" to begin with [Fourakis and Iverson 1984], to celebration of it as the clearest expression on record of the true nature of the relationship between phonetics and phonology [Gafos, 2006; Pierrehumbert, 2002; Port, *passim*]. Perhaps the most prominent current manifestation of this latter view [Ernestus and Baayen, 2006; Gafos, 2006; Port and Crawford, 1989; Yu, 2006] holds, in so many words, that incomplete neutralization is in fact nothing other than the deep enhancement of contrasts counterfactually imagined above in our hyperarticulation study. While researchers differ in the details of their proposals, held in common is the view that there is nothing unusual or "unphonological" about the phonological process responsible for final devoicing in languages displaying incomplete neutralization; indeed, neutralization is as complete or categorical in these cases as it is ever going to be. The appearance of "incompleteness" arises through a process I have elsewhere called morphophonetic gravitation, and which others have termed phonetic or subphonemic analogy [e.g., Steriade 2000]. Such a phenomenon, if real, would involve the biasing of production targets for a given segment in the direction of production targets for the corresponding segment in some other, morphologically related, surface form. Take again the example of the Dutch underlying final /d/ that, upon apparent phonological devoicing, nonetheless remains ever so slightly more /d/-like than instances of true /t/ in the same position. This "slight voicing" (as Ernestus and Baayen [2006] have termed it), according to the gravitation approach, is caused by the attractive force exerted by paradigmatically related forms in which the underlying /d/ is not in a position of surface neutralization, and hence surfaces voiced; a Dutch form such as *Zweed*, /zwed/~[zwet], 'Swede', comes to differ slightly from a form like *Zweet*, /zwet/~[zwet], 'sweat', through gravitation toward, or on analogy with, related forms such as *Zweden,* /zwedən/~[zwedən], 'Sweden'. What is important here is the causal role played in all the works cited here by the morphophonemic alternant in the creation of these effectively skewed productions. The way in which morphophonetic gravitation resembles our deep enhancement should be clear: both involve the deployment of elements of subphonemic detail for the purpose of signaling lexical identity in spite of constraints on phonological representations that would otherwise obscure it. The question then becomes to what extent incomplete neutralization is in fact hyperarticulatory in nature. It could be, for example, that incomplete neutralization does involve biasing from the production targets of morphologically related forms, but that this biasing is neither voluntary nor gradable in the way that hyperarticulation typically is. In fact, such a view of gravitation as an involuntary consequence of the structure of the lexicon and the architecture of the speech production mechanism seems to be what is advocated by Pierrehumbert [2002], and is perhaps consistent with the account of phonetic analogy given by Steriade [2000] as well. Interestingly, though, several authors have identified precisely this kind of speaker-controlled, hyperarticulatory character as a hallmark of incomplete neutralization phenomena. The foundational result for this strain of thought is that of Port and Crawford [1989], who showed that the "incompleteness" of neutralization of voicing in German final obstruents differs in degree depending on the pragmatic context of the task used to elicit the forms for comparison. Specifically, voiced and voiceless final obstruents in Port and Crawford's study showed the least differentiation from one another in situations most like ordinary speech (target words embedded in sentences read in non-contrastive contexts), and showed the most differentiation in the most metalinguistic, or least "natural" situation tested (dictation of isolation forms to a waiting transcriber). Gafos in particular focuses on this apparently voluntary, hyperarticulatory aspect of incomplete neutralization, as do Warner et al., who go further still in equating incomplete neutralization ultimately with phonetic differences arising from hypercorrect renderings of distinctions that are purely orthographic, rather than phonological in nature.

Assuming that incomplete neutralization does have this sort of gradient, speaker-controlled implementation as a fundamental characteristic, the importance of the present study becomes immediately apparent. We have demonstrated that in the case of Russian vowel reduction, hyperarticulation results in the enhancement of phonological contrasts as expected, but that this enhancement is strictly shallow. The surface identity of underlying /a/ and /o/ appears impenetrable to hyperarticulation. Let us now assume that this is the case more generally, *viz.* that hyperarticulation is only ever capable of shallow enhancement, such that phonological neutralization is always opaque to it. If this is true, and if hyperarticulation does indeed enhance a contrast between word-final voiced and voiceless obstruents in Dutch (or German, or Polish...), then contrary to most analyses, that contrast must in fact be present (i.e. unneutralized) in the output of the phonology. But if this is true, then the phonological business-as-usual gravitation approach to incomplete neutralization must be wrong after all. In other words, there must indeed be something incomplete about incomplete neutralization. In Barnes [2006] I suggest the possibility that incomplete neutralizations are not in fact phonological neutralizations, but in fact just gradient processes of extreme contextual phonetic approximation of distinct phonological categories. This approach equates incomplete neutralization with the cases of near-merger familiar from the dialectological literature [Labov, Karan and Miller, 1991; Labov 1994] in a way that the gravitation approach has a harder time doing.

There were, of course, several big "ifs" in the above proposal. It may be that some otherwise categorical neutralizations are in fact subject to Deep Enhancement under hyperarticulation, making Russian somehow anomalous in this respect. It might also turn out upon more comprehensive testing that clear speech does not in fact augment the incomplete neutralization result in the way that was initially reported. Both of these possibilities are real and need empirical testing in a larger number of cases before we can feel confident in our understanding of the situation. It may also turn out in the course of this testing that the distinction between a categorical phonology and a gradient phonetics is itself, as many have suggested, fundamentally ill-conceived, and as such inadequate to a proper analysis of the facts of these cases. The depth of contrast enhancement under hyperarticulation and phenomena such as incomplete neutralization will in any event I believe constitute central proving grounds for competing theories in this area.

4.6 On hyperarticulation as a tool for investigating category membership

Beyond the questions raised in the preceding section, this study has shown that the elicitation of hyperarticulated or clear speech productions of target forms can be a valuable tool for assessing phonological category membership in cases where phonetic realization in ordinary speech leaves ambiguities of interpretation. As noted above, among the most consistent findings in the study of clear speech have been extended segment durations and an expanded vowel space, with at least a partially causal relationship between the former and the latter. Improved dispersion in the vowel space is believed to enhance intelligibility by increasing the perceptual distance between contrasting elements. The decrease in undershoot allows vowels to be realized closer to what we assume are their ideal targets, and hence, presumably, farther from one another, minimizing confusability. In some circumstances (e.g., minimal undershoot, no phonological neutralization), we have a clear sense of what this kind of contrast enhancement should mean phonetically, at least for peripheral vowels: front vowels should be fronter, and back vowels backer; high vowels should be higher, and low vowels lower. In other cases, however, such as where undershoot is more extreme, or phonological neutralizations have potentially taken place, it is less clear what we should expect from the enhancement of contrasts. The preceding section sketched competing scenarios for the latter problem under the rubrics of shallow and deep enhancement. To the extent that what we observe is in fact only shallow enhancement, the elicitation of hyperarticulated forms becomes a valuable methodological device for the determination of surface phonological category membership.

The idea that hyperarticulation could actually be used as a diagnostic tool of this kind has so far, to my knowledge, been employed only in the study of intonational categories. (Note, however, the use of manipulation of speech rate [Solé 1992] or focus structure [de Jong 2004] to achieve similar ends in the area of contrasts in segmental phonology.) Acting on an assertion by Liberman and Pierrehumbert [1984], Gussenhoven and Rietveld [2000] investigate the distinction between two intonation contours in Dutch ("high rise" and "low rise"), the phonological identity of which had been a matter of uncertainty in the literature. One possibility is that the two contours are categorically distinct, the phonetic realization of contrasting phonological representations. The other possibility is that the distinction is gradient, with the two contours ultimately being variant realizations of a single phonological category. Gussenhoven and Rietveld propose to investigate the question through the manipulation of pitch span—effectively hyperarticulation. The premise of the experiment is that the phonological contrast in question, to the extent that one exists, is between a high pitch accent and a low pitch accent at the beginning of the string. Accordingly, if an accent is a phonological H, enhancement of contrasts under hyperarticulation should cause it to be realized higher than usual; if, on the other hand, it is actually an L, it should be realized lower under the same circumstances. If the relevant tones in the two contours move in opposite directions under hyperarticulation, the contours would be judged phonologically distinct, and the tones contrasting. The study Gussenhoven and Rietveld in fact carry out involves native-speaker evaluations of synthetic versions of the two pitch contours with pitch ranges expanded in the ways described above. Speakers were asked to rate the target contours for the degree of "surprise" they conveyed. (Since the relevant contours are for questions in Dutch, surprise seemed a reasonable way of describing emphasis or degree of involvement.) The result argued for a phonological contrast between the two contours: the lower the low rise contour was made to begin, the greater the degree of surprise listeners attributed to the utterance. Likewise, the higher the beginning of the high rise contour, the more surprised it sounded to subjects. The same logic was applied in the analysis of hyperarticulated vowel formant targets here in Russian unstressed syllables: if two underlyingly distinct vowels that may or may not have been neutralized on the surface move toward the same target under hyperarticulation, then they do not contrast phonologically on the surface. If they move toward different targets, then, *modulo* the possibility of deep enhancement in some circumstances as yet to be determined, they remain phonologically distinct. It was furthermore argued that this logic may be fruitfully applied in cases of so-called incomplete neutralization.

5 Conclusion

I have argued in the above that data from the hyperarticulation of unstressed vowels in Russian provides support for the conclusions of Barnes [2006] regarding the nature of the vowel reduction system in that language. This analysis holds that Russian does indeed have two vowel reduction patterns, as traditional analyses contend. The difference between them, however, is not, as previous analyses have held, a matter of "degree", such that a more moderate process occurs in one set of unstressed environments while a more extreme process occurs in another, complementary set. Rather, both processes apply equally in all unstressed syllables. One of these is a categorical, phonological neutralization process preventing underlying mid vowels from surfacing as such in unstressed syllables. The second pattern is gradient and phonetic, a continuous function relating vowel height to vowel duration. Where vowel durations are typically shorter (e.g., the second pretonic syllable), duration-dependent undershoot causes significant raising of phonological low vowels toward schwa. Where vowel durations are longer (e.g., in stressed syllables, first pretonic syllables, absolute word-initial or phrase-final position, in hiatus, at slower speech rates, or under hyperarticulation in second pretonic syllables), undershoot decreases, allowing closer approximation of low vowel targets in proportion to the degree of additional duration involved. The impressionistic consequence of this gradient mitigation of undershoot in certain contexts is what has previously traditionally described as failure to reduce to schwa in specific exceptional positions. The results of this study are important both for the analysis of Russian, and for theories of vowel reduction more generally. In particular, the combined results of this study and the speech rate study of Barnes [2006] raise two serious problems for theories of vowel reduction that take duration-dependent undershoot, with its concomitant compression of the vowel space, to be a necessary condition for synchronic phonological vowel reduction to occur. The first problem, the well-known stabilization problem, is tractable. The second problem, I believe, is much less so; there are documented instances, such as the first pretonic syllable in Moscow Russian, in which phonological neutralizations take place in unstressed syllables even in the systematic absence of any significant undershoot or vowel space compression. This study also identifies several promising areas for future research, including the role of increased articulatory effort as a co-predictor along with duration of F1 in unstressed syllables of Russian, possibly as a matter of interspeaker variation, or contextual variation, or both. The need for a closer study of subtle regional differences in the realization of unstressed vowels in Russian was also underscored.

Finally, hyperarticulation was shown to be a valuable tool for the investigation of phonological category membership, and possibly for distinguishing the activities of categorical, phonological processes from gradient phonetic ones more generally. The notions of deep and shallow enhancement of contrast were introduced and shown to have serious implications for the analysis of certain perennially recalcitrant questions in the phonetics-phonology interface, incomplete neutralization in particular.

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Appendix

Word list (all in citation form unless otherwise noted)

SECOND PRETONIC UNDERLYING /a/			SECOND PRETONIC UNDERLYING /o/		
Orthography	IPA	Gloss	Orthography	IPA	Gloss
багажа	bəgɐˈʒa	‘baggage’ (gen.sg.)	богатырь	bəgɐˈtɨrʲ	‘bogatyr’
батальон	bətɐˈlʲon	‘battalion’	боковой	bəkɐˈvoj	‘side’ (adj.)
кабаре	kəbɐˈre	‘cabaret’	годовой	gədɐˈvoj	‘year’ (adj.)
лаборант	ləbɐˈrant	‘lab worker’	доказать	dəkɐˈzatʲ	‘to prove’
паковать	pəkɐˈvatʲ	‘to pack’	подошёл	pədɐˈʃol	‘approached’ (m.sg.)
патовать	pətɐˈvatʲ	‘to stalemate’	погадал	pəgɐˈdal	‘told fortunes’ (m.sg.)
табачок	təbɐˈtʃʲok	‘tobacco’ (dim.)	потакать	pətɐˈkatʲ	‘to indulge’
таковой	təkɐˈvoj	‘such’ (adj.)	локоток	ləkɐˈtok	‘elbow’ (dim.)
лапоток	ləpɐˈtok	‘bast sandal’ (dim.)	лопотать	ləpɐˈtatʲ	‘to blather, mutter’

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Table 1. Mean first formant values in Hz and standard deviations

Speaker	2nd pretonic		1st pretonic		stressed	
	/a/	/o/	/a/	/o/	/a/	/o/
RR	482	490	734	720	723	450
	(54)	(49)	(53)	(45)	(53)	(25)
TM	443	449	713	695	691	444
	(36)	(42)	(79)	(90)	(88)	(38)
DT	492	506	641	640	637	455
	(42)	(63)	(34)	(32)	(32)	(30)
M	484	483	734	742	784	503
	(59)	(50)	(52)	(70)	(42)	(34)
All	475	481	705	694	700	461
	(52)	(55)	(68.5)	(73)	(78)	(39)

Table 2. Mean vowel durations in ms. and standard deviations

Speaker	2nd pretonic		1st pretonic		stressed	
	/a/	/o/	/a/	/o/	/a/	/o/
RR	21.7	26.2	65.9	69.1	85.9	77.6
	(7.2)	(7.6)	(9.9)	(11.6)	(14)	(18.1)
TM	24.2	26.6	81.1	80.4	91.7	81.4
	(7.5)	(9.4)	(19.3)	(18.5)	(25.7)	(32)
DT	26.3	32.6	58.2	60.7	72.6	69.3
	(10)	(10.6)	(13.6)	(13.5)	(13.2)	(12.6)
M	28.1	31.6	70.9	70.9	75.2	68.7
	(10.4)	(9.9)	(14.5)	(13.7)	(11.4)	(15.4)
All	25.2	28.9	69	69.9	81.8	74.5
	(9.2)	(9.7)	(16.9)	(16.2)	(19.3)	(21.5)

Table 3. Mean first formant values in Hz and standard deviations

Speaker	2nd pretonic	
	/a/	/o/
RR	548 (57)	529 (55)
TM	581 (153)	558 (159)
DT	618 (110)	574 (110)
M	553 (81)	547 (92)
All	576 (110)	552 (109)

Table 4. Mean vowel durations in ms and standard deviations

Speaker	2nd pretonic /a/	2nd pretonic /o/
RR	32.5 (7.7)	33.4 (8.6)
TM	71.3 (54.5)	75.5 (55.8)
DT	38.2 (10.3)	39.5 (11)
M	35.5 (16.1)	40.9 (22.7)
All	44.9 (33.4)	47.1 (34.5)

Table 5. ANOVA results assessing the effect of underlying vowel on F1 for each speaker

SPEAKER	FIRST FORMANT	DURATION
RR	F(1, 49) = 1.565, p = .217	F(1, 49) = .153, p = .697
TM	F(1, 51) = .291, p = .592	F(1, 51) = .076, p = .784
DT	F(1, 50) = 2.063, p = .157	F(1, 50) = .185, p = .669
M	F(1, 51) = .065, p = .799	F(1, 51) = 1.005, p = .321

Table 6. Mean and Standard Deviation for F1 and duration of /o/: prefix vs. root

	/o/	
	Root	Prefix
Mean F1	560 (122)	542 (92)
Duration	49.8 (35)	43.9 (33.9)

Table 7. Linear regression models for F1 as a function of duration for all speakers in the hyperarticulation study.

SPEAKER	LINEAR REGRESSION MODEL	R-SQUARED
RR	$y = 4.0109x + 405.48$	R^2 (51) = 0.3391; $p < .001$
TM	$y = 2.6285x + 377.08$	R^2 (53) = 0.8608; $p < .001$
DT	$y = 7.4933x + 304.66$	R^2 (52) = 0.5067; $p < .001$
M	$y = 3.6662x + 410.1$	R^2 (53) = 0.7077; $p < .001$

Figure 1. Russian second pretonic /a/, /o/, all speakers: F1 vs. Duration (after Barnes [2006: 58])

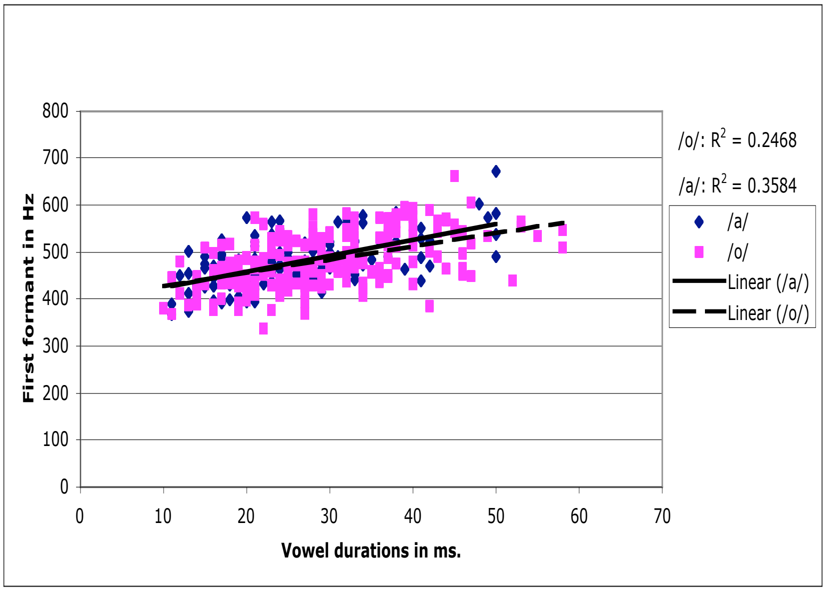


Figure 2. Unstressed /a, o/ for all speakers, contexts combined

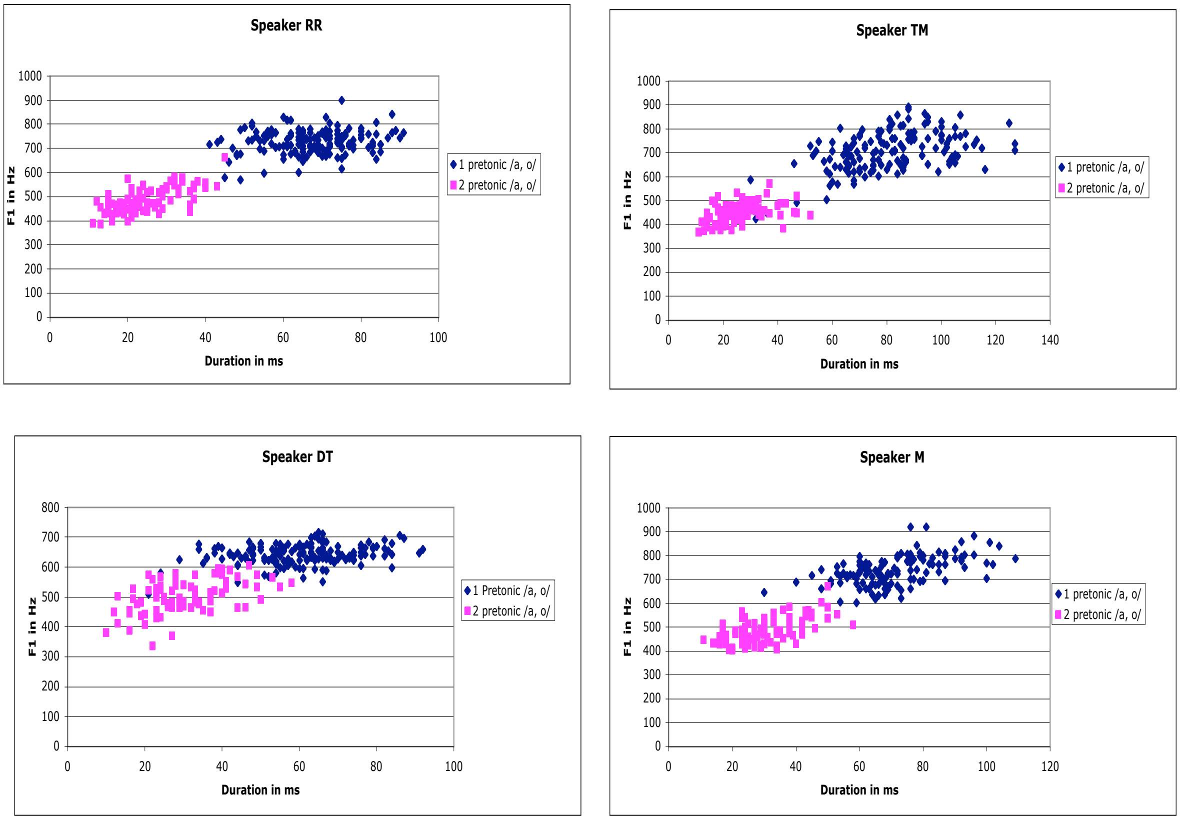


Figure 3. Mean first and second formant values, pooled across speakers, for stressed /a/ and /o/, and three repetitions, one casual and two hyperarticulated, of second pretonic underlying /a/ and /o/.

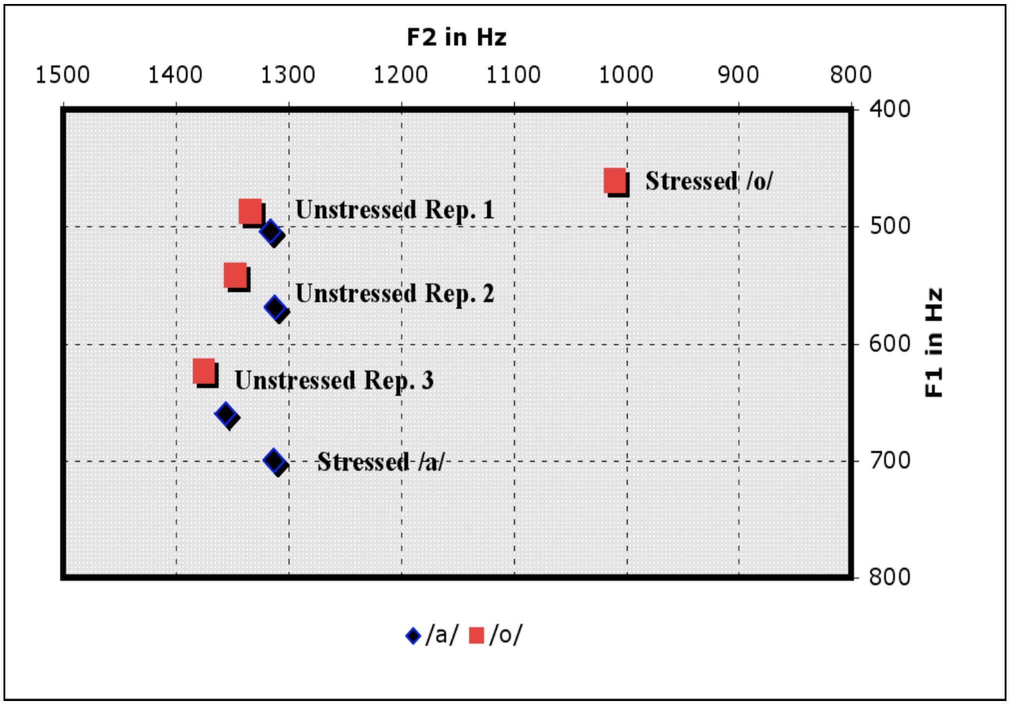
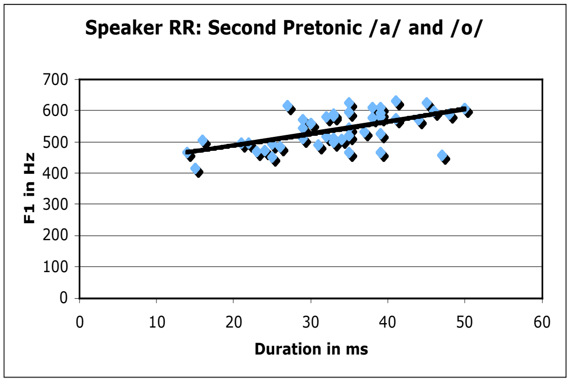
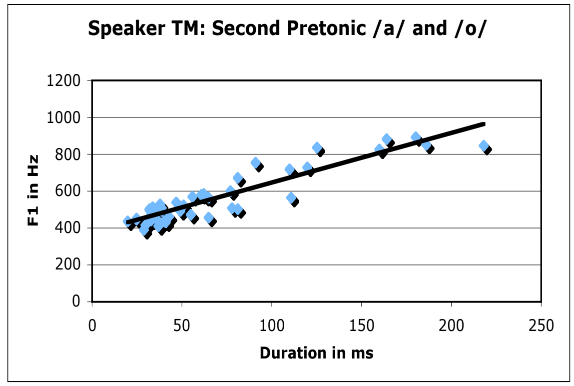
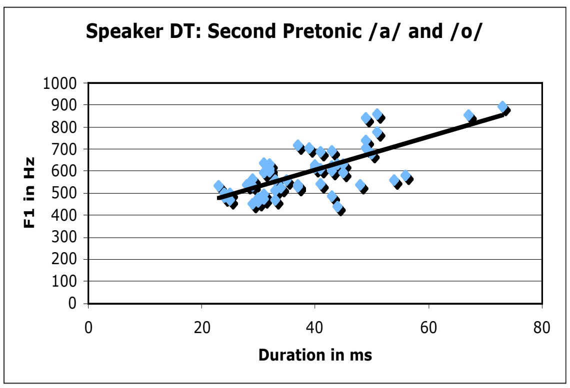


Figure 4. Vowel height as a function of phonetic duration, speaker by speaker







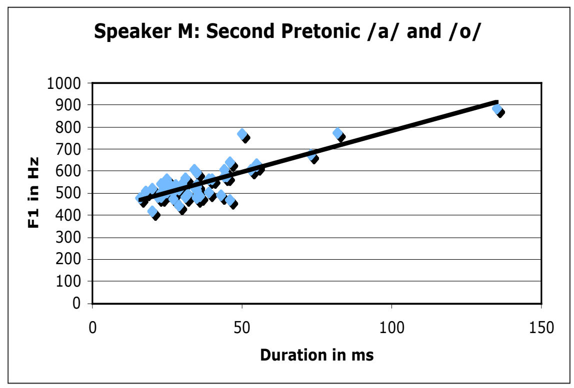


Figure 5. Speaker TM: Underlying /a/ and /o/ coded for repetition number**.**

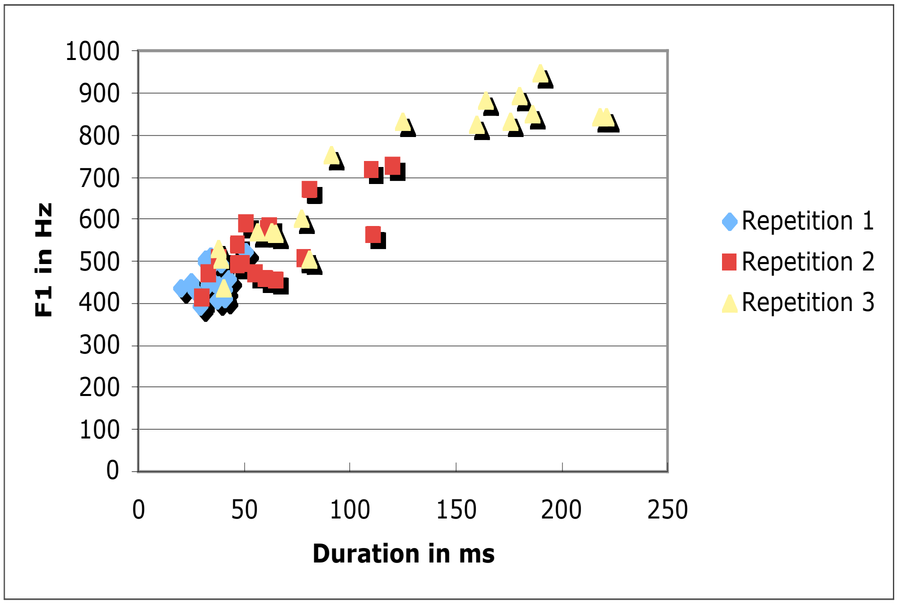


Figure 6. Speaker RR: Underlying /a/ and /o/ coded for repetition number.

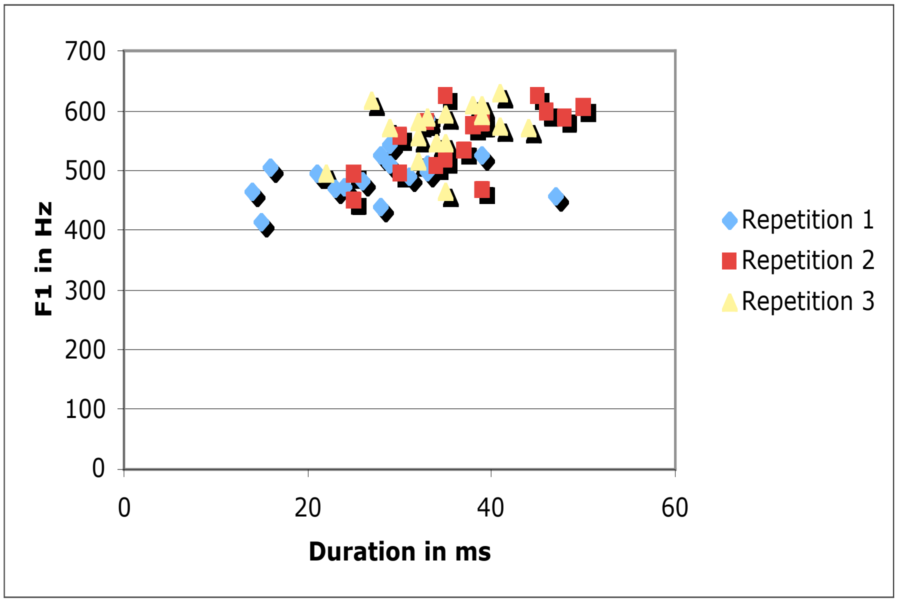


Figure 7. Vowel height as a function of duration. All speakers: Second Pretonic /a/ and /o/.

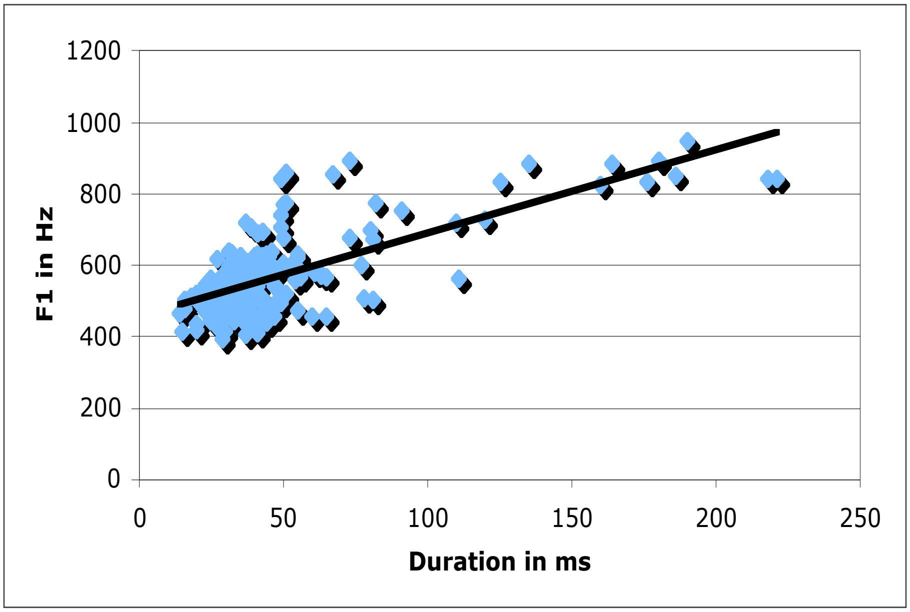


Figure 8. All speakers: Second Pretonic /a/ and /o/, Standardized Scores.

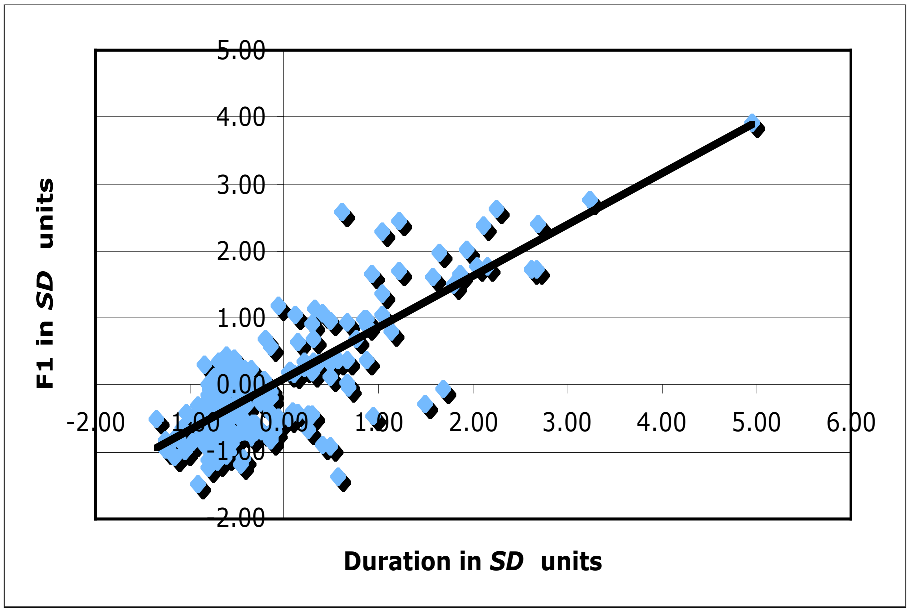


Figure 9. Second Pretonic /a/ and /o/, Speaker DT excluded.

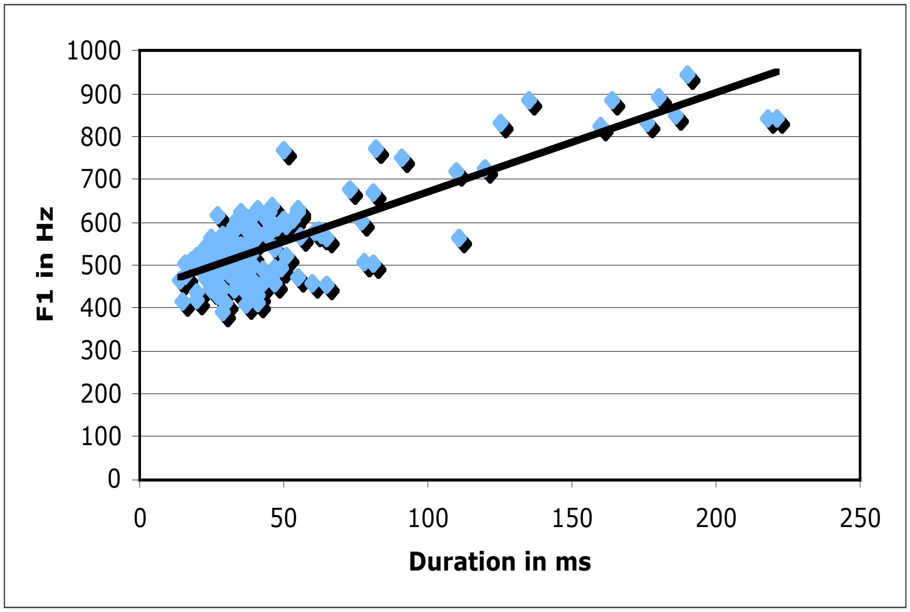


Figure 10. All speakers: second pretonic /a/ and /o/. Influential cases removed**.**

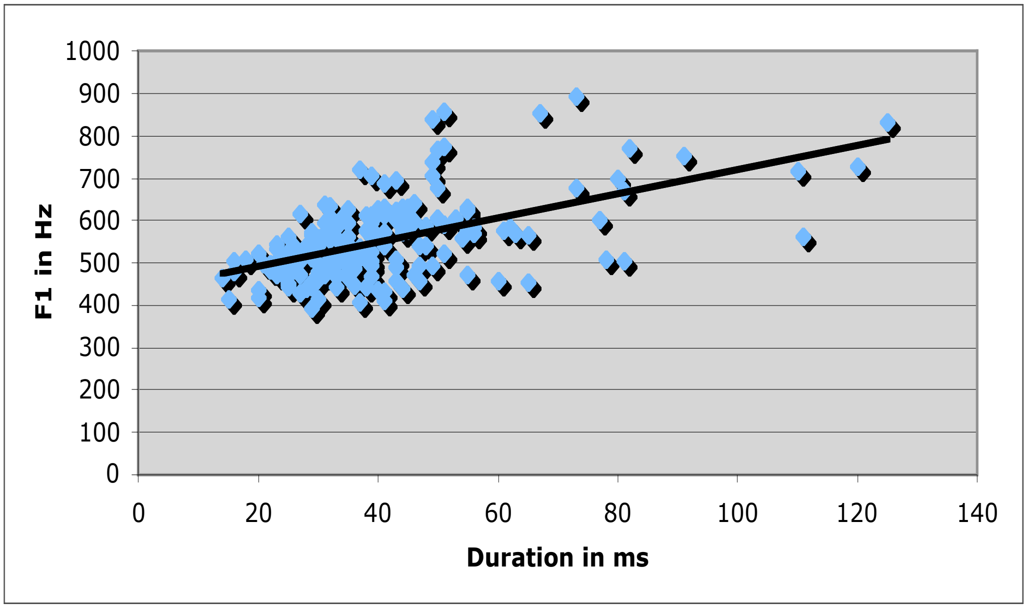


Figure 11. Comparison of the spread of duration and F1 values in the hyperarticulation experiment and the speech rate study of Barnes [2006]. Boxes represent the interquartile ranges of values for each speaker in the two studies, with the median indicated by a heavy horizontal line across each box. Whiskers denote the full range of values obtained, excluding outliers**.**