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Bulgarian Unstressed Vowel Reduction: Received Views vs Corpus Findings

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Abstract

Bulgarian is often cited in phonological work for its vowel reduction, with the assumption that the six-vowel stressed inventory, /ɛ a ɔ i ɤ u/, shrinks to three unstressed contrastive vowels, /i ɤ u/, by virtue of /ɛ a ɔ/ raising and merging with /i ɤ u/. The literature in Bulgarian, on the other hand, maintains that /ɛ–i/ do not merge in Standard Bulgarian; that vowels are less reduced in immediately pretonic syllables than elsewhere; that unstressed high vowels are lowered, while nonhigh vowels are raised; and that /a–ɤ/ are more likely to merge than /ɔ–u/. These claims have been challenged in recent work, and we present a new investigation based on 11,615 vowel tokens from 140 speakers in the BulPhonC speech corpus. MANOVA and GLMM results provide clear evidence that there is no unstressed high-vowel lowering, no difference between pretonic vs other unstressed vowels, and that both unstressed /a–ɤ/ and /ɔ–u/ merge completely, while /ɛ–i/ remain spectrally distinct.

Index Terms: vowel reduction, stress, neutralisation, Bulgarian

1. Introduction

Contemporary Standard Bulgarian (CSB) has six contrastive vowels in stressed position, whose canonical realisations range from high /i u/, to mid /ɛ ɤ ɔ/, to low /a/. [1] and [2] argue that there are only two contrastive, phonological vowel heights in Bulgarian, based on the neutralisation patterns claimed to occur in unstressed position: the **nonhigh /ɛ a ɔ/** are raised and merge with their **high**(er) counterparts, **/i ɤ u/**, respectively. Such contraction to a three-vowel unstressed sub-inventory is also assumed in various later phonological analyses of Bulgarian unstressed vowel reduction (UVR) [3–5]. However, the received view of UVR in the Bulgarian literature, most extensively discussed in the 'Academy Grammar' [6], does not corroborate the assumption that unstressed /ɛ a ɔ/ reduce to [i ɤ u]. Instead, [6] maintains that only the nonfront unstressed pairs, /a–ɤ/ and /ɔ–u/, may merge in CSB, and that /a–ɤ/ are more likely to merge than /ɔ–u/. The merger of unstressed /ɛ–i/, on the other hand, is restricted to eastern dialects. It is also claimed that the neutralised unstressed qualities are not those of the higher vowel in each pair, but rather realisations of intermediate heights, such as [ʌ o]. In other words, not only are nonhigh vowels raised, but high vowels are also lowered in unstressed position. Another received view of Bulgarian UVR is that there are in fact two distinct degrees of reduction such that vowels in **pretonic** syllables, i.e. syllables immediately preceding the stressed syllable, are more open than other unstressed realisations. [6] has been very influential to the present day, and these received views of Bulgarian UVR have often been repeated or confirmed in the subsequent literature [7–10].

More recent experimental work has challenged these claims and assumptions. [11] is a corpus study of speech read by 20 CSB speakers which found no evidence of unstressed high vowel lowering, nor of /a–ɤ/ being more likely to merge than /ɔ–u/, while at the same time confirming that unstressed /ɛ–i/ do not merge in CSB. These findings were corroborated by [12], an ultrasound and acoustic investigation of the speech of three male informants. [13, 14] report the results of an acoustic study of careful speech (highly controlled nonsense words in carrier sentences) read by 12 western (CSB) and 8 eastern Bulgarian speakers, which also found no lowering in unstressed high vowels and confirmed that unstressed /ɛ–i/ do merge in eastern, but not in western, Bulgarian. In addition and contrary to the received view, [13, 14] found that western Bulgarian unstressed /ɔ–u/ underwent greater contrast reduction than unstressed /a–ɤ/, and that vowels had significantly *higher* realisations in pretonic than in other unstressed syllables in the CSB, while in eastern Bulgarian the various unstressed positions were undifferentiated in vowel height.

While the recent empirical work outlined above has challenged and disproved various received views of Bulgarian UVR, it has been based on data from relatively small groups of informants (i.e. 3–20). The aim of the present study is to verify recent findings on UVR by analysing vowel F_1, F_2 frequencies and durations in a large corpus of speech read by 140 CSB speakers, and to provide definitive answers to the following questions.

1. *Do (nonhigh) vowels have lower realisations in pretonic than in other unstressed syllables, as traditionally claimed?* Based on recent findings in [13, 14], our hypothesis is that, contrary to the received view, pretonic vowels are not lower than other unstressed vowels.
2. *What are the magnitude, acoustic dimensions, and spectral direction of vowel reduction in CSB?* In other words, we aim to determine how different stressed and unstressed vowels are, what their significant distinguishing acoustic variables are, and whether reduction leads to raising or lowering, as well as any fronting or retraction. We predict that the nonhigh vowels, /ɛ a ɔ/, are raised and shortened in unstressed position, that /ɛ/ reduces less than /a/ and /ɔ/, and that – consistent with [11–14] but in contrast to the received view – the high /i ɤ u/ are not lowered when unstressed.
3. *What are the strength and acoustic dimensions of the height contrast, and to what extent is the contrast reduced in unstressed position?* We expect to find that the contrast is primarily realised by F_1 frequency; that the contrast is strong in stressed position and that it may be neutralised in unstressed /a–ɤ/ and /ɔ–u/ but not in /ɛ–i/. We also expect to confirm the findings in [11, 13, 14] that /a–ɤ/ are not more likely to merge than /ɔ–u/, as traditionally maintained.

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2. Material and methods

The material analysed is continuous read speech from the Bulgarian Phonetic Corpus *BulPhonC*, version 3, consisting of 319 phonetically rich sentences [15]. The corpus was designed for the development of ASR technology. The recordings were made in an echo-cancelling studio with a Sennheiser MK 4 omnidirectional microphone on a TASCAM DP32 digital recorder at a sampling rate of 48 kHz and 24 bits, filtered and down-sampled to 16 kHz. Canonical transcriptions and automatic phoneme segmentation are available [16]. We used a subset of the data, containing the vowels in CV syllables, read by 140 speakers of CSB (59 male and 81 female). The mean speaker age was 37.

Vowel duration, and F_1 and F_2 frequencies at the temporal midpoint in vocalic nuclei, were measured using Praat[1] scripts. Formant analysis was conducted with the Burg algorithm in Praat with a maximum of five formants, window size of 0.025 s, pre-emphasis from 50 Hz, and maximum formant thresholds of 5000 Hz (male) and 5500 Hz (female speakers).

Vowel formant frequencies and durations were normalised using Lobanov's speaker-intrinsic, vowel-extrinsic, formant-intrinsic z-transformation method [17]. Except for Table 2, all reported results are based on normalised values. Outliers, defined as values outside IQR by 1.5 times IQR, were removed (3.31% for F_1, 3.19% for F_2 frequency, 2.10% for duration). Formant frequencies and duration were compared across three positions at first: **stressed**, **pretonic** and **other unstressed**. 11,615 vowel tokens were analysed in total; Figure 1 shows the numbers by vowel and position. There were no instances of /ɤ/ in the "other unstressed" position.

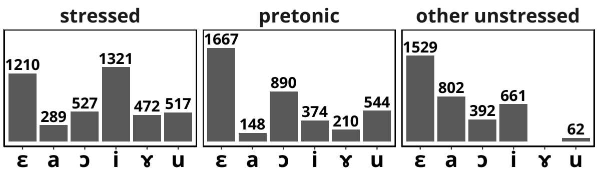

Figure 1: *Number of vowel tokens by phoneme and position.*

To address the first research question, *whether nonhigh vowels have lower realisations in pretonic than in other unstressed syllables*, three Generalised Linear Mixed Models (GLMM) were constructed for each vowel, one for each acoustic variable (F_1, F_2, duration) as the response, and position (stressed/pretonic/other unstressed) as the predictor variable. Since the Lobanov normalisation method factors out physiologically induced acoustic variation while also retaining sociolinguistic differences [18], speaker was included as a random effect, along with phonological context (adjacent consonants) and word length (in syllables). Tukey's HSD post hoc tests were computed for pairwise comparisons across the three positions.

To identify *the magnitude, dimensions and direction of UVR* (Question 2), MANOVA's were performed for each vowel with the three acoustic variables taken together as the response and stress as the predictor. Pillai's trace (PT) from significant MANOVA's was used to quantify UVR for each vowel; this statistic can range from 0 to 1, high values indicating strong separation, and low values strong overlap [14,19]. The MANOVA's were followed up with GLMM's, with the acoustic variables as responses, stress as a fixed effect and the same random effects as above, to find which of the variables were significantly affected by stress. In addition, to assess the overall extent and direction of spectral reduction, the areas and centroids of mean $F_1 \times F_2$ vowel spaces were calculated using R package *geosphere*.[2]

MANOVA and GLMM were also used to address the third question, which seeks to establish *the extent of contrast reduction in unstressed position*. MANOVA's were computed for each height-contrasting pair, in stressed and unstressed position, with the acoustic variables as combined response and vowel as predictor. High PT here indicates high contrastiveness. Since the distributions of any two adjacent phonemes in the acoustic space are bound to exhibit some degree of overlap, we follow [13,14] and use a metric of contrast reduction (CR), defined as the amount of contrast that is lost in unstressed position relative to contrast in the maximally contrastive stressed position: $\mathrm{CR} = (\mathrm{PT}_s - \mathrm{PT}_u)/\mathrm{PT}_s$, where s = stressed, u = unstressed. GLMM was then fitted to test the significance of each acoustic variable in discriminating between high and nonhigh vowels.

3. Results

3.1. Pretonic vs other unstressed syllables

The results of GLMM and pairwise Tukey's HSD tests for the effect of position (stressed/pretonic/other unstressed) on F_1, F_2 frequencies and duration are shown in Table 1. There are no significant differences between pretonic and other unstressed vowels in any of the variables. We therefore focus the rest of this investigation on comparisons of **stressed** vs (all) **unstressed** realisations.

Table 1: *Effect of position on vowel* $\boldsymbol{F_1}$, $\boldsymbol{F_2}$ *frequencies and* ***dur****ation.* ***S:*** *stressed,* ***P:*** *pretonic,* ***oU:*** *other unstressed. Random effects: word length, segmental context, speaker.*

		GLMM		Tukey's HSD Test (p)		
		p	r^2	S–P	S–oU	P–oU
F_1	/e/	**0.0000**	**0.44**	**0.0005**	**0.0000**	0.3542
	/a/	**0.0000**	**0.65**	**0.0001**	**0.0000**	0.2624
	/o/	**0.0000**	**0.38**	**0.0000**	**0.0002**	0.9458
	/i/	0.6804				
	/ɤ/	0.2247				
	/u/	0.0627				
F_2	/e/	**0.0000**	**0.45**	**0.0000**	**0.0000**	0.9421
	/a/	0.2039				
	/o/	**0.0044**	**0.18**	**0.0032**	0.2081	0.7848
	/i/	0.1504				
	/ɤ/	0.9377				
	/u/	**0.0092**	**0.33**	**0.0069**	0.3691	0.3621
dur	/e/	**0.0000**	**0.45**	**0.0000**	**0.0000**	0.6839
	/a/	**0.0004**	**0.55**	**0.0025**	**0.0003**	0.9690
	/o/	**0.0011**	**0.59**	**0.0033**	**0.0026**	0.4945
	/i/	0.9966				
	/ɤ/	0.4716				
	/u/	0.7795				

3.2. Reduction: magnitude, dimensions and direction

The mean formant frequencies and durations of stressed and unstressed vowels are listed in Table 2. Figure 2 shows the

[1] P. Boersma, and D. Weenink, "Praat: doing phonetics by computer," version 6.3.02, `http://www.praat.org/`, 2022.

[2] R. Hijmans, C. Karney, E. Williams, and C. Vennes, "geosphere: Spherical Trigonometry," `https://CRAN.R-project.org/package=geosphere`, 2022.

Table 2: F_1, F_2 *frequency and duration (unnormalised) means (M) and standard deviations (SD).*

		$\boldsymbol{F_1}$ (Hz)		$\boldsymbol{F_2}$ (Hz)		**Dur** (ms)	
Female		M	SD	M	SD	M	SD
/ɛ/	stressed	573	101	2121	269	96	28
	unstressed	466	109	1885	268	61	26
/a/	stressed	847	165	1593	168	118	28
	unstressed	461	150	1441	246	68	28
/ɔ/	stressed	587	144	1041	147	91	27
	unstressed	398	136	1153	443	57	25
/i/	stressed	393	88	2295	390	62	20
	unstressed	387	112	2157	525	59	29
/ɤ/	stressed	486	65	1361	182	58	19
	unstressed	446	106	1534	269	59	21
/u/	stressed	399	87	1017	290	77	26
	unstressed	388	220	1316	376	62	23
Male							
/ɛ/	stressed	468	70	1707	176	83	23
	unstressed	395	95	1543	211	60	28
/a/	stressed	627	99	1282	167	109	28
	unstressed	391	132	1276	239	70	32
/ɔ/	stressed	494	97	923	315	88	24
	unstressed	379	154	1209	542	56	25
/i/	stressed	319	57	1848	260	55	18
	unstressed	314	62	1809	318	60	33
/ɤ/	stressed	423	61	1188	172	52	17
	unstressed	398	185	1339	257	54	20
/u/	stressed	349	87	999	347	67	18
	unstressed	406	267	1257	438	56	21

mean $F_1 \times F_2$ vowel space in stressed and unstressed syllables. There is considerable upward contraction in unstressed position caused by the raising of nonhigh vowels. There is also apparent centralisation[3] of unstressed /ɛ i ɔ u/. The centroids plotted in the diagram confirm a general raising and also suggest a slight cumulative fronting of the unstressed space. The ratio of the stressed to unstressed areas is 1 : 0.13, which reveals a particularly dramatic UVR-induced shrinkage of the vowel space.

MANOVA's for the effect of stress on F_1, F_2 frequencies and duration, taken as whole, yielded significant results for each

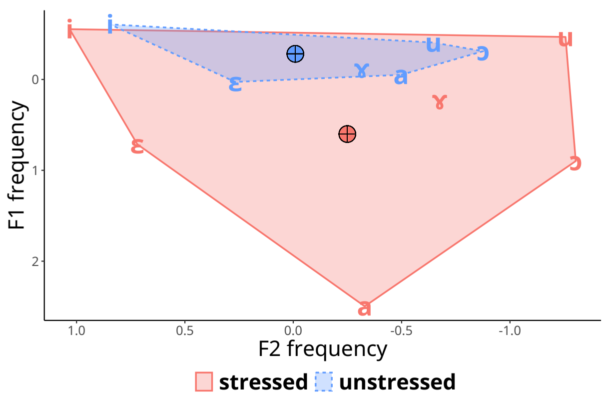

Figure 2: *Mean* $F_1 \times F_2$ *vowel space by stress.* ⊕*: centroids.*

[3] We use 'centralisation' in a strict phonetic sense, to denote the fronting of back and retraction of front vowels, rather than in the sense of *mid*-centralisation.

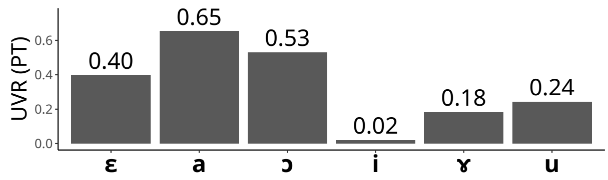

Figure 3: *Pillai's traces for UVR:* $(F_1 + F_2 + dur) \sim stress$.

vowel ($p < 0.0001$). Pillai's traces, plotted in Figure 3, indicate that, in the nonhigh vowels, UVR is strongest in /a/ and weakest in /ɛ/. There is practically no stress-dependent variation in /i/, while the scores for /ɤ u/ are higher.

The results from post hoc GLMM's for the effect of stress on each acoustic variable are reported in Table 3. All three nonhigh vowels show significant differences in F_1 frequency and duration, while stressed vs unstressed /ɛ/ and /ɔ/ also significantly differ in F_2 frequency. In the high vowels, there are no significant differences in F_1 frequency or duration, and the only significant difference in F_2 frequency is in /u/ (evidencing fronting).

Table 3: *Effect of stress on vowel* $\boldsymbol{F_1}$, $\boldsymbol{F_2}$ *frequencies and* ***dur****ation (GLMM). Random effects as above.*

		p	r^2		p	r^2
F_1	/ɛ/	**0.0229**	**0.44**	/i/	0.6326	
	/a/	**0.0000**	**0.65**	/ɤ/	0.2247	
	/ɔ/	**0.0000**	**0.38**	/u/	0.0835	
F_2	/ɛ/	**0.0000**	**0.45**	/i/	0.0719	
	/a/	0.4923		/ɤ/	0.9977	
	/ɔ/	**0.0009**	**0.18**	/u/	**0.0062**	**0.33**
dur	/ɛ/	**0.0000**	**0.45**	/i/	0.9336	
	/a/	**0.0001**	**0.55**	/ɤ/	0.4716	
	/ɔ/	**0.0003**	**0.59**	/u/	0.4689	

3.3. Contrast: strength, dimensions and neutralisation

Pillai's traces from MANOVA's ($p < 0.0001$ for all) comparing high and nonhigh vowels, in both stressed and unstressed position, are shown in Figure 4. All pairs are highly contrastive in stressed position; /a–ɤ/ show the greatest separation, while stressed /ɔ–u/ tolerate considerably more overlap. There is drastic contrast reduction in unstressed /ɔ–u/, with /a–ɤ/ close behind; contrast reduction is less pronounced in /ɛ–i/, which retain relatively high contrastiveness in unstressed syllables.

The outcomes of GLMM for the effect of vowel height on each acoustic variable in stressed and unstressed position are

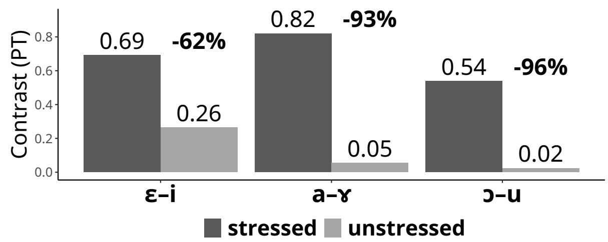

Figure 4: *PT for contrast:* $(F_1 + F_2 + dur) \sim vowel$*. Contrast reduction in unstressed position shown as percentages.*

Table 4: *Effect of vowel height on F_1, F_2 frequencies and **dur**ation (GLMM). Random effects as above.*

		stressed		**unstressed**	
		p	r^2	p	r^2
F_1	/ɛ–i/	**0.0000**	**0.68**	**0.0000**	**0.39**
	/a–ɤ/	**0.0022**	**0.77**	0.4089	
	/ɔ–u/	**0.0000**	**0.56**	0.8553	
F_2	/ɛ–i/	**0.0017**	**0.23**	**0.0092**	**0.35**
	/a–ɤ/	0.6512		0.6204	
	/ɔ–u/	0.8723		0.5203	
dur	/ɛ–i/	**0.0000**	**0.63**	0.5201	
	/a–ɤ/	**0.0489**	**0.81**	0.2050	
	/ɔ–u/	**0.0433**	**0.45**	0.7690	

given in Table 4. In stressed syllables, the vowels in all pairs differ significantly in F_1 frequency and duration, and /ɛ–i/ are additionally differentiated by F_2 frequency. Unstressed /a–ɤ/ and /ɔ–u/ lack any significant differences, while unstressed /ɛ–i/ remain significantly different in both F_1 and F_2 frequency. Since /ɛ/ is centralised in unstressed position, GLMM's were also fitted to compare unstressed /ɛ/ and /ɤ/, and the two remain distinct in F_2 frequency (F_1: p = 0.8125; F_2: p = 0.0000, r^2 = 0.45; duration: p = 0.4077).

4. Discussion and conclusions

A body of published work in phonology has previously assumed that Bulgarian /ɛ a ɔ/ are raised in unstressed position and, as a result, merge with /i ɤ u/, respectively [1–5]. The traditional literature in Bulgarian and sources drawing on it deny neutralising reduction for /ɛ/ and also claim that not only are unstressed nonhigh vowels raised, but unstressed high vowels are also lowered to merge in intermediate vowel qualities [6–10]. In addition, the traditional literature maintains that reduced vowels have more open realisations in pretonic than in other unstressed syllables, thus echoing the two-level UVR system standardly associated with Russian [20, 21]. The results of an analysis of 11,615 vowel tokens from a contemporary spoken corpus of CSB reported here are at variance with these received views.

The first question we set out to answer is *whether (nonhigh) vowels are lower in pretonic than in other unstressed syllables*. GLMM and post hoc Tukey's HSD tests found no significant differences between pretonic and other unstressed vowels in any of the variables analysed: F_1, F_2 frequency and duration (Table 1). We must therefore conclude that CSB phonology does not maintain a two-level UVR system, and that vowels are equally reduced in all unstressed positions.

We ran a set of MANOVA's and follow-up GLMM's to establish *the magnitude, acoustic dimensions and spectral direction of UVR* – our second question. As expected, UVR is strongest in the nonhigh vowels, as revealed by Pillai's trace (Figure 3), which is highest for /a/, somewhat lower for /ɔ/ and lower still for /ɛ/. This corroborates earlier findings that, in CSB, /ɛ/ is reduced considerably less than the other nonhigh vowels. The GLMM results (Table 3) show that all three nonhigh vowels undergo a significant reduction in F_1 frequency and duration in unstressed position. In addition to this overall raising and shortening, the peripheral mid vowels, /ɛ ɔ/, exhibit significant F_2 differences, indicating centralisation (and centralisation of unstressed /ɛ/ is also acknowledged in the traditional literature). At the same time, no evidence of any centralisation was found in recent experimental work [11–14,22]. The data in most of those studies, however, are from careful speech, which suggests that centralisation is likely to be a function of speech rate and, more generally, speaking style [23, 24], rather than a categorical process. F_2 frequency is significant for /u/ as well, indicating fronting in unstressed position, which also contributes to overall centralisation. We note that even though unstressed /u/ appears to be more advanced than unstressed /ɔ/ in Figure 2, the difference in F_2 frequency is not significant (Table 4).

The GLMM results also demonstrate that there are no significant F_1 differences between stressed and unstressed high vowels, /i ɤ u/. We may thus conclude that the claim that unstressed high vowels are lowered is incorrect with regard to present-day Bulgarian. We also note that stress does not give rise to significant durational differences in high vowels either, which is unexpected. We should point out, however, that position within phrases and focus were not controlled for, and such linguistic variables may have affected the results for duration. It should also be borne in mind that /ɤ u/ are the rarest vowels in CSB in general [13, 14], and they are also under-represented in our sample, which may have further biased some of the results.

MANOVA's conducted to measure the contrastiveness of vowels in the pairs /ɛ–i, a–ɤ, ɔ–u/ in stressed and unstressed position, and the contrast reduction ratios calculated from Pillai's trace (Figure 4), indicate that both unstressed /a–ɤ/ and /ɔ–u/ undergo severe reduction in contrastiveness (slightly stronger in /ɔ–u/), whereas contrast reduction in /ɛ–i/ is milder. In stressed position, the GLMM comparisons (Table 4) reveal significant differences not only in F_1 frequency, which is to be expected, but also in duration, which reflects a cross-linguistic tendency for lower vowels to be longer. In addition, stressed /ɛ–i/ are significantly different in F_2 frequency. In unstressed position, there are no significant differences in any of the acoustic variables for /a–ɤ/ and /ɔ–u/, which shows beyond doubt that both of these pairs are completely merged, and we may now reject the received view that /a–ɤ/ neutralise more readily than /ɔ–u/. Unstressed /ɛ–i/, on the other hand, remain distinct in both formant frequencies. Unstressed /ɛ/ is both raised and centralised, though not to the extent of merger with /ɤ/.

The results of this extensive corpus study of stressed and unstressed vowels in Contemporary Standard Bulgarian present a very clear picture of the phonetic nature and phonological effects of unstressed vowel reduction. Unstressed nonhigh vowels, /ɛ a ɔ/, are raised and shortened. In addition, /ɛ/ and /ɔ/ are centralised. Apart from /u/-fronting, there are no spectral or durational stress-conditioned changes in the high vowels, /i ɤ u/, and the received view that these vowels are lowered when unstressed is once again disproven. No differences were found between pretonic and other unstressed vowels, demonstrating that another persistent claim, that Bulgarian vowels are less reduced in pretonic syllables than elsewhere, does not hold true, at least not for the present state of the language. The reduction of /a ɔ/ results in their complete merger with /ɤ u/, respectively, which refutes an earlier claim that /a–ɤ/ are more likely to merge than /ɔ–u/. Unstressed /ɛ–i/ remain spectrally distinct, which is in line with recent experimental work and the received view, but at odds with common assumptions in the phonological literature.

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