BULGARIAN VOWEL REDUCTION IN UNSTRESSED POSITION: AN ULTRASOUND AND ACOUSTIC INVESTIGATION

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ABSTRACT

Vowel reduction in Contemporary Standard Bulgarian (CSB) has been variously claimed to involve raising, no change or lowering of the high vowels /iəu/. There is a general agreement that the low vowels /ɛaɔ/ are raised when unstressed. This paper directly measures tongue height using Ultrasound Tongue Imaging (UTI) and relates this measure to the acoustic correlate F1 at vowel midpoint. The six vowels of CSB were paired with respect to frontness (/ɛ, i/, /a, ə/, /ɔ, u/), and the overlap in height of the unstressed lower vowel in each pair was assessed relative to (a) its stressed counterpart and (b) the stressed and (c) unstressed realisations of the lower vowel. There was no evidence of the higher unstressed vowel in each pair being different from its stressed counterpart. The articulatory and acoustic results are not completely aligned, but both diverge from the traditional model of vowel reduction in CSB.

Keywords: Bulgarian, neutralization, reduction, ultrasound imaging, acoustics, stress, articulation

1. INTRODUCTION

The question of vowel reduction in Contemporary Standard Bulgarian (CSB) has been studied for over five decades, yet there are still some conflicting accounts. This should not be surprising as the fields of phonetics and statistics have developed over that time and it is also possible that moderate language change has occurred.

Vowel duration has emerged as one of the most consistent markers of vowel reduction in Bulgarian. Stressed vowels are consistently longer than unstressed ones [1, 9, 12, 15, 17]. It is possible to hypothesise that in some cases the quantitative vowel reduction could be related to the qualitative reduction by preventing the underlying gesture to be carried out to completion. Without focusing on vowel duration [16] describe Bulgarian vowel reduction as a gradient process of decreased mandibular opening, the extent of which depends on the context and style of speech. This account of vowel reduction would predict that the tongue position in unstressed vowels is higher than in their stressed counterparts, especially for vowels with a more mid or low place of articulation, while the higher vowels would not change much. The raising of the mid to low vowels /ɛ, a, ɔ/ (referred to as "lower" in this paper) in unstressed position is described by [12] without mention of the higher vowels /i, ə, u/, implying that they do not undergo important changes. Around the same time, [15]'s articulatory investigation concludes that unstressed /a/ and /ɔ/ are raised, /ə/ is lowered, and /e, i, u/ are unchanged.

According to the dominant theoretical account of Bulgarian vowel reduction [5, 13, 14], unstressed vowels are neutralised into an intermediate centralised position, involving raising for the lower vowels and lowering for the higher vowels. The unstressed central vowels /a/ and /ə/ are completely neutralised in all dialects, /ɔ/ and /u/ are less so, while /ɛ/ and /i/ only neutralise in Eastern dialects. This account has been supported by [17] although none of these authors report any experiments from which they have obtained the formant data that they cite and is possible that some are based on perceptual judgement. For instance, [13] transcribe unstressed /a/ and /ə/ as [ɐ] and /ɔ/ and /u/ as [o].

In the first and only corpus-based acoustic study of casual Bulgarian speech, drawing from a more representative sample, [1] find no evidence of higher vowels being lowered in unstressed position. On the contrary, they find that the lower unstressed vowels are consistently raised, while the higher unstressed vowels are either higher than or equal to their stressed counterpart (as inferred from F1). [9]'s recent study confirms these findings for the back vowels but finds evidence of lowering for unstressed /ə/. He reports that unstressed /ɔ/, /u/ and stressed /u/ overlap in F1. In addition, [9]'s perceptual experiment demonstrates that native Bulgarian listeners cannot reliably discriminate between unstressed central and back vowels, although they do discriminate between the front vowels.

Considering that the major point of inconsistency between the different studies and theoretical accounts on Bulgarian vowel reduction is the behaviour of the unstressed higher vowel in each pair, this study focuses on its height realisation. The concept of height is complex and is expected to affect vowels slightly differently depending on the operationalisation (articulatory or acoustic) and the vowels' typical place of articulation. It is beyond the scope of this paper to address all the nuance regarding the expected realisations for each vowel.

2. RESEARCH QUESTIONS

The purpose of this study is to explore the effects of Vowel and Stress on tongue height and F1 of the six Bulgarian vowels (front: /e, i/, central: /a, ə/, back: /o, u/).

First, it is expected that the unstressed allophone of the higher vowel in each pair will be higher than the stressed allophone of the lower vowel. Second, the traditional account states the unstressed higher vowel will be lower than its stressed counterpart and merging with the lower unstressed vowel (mostly for mid and back vowels). However, according to the alternative account, the higher unstressed vowel will be higher than or similar to its stressed counterpart. It might merge with the lower unstressed vowel only for the back vowels. [1, 12, 16]

2. METHODS

2.1. Participants

The participants were three male speakers, aged 25-30, who were raised in Sofia. All the participants have completed their secondary education in Bulgaria and their further higher education in UK universities, having moved to the UK around the age of 19. As the available ultrasound equipment cannot be transported and is located in the UK, outside of the nearest urban centre, only three Bulgarian participants responded. Even so, this sample is larger than those used by [12, 15, 16] and to our knowledge this is the first ultrasound study on CSB vowel reduction. Therefore, we believe it is a valuable addition to the existing discussion.

2.2 Stimuli

There were 72 Bulgarian words as stimuli. Each of the six vowels appeared in 4 words in stressed syllables in either word initial or non-initial position (24 words). Each of the 6 vowels also appeared in four pretonic (2 initial and 2 non-initial) and four posttonic positions (2 final and 2 non-final) (48 words). Attention was paid to ensure that there was a balanced number of front and back consonants following the vowel of interest. As there are no words in Bulgarian which end with the grapheme „ъ" (corresponding to an underlying phoneme /ə/) the list included the word "кажа", which historically ends with an underlying /ə/, even though is spelled with /a/. The word „полъх" ending in /əx/ was included to complete the list of word-final /ə/ tokens.

Each prompt was embedded in a carrier sentence "Kazah … pak" ("I said … again").

2.3. Recordings

The speakers were recorded in a quiet room at Queen Margaret University, Edinburgh. They were fitted with a probe-stabilising headset [10]. The purpose of the headset was to ensure that the angle of the probe remained the same throughout the recording of each participant, allowing them to move their head and upper body. To obtain occlusal planes the participants were asked to gently bite and press their tongues against a flat plastic plate before and after recording the stimuli. The plate records the occlusal plane, a reliable method of defining horizontal and vertical orientations in the vocal tract.

The Cyrillic alphabet is not compatible with the Articulate Assistant software, which made it impossible to directly present the stimuli on the screen. The consecutive number of the prompt was displayed on the screen and the participants read the corresponding prompt from a sheet of paper next to the screen. In order to keep the task under 15 minutes and prevent discomfort from wearing the headset, no fillers were included. Instead, the stimuli were randomised. The list was recorded twice. After the recordings the participants answered a short questionnaire on their linguistic and demographic background.

Sound was recorded at sampling frequency 22.5 kHz using Omnidirectional Condenser Lavalier Microphone AT803d attached to the headset. A midsagittal view of the tongue during speech was obtained using a Sonix RP ultrasound system and a microconvex probe with an angle of view of 135°, image depth 80 mm, 63 scanlines and speed of 100 fps.

3. ANALYSIS

A total of 432 tokens were recorded from the three participants, however, due to one of the participants not finishing the target word before the end of the recording window, 12 vowel splines were missing in the analysis, leaving 420 spline tokens for analysis.

The data was coded using the Articulate Assistant Advanced software [2]. The vowels of interest were segmented using the onset and offset of regular periodicity of the waveform as a primary cue and the formants on the spectrogram as a secondary cue. In order to fit measurement splines to the participants' tongue images, first, a template was prepared of each speaker's tongue for the vowel /ə/ (the most central vowel of the set). That was used to automatically fit tongue splines to the tongue images at every frame of the vowel. Each frame was manually inspected. If there were mistakes in the automatic fitting, the tongue was manually retraced and then the Snap-to-fit correction was applied to ensure the spline was smooth.

The cartesian x, y coordinates of the tongue splines were extracted at the vowel midpoint, which consistently contained an articulatorily steady part of the vowel. Before further analysis all tongue measurements were rotated so that the occlusal planes appeared horizontal across the participants. The y coordinates were then centered around the occlusal plane. Further mentions of tongue height from UTI refer to this adjusted measure.

Each spline contains 42 measurement points and the highest y coordinate from each spline was selected for further analysis.

In addition, the first and second formant were extracted also at the mid-point of the vowel (using script [8] with Praat [4] and the same segmentations as for the tongue curve analysis). The measures were normalised using the Labov transformation from the "vowels" package [6] on R [7].

Statistical analysis was performed on R [7] using linear mixed effects models from the lme4 package [3] and p-values were obtained from the afex package [11]. Linear mixed effects model of tongue height and F1 were built for each vowel pair according to frontness. The predictors were *Vowel* (the lower vowel as default), *Stress* ('unstressed' as default) and their interaction, as well as random slopes of these predictors with *Speaker* and a random intercept for *Word*.

4. RESULTS

4.1. Statistical results for tongue height from UTI

The results for the models on tongue height are presented in Table 1.

The tongue height for unstressed /i/ was the same as for stressed /i/. It was also distinctly higher than the height for stressed and unstressed /ɛ/.

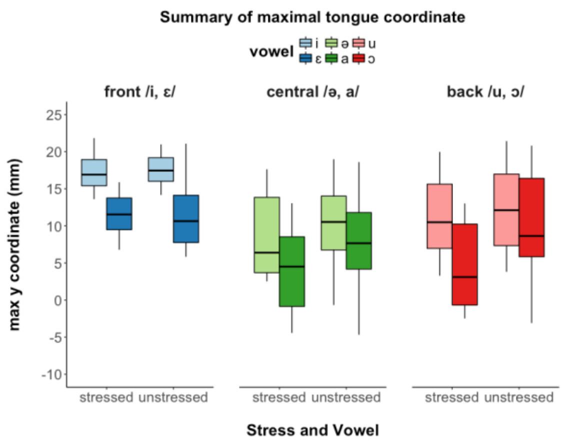
The central vowels showed a different pattern. The tongue height of unstressed /ə/ was higher than unstressed /a/ (although with a small effect size) but it was indistinguishable from stressed /a/ and stressed /ə/, although it had a tendency to be higher than both of them. This result is unexpected when observing Figure 1. It might be an artefact due to the large variability and a lower number of tokens for unstressed /ə/ (n = 40) compared to unstressed /i/ (n = 49) and unstressed /u/ (n = 52).

Table 1. Results of lmer for the effects of *Vowel* and *Stress* on tongue height for each vowel pair.

Vowel Pair	Predictor	*Estimate*	*Std. Error*	*t*-value	*p*
front	*Intercept* (unstressed /i/)	17.4	1.3	13.0	0.004
	Vowel (unstr. /i/ vs. unstr. /e/)	-6.1	0.6	-10.4	<0.0001
	Stress (unstr. /i/ vs. str. /i/)	1.3	0.7	2.8	0.086
	Vowel : Stress (unstr. /i/ vs. str. /e/)	-2.6	0.9	-2.9	0.004
mid	*Intercept* (unstressed /ə/)	10.7	2.6	4.2	0.049
	Vowel (unstr. /ə/ vs. unstr. /a/)	-3.1	1.0	-3.2	0.019
	Stress (unstr. /ə/ vs. str. /ə/)	-1.7	1.4	-1.2	0.314
	Vowel : Stress (unstr. /ə/ vs. str. /a/)	-1.4	1.3	-1.1	0.286
back	*Intercept* (unstressed /u/)	11.8	3.5	3.4	0.078
	Vowel (unstr. /u/ vs. unstr. /o/)	-1.6	0.6	-2.7	0.025
	Stress (unstr. /u/ vs. str. /u/)	-0.3	0.8	-0.3	0.762
	Vowel : Stress (unstr. /u/ vs. str. /o/)	-4.7	1.1	-4.3	<0.0001

The back vowels had a similar pattern to the front vowels. Unstressed /u/ was the same as stressed /u/ and higher than stressed and unstressed /ɔ/.

Figure 1. Boxplot of maximal tongue height centered around the occlusal plane for Bulgarian vowels in different stress positions.



4.2. Statistical results for F1

The results for the models on F1 are presented in Table 2.

The results for the front vowels are consistent with the tongue height measurement. F1 of unstressed /i/ was the same as stressed /i/ and lower than stressed and unstressed /ɛ/.

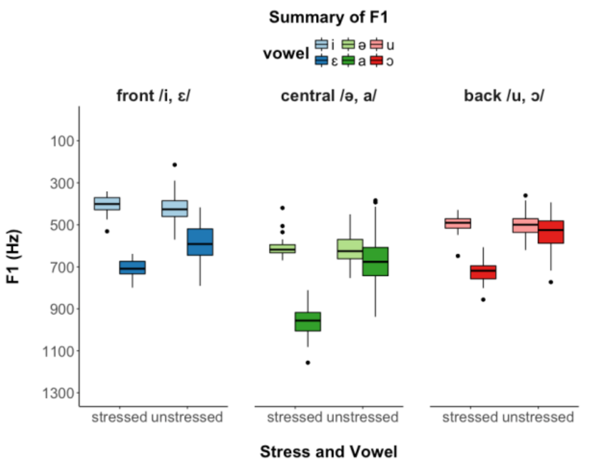
The central vowels showed the same pattern. Unstressed /ə/ was not different from stressed /ə/ and it had significantly lower F1 than stressed and unstressed /a/. This pattern diverged from the UTI findings, which showed that unstressed /ə/ was not different from stressed /a/.

Lastly, the back vowels had more overlap. Similarly to the previous formant comparisons, unstressed /u/ was the same as stressed /u/ and it had significantly lower F1 than stressed /ɔ/. However, it was also the same as unstressed /ɔ/.

Table 2. Results of lmer for the effects of *Vowel* and *Stress* on F1 for each vowel pair.

Vowel Pair	Predictor	*Estimate*	*Std. Error*	*t-value*	*p*
front	*Intercept* (unstressed /i/)	421.3	12.5	33.7	<0.0001
	Vowel (unstr. /i/ vs. unstr. /e/)	168.1	21.8	7.7	0.0005
	Stress (unstr. /i/ vs. str. /i/)	-15.6	21.7	-0.7	0.478
	Vowel : Stress (unstr. /i/ vs. str. /e/)	152.1	28.3	5.4	<0.0001
mid	*Intercept* (unstressed /ə/)	609.6	41.2	14.8	0.001
	Vowel (unstr. /ə/ vs. unstr. /a/)	71.1	28.1	2.5	0.026
	Stress (unstr. /ə/ vs. str. /ə/)	-17.4	34.7	-0.5	0.627
	Vowel : Stress (unstr. /ə/ vs. str. /a/)	282.1	38.5	7.3	<0.0001
back	*Intercept* (unstressed /u/)	505.6	12.7	39.7	<0.0001
	Vowel (unstr. /u/ vs. unstr. /o/)	23.2	17.2	1.3	0.208
	Stress (unstr. /u/ vs. str. /u/)	-22.3	23.3	-1.0	0.353
	Vowel : Stress (unstr. /u/ vs. str. /o/)	235.8	30.1	7.8	<0.0001

Figure 2. Boxplot of F1 distinctions between Bulgarian vowels in different stress positions (reversed F1 scale).



5. DISCUSSION

Overall, there is no evidence that the higher unstressed vowels become systematically lowered to merge with the lower unstressed vowels, contrary to the traditional account of Bulgarian vowel reduction [5, 13, 14]. The present results are in line with the predictions of the reduction-as-raising model supported by [1, 16]. They are also generally in line with the results of the auditory experiment by [9]. In all cases, both in tongue and F1 analyses, the higher unstressed vowels were not significantly different from their stressed counterpart. The unstressed higher vowel tended to be higher than the stressed and unstressed lower vowel in each pair. The two exceptions are unstressed /ə/ being the same as stressed /a/ (from the UTI analysis) and unstressed /u/ and /ɔ/ being the same (from the formant analysis).

Considering Fig.1 and Fig.2, it appears that the maximal tongue coordinate data is a lot more variable than the formant data. This suggests that the highest point of the tongue is possibly a less reliable descriptor of the identity of the Bulgarian vowels than F1. The greater variability in the tongue data, combined with fewer tokens than the other two vowel pairs, might explain the inconsistent result for the central vowels, where unstressed /ə/ was not different from stressed /a/. At the same time two of the results for the central and back vowels that were significant had very small effect sizes of about 2 mm (unstressed /ə/ vs. unstressed /a/, and unstressed /u/ vs. unstressed /ɔ/). These results should be interpreted cautiously as they also correspond to small or non-significant effects in the F1 analysis. It is possible that they are false positives. Future studies could try to improve the precision of articulatory data by investigating the effect of raising the whole tongue using generalised mixed effect models as opposed to focusing on the highest point only.

In addition to this variability, the F1 data is more variable for unstressed vowels than for stressed vowels (see Figure 2). This suggests that the reduced vowels have less precise targets than the stressed ones. While there is no evidence of a systematic lowering or raising of the unstressed higher vowels compared to their stressed counterparts, the variance suggests that both lowering and raising were observed. However, descriptively it appears that the lower vowel shows much more consistent raising (except the articulatory data for /ɛ/), hence any merger or closeness between the unstressed vowels in each pair is more likely to be a result of the behaviour of the lower vowel. This result for the higher vowels is more likely explained by the account of selective relaxation of articulatory control, proposed by [16], rather than a manifestation of a different gestural target.

6. CONCLUSION

There was no difference between the higher stressed and unstressed Bulgarian vowels in each pair. The unstressed front vowels are significantly different from each other in terms of tongue height and F1, while the central and back unstressed vowels are less reliably distinguished, similar to the findings of [1, 9, 16] and differing from the traditional account of CSB reduction [5, 13, 14]. The F1 analysis appeared more precise than the articulatory one. It showed a larger variability for the unstressed vowels, suggesting less precise manifestations of the articulation targets. A potential path for future research would be to investigate the effects of specific surrounding environments on the amount of raising. It is also recommended that future articulatory studies on Bulgarian vowels explore the raising of the whole tongue body as opposed to the highest point only.

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