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JUDEO-SPANISH AND BULGARIAN VOWELS IN CONTACT: THE EFFECT OF WORD STRESS ACROSS SPEAKING STYLES*

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ЮДЕО-ИСПАНСКИТЕ И БЪЛГАРСКИТЕ ГЛАСНИ В КОНТАКТ: ВЛИЯНИЕ НА СЛОВНОТО УДАРЕНИЕ СПОРЕД РЕЧЕВИЯ СТИЛ

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Abstract: We present an acoustic analysis of Bulgarian Judeo-Spanish vowels, comparing them to the bilingual speakers' Bulgarian vowels and those of monolingual Bulgarians. Careful and spontaneous speaking styles were examined, focusing on stress-induced variation, given Bulgarian's height-neutralising vowel reduction. Analysis of 7058 tokens showed minor spectral differences in stressed vowels, indicating shared targets among bilinguals. Reduction was stronger in spontaneous speech, neutralising contrasts in Bulgarian /a–ɤ/ and /ɔ–u/ but not in Judeo-Spanish. Bulgarian /ɤ/ lowering in careful speech suggests age-graded variation.

Keywords: Judeo-Spanish; Bulgarian; vowel acoustics; speaking styles; word stress; contrast neutralisation

Резюме: Представяме акустичен анализ на гласните в българския юдео-испански език в сравнение с гласните на двуезичните говорители на български език и на едноезични българи. Разгледани са прецизен и спонтанен речеви стил с акцент върху вариативността, предизвикана от ударението, предвид неутрализацията на гласните по

отвореност при редукция в български. Анализът на 7058 гласни показа незначителни спектрални разлики под ударение, което показва общи цели сред двуезичните. Редукцията е по-силна в спонтанната реч, като контрастът в двойките /a–ɤ/ и /ɔ–u/ се неутрализира в български, но не и в юдео-испански. Отваряне на неударено българско /ɤ/ в прецизния стил предполага възрастово-обусловена вариативност.

Ключови думи: юдео-испански език; български език; акустика на гласните; речеви стилове; словно ударение; неутрализация

1. INTRODUCTION

Judeo-Spanish, also known as Ladino or Judezmo, refers to the language spoken by the Sephardic Jews after their expulsion from Spain in 1492. The Sephardim's new areas of settlement were primarily in the Ottoman Empire and North Africa, and their language developed independently of other Spanish varieties, in close contact with various local languages, including Greek, Turkish, and Bulgarian. In Bulgaria, there were approximately 50,000 Jews by the beginning of the Second World War (Abramson 2005). After the war, most of the Jewish population in Bulgaria, who had largely been spared from deportation, left for Israel. In a 2011 census, 120 respondents selected "Jewish" as their mother tongue.[1] The motivation behind the label "Jewish language" used in the census is unclear; however, it should be safe to assume that Judeo-Spanish was meant and understood. It is estimated that there are no more than 30 native speakers of Judeo-Spanish today (Grünke et al. 2023a), all of whom are (at least) bilingual and dominant in Bulgarian. Bulgarian Judeo-Spanish, therefore, is a severely endangered linguistic variety, one that is on the verge of extinction.

A growing body of experimental research has been devoted to Bulgarian Judeo-Spanish phonetics and phonology in recent years. Whilst the bulk of it has focused on aspects of speech prosody (Andreeva et al. 2019, 2021; Gabriel, Kireva 2014; Grünke et al. 2023a), some work has addressed segmental issues as well, in particular unstressed vowel reduction (Gabriel, Grünke 2018; Gabriel, Kireva 2014; Grünke et al. 2023b). Nonetheless, a thorough investigation of the Bulgarian Judeo-Spanish vowel system, in comparison with the Bulgarian of the bilingual speakers, as well as with ambient monolingual Bulgarian, is still lacking, and this article aims to fill in that gap.

Judeo-Spanish descends from Castilian Spanish, which has five contrastive vowels, /i e a o u/, typically with close mid, rather than open mid, /e/ and /o/ (Martínez-

[1] https://censusresults.nsi.bg/Census/Reports/2/2/R9.aspx (Accessed 18th February 2025).

Celdrán et al. 2003). Bulgarian Judeo-Spanish has the same vowel inventory, but the precise vowel qualities are to be determined in the course of the present study. Spanish does not exhibit any consistent patterns of unstressed vowel reduction (Nadeu 2014), and nor does, for example, Istanbul Judeo-Spanish (Gabriel et al. 2024).

The Standard Bulgarian stressed vowel system consists of six contrastive vowels, which phonetically range from high /i u/, to mid /ɛ ɤ ɔ/, to low /a/. Based on the assumption that – at least in some Bulgarian dialects – the non-high /ɛ a ɔ/ are raised in unstressed position and merge with their higher counterparts /i ɤ u/, respectively, both Trubetzkoy (1939) and Jakobson (1962) argued that there were only two phonological vowel heights in Bulgarian: high /i ɤ u/, and non-high /ɛ a ɔ/, as schematised in Table 1. This two-height system has generally been adopted in the literature published in Bulgarian, and is also adhered to in this article. However, the received view of vowel reduction in the Bulgarian literature, most thoroughly spelt out in the 'Academy Grammar' (Tilkov et al. 1982), does not corroborate the assumption that unstressed /ɛ a ɔ/ reduce to /i ɤ u/. Instead, the Academy Grammar maintains that only the non-front unstressed pairs, /a–ɤ/ and /ɔ–u/, may merge in Standard Bulgarian, 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 [ɐ o], respectively. In other words, not only are non-high vowels raised, but high vowels are also lowered in unstressed position. The Academy Grammar has been very influential, and such traditional views of Bulgarian vowel reduction have often been repeated in subsequent published work (Boyadzhiev et al. 1998; Scatton 1984; Zhobov 2004), including the IPA illustration for Bulgarian (Ternes, Vladimirova-Buhtz 1990).

Table 1. The Bulgarian stressed vowel system.

	Front	Non-front	
		Unrounded	Rounded
High(er)	**i**	**ɤ**	**u**
Non-high	**ɛ**	**a**	**ɔ**

A series of recent publications on Bulgarian vowel reduction, and vowel acoustics in general, have challenged and rejected these traditional views. In a corpus study of Standard Bulgarian, Andreeva et al. (2013) 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/ did not merge. These findings were corroborated by Dokovova et al. (2019) in an ultrasound and acoustic investigation.

A more extensive acoustic study of careful speech (Sabev 2023) also found no lowering in unstressed high vowels and confirmed that unstressed /ɛ–i/ did merge in eastern, but not in western (Standard) Bulgarian; Sabev (2023) further found that, contrary to the received view, western Bulgarian unstressed /ɔ–u/ underwent greater contrast reduction than unstressed /a–ɤ/. Sabev, Andreeva (2024) is an investigation of a large spoken corpus of read speech (140 speakers) which also found no evidence of unstressed high vowel lowering and demonstrated that both /a–ɤ/ and /ɔ–u/ were completely merged in unstressed position.

Vowel realisation is a central aspect of phonetic variation determined by numerous linguistic and extralinguistic factors. Among these, speaking style plays a notable role in shaping vowel quality and duration. Different speaking styles, such as careful and spontaneous speech, impose varying demands on articulation, resulting in systematic differences in vowel production. In careful speech, speakers tend to exhibit more precise articulation and less variability. Careful style often reflects an effort to ensure intelligibility and maintain received language norms. Conversely, spontaneous speech is characterised by a faster speech rate and greater articulatory economy, which can lead to vowel reduction, vowel space shrinkage, and increased overlap. The interplay between vowel realisation and speaking style is particularly important in languages with stress-induced vowel alternations or reduction patterns. While stress in such languages influences vowel quality, it also interacts with speaking style, which may amplify or mitigate its effects. Understanding these dynamics offers insights into the flexibility of the vowel system and the underlying phonological constraints of a language.

The present study investigates the Judeo-Spanish and Bulgarian speech of bilingual speakers, as well as the speech of monolingual Bulgarians. The three varieties are referred to as Judeo-Spanish (JSp), Bilingual Bulgarian (BB) and Monolingual Bulgarian (MB). The mid vowels are transcribed phonemically as /ɛ ɔ/ for all varieties, and their phonetic realisations will be discussed later. Vowels are contrasted between two stress conditions, stressed versus unstressed, and between two speaking styles, careful versus spontaneous speech.

We set out to determine the effect of the following variables on vowel quality (as measured by the first two formant frequencies) and duration.

1. *Linguistic variety: Judeo-Spanish vs. Bilingual Bulgarian vs. Monolingual Bulgarian*

Since Judeo-Spanish and Bulgarian have been in long-term contact, we do not expect to find major spectral differences in canonical realisations, that is, in stressed syllables. In unstressed syllables, however, different magnitudes of vowel reduction

may emerge. Since Bulgarian is the bilinguals' dominant language, one can expect their speech rate to be slower in Judeo-Spanish, which would in turn result in longer vowel durations.

2. *Speaking style: careful versus spontaneous speech*

Overall longer vowel durations can be expected in careful than in spontaneous speech, owing to differences in speech rate. As regards the formant frequencies, no major differences should be expected in stressed syllables, as target overshoot is unlikely at durations that are longer than in spontaneous speech. In unstressed syllables, on the other hand, spectral differences are more probable, as greater temporal pressure may be present in spontaneous speech, making target undershoot more likely. Judeo-Spanish, which is predicted to have longer vowel durations across the board, may also be expected to exhibit less undershoot than the Bulgarian varieties.

3. *Word stress: stressed versus unstressed*

Based on previous research, vowels are expected to be longer in stressed than in unstressed position. In addition, non-high vowels are highly likely to undergo raising in unstressed position (e.g. Andreeva et al. 2013; Gabriel, Kireva 2014; Grünke et al. 2023b; Sabev 2023; Sabev, Andreeva 2024). Both cross-varietal and style-conditioned differences in reduction patterns may also be expected.

4. *Height contrast: non-high versus high*

On the basis on earlier work again, one should expect Bulgarian unstressed /a–ɤ/ and /ɔ–u/ to merge (Andreeva et al. 2013; Sabev 2023; Sabev, Andreeva 2024). It remains to be established whether this is consistent across the speaking styles examined, and whether stresslessness affects the height contrast in Judeo-Spanish as well.

2. MATERIAL AND METHODS

Table 2. shows the number of speakers recorded for each linguistic variety, speaking style and gender, as well as the age range, mean age and year of recording for each variety–style condition. One of the Judeo-Spanish and Bilingual Bulgarian speakers, and two of the Monolingual Bulgarians took part in the elicitation of both careful and spontaneous speech. Two of the participants in the Judeo-Spanish careful speech session did not agree to be recorded in Bulgarian. All participants had lived in Sofia for most of their lives.

Table 2. Number of speakers by variety, gender and speaking style.

	Judeo-Spanish		Bilingual Bulgarian		Monolingual Bulgarian	
	Careful	**Spontaneous**	**Careful**	**Spontaneous**	**Careful**	**Spontaneous**
Female	4	4	2	4	4	4
Male	4	0	4	0	1	0
Total	8	4	6	4	5	4
Age range	70–99	80–88	70–90	80–88	87–97	83–85
Mean age	80	84.5	76.6	84.5	90.4	84
Recording	2022	2012	2022	2012	2022	2016

Individual recordings were made in quiet rooms, with a Shure WH20 dynamic headset mounted microphone, digitised with a Behringer U-Phoria UMC202HD audio interface unit at a sampling rate of 44,100 Hz and a 24-bit resolution, stored as PCM-encoded single-channel wav files.

A picture naming task was used to elicit careful speech. The target words (imageable items) were designed to capture vowels in stressed and unstressed position and were incorporated in carrier sentences: *Digo ... otra vez* /ˈdigɔ … ˈɔtra vɛz/ (‘I [will] say … again’) for Judeo-Spanish, and *Ще кажа ... пак* /ʃtɛ ˈkaʒɤ … pak/ (‘I will say … again’) for Bulgarian. The stimuli and carrier sentences were displayed to participants on a computer screen, one at a time in randomised order. Two elicitations of each stimulus were recorded. The task design aimed to mitigate potential effects of orthography on pronunciation, and unlike spontaneous speech, this approach ensured well-controlled experimental conditions. To attain more fluent and confident production, participants were invited to familiarise themselves with the stimuli prior to recording; any queries or uncertainties were addressed at this stage. Target words for careful speech are given in Appendix 1.

For spontaneous speech, the material consisted of three-minute extracts from semi-focused interviews, in which the speakers were asked to talk about their childhood and family history, their daily lives and, in the case of the bilinguals, about their language use. Vowels in phrase-final (pre-pause) syllables were excluded from analysis, as they often exhibited extreme lengthening. Bilingual speakers were recorded in Judeo-Spanish first, then in Bulgarian a few days later. The interval between the two language sessions aimed to minimise potential interference.

Vowels were manually segmented in Praat (Boersma, Weenink 2022), on the basis of the synchronised wideband spectrogram (Gaussian window shape, 0.004 s

window length, 0.001 s time step), waveform, and auditory inspection. A Praat script was used to extract vowel duration and midpoint F1 and F2 frequencies. The values measured for all three acoustic variables were normalised using speaker-intrinsic, vowel-extrinsic z-transformation (Lobanov 1971). All reported results and graphs are based on normalised values. Outliers by vowel and stress condition, defined as values outside IQR by 1.5 × IQR, were removed (2.86% for F1, 2.54% for F2 frequency, 3.10% for duration). 7058 vowel tokens were analysed in total; a breakdown by vowel, variety, speaking style and stress condition is given in Table 3.

Table 3. Number of vowel tokens analysed by vowel, variety, speaking style and word stress; S: stressed, U: unstressed.

	Judeo-Spanish				**Bilingual Bulgarian**				**Monolingual Bulgarian**			
	Careful		**Spontaneous**		**Careful**		**Spontaneous**		**Careful**		**Spontaneous**	
	S	U	S	U	S	U	S	U	S	U	S	U
/ɛ/	21	34	147	425	12	23	184	350	10	20	171	261
/a/	16	32	210	387	12	23	248	525	10	20	223	388
/ɔ/	17	47	150	274	12	23	144	282	10	20	163	260
/i/	15	33	122	131	12	24	152	263	10	20	148	199
/ɤ/	—	—	—	—	12	25	70	99	9	20	49	78
/u/	16	32	53	86	12	24	53	31	10	20	59	17

A series of linear mixed effects models (LMM) were constructed to perform the four vowel comparisons introduced in Section 1 above: across the varieties, between careful and spontaneous speech, between stressed and unstressed syllables, and between non-high and high vowels. In all models, the three acoustic parameters under examination were used as response variables, while speaker and consonantal context (i.e., flanking consonants) were included as random effects, as shown in (1.).

1.

$$\{F1\ frequency\ F2\ frequency\ duration\} \sim Predictor + (speaker) + (1|context)$$

The fixed effect, or predictor variable, was determined by the comparison being carried out. Table 4. summarises the predictors and grouping variables for each model. Grouping variable levels represent the structure of the reporting of results in the next section of the article: level I corresponds to subsubsections, level II to panels in LMM and vowel space graphs, and level III to columns in LMM graphs.

Table 4. Predictor and grouping variables in the LMM's.

	Predictor		Grouping variables		
Section	**Variable**	**Levels**	**I**	**II**	**III**
3.1	VARIETY	JSp vs. BB vs. MB	STYLE	STRESS	VOWEL
3.2	STYLE	careful vs. spontaneous	STRESS	VARIETY	VOWEL
3.3	STRESS	stressed vs. unstressed	STYLE	VARIETY	VOWEL
3.4	VOWEL	/ɛ/ vs. /i/, or /a/ vs. /ɤ/, or /ɔ/ vs. /u/	STYLE	VARIETY	STRESS

Since the predictor variable in the first model, variety, has three levels – Judeo-Spanish, Bilingual Bulgarian and Monolingual Bulgarian – the linear mixed model was followed up by Tukey's HSD test for adjusted pairwise comparisons of the varieties. The rest of the models have two-level predictors and therefore require no post hoc tests.

As has been demonstrated in earlier work, Bulgarian vowel reduction manifests itself primarily as the raising of the non-high vowels, /ɛ a ɔ/ (Andreeva et al. 2013; Dokovova et al. 2019; Sabev 2023; Sabev, Andreeva 2024). To determine whether reduction is a categorical process or merely gradient undershoot, in Section 3.3, bimodality coefficients were computed for the entire F1 frequency distributions (stressed and unstressed together) for each non-high vowel. The bimodality coefficient (BC) is defined in (2.), following Pfister et al. (2013).

2. $$BC = \frac{m_3^2 + 1}{m_4 + 3 \cdot \frac{(n-1)^2}{(n-2)(n-3)}},$$

where m3 refers to the third moment, or skewness, of the distribution, and m4 to its fourth moment, or excess kurtosis. Pfister et al. (2013: 1) give the following interpretation of the bimodality coefficient, which is adopted here:

> The BC of a given empirical distribution is then compared to a benchmark value of BCcrit = 5/9 ≈ 0.555 that would be expected for a uniform distribution; higher numbers point toward bimodality whereas lower numbers point toward unimodality.

A unimodal distribution (BC < 0.555…) is indicative of a continuous range of F1 frequency values, and is interpreted here as evidence of gradient target undershoot under temporal pressure. A bimodal distribution (BC > 0.555…), on the other hand,

suggests that F1 frequency cannot be predicted from duration alone and such reduction may therefore be categorical.

All statistical analyses and graphs were made in R (R Core Team 2022). The areas of F1 × F2 vowel spaces were calculated using R package Geosphere (Hijmans et al. 2022).

3. RESULTS

This section reports the results of a series linear mixed models, constructed to assess the distinctions between vowels across the three varieties (3.1), between vowels in careful versus spontaneous speech (3.2), between vowels in stressed versus unstressed position (3.3), and between non-high and corresponding high vowels (3.4). The response variables were the acoustic parameters under study: F1 frequency, F2 frequency and duration. The random effects were speaker and consonantal context. A different fixed effect was selected in each subsection that follows, according to the distinction being examined.

3.1. Linguistic variety: Judeo-Spanish vs. Bilingual Bulgarian vs. Monolingual Bulgarian

To compare vowels across the three varieties, a set of LMM's were fitted with variety as a fixed effect. These were followed up by Tukey's HSD pairwise tests. Results for comparisons of careful speech are presented first, and those for spontaneous speech second.

3.1.1. Careful speech

Figure 1 shows group means and standard deviations (SD's), and summarises the results of Tukey's HSD pairwise comparisons for each vowel in stressed and unstressed syllables. Significance is indicated as compact letter displays: vowels that share at least one letter are statistically indistinguishable by the examined acoustic variable, whereas vowels that share no letters are significantly different. Detailed LMM and pairwise results are reported in Appendix 2.

In stressed position, /a/ is more open in Monolingual Bulgarian than in the bilingual varieties, /ɛ/ and /a/ are more advanced in Judeo-Spanish than in Bilingual Bulgarian, /u/ is more advanced in Judeo-Spanish than in Monolingual Bulgarian, and MB /ɤ/ is more advanced than BB /ɤ/; stressed /a ɔ u/ are longer in Judeo-Spanish than in Bilingual Bulgarian. In unstressed syllables, all vowels are closer in Bilingual Bulgarian than in Judeo-Spanish, while /ɛ a ɤ/ are also closer than in Monolingual Bulgarian; unstressed /ɛ/ and /ɤ/ are more advanced in Monolingual than in Bilingual Bulgarian; all unstressed vowels are longer in Judeo-Spanish than in Bilingual Bulgarian.

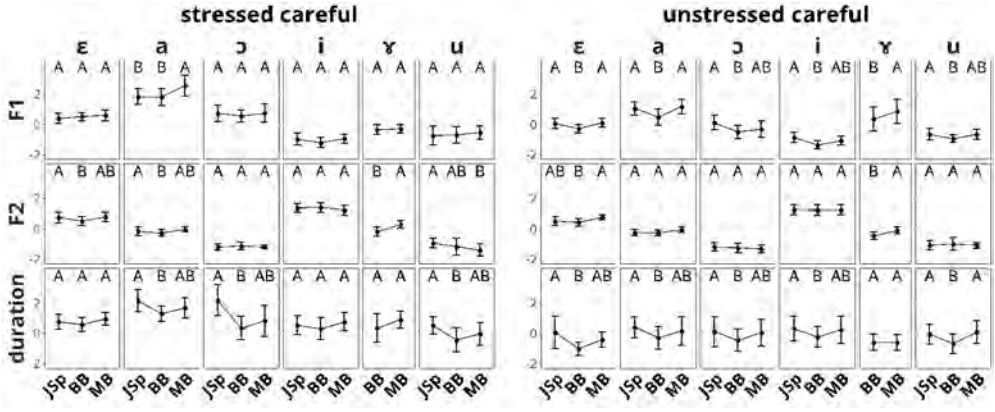

Figure 1. Tukey's HSD comparisons of vowels across varieties in careful speech, grouped by stress condition. LMM and detailed pairwise results are given in Appendix 2. Dots: means; error bars: SD's.

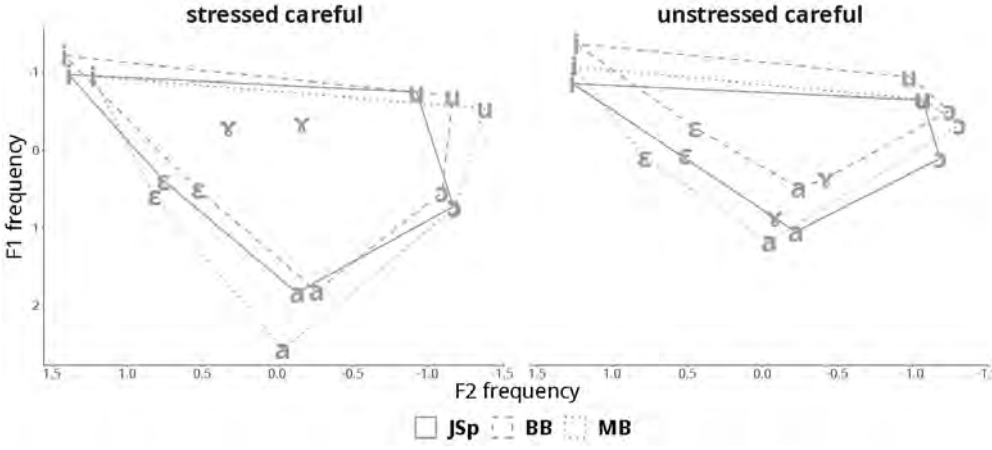

Figure 2. Vowels in the F1 × F2 space (means) across varieties in careful speech, grouped by stress condition. Stressed area ratios: JSp : BB : MB = 1 : 0.98 : 1.24; unstressed area ratios: JSp : BB : MB = 1 : 0.88 : 1.19.

Figure 2. contrasts the careful speech F1 × F2 vowel spaces of the three varieties. The bilingual varieties have very similar stressed spaces, whereas the Bilingual Bulgarian space area is smaller in unstressed position. Monolingual Bulgarian has a larger space area than the rest in both stress conditions.

3.1.2. Spontaneous speech

Group means and SD's for stressed and unstressed vowels in spontaneous speech are shown in Figure 3, along with the results of cross-varietal pairwise comparisons as compact letter displays. In stressed syllables, /a i/ are somewhat more open and /ɛ i/ more advanced in Judeo-Spanish than in Bilingual Bulgarian, while /u/ is fronted in Monolingual Bulgarian compared to the bilingual varieties; /ɛ a/ are longer in Judeo-Spanish than in Bilingual Bulgarian, and /i u/ are longer in Judeo-Spanish than in both varieties of Bulgarian. In unstressed position, /a/ is considerably more open in Judeo-Spanish than in Bulgarian, and /ɔ/ is more open, while /i/ is closer in Judeo-Spanish than in Bilingual Bulgarian; unstressed /ɛ/ is most advanced in Judeo-Spanish, less front in Bilingual Bulgarian and most centralised in Monolingual Bulgarian; /a/ is more retracted in Judeo-Spanish than in Bilingual Bulgarian. Unstressed vowels tend to be longer in Judeo-Spanish than in Bilingual Bulgarian or both Bulgarian varieties.

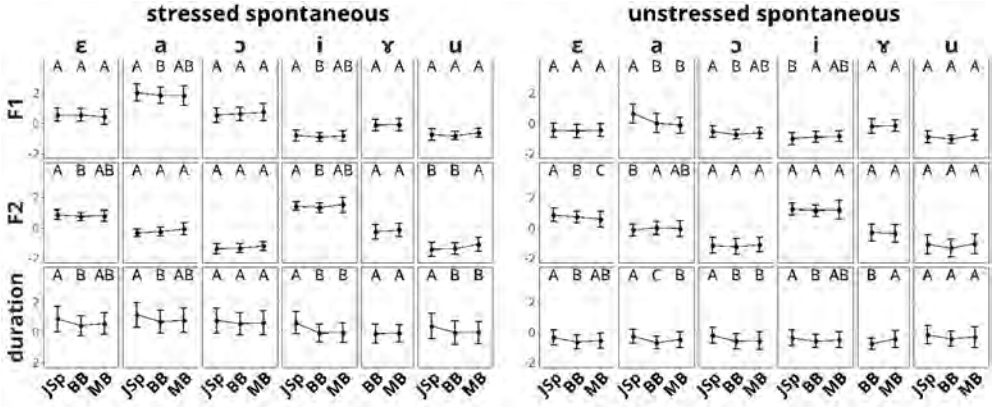

Figure 3. Tukey's HSD comparisons of vowels across varieties in spontaneous speech, grouped by stress condition. LMM and detailed pairwise results are reported in Appendix 2. Dots: means; error bars: SD's.

Stressed and unstressed vowel spaces in spontaneous speech are plotted in Figure 4. Judeo-Spanish and Bilingual Bulgarian have comparable stressed space areas, while that of Monolingual Bulgarian is smaller, primarily as a result of appreciable /u/-fronting. Unstressed space area is by far the largest in Judeo-Spanish, markedly smaller in Bilingual Bulgarian and smallest in Monolingual Bulgarian.

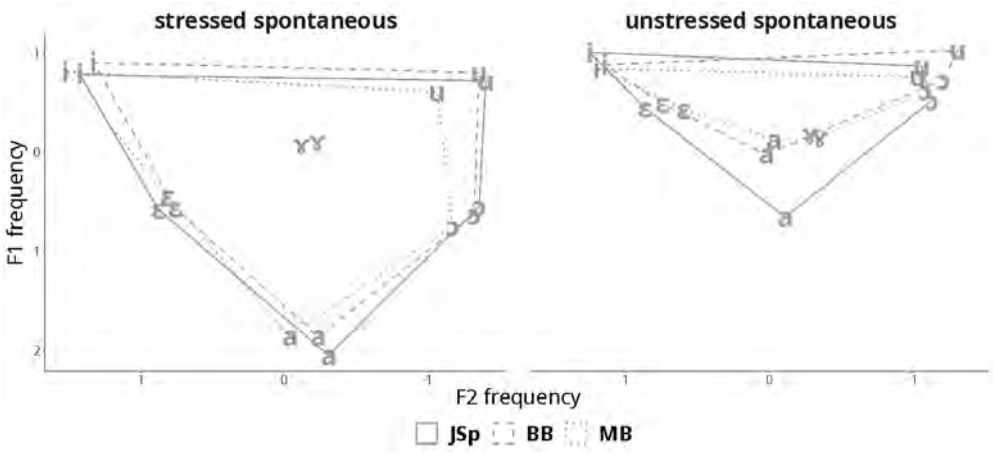

Figure 4. Vowels in the F1 × F2 space (means) across varieties in spontaneous speech, grouped by stress condition. Stressed area ratios: JSp : BB : MB = 1 : 0.95 : 0.83; unstressed area ratios: JSp : BB : MB = 1 : 0.66 : 0.45.

3.2. Speaking style: careful vs. spontaneous speech

To compare vowel realisations in careful versus spontaneous speech, LMM's were constructed with speaking style as a fixed effect. Only significance is reported here; detailed results can be found in Appendix 3. Results for comparisons in stressed position are followed by those for unstressed syllables.

3.2.1. Stressed syllables

Group means and SD's for vowels in stressed position are shown in Figure 5, along with the significance obtained from LMM. MB /a/ is more open, and BB /i/ closer, in careful than in spontaneous speech. JSp /u/ and MB /ɤ/ are more advanced in careful speech, while MB /i/ and /u/ are more retracted. JSp /a ɔ/, as well Bulgarian /a i ɤ/, are significantly longer in careful speech.

Careful and spontaneous speech stressed vowel spaces are compared in Figure 6. Significant spectral differences in the Monolingual Bulgarian corner vowels /i a u/ result in a smaller vowel space in spontaneous speech. In the bilingual varieties, the vowel space appears to be somewhat larger in spontaneous speech. However, apart from F2 of JSp /u/ and F1 of BB /i/, there are no significant spectral differences, and therefore the apparent differences in vowel space areas are not genuine.

3.2.2. Unstressed syllables

Differences between vowels in careful and spontaneous speech are considerably more numerous in unstressed than in stressed position, as can be seen in Figure 7.

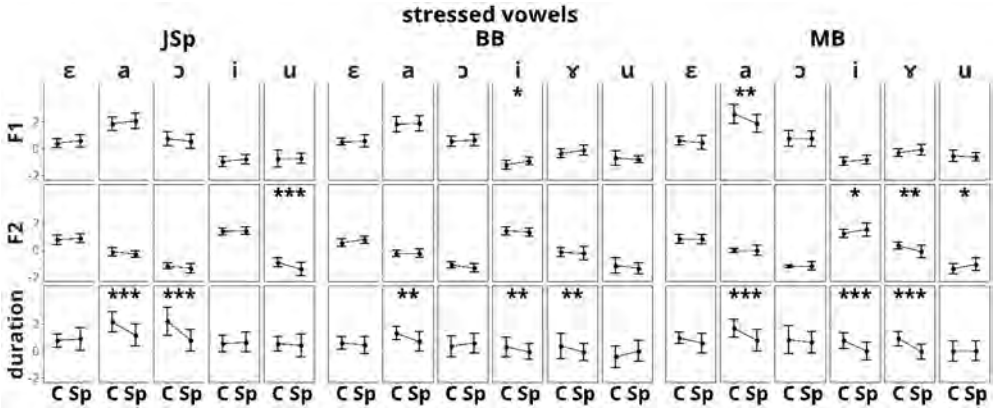

Figure 5. Stressed vowels in careful (C) vs. spontaneous (Sp) speech. LMM: {F1, F2, duration} ~ style + (1|speaker) + (1|context). *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$. Detailed results are reported in Appendix 3. Dots: means; error bars: SD's.

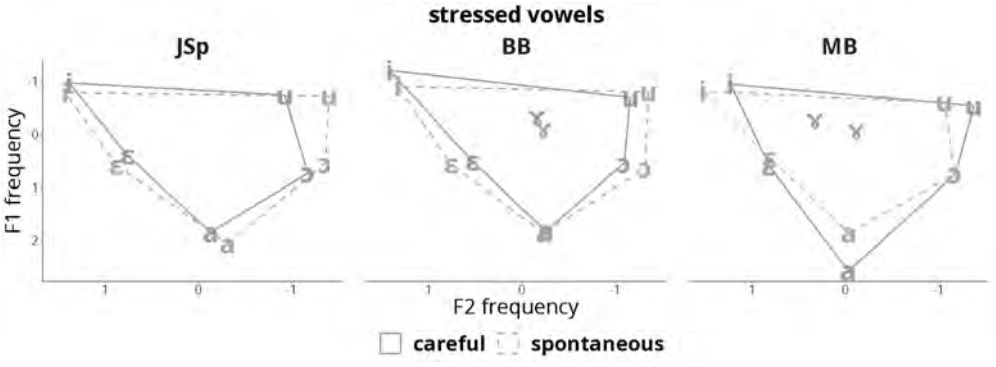

Figure 6. Stressed vowels in the F1 × F2 space (means) in careful vs. spontaneous speech. Careful : spontaneous speech area ratios: JSp 1 : 1.21, BB 1 : 1.18, MB 1 : 0.81.

With the exception of BB /ɛ/, the non-high vowels, /ɛ a ɔ/, are significantly closer in spontaneous than in careful speech. In the Bulgarian varieties, /i/ is more open, while /ɤ/ is closer, in spontaneous speech. Spontaneous /ɛ/ is more advanced in both bilingual varieties, and so is BB /a/. MB /ɤ/ is more retracted in spontaneous speech. JSp /ɛ a ɔ i/, BB /a i/ and MB /a ɔ i/ have significantly longer durations in careful speech.

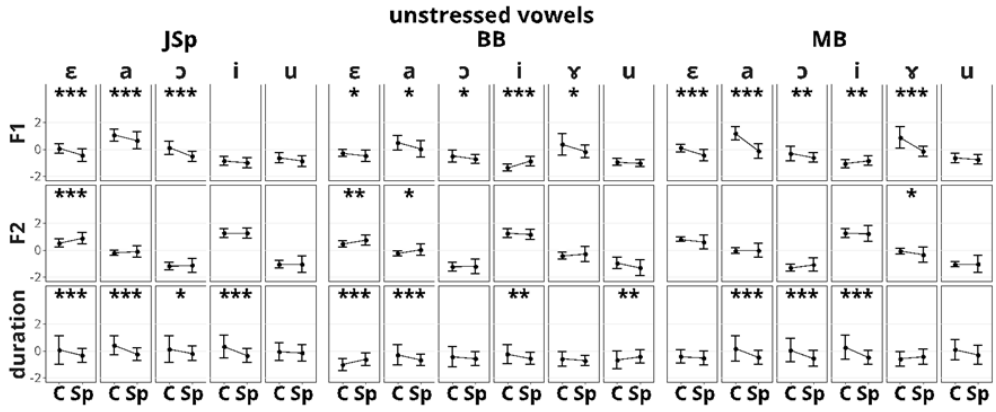

Figure 7. Unstressed vowels in careful (C) vs. spontaneous (Sp) speech. LMM: {F1, F2, duration} ~ style + (1|speaker) + (1|context). *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$. Detailed results are reported in Appendix 3. Dots: means; error bars: SD's.

In all three varieties, the unstressed F1 × F2 frequency space, plotted in Figure 8., is smaller in spontaneous than in careful speech. The area difference is smallest in Judeo-Spanish, larger in Bilingual Bulgarian, and most dramatic in Monolingual Bulgarian.

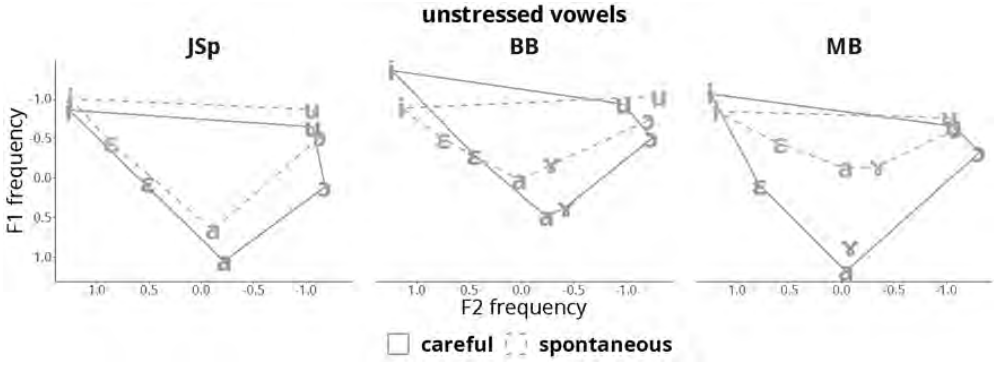

Figure 8. Unstressed vowels in the F1 × F2 space (means) in careful vs. spontaneous speech. Careful : spontaneous speech area ratios: JSp 1 : 0.85, BB 1 : 0.63, MB 1 : 0.32.

3.3. Word stress: stressed vs. unstressed vowels

In order to assess the differences between stressed and unstressed vowels, LMM's with stress as a fixed effect were computed. Only significance is reported here; detailed results are given in Appendix 4. In addition, a bimodality coefficient was calculated for the F1 frequency distribution of each non-high vowel. Results for careful speech are followed by those for spontaneous speech.

3.3.1. Careful speech

Group means, SD's and LMM results comparing stressed versus unstressed vowels in careful speech are shown in Figure 9. All non-high vowels, /ɛ a ɔ/, are significantly closer in unstressed than in stressed position in all three varieties. Unstressed BB /i/ is also somewhat closer, while /ɤ/ is more open in unstressed than in stressed syllables in careful speech in both Bulgarian varieties. In addition, JSp /ɛ/, BB /i ɤ/ and MB /ɤ/ are more retracted in unstressed syllables, while MB /u/ is more advanced. All non-high vowels, as well as JSp /u/, BB /i ɤ/ and MB /ɤ/, are significantly longer in stressed position.

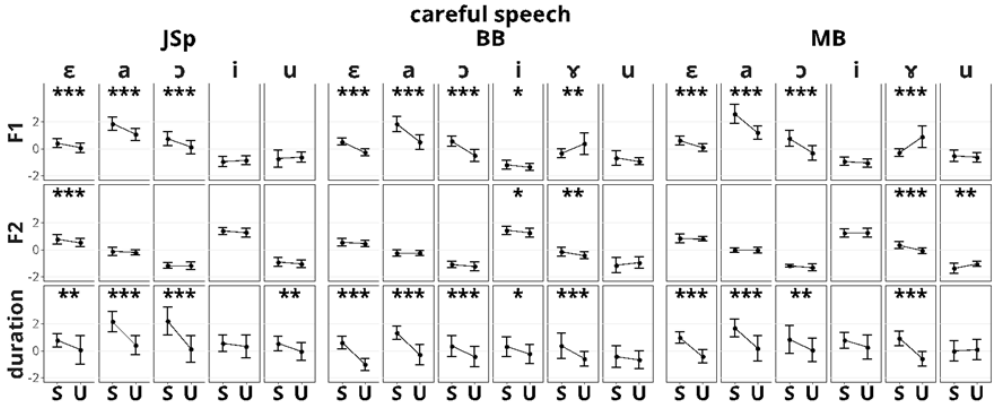

Figure 9. Stressed (S) vs. unstressed (U) vowels in careful speech. LMM: {F1, F2, duration} ~ stress + (1|speaker) + (1|context). *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$. Detailed results are reported in Appendix 4. Dots: means; error bars: SD's.

As can be gleaned from Figure 10., the vowel space undergoes appreciable contraction in unstressed position in all three varieties, though the unstressed area remains larger than half the stressed area in careful speech.

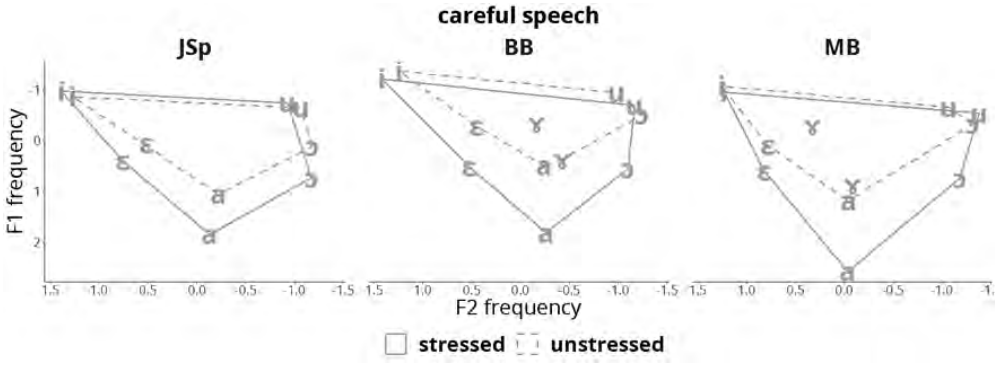

Figure 10. Stressed vs. unstressed vowels in the F1 × F2 space (means) in careful speech. Stressed : unstressed area ratios: JSp 1 : 0.60, BB 1 : 0.54, MB 1 : 0.58.

Probability density functions and bimodality coefficients (BC) for F1 frequency of the non-high vowels, in both stressed and unstressed position, are plotted in Figure 11. Only BB /ɛ/ has a coefficient that exceeds the bimodality benchmark value of 0.555 in careful speech.

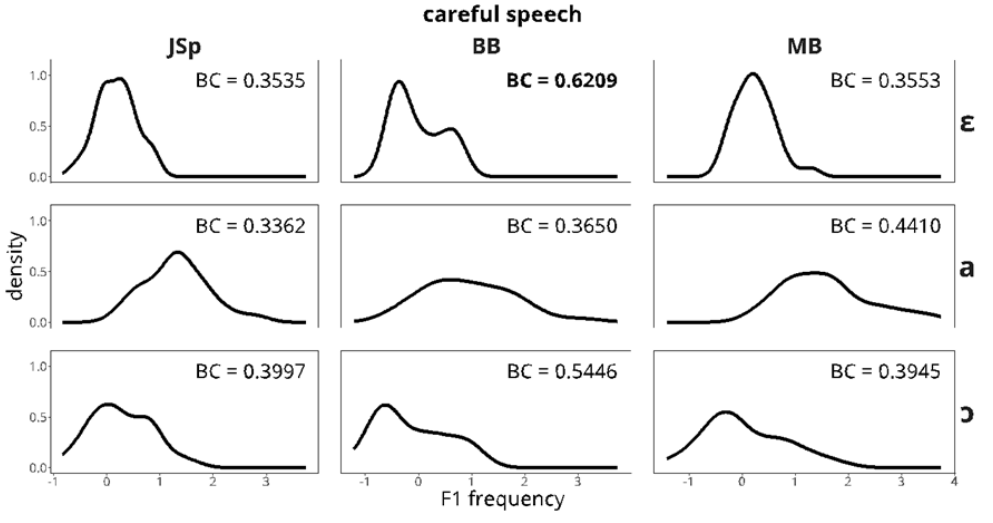

Figure 11. Probability density functions and bimodality coefficients (BC) for F1 frequency of non-high vowels in careful speech (stressed and unstressed together). A distribution is bimodal if BC > 0.555 (shown in bold).

3.3.2. Spontaneous speech

Group means, SD's and LMM results comparing stressed versus unstressed vowels in spontaneous speech are reported in Figure 12. As in careful speech, the unstressed non-high vowels, /ɛ a ɔ/, undergo raising compared to stressed realisations in all varieties. The same applies, albeit to a lesser extent, to JSp /i/, BB /ɤ/, as well as /u/ in all varieties. The high front /i/ is more retracted in unstressed syllables in all varieties, while the same holds true for the non-high front /ɛ/ in Monolingual Bulgarian only. MB /ɤ/ is also retracted when unstressed. On the other hand, JSp /a ɔ u/, BB /a ɔ/ and MB /ɔ/ are more advanced in unstressed position. All vowels except MB /u/ are significantly longer in stressed than in unstressed position in spontaneous speech.

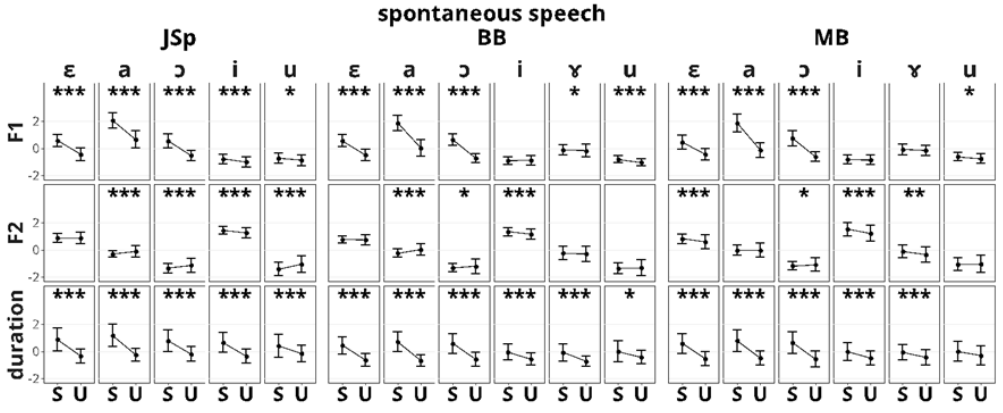

Figure 12. Stressed (S) vs. unstressed (U) vowels in spontaneous speech. LMM: {F1, F2, duration} ~ stress + (1|speaker) + (1|context). *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$. Detailed results are reported in Appendix 4. Dots: means; error bars: SD's.

The stressed versus unstressed F1 × F2 frequency spaces in Figure 13. point to a stronger shrinkage of the unstressed vowel space in spontaneous speech than was the case in careful speech: the unstressed space spans less than half the area of the stressed space, the area reduction being strongest in Monolingual Bulgarian and weakest in Judeo-Spanish.

Probability density functions and bimodality coefficients for F1 frequency of the non-high vowels, in both stress conditions together, are shown in Figure 14, and indicate that bimodality is reached in the non-front vowels, /a ɔ/, in both Bulgarian varieties, but not in Judeo-Spanish.

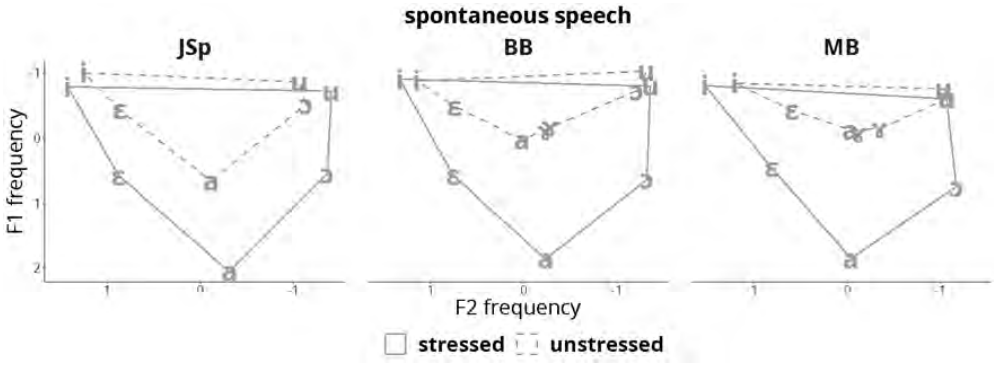

Figure 13. Stressed vs. unstressed vowels in the F1 × F2 space (means) in spontaneous speech. Stressed : unstressed area ratios: JSp 1 : 0.42, BB 1 : 0.29, MB 1 : 0.23.

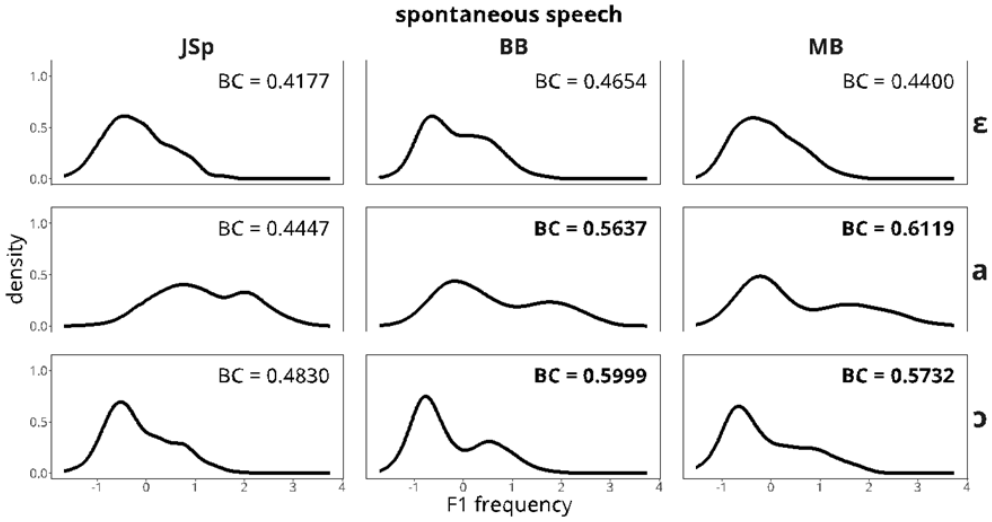

Figure 14. Probability density functions and bimodality coefficients (BC) for F1 frequency of non-high vowels in spontaneous speech (stressed and unstressed together). A distribution is bimodal if BC >0.555 (shown in bold).

3.4. Height contrast: non-high vs. high vowels

The final set of LMM's constructed had vowel as a fixed effect, in order to assess the contrast between non-high and corresponding high vowels, in both stressed and unstressed position. Only significance is indicated here as well; detailed results are

provided in Appendix 5. Once more, careful speech results are followed by those for spontaneous speech.

3.4.1. Careful speech

LMM results for comparisons of non-high versus high vowels in careful speech are given in Figure 15. In stressed position, all three vowel pairs contrast in height in all varieties, as evidenced by the significant differences in F1 frequency. In addition, stressed /i/ is more advanced that stressed /ɛ/ in all varieties, stressed /u/ is more advanced than stressed /ɔ/ in Judeo-Spanish, and stressed /ɤ/ is more advanced than stressed /a/ in Monolingual Bulgarian. Non-high vowels are significantly longer than their high counterparts in all pairs in Bilingual Bulgarian, in MB /a–ɤ/ and /ɔ–u/, and in JSp /ɔ–u/.

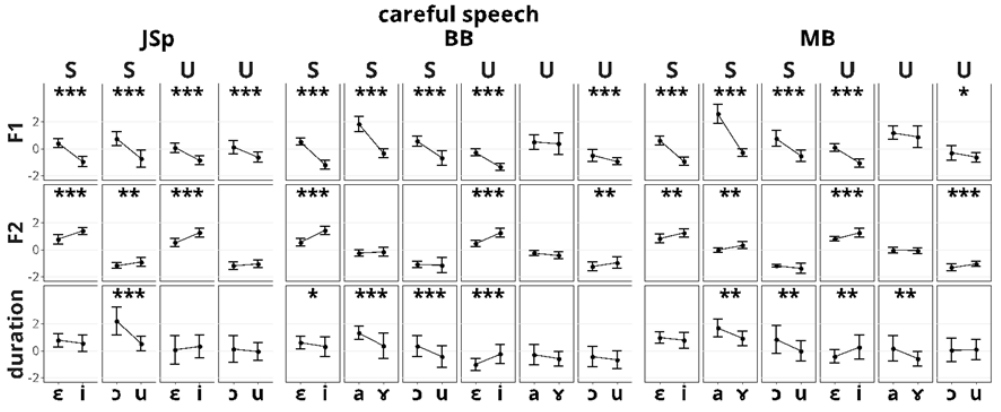

Figure 15. Non-high vs. high vowels in stressed (S) and unstressed (U) position in careful speech. LMM: {F1, F2, duration} ~ vowel + (1|speaker) + (1|context). *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$. Detailed results are reported in Appendix 5. Dots: means; error bars: SD's.

In unstressed syllables in careful speech, contrast is retained in the pairs /ɛ–i/ and /ɔ–u/ in all varieties: unstressed /ɛ/ remains both more open and more retracted than unstressed /i/, and unstressed /ɔ/ remains more open than unstressed /u/, while at the same time unstressed /u/ is now also significantly fronted compared to unstressed /ɔ/ in Bulgarian. In addition and somewhat oddly, in the Bulgarian varieties unstressed /i/ is significantly longer than unstressed /ɛ/. All spectral distinctions are lost in the pair /a–ɤ/ in both Bulgarian varieties. Monolingual Bulgarian, however, retains a significant length difference in this pair, unstressed /a/ remaining longer than unstressed /ɤ/.

3.4.2. Spontaneous speech

Figure 16. compares non-high with corresponding high vowels in spontaneous speech. In stressed syllables, the non-high vowel in each pair is more open, while /ɛ/ is also more retracted than /i/ in all varieties. In Monolingual Bulgarian, stressed /u/ is more advanced than stressed /ɔ/. The non-high vowel in each stressed pair is significantly longer than the corresponding high vowel in all varieties.

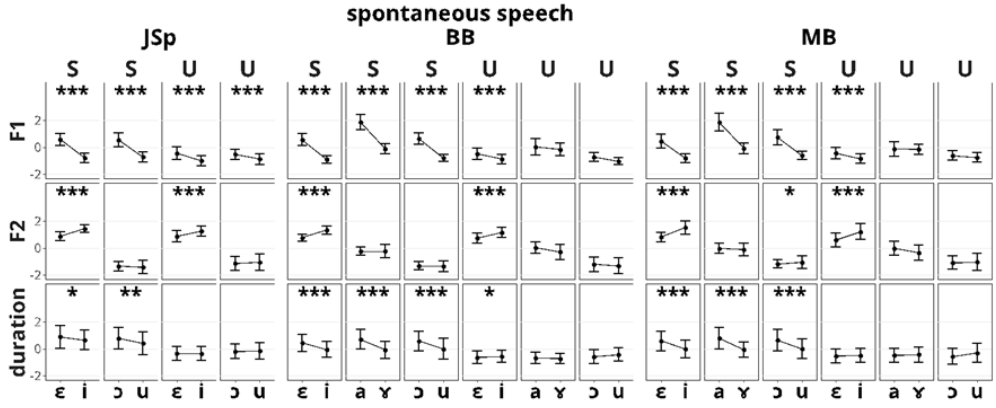

Figure 16. Non-high vs. high vowels in stressed (S) and unstressed (U) position in spontaneous speech. LMM: {F1, F2, duration} ~ vowel + (1|speaker) + (1|context). *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$. Detailed results are reported in Appendix 5. Dots: means; error bars: SD's.

In unstressed position, /ɛ–i/ remain contrastive in all varieties: unstressed /ɛ/ is both more open and more retracted than unstressed /i/. Judeo-Spanish also retains the height contrast in unstressed /ɔ–u/. In both Bulgarian varieties, contrast is completely neutralised in the unstressed non-front pairs, /a–ɤ/ and /ɔ–u/. No durational differences remain significant in unstressed syllables, except for BB /i/ being somewhat longer than BB /ɛ/.

4. DISCUSSION

The preceding sections reported the results of extensive acoustic and statistical analyses, comparing vowel quality and duration across the varieties, speaking styles, stress conditions and within height-contrasting pairs. We now move on to reviewing and interpreting the obtained results.

4.1. Linguistic variety: Judeo-Spanish vs. Bilingual Bulgarian vs. Monolingual Bulgarian

The cross-varietal pairwise comparisons of vowels in Section 3.1 showed that differences are more numerous in duration (N = 23) than in F1 (N = 16) or F2 frequency (N = 14). Overall, vowels tend to be longer in Judeo-Spanish, which in all likelihood is due to a slower speech rate in that variety. Where significant differences in the formant frequencies do exist, they are predominantly small and do not form a clear pattern. It is worth noting that the majority of statistically significant differences are between Judeo-Spanish and Bilingual Bulgarian: 32 out of 53. Of those half are duration, 10 in F1 and 6 in F2 frequency. Virtually all F1 differences between Judeo-Spanish and Bilingual Bulgarian are in unstressed syllables and are paired with significant durational differences. Thus, the more open – and therefore less reduced – realisation of Judeo-Spanish unstressed vowels is at least partly attributable to longer duration. There are very few and very small spectral differences between Judeo-Spanish and Bilingual Bulgarian stressed vowels, and we may therefore conclude that the two bilingual varieties share the same vowel targets. It should be noted, in particular, that there are no significant differences across the three varieties in terms of the first formant frequency of stressed /ɛ/ and /ɔ/, which indicates that Judeo-Spanish does not feature the closer mid qualities [e o] that are typical of Castilian Spanish.

Further patterns emerge from examining the total area of the spectral vowel space. In careful speech, the Monolingual Bulgarian space area is larger than in the bilingual varieties in both stressed and unstressed syllables. In addition, the unstressed area is smaller in Bilingual Bulgarian than in Judeo-Spanish. Spontaneous speech exhibits a different pattern: the vowel space area is largest in Judeo-Spanish, smaller in Bilingual Bulgarian, and smallest in Monolingual Bulgarian, and these differences are considerably more pronounced in unstressed than in stressed position.

4.2. Speaking style: careful vs. spontaneous speech

Vowels in careful speech were compared to those in spontaneous speech in Section 3.2. In stressed syllables, roughly half the vowels in each variety are significantly longer in careful speech, and there are also a few noticeable spectral differences: in spontaneous speech, JSp /u/ is more retracted, while in Monolingual Bulgarian /a/ is closer, /i u/ are fronted and /ɤ/ is retracted. The majority of significant spectral differences are accompanied by significant durational differences. The total vowel space area is smaller in spontaneous speech in Monolingual Bulgarian. In the bilingual varieties, on the other hand, the area appears to be larger in spontaneous than in careful speech. However, given that there are hardly any significant spectral differences in both varieties (one in each), the apparent differences in stressed vowel space areas are merely spurious.

A relatively small number and magnitude of style-related spectral differences in stressed position is not surprising, as vowels are unlikely to overshoot their targets at slower speech rates. In unstressed syllables, on the other hand, one can expect to find a greater number of more conspicuous differences between vowels in careful and spontaneous speech, and indeed that is the case here: there are 17 significant spectral and 13 durational differences in unstressed position, as opposed to 6 spectral and 8 durational differences in stressed syllables. In all varieties, the unstressed non-high vowels, /ɛ a ɔ/, are less raised – and thus less reduced – in careful than in spontaneous speech. Bulgarian unstressed /ɤ/ too has a markedly closer realisation in spontaneous speech. About half the unstressed vowels are significantly longer in careful than in spontaneous speech. Rather surprisingly, Bilingual Bulgarian unstressed /ɛ/ and /u/ happen to be somewhat longer in spontaneous speech. The area of the spectral space is reduced in spontaneous speech when unstressed vowels are concerned, with a clear gradation from minor contraction in Judeo-Spanish, to moderate in Bilingual Bulgarian, to very substantial in Monolingual Bulgarian.

4.3. Word stress: stressed vs. unstressed vowels

Results for the effect of word stress on vowel quality and duration were set out in Section 3.3.

4.3.1. Careful speech

In careful speech, all non-high vowels are raised in unstressed syllables in all varieties, as expected. Bulgarian /ɤ/, on the other hand, is lowered in unstressed position in both varieties. This is a rather intriguing finding, which is in line with the traditional view of Bulgarian vowel reduction, that not only are non-high vowels raised, but high vowels are also lowered, when unstressed (Ternes, Vladimirova-Buhtz 1990; Tilkov et al. 1982). No such lowering was detected in recent experimental research on both careful (Sabev 2023) and read speech (Andreeva et al. 2013; Sabev, Andreeva 2024). The subjects in all those experiments, however, were considerably younger than the participants in the present study, and it is therefore very likely that we are observing age-graded variation. At the same time, while the traditional view of Bulgarian vowel reduction maintains that all high vowels are lowered in unstressed position, the results reported in Section 3.3 offer no evidence of lowering of /i/ and /u/; in fact, Bilingual Bulgarian unstressed /i/ is slightly yet significantly raised.

JSp /ɛ/, BB /i ɤ/ and MB /ɤ/ are retracted in unstressed syllables in careful speech, whereas MB /u/ is fronted. Stressed vowels are, as a rule, significantly longer in all varieties, with only a handful of exceptions, where stressed–unstressed differences are non-significant: JSp /i/, BB /u/, MB /i u/. The contraction of the vowel space in unstressed position in careful speech is only moderate in Judeo-Spanish and

Monolingual Bulgarian, and slightly stronger in Bilingual Bulgarian.

The primary manifestation of Bulgarian vowel reduction is in the raising, or F1 frequency reduction, of unstressed non-high vowels. To determine whether reduction is gradient or categorical, bimodality coefficients were calculated for F1 frequency over all tokens – both stressed and unstressed – of the non-high vowels. The careful speech distributions are unimodal for all Judeo-Spanish and Monolingual Bulgarian vowels, as well as for BB /a/ and /ɔ/, pointing to gradient undershoot under temporal pressure. BB /ɛ/ emerged as bimodal, which is unexpected, since this vowel is least affected by reduction in Standard Bulgarian (Andreeva et al. 2013; Sabev 2023; Sabev, Andreeva 2024; Tilkov et al. 1982). In order to verify whether this puzzling bimodal distribution may be due to inter-speaker variation, individual Bilingual Bulgarian speakers' F1 probability density functions for /ɛ/ were considered, and are plotted in Figure 17. There are indeed some noticeable between-speaker differences; for example, speaker BB1's density peak is at a lower frequency than the peaks of the rest of the speakers. If removed from the calculation, the bimodality coefficient for the rest of the group is 0.5523, which is now below the bimodality threshold of 0.555. We therefore conclude that the bimodal distribution at issue is a consequence of inter-speaker differences, and that – like all other careful speech non-high vowels across the varieties – BB /ɛ/ is subject to gradient undershoot rather than categorical reduction.

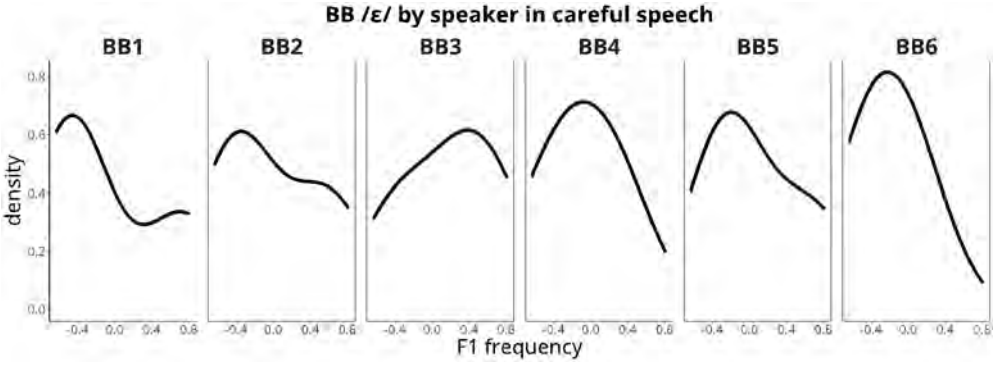

Figure 17. Individual Bilingual Bulgarian speakers' probability density functions for F1 frequency of /ɛ/ in careful speech.

4.3.2. Spontaneous speech

In spontaneous speech too, all unstressed non-high vowels undergo substantial raising in each variety. At the same time, there remains no trace of the lowering of Bulgarian /ɤ/ that was observed in careful speech, nor is there any lowering in the

other high vowels; on the contrary, BB /ɤ u/ and MB /u/ are closer in unstressed than in stressed position. JSp /a ɔ u/, BB /a ɔ/ and MB /ɔ/ are fronted in unstressed syllables, while JSp and BB /i/, as well as MB /ɛ i ɤ/, are retracted. There is significant durational reduction in unstressed position in all vowels across all three varieties, with the sole exception of MB /u/, where there is no significant difference.

Vowel space contraction is considerably greater in spontaneous than in careful speech, with the resultant unstressed space area shrinking to 42% of the stressed area in Judeo-Spanish, to 29% in Bilingual Bulgarian, and to a mere 23% in Monolingual Bulgarian. The lesser vowel space contraction in Judeo-Spanish, however, should be construed in the context of the cross-varietal comparison presented in Section 3.1.2 (Figures 3, 4). While the Judeo-Spanish unstressed spontaneous vowel space is clearly larger than the Bulgarian spaces, the primary source of that size difference is the fact that unstressed /a/ is substantially more open (and thus less reduced) in Judeo-Spanish than in Bulgarian. The rest of the non-high vowels (/ɛ ɔ/), on the other hand, are as raised (and therefore as reduced) in Judeo-Spanish as they are in Bulgarian.

All Judeo-Spanish non-high vowels have unimodal F1 frequency distributions, indicating that unstressed vowel reduction there is – across the board – a product of gradient undershoot in spontaneous speech as well. In the Bulgarian varieties, only /ɛ/ is characterised by a unimodal F1 distribution and therefore gradient undershoot, as expected in accordance with earlier work. The non-front /a/ and /ɔ/, on the other hand, have bimodal F1 frequency distributions. Since L1 learners are typically exposed to spontaneous (if child-directed) speech, and not to citation forms, a next generation is likely to have interpreted such bimodality as two separate targets, one for stressed and one for unstressed vowels. Indeed, Sabev (2023) reports categorical reduction of western Bulgarian /a/ and /ɔ/ in careful speech elicited from younger speakers. In other words, what we witness here is emergent categoricity, or variability that will give rise to the phonologisation of unstressed vowel reduction in a next generation of (western) Bulgarian speakers.

4.4. Height contrast: non-high vs. high vowels

Finally, in Section 3.4., the non-high vowels, /ɛ a ɔ/, were compared to their high counterparts, /i ɤ u/, respectively, in order to determine whether and in what cases the height contrast is neutralised in unstressed position. In stressed syllables in careful speech, all three pairs are significantly distinguished by F1 frequency in all varieties, as expected. Stressed /i/ is more advanced than stressed /ɛ/ in all varieties, which is also predictable. In addition JSp stressed /u/ and MB stressed /ɤ/ are more advanced than their non-high matches, /ɔ/ and /a/, respectively. Stressed non-high vowels are consistently longer than high vowels in Bilingual Bulgarian, while in Monolingual Bulgarian the durational distinction obtains in /a–ɤ/ and /ɔ–u/, and in Judeo-Spanish in /ɔ–u/ only.

In unstressed syllables in careful speech, the contrast is preserved in /ɛ–i/ and /ɔ–u/ in all varieties. There are no significant spectral differences in unstressed /a–ɤ/ in both Bulgarian varieties. In Monolingual Bulgarian, /a/ remains significantly longer than /ɤ/ in unstressed position. However, it is doubtful that this durational difference alone is sufficient to keep the vowels perceptually distinct, as vowel length is not employed on its own as a cue to segmental contrasts in Standard Bulgarian (Sabev, Andreeva 2024). Unstressed /ɛ–i/ are not expected to merge in Standard Bulgarian, and this is confirmed by our results. What is more remarkable is that unstressed /a–ɤ/ are merged, while /ɔ–u/ are not. Thus, unstressed careful speech elicitations lend support to yet another traditional claim about Bulgarian vowel reduction that has been rejected in recent empirical research (Andreeva et al. 2013; Sabev 2023; Sabev, Andreeva 2024), namely that the height contrast is more likely to be neutralised in the unstressed pair /a–ɤ/ than in /ɔ–u/ (Tilkov et al. 1982). As noted in Section 4.3, in careful speech, Bulgarian /ɤ/ is lowered, while /a/ is raised, in unstressed position, meaning that the neutralised quality is of a height that is intermediate between the stressed vowels in the pair – which is what the traditional view maintains (albeit for both non-front pairs).

In spontaneous speech as well, the vowels in the stressed pairs are significantly distinguished by F1 frequency in all varieties. In addition, stressed /i/ is more advanced than stressed /ɛ/ in all varieties once again. Stressed non-high vowels are consistently longer than their high counterparts in spontaneous speech across the varieties. In unstressed position in spontaneous speech, /ɛ–i/ remain contrastive in all varieties and are distinguished by both formant frequencies but not duration, which again is in line with earlier work. In both Bulgarian varieties, the contrast is completely neutralised in the unstressed non-front pairs /a–ɤ/ and /ɔ–u/ in spontaneous speech. In Judeo-Spanish, on the other had, the contrast between unstressed /ɔ–u/ is preserved. This contrast, however, needs to be contextualised in light of our findings in Section 3.1.2, on cross-varietal comparisons, and Section 3.3.2, on the effects of word-stress. As was noted above, unstressed spontaneous /ɔ/ is raised to the same height in Judeo-Spanish as in Bulgarian. What is different is that in Judeo-Spanish unstressed /u/ is also raised in spontaneous speech, creating a pattern that may be understood as a push chain, in which the raising of unstressed /ɔ/ triggers raising in /u/. A parallel high vowel raising can be noted in the front of the vowel space: Judeo-Spanish unstressed /i/ is significantly closer than stressed /i/ in spontaneous speech.

5. CONCLUSIONS

We have presented a comprehensive, systematic acoustic investigation of the vowel system of Bulgarian Judeo-Spanish, an extremely endangered language with only a few elderly speakers still living. Judeo-Spanish vowels were examined in direct comparison with the bilingual speaker's Bulgarian vowels, as well as with the

vowels of monolingual Bulgarian speakers of the same age group. Since Bulgarian is known for its height-neutralising system of unstressed vowel reduction, a special focus was placed on stress-induced differences in vowel quality and duration, as well as on differences between non-high and corresponding high vowels. Two speaking styles were compared for the first time, namely careful and spontaneous speech.

Our vowel comparisons across the three varieties have shown that, in stressed position, there are only negligible spectral differences between Judeo-Spanish and Bilingual Bulgarian, indicating that the bilingual speakers utilise a single system of vowel targets and contrasts, which itself is not different from that of Monolingual Bulgarian. At the same time, vowels tend to be longer in Judeo-Spanish, pointing to a generally slower speech rate in that variety.

A direct comparison of speaking styles detected differences that may be deemed banal: vowels tend to be shorter and, in unstressed syllables, more reduced in spontaneous than in careful speech in all three varieties. However, our differentiated treatment of speaking styles in the rest of the comparisons has also revealed various intriguing dissimilarities in patterns of unstressed vowel reduction and contrast neutralisation. In careful speech, the three varieties exhibit comparable degrees of moderate and gradient unstressed vowel reduction. In spontaneous speech, on the other hand, reduction is considerably stronger. The mid vowels, /ɛ/ and /ɔ/, undergo the same degree of raising in all varieties. The low vowel /a/, on the other hand, is appreciably more reduced in Bulgarian than in Judeo-Spanish. Unstressed vowel reduction remains clearly gradient in spontaneous speech in all three Judeo-Spanish non-high vowels, /ɛ a ɔ/, as well as in Bulgarian /ɛ/. The first formant frequencies of Bulgarian /a/ and /ɔ/, however, follow a discontinuous, bimodal distribution in spontaneous speech which, had gradience not been established in careful speech, could be interpreted as an indication of categorical reduction. We argue that such a bimodal distribution in the speech of the generation under study will have been interpreted as resulting from two categorically separated – stressed versus unstressed – targets by a next generation, and will have thus given rise to the phonologisation of vowel reduction in Standard Bulgarian.

Speaking style also proved to interact with contrast neutralisation in unstressed syllables. In careful speech, the vowels in the pairs /ɛ–i/ and /ɔ–u/ remain distinct in all varieties, while Bulgarian /a–ɤ/ merge. In spontaneous speech too, /ɛ–i/ remain differentiated in all varieties, which is consistent with earlier research. On the other hand, not only /a–ɤ/, but also /ɔ–u/, merge in both Bulgarian varieties in spontaneous speech, which is also in line with recent work. In Judeo-Spanish /ɔ–u/, on the other hand, the contrast is preserved by virtue of a local push chain: both unstressed /ɔ/ and /u/ are raised in spontaneous speech and thus remain acoustically separated.

Finally, two unexpected phenomena were discovered with regard to Bulgarian unstressed vowel reduction and contrast neutralisation. These phenomena were

revealed in careful speech only, and the findings are unexpected, as they corroborate certain traditional claims about Bulgarian vowel reduction that have been repeatedly refuted in recent empirical research. The first of these traditional claims is that Bulgarian high vowels (i.e., /i ɤ u/) are lowered in unstressed position, the second – that /a–ɤ/ are more likely to merge in unstressed position than /ɔ–u/. We found that, for both our monolingual and bilingual Bulgarian speakers, unstressed /ɤ/ is indeed lowered in careful (but not spontaneous) speech. The same is not true for the other high vowels, /i u/, however. Secondly, only unstressed /a–ɤ/, but not /ɔ–u/, were merged in our Bulgarian speakers' careful speech. Recent experimental work based on the speech of much younger speakers found no evidence for either of these phenomena, and this strongly suggests that we have uncovered two cases of age-graded variation. In order to demonstrate conclusively that age-grading is indeed at work here, however, the same experimental design as in this study will have to applied to a cohort of young Bulgarian speakers, and that is a promising avenue for future research.[2]

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[2] In addition, extending the scope of this investigation to other varieties of Judeo-Spanish, such as those spoken in Turkey, Greece and Israel, could cast new light on subtle aspects of language contact that are not clearly evident from comparisons of fewer linguistic varieties.

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Appendix 1: Target words for careful speech
Words and target vowels elicited in careful speech are listed in Table 5.

Table 5. Target words for careful speech, with target vowels underlined.

Judeo-Spanish			Bulgarian		
Word	**Transcription**	**Meaning**	**Word**	**Transcription**	**Meaning**
leche	/ˈlɛ̲tʃɛ/	milk	*цвете*	/ˈ tsvɛ̲tɛ/	flower
derecha	/dɛ̲ˈrɛtʃa/	right	*петел*	/pɛ̲ˈtɛl/	cockerel
leche	/ˈlɛtʃɛ̲/	milk	*цвете*	/ˈtsvɛtɛ̲/	flower
kaza	/ˈka̲za/	house	*маса*	/ˈma̲sa/	table
paras	/pa̲ˈras/	money	*тава*	/ta̲ˈva/	(baking) tray
kaza	/ˈkaza̲/	house	*маса*	/ˈmasa̲/	table
lovo	/ˈlɔ̲vɔ/	wolf	*кофа*	/ˈkɔ̲fa/	bucket
kolores	/kɔ̲ˈlɔrɛs/	colours	*колан*	/kɔ̲ˈlan/	belt
lovo	/ˈlɔvɔ̲/	wolf	*ято*	/ˈjatɔ̲/	flock
dirito	/diˈri̲tɔ/	law	*пиле*	/ˈpi̲lɛ/	chicken
dirito	/di̲ˈritɔ/	law	*листа*	/li̲ˈsta/	leaves (n.)
Amerika	/aˈmɛri̲ka/	America	*сливи*	/ˈsliviˍ/	plums
			гъба	/ˈgɤ̲ba/	mushroom
			фъстък	/fɤ̲ˈstɤk/	peanut
			пламък	/ˈplamɤ̲k/	flame
duda	/ˈdu̲da/	doubt	*куфар*	/ˈku̲far/	suitcase
muzeo	/mu̲ˈzɛ.ɔ/	museum	*бутон*	/bu̲ˈtɔn/	button
sirkulo	/ˈsirku̲lɔ/	circle	*вуду*	/ˈvudu̲/	voodoo

Appendix 2: Cross-varietal comparisons
LMM: {F1, F2, DURATION} ~ VARIETY + (1|SPEAKER) + (1|CONTEXT). Significant LMM's were followed up by Tukey's HSD pairwise tests. Results are shown in Tables 6–9.

Table 6. Cross-varietal comparison of *stressed* vowels in *careful* speech.

		LMM		Tukey's HSD (*p*)		
		p	***r*²**	**JSp–BB**	**BB–MB**	**JSp–MB**
/ɛ/	F1 frequency	0.3139				
	F2 frequency	0.0183	0.12	0.0058	0.1656	0.9515
	duration	0.0509				
/a/	F1 frequency	0.0104	0.23	0.9914	0.0173	0.0153
	F2 frequency	0.0076	0.12	0.0009	0.1787	0.7608
	duration	0.0002	0.26	0.0000	0.3957	0.3567
/ɔ/	F1 frequency	0.2101				
	F2 frequency	0.9272				
	duration	0.0000	0.44	0.0000	0.4297	0.0517
/i/	F1 frequency	0.1996				
	F2 frequency	0.3470				
	duration	0.2540				
/ɤ/	F1 frequency	0.6789		—	—	—
	F2 frequency	0.0130	0.41	—	—	—
	duration	0.3241		—	—	—
/u/	F1 frequency	0.6991				
	F2 frequency	0.0493	0.16	0.3656	0.4944	0.0410
	duration	0.0003	0.29	0.0000	0.5747	0.1518

Table 7. Cross-varietal comparison of unstressed vowels in careful speech.

		LMM		Tukey's HSD (*p*)		
		p	***r*²**	**JSp–BB**	**BB–MB**	**JSp–MB**
/ɛ/	F1 frequency	0.0028	0.17	0.0006	0.0181	0.8763
	F2 frequency	0.0223	0.23	0.3591	0.0066	0.0524
	duration	0.0001	0.27	0.0000	0.1013	0.2002
/a/	F1 frequency	0.0003	0.24	0.0001	0.0004	0.7176
	F2 frequency	0.2096				
	duration	0.0109	0.13	0.0025	0.1691	0.5561
/ɔ/	F1 frequency	0.0002	0.20	0.0000	0.8833	0.0561
	F2 frequency	0.3286				
	duration	0.0177	0.09	0.0043	0.2425	0.9338
/i/	F1 frequency	0.0001	0.30	0.0000	0.0596	0.1017
	F2 frequency	0.7347				

	duration	0.0228	0.09	0.0068	0.2492	0.9995
/ɤ/	F1 frequency	0.0445	0.09	—	—	—
	F2 frequency	0.0055	0.33	—	—	—
	duration	0.9784		—	—	—
/u/	F1 frequency	0.0191	0.13	0.0089	0.9877	0.0660
	F2 frequency	0.4692				
	duration	0.0013	0.20	0.0002	0.8148	0.0043

Table 8. Cross-varietal comparison of stressed vowels in spontaneous speech.

		LMM		**Tukey's HSD (*p*)**		
		p	***r*²**	**JSp–BB**	**BB–MB**	**JSp–MB**
/ɛ/	F1 frequency	0.6741				
	F2 frequency	0.0070	0.03	0.0001	0.3420	0.8127
	duration	0.0007	0.06	0.0000	0.1372	0.8107
/a/	F1 frequency	0.0368	0.02	0.0123	0.1799	0.9785
	F2 frequency	0.0585				
	duration	0.0009	0.04	0.0000	0.2061	0.9216
/ɔ/	F1 frequency	0.2510				
	F2 frequency	0.3660				
	duration	0.1801				
/i/	F1 frequency	0.0401	0.03	0.0096	0.9997	0.3383
	F2 frequency	0.0494	0.04	0.0279	0.7427	0.2052
	duration	0.0000	0.17	0.0000	0.0000	0.9423
/ɤ/	F1 frequency	0.9279	0.09	—	—	—
	F2 frequency	0.4238	0.09	—	—	—
	duration	0.8620	0.09	—	—	—
/u/	F1 frequency	0.1952				
	F2 frequency	0.0001	0.10	0.8432	0.0002	0.0018
	duration	0.0066	0.06	0.0137	0.0143	0.9955

Table 9. Cross-varietal comparison of *unstressed* vowels in *spontaneous* speech.

		LMM		**Tukey's HSD (*p*)**		
		p	***r*²**	**JSp–BB**	**BB–MB**	**JSp–MB**
/ɛ/	F1 frequency	0.4718				
	F2 frequency	0.0006	0.07	0.0002	0.0184	0.0000
	duration	0.0003	0.07	0.0001	0.3200	0.0512

/a/	F1 frequency	0.0000	0.22	0.0000	0.0541	0.0000
	F2 frequency	0.0032	0.02	0.0000	0.8971	0.5336
	duration	0.0000	0.12	0.0000	0.0000	0.0000
/ɔ/	F1 frequency	0.0001	0.06	0.0000	0.0591	0.0588
	F2 frequency	0.1199				
	duration	0.0000	0.10	0.0000	0.9611	0.0000
/i/	F1 frequency	0.0311	0.03	0.0077	0.8226	0.1271
	F2 frequency	0.2242				
	duration	0.0068	0.03	0.0001	0.4860	0.2623
/ɤ/	F1 frequency	0.7907		—	—	—
	F2 frequency	0.7971		—	—	—
	duration	0.0493	0.09	—	—	—
/u/	F1 frequency	0.1518				
	F2 frequency	0.2054				
	duration	0.1689				

Appendix 3: Speaking style
LMM: {F1, F2, DURATION} ~ `style + (1|`SPEAKER) + (1|CONTEXT)
Results are shown in Tables 10 and 11.

Table 10. Careful vs. spontaneous speech: *stressed* vowels.

		JSp		**BB**		**MB**	
		p	***r*²**	***p***	***r*²**	***p***	***r*²**
/ɛ/	F1 frequency	0.0645		0.8341		0.2207	
	F2 frequency	0.6897		0.1286		0.9532	
	duration	0.5494		0.2815		0.0564	
/a/	F1 frequency	0.2876		0.9467		0.0029	0.04
	F2 frequency	0.6766		0.5496		0.6752	
	duration	0.0000	0.10	0.0084	0.04	0.0003	0.06
/ɔ/	F1 frequency	0.1492		0.5053		0.9839	
	F2 frequency	0.1011		0.7499		0.6458	
	duration	0.0000	0.23	0.7892		0.1396	
/i/	F1 frequency	0.2407		0.0385	0.05	0.1971	
	F2 frequency	0.4634		0.6133		0.0412	0.04
	duration	0.6115		0.0028	0.10	0.0009	0.07
/ɤ/	F1 frequency	—		0.0741		0.1598	
	F2 frequency	—		0.7113		0.0094	0.12

	duration	—		0.0013	0.19	0.0000	0.28
/u/	F1 frequency	0.5822		0.3022		0.3430	
	F2 frequency	0.0007	0.16	0.9948		0.0485	0.06
	duration	0.6521		0.2163		0.9298	

Table 11. Careful vs. spontaneous speech: *unstressed* vowels.

		JSp		BB		MB	
		p	***r*²**	***p***	***r*²**	***p***	***r*²**
/ɛ/	F1 frequency	0.0000	0.08	0.0288	0.01	0.0000	0.10
	F2 frequency	0.0000	0.05	0.0060	0.04	0.1529	
	duration	0.0000	0.10	0.0005	0.04	0.3244	
/a/	F1 frequency	0.0006	0.03	0.0142	0.02	0.0000	0.21
	F2 frequency	0.1638		0.0133	0.02	0.6890	
	duration	0.0000	0.11	0.0005	0.03	0.0000	0.06
/ɔ/	F1 frequency	0.0000	0.21	0.0157	0.03	0.0014	0.04
	F2 frequency	0.5695		0.6648		0.0597	
	duration	0.0231	0.04	0.0701		0.0001	0.06
/i/	F1 frequency	0.0970		0.0000	0.14	0.0044	0.05
	F2 frequency	0.3135		0.3813		0.8529	
	duration	0.0000	0.23	0.0051	0.05	0.0000	0.20
/ɤ/	F1 frequency	—		0.0141	0.10	0.0000	0.48
	F2 frequency	—		0.2441		0.0210	0.07
	duration	—		0.1612		0.6603	
/u/	F1 frequency	0.0616		0.2206		0.3465	
	F2 frequency	0.7500		0.1405		0.1166	
	duration	0.3295		0.0044	0.14	0.1066	

Appendix 4: Word stress
LMM: {F1, F2, DURATION} ~ STRESS + (1|SPEAKER) + (1|CONTEXT)
Results are shown in Tables 12 and 13.

Table 12. Stressed vs. unstressed vowels in *careful* speech.

		JSp		BB		MB	
		p	***r*²**	***p***	***r*²**	***p***	***r*²**
/ɛ/	F1 frequency	0.0000	0.21	0.0000	0.67	0.0005	0.38
	F2 frequency	0.0001	0.14	0.1672		0.6778	

	duration	0.0012	0.14	0.0000	0.75	0.0000	0.65
/a/	F1 frequency	0.0000	0.39	0.0000	0.53	0.0000	0.58
	F2 frequency	0.0732		0.3618		0.8621	
	duration	0.0000	0.57	0.0000	0.57	0.0000	0.40
/ɔ/	F1 frequency	0.0000	0.21	0.0000	0.59	0.0000	0.44
	F2 frequency	0.6044		0.1993		0.1157	
	duration	0.0000	0.44	0.0006	0.19	0.0082	0.13
/i/	F1 frequency	0.1929		0.0356	0.06	0.2974	
	F2 frequency	0.0990		0.0153	0.06	0.9491	
	duration	0.1706		0.0270	0.12	0.0632	
/ɤ/	F1 frequency	—		0.0053	0.20	0.0005	0.36
	F2 frequency	—		0.0071	0.16	0.0000	0.41
	duration	—		0.0001	0.29	0.0000	0.60
/u/	F1 frequency	0.3716		0.0843		0.4059	
	F2 frequency	0.1726		0.1929		0.0017	0.22
	duration	0.0028	0.17	0.1208		0.6270	

Table 13. Stressed vs. unstressed vowels in *spontaneous* speech.

		JSp		**BB**		**MB**	
		p	***r*²**	***p***	***r*²**	***p***	***r*²**
/ɛ/	F1 frequency	0.0000	0.50	0.0000	0.56	0.0000	0.47
	F2 frequency	0.5650		0.5416		0.0000	0.05
	duration	0.0000	0.43	0.0000	0.49	0.0000	0.46
/a/	F1 frequency	0.0000	0.54	0.0000	0.67	0.0000	0.72
	F2 frequency	0.0000	0.06	0.0000	0.08	0.8880	
	duration	0.0000	0.55	0.0000	0.59	0.0000	0.49
/ɔ/	F1 frequency	0.0000	0.58	0.0000	0.76	0.0000	0.68
	F2 frequency	0.0000	0.05	0.0186	0.01	0.0431	0.01
	duration	0.0000	0.35	0.0000	0.46	0.0000	0.43
/i/	F1 frequency	0.0000	0.06	0.4973		0.3353	
	F2 frequency	0.0000	0.08	0.0000	0.06	0.0000	0.08
	duration	0.0000	0.38	0.0000	0.19	0.0000	0.14
/ɤ/	F1 frequency	—		0.0318	0.02	0.3253	
	F2 frequency	—		0.2488		0.0021	0.06
	duration	—		0.0000	0.29	0.0005	0.10
/u/	F1 frequency	0.0382	0.03	0.0005	0.14	0.0129	0.06
	F2 frequency	0.0002	0.09	0.9611		0.7526	
	duration	0.0000	0.14	0.0215	0.05	0.1646	

Appendix 5: Height contrast
LMM: {F1, F2, duration} ~ vowel + (1|speaker) + (1|context)
Results are shown in Tables 14–17.

Table 14. Non-high vs. high *stressed* vowels in *careful* speech.

		JSp		BB		MB	
		p	***r*²**	***p***	***r*²**	***p***	***r*²**
/ɛ–i/	F1 frequency	0.0000	0.79	0.0000	0.89	0.0000	0.86
	F2 frequency	0.0000	0.46	0.0000	0.69	0.0090	0.31
	duration	0.0927		0.0293	0.05	0.3862	
/a–ɤ/	F1 frequency	—		0.0000	0.85	0.0000	0.88
	F2 frequency	—		0.3619		0.0018	0.44
	duration	—		0.0001	0.28	0.0010	0.30
/ɔ–u/	F1 frequency	0.0000	0.62	0.0000	0.65	0.0000	0.60
	F2 frequency	0.0036	0.16	0.4966		0.0504	
	duration	0.0000	0.40	0.0001	0.19	0.0031	0.18

Table 15. Non-high vs. high *unstressed* vowels in *careful* speech.

		JSp		BB		MB	
		p	***r*²**	***p***	***r*²**	***p***	***r*²**
/ɛ–i/	F1 frequency	0.0000	0.64	0.0000	0.80	0.0000	0.80
	F2 frequency	0.0000	0.59	0.0000	0.63	0.0000	0.46
	duration	0.2502		0.0000	0.31	0.0013	0.18
/a–ɤ/	F1 frequency	—		0.4902		0.1099	
	F2 frequency	—		0.1482		0.4184	
	duration	—		0.1108		0.0012	0.19
/ɔ–u/	F1 frequency	0.0000	0.36	0.0006	0.26	0.0257	0.11
	F2 frequency	0.1373		0.0079	0.11	0.0008	0.22
	duration	0.3137		0.1695		0.8052	

Table 16. Non-high vs. high *stressed* vowels in *spontaneous* speech.

		JSp		BB		MB	
		p	***r*²**	***p***	***r*²**	***p***	***r*²**
/ɛ–i/	F1 frequency	0.0000	0.73	0.0000	0.79	0.0000	0.67
	F2 frequency	0.0000	0.43	0.0000	0.52	0.0000	0.41
	duration	0.0118	0.02	0.0000	0.15	0.0000	0.15
/a–ɤ/	F1 frequency	—		0.0000	0.72	0.0000	0.59
	F2 frequency	—		0.8179		0.3900	
	duration	—		0.0000	0.19	0.0000	0.15
/ɔ–u/	F1 frequency	0.0000	0.58	0.0000	0.72	0.0000	0.58
	F2 frequency	0.4836		0.5332		0.0465	0.02
	duration	0.0049	0.04	0.0000	0.10	0.0000	0.12

Table 17. Non-high vs. high *unstressed* vowels in *spontaneous* speech.

		JSp		BB		MB	
		p	***r*²**	***p***	***r*²**	***p***	***r*²**
/ɛ–i/	F1 frequency	0.0000	0.22	0.0000	0.19	0.0000	0.21
	F2 frequency	0.0000	0.13	0.0000	0.22	0.0000	0.23
	duration	0.8155		0.0399	0.01	0.2600	
/a–ɤ/	F1 frequency	—		0.3374		0.7105	
	F2 frequency	—		0.5664		0.1779	
	duration	—		0.2352		0.4341	
/ɔ–u/	F1 frequency	0.0000	0.14	0.2557		0.1015	
	F2 frequency	0.2855		0.3565		0.4250	
	duration	0.6467		0.1046		0.0950	

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