VOWEL ACOUSTICS OF VOLGA TATAR

Jenna Conklin[1], Olga Dmitrieva[1]

[1]Purdue University
jconkli@purdue.edu, odmitrie@purdue.edu

ABSTRACT

This paper presents an acoustic analysis of the vocalic system of Volga Tatar, an understudied Turkic language of Russia exhibiting front-back vowel harmony, based on data from 27 native speakers recorded in Tatarstan. The Tatar vowel system is phonologically symmetric, with five [-back] and five [+back] vowel phonemes. However, for many phonemes, the phonetic realization does not reflect the clean symmetry of the phonological system: rather than being equally dispersed throughout the vowel space, five of the ten phonemes are centralized, crowding the center of the F2xF1 vowel space. As the first large-scale spectrographic analysis of Tatar vowels, this paper outlines the acoustic profile of each phoneme, discusses selected allophonic alternations, and examines the effect of word-level prominence on vowel production.

Keywords: Tatar; vowels; stress; acoustics.

1. INTRODUCTION

Volga Tatar [ISO 639-3 code tat] is a member of the Kipchak branch of the Turkic language family spoken by 5 million speakers around the world [5]; its largest community is located in the Republic of Tatarstan in Russia [13]. Like many Turkic languages, Tatar is known for its vowel harmony: backness harmony in Tatar is well-attested and affects all the vowels of the language, while rounding harmony is restricted to mid vowels and has a disputed status (see [5][7][11] for varying accounts of Tatar rounding harmony). Work on Tatar phonology typically focuses on vowel harmony, but despite this focus on vocalic processes, no formal acoustic description of the Tatar vowel system is available. The purpose of this paper is to provide an acoustic description of Tatar vowel phonemes across a wide cross-section of speakers.

Previous descriptions of the Tatar vowel inventory do not agree about how many vowel phonemes exist in Tatar; some report nine [3][11][13] and some ten [5] (see Table 1). This discrepancy arises due to differing treatment of the vowel /ɨ/, which is analysed either as a VC sequence /əj/ [3] or as a single, frequently diphthongized, phoneme /ɨ/ [5]. The argument for the phonemic status of /ɨ/ rests on parallel diphthongization of the high vowel /i/, as well as established harmonic alternations between /i/ and /ɨ/ [5]. This paper argues for independent phonemic status for /ɨ/ on phonological and acoustic grounds.

Table 1: Vowels of Tatar (* marks disputed status)

	[-back]		[+back]	
	[-rnd]	[+rnd]	[-rnd]	[+rnd]
[+hi][-lo]	/i/	/ʉ/	/ɨ/*	/u/
[-hi][-lo]	/e/	/ø/	/ə/	/o/
[-hi][+lo]	/æ/		/ɑ/	

While the Tatar vowel system is phonologically symmetrical, exhibiting a satisfying balance between front and back vowels, the phonetic distribution of Tatar vowels is not so even. The four mid vowels and /ʉ/ are highly centralized [5][11]; mid vowel centralization hearkens back to the Volga vowel shift, a historical change that reversed the high and mid vowels in Volga Turkic languages [2]. Because of this, the acoustic analysis is expected to reveal a high degree of crowding in the centre of the vowel space.

This paper will also examine allophonic alternations for /ɨ/ and /ɑ/. It is widely recognized that the phoneme /ɑ/ has two allophones, a rounded allophone [ɒ] surfacing in initial syllables and an unrounded allophone [ɑ] in non-initial syllables [3][5][11], while /ɨ/ undergoes diphthongization in stressed syllables [5]. This paper will verify acoustically what previous work has established impressionistically, recording the acoustic qualities of these phonemes and allophones and exploring the influence of stress on Tatar vowel production.

1.1. Tatar vowel harmony

Backness harmony is widespread and well-described in Tatar, while rounding harmony is disputed. In backness harmony, the vocalic system is divided evenly into two classes of five, such that allomorphs with front vowels surface when the stem is front and back allomorphs appear with back vowel stems. This process is most consistent in lexemes of Turkic origin and older loans from Arabic or Farsi, although many disharmonic roots exist among loanwords. Recent loans, particularly from Russian, introduce additional vowels and frequently disobey harmony; due to high levels of bilingualism, Russian loans generally exhibit Russian phonology [5].

Previous descriptions of Tatar agree that Tatar mid vowel sequences led by /o/ or /ø/ show unusual behaviour; conflicting accounts ascribe this to rounding harmony [7], phonotactics [11], and gradient assimilation [5]. To avoid any confusion, this work only examines initial /o/ and /ø/ and instances of /e/ and /ə/ not preceded by /o/ or /ø/.

1.2. Tatar stress

Previous works agree that Tatar word-level stress falls on the final syllable, with a few exceptions controlled by morphology and syntax [3][5][11][13].

2. METHODS

Twenty-seven native Tatar speakers raised in Tatarstan (26 F, 1 M; 18 – 68 years) completed a sentence reading task recorded with a Lavalier AT831b lapel-mounted cardioid condenser microphone and a Marantz PMD661MKII solid state recorder in a quiet room in Kazan. Recordings were digitized at 44.1 kHz and target vowels segmented by hand in Praat [4]. The first two formants were extracted at vowel midpoint with Praat's LPC algorithm; values were checked visually and corrected by hand where necessary. For oft-diphthongized /ɨ/, additional formant measurements were taken at 10, 20, 80, and 90% of vowel duration. Log-additive regression normalization was applied to reduce interspeaker variation [1]. Two linear mixed models were used to determine the degree of difference between vowels in SPSS v. 24.0.0.0 [6].

2.1. Stimuli

Thirty Tatar words provided samples of each vowel in a variety of consonantal contexts, exemplified in Table 2; all target words exhibit canonical, word-final stress. Due to phonotactic restrictions and concerns about rounding harmony, stressed /o/, stressed /ø/, and unstressed /e/ were not included.

Table 2: Sample stimuli

Tatar	IPA	Gloss
үрмәкүч	/ʉrmækʉɕ/	'spider'
колак	/qolɑq/	'ear'
сәке	/sæke/	'plank bed'
ипи	/ipi/	'bread'
урман	/urmɑn/	'forest'

3. RESULTS

3.1. Tatar vowel space

Figure 1 displays the Tatar vowel space occupied by its ten phonemes (shown with 68% confidence ellipses) [9]. Table 3 displays average formant values (in Hz) at midpoint for each vowel, with separate values for the stressed and unstressed variants.

Figure 1: Tatar vowels (/ɨ/ restricted to unstressed syllables to exclude diphthongized variant)

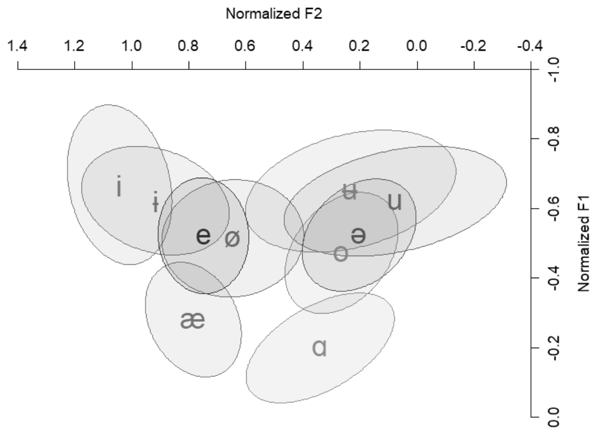


Table 3: F1 & F2 means at vowel midpoint in stressed and unstressed syllables by vowel

Phoneme	N=Stressed, Unstressed	Stressed		Unstressed	
		F1 (Hz)	F2 (Hz)	F1 (Hz)	F2 (Hz)
/i/	N=220, 368	476.25	2584.40	462.94	2565.53
/e/	N=351, 0	539.11	1916.83	--	--
/æ/	N=524, 943	672.52	1977.73	691.54	1990.17
/ʉ/	N=70, 217	494.47	1489.13	469.46	1077.76
/ø/	N=0, 150	--	--	543.33	1742.22
/ə/	N=76, 77	545.91	1027.03	533.57	1208.62
/ɑ/	N=492, 305	771.97	1392.64	696.87	1110.46
/o/	N=0, 187	--	--	567.28	1187.13
/u/	N=75, 189	508.13	1345.96	482.39	878.85
/ɨ/	N=73, 136	515.88	1927.55	487.21	2285.63

3.2. Results of LMMs: Vowels

Two linear mixed models with dependent variables of normalized F1 and F2 were used to confirm the efficacy of F1 and F2 in distinguishing the ten vowels across stress positions. A random factor of Subject, fixed factors of Vowel (ten levels) and Stress (Stressed vs. Unstressed), and a Vowel by Stress interaction were included in each model. The factor Vowel was significant in both models (F1 model: $F(9, 4410.411) = 1188.224$, $p < 0.001$; F2 model: $F(9, 4410.795) = 2093.162$, $p < 0.001$); Table 4 presents the pairwise comparisons between vowels (with

Table 4: Pairwise comparison of factor Vowel with Bonferroni correction. *** indicates p < 0.001, ** p < 0.01, and * p < 0.05. "NS" indicates not significant. Cells right of the grey diagonal correspond to F2; those left of the grey cells, F1.

	/i/	/e/	/æ/	/ʉ/	/ø/	/ə/	/ɑ/	/o/	/u/	/ɨ/
/i/		***	***	***	***	***	***	***	***	***
/e/	***		**	***	***	***	***	***	***	***
/æ/	***	***		***	***	***	***	***	***	***
/ʉ/	NS	***	***		***	***	NS	*	***	***
/ø/	***	NS	***	***		***	***	***	***	***
/ə/	***	NS	***	***	NS		***	**	NS	***
/ɑ/	***	***	***	***	***	***		**	***	***
/o/	***	***	***	***	*	***	***		***	***
/u/	***	***	***	NS	***	***	***	***		***
/ɨ/	***	***	***	**	***	***	***	***	NS	

Bonferroni adjustment). Across the models, eight vowel pairs failed to differ significantly with regard to either F1 or F2; all vowel pairs were significantly different in at least in one dimension (F1 or F2).

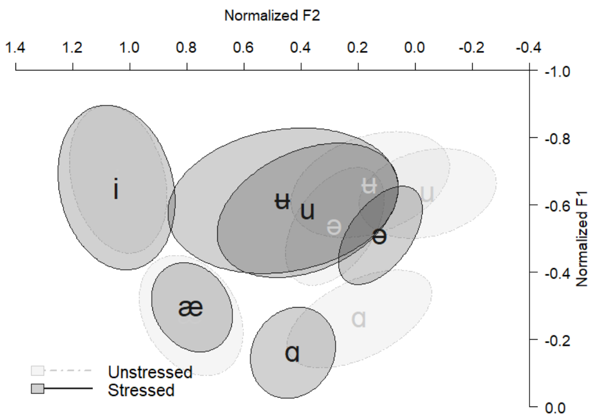
3.3. Results of LMMs: Stress and Stress by Vowel

The main effect of Stress was significant in both models (F1: F(1, 4410.167) = 69.039, $p < 0.001$; F2: F(1, 4410.351) = 226.731, $p < 0.001$), as was the Stress by Vowel interaction (F1: F(6, 4410.288) = 28.356, $p < 0.001$; F2: F(6, 4410.573) = 212.908, $p < 0.001$). Pairwise comparisons of the interaction with Bonferroni adjustment indicated a significant effect of stress on each vowel for either F1 or for F2, as summarized in Table 5.

Table 5: Significance (value of p) for pairwise comparisons for Stress by Vowel interaction

	F1	F2		F1	F2
/i/	<0.01	NS	/ɨ/	<0.001	<0.001
/e/	--	--	/ə/	NS	<0.001
/æ/	<0.001	NS	/ɑ/	<0.001	<0.001
/ʉ/	<0.01	<0.001	/u/	<0.01	<0.001
/ø/	--	--	/o/	--	--

Figure 2: Stressed and unstressed Tatar vowels in F2xF1 space with 68% confidence ellipses

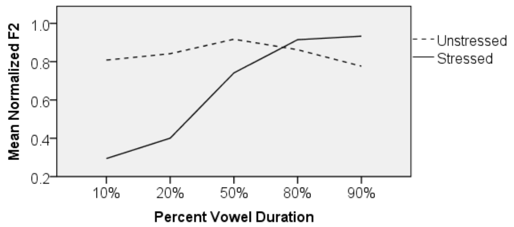


The direction of these effects is illustrated in Figure 2, which displays the F2xF1 space for stressed and unstressed vowels (excluding /ɨ/, which is discussed in 3.3.1, and /o/, /ø/, and /e/, for which both stressed and unstressed measurements were not available). Striking changes to the position and variability of several phonemes emerge under stress. The high round vowels /ʉ/ and /u/, in particular, exhibit far greater variability when stressed, while the front vowel /æ/ exhibits greater variability when stressed. F2 of stressed /ə/ falls, pushing this variant toward the periphery of the vowel space, while /ɑ/ shifts down and forward under stress. For /ɑ/, the stressed/unstressed division corresponds to the distribution of its rounded and unrounded allophones, with stress falling on the non-initial, unrounded allophone (in the stimuli used here).

3.3.1. High back unrounded vowel

Stress triggers a marked change in the behaviour of the phoneme /ɨ/, which diphthongizes under stress. This change is reflected acoustically through F2 movement, as shown in Figure 3.

Figure 3: F2 values of Tatar /ɨ/ across five time points in the stressed and unstressed conditions

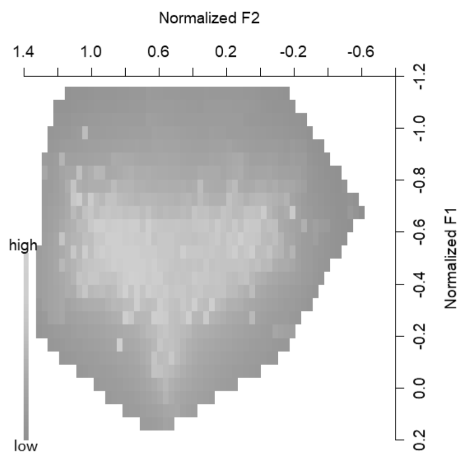


F2 of stressed [ɨj] begins low, rises by vowel midpoint, and remains high until offset. By contrast, unstressed [ɨ] has a relatively steady F2, arcing neatly from onset to offset with the highest F2 at midpoint, as is typical for monophthongs. Stressed [ɨj] also has a greater duration (M=99.70 ms; SD=34.061) than unstressed [ɨ] (M=66.45 ms; SD=21.106), which may have reinforced its propensity to diphthongize.

3.4. Repulsive force

To confirm the visual impression of central vowel space crowding given in Figure 1, the degree of repulsive force between vowels was calculated using the phonR package [9] in R [12]. Repulsive force is calculated using the inverse squared sum of the Euclidean distance between each vowel as a measure of dispersion [8][17]. Higher values of repulsive force

Figure 4: Heatmap of Tatar vowel space



indicate greater overlap between phonemes [10]. Figure 4 (above) shows a heatmap displaying the degree of repulsive force at each F2xF1 point in the Tatar vowel space. In Figure 4, the greatest crowding appears just forward of the centre of the vowel space, particularly in the high-mid range, and central crowding is not as pronounced as in the F2xF1 plot.

4. DISCUSSION

The phonological structure of the Tatar vowel system is symmetrical, with ten vowels evenly distributed across three levels of height, two of backness, and two of rounding. Phonetically, several Tatar vowels congregate in the central vowel space; the centralized mid vowels, alongside /ʉ/ and /ɨ/, contribute to overlap and greater repulsive force just inside the periphery. This central vowel space crowding contradicts an established typological trend for vowels to be evenly dispersed in the vowel space or concentrated in the periphery [15], rendering Tatar cross-linguistically unusual with regard to its vowel inventory. This rare trait is due in part to the Volga vowel shift, which reduced, centralized, and lowered once-high vowels to modern /e, ɘ, o, ø/ and raised historically mid vowels to /i, ɨ, u, ʉ/. The resultant centralization may owe its preservation in part to vowel harmony, which weakens the need for a clear distinction in backness, since the value of [back] for an entire word can be inferred from the initial vowel. If this is true, we may expect to find similarly weak F2 distinctions in other harmonizing languages, including those without a historical centralization process. [16] documents notable formant overlap across phonemes in three such languages, Turkish, Kyrgyz, and, to some degree, Kazakh, lending merit to the idea that backness harmony weakens the need for F2 to serve as a strong cue of vowel backness.

4.1. The phonological status of /ɨ/

One major disagreement in earlier work on the Tatar vowel system relates to the number of phonemes, specifically whether the high back unrounded vowel /ɨ/ consists underlyingly of one phoneme or two. Standard Tatar orthography reinforces the perception of /ɨ/ as a two-phoneme sequence by representing it with two graphemes, biasing native speaker intuitions on the question. Because of this, acoustic and phonological evidence provide more reliable arguments for phonemicity, and both plead in favour of /ɨ/ as a phoneme. Acoustic analysis shows that diphthongization of /ɨ/ occurs only in stressed environments; when unstressed, /ɨ/ is monophthongal. Furthermore, mean F2 of unstressed, monophthongal /ɨ/ differs significantly from that of unstressed /ɘ/, the phoneme proposed by [3] to fill the place of /ɨ/ in the nine-phoneme inventory (1088 Hz difference, $p<0.001$ in pairwise comparisons of Vowel by Stress). Thus, acoustic evidence argues for inclusion of /ɨ/ as a distinct phoneme. Phonological evidence strengthens this argument. In the negative suffix -/mI/, /ɨ/ alternates with /i/ with regard to harmony, suggesting that these vowels occupy parallel positions in Tatar phonology.

4.2. The impact of stress on the Tatar vowel space

Stress affects Tatar vowel articulation profoundly, causing /ɨ/ to diphthongize and /y/, /u/, /ɑ/, and /ɨ/ to shift their position within the F2xF1 space. But by far the most dramatic change accompanying stress is the increase in F2 variability exhibited by stressed (but not unstressed) /u/ and /ʉ/. This may be due to vowel harmony: since the value of the feature [back] is specified for the word in the first syllable, and since stressed vowels are always word-final, the value of [back] and thus, the distinction between /u/ and /ʉ/ can be inferred from the first syllable of the word. Thus, in multisyllabic words, greater variability in the final syllable does not automatically result in a loss of intelligibility.

4.4. Allophones of /ɑ/

Previous impressionistic accounts have proposed that Tatar /ɑ/ alternates between an initial round allophone [ɒ] and unrounded, noninitial [ɑ], corresponding in the present stimuli to stressed [ɑ] and unstressed [ɒ]. (This division typifies the standard variety of Tatar; degree of rounding in /ɑ/ is also a dialectal marker that undergoes significant geographic variation [14].) The present data confirm this assessment by demonstrating that /ɑ/ is higher and more retracted when unstressed, as visible in Figure 2, a change compatible with the effect of lip rounding.

5. CONCLUSIONS

This paper reports the first large-scale spectrographic description of Tatar vowels and documents two typologically unusual traits: crowding of the central vowel space and dramatically increased F2 variability among stressed high round vowels. Both are potentially explainable by vowel harmony, which pre-specifies the backness of all noninitial vowels. This theory is supported by data from other harmonizing languages displaying a weak F2 backness distinction [16].

6. REFERENCES

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