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Place And Manner Contrasts In Komi-Permyak Obstruents: An Acoustic Study

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ABSTRACT

In this study we examine the acoustic properties of a relatively complex set of obstruents found in Komi-Permyak: voiceless and voiced denti-alveolar stops and fricatives, apical and laminal post-alveolar affricates and fricatives, and palatal stops. The results show that these consonants are well differentiated by a range of acoustic properties – both durational and spectral – as a combined effect of their differences in place and manner of articulation. The study provides an acoustic record of this endangered Finno-Ugric language. It also presents an example of how a language can exploit non-linear articulatory/acoustic relations to maintain a marked set of phonological contrasts.

1 INTRODUCTION

Investigations of the sound inventories of world languages have shown that there are certain cross-linguistic preferences as to the number of place of articulation contrasts as well as their realization [1]. Most languages tend to limit their place contrasts in stops/affricates to 3 or 4 consonants (63.4% of 317 languages in the UCLA Phonological Segment Inventory Database [1]); very often these consonants are /p t k/ or /p t tʃ k/. A smaller number of languages allow a five-way place contrast (27.4%); this commonly involves a more elaborate set of coronal consonants, resulting from the addition of a palatal or a retroflex stop, /c/ or /ʈ/. A yet a much smaller number of languages permit six-way (7.9%) or seven-way (0.2%) place contrasts in stops and affricates.

Komi-Permyak is one of the languages that exhibit multiple contrasts of this type: it allows six places of articulation among stops/affricates, four of which involve coronal consonants. In addition, the language shows a relatively unusual three-way distinction among sibilant fricatives. In this paper we investigate the acoustic properties of some of these Komi-Permyak obstruents. By doing this we also aim to provide an acoustic record of this endangered language. The paper is organized as follows: Section 2 discusses the consonant inventory of Komi-Permyak and focuses on the contrasts of particular interest. Section 3 outlines the methodology used in the acoustic experiments. Sections 4 and 5 present the main results and discuss the findings.

2 THE KOMI-PERMYAK CONSONANT INVENTORY

Komi-Permyak is a Finno-Ugric language spoken mainly in the Komi-Permyak Autonomous District of the Perm' Region of Russia. It is closely related to Komi (Zyryan) and Udmurt (Votyak), the other two Permian Finno-Ugric languages. As shown in Table 1, Komi-Permyak exhibits a rich set of phonological place contrasts including bilabials, labio-dentals, denti-alveolars (or dentals), apical post-alveolars (retroflexes), laminal post-alveolars (alveolo-palatals), palatals, and velars [2, 3].[1]

	I	II	III	IV	V	VI	VII
stop	p b		**t d**			c ɟ	k g
affricate			(ts)	**ʈʂ ɖʐ**	**t̠ɕ d̠ʑ**		
fricative		(f) v	**s z**	**ʂ ʐ**	**ɕ ʑ**		(x)
nasal	m		n			ɲ	
liquid			l	r (rʲ)		ʎ	
glide						j	

Table 1. The Komi-Permyak consonant inventory; I - bilabial, II - labiodental, III - laminal denti-alveolar, IV - apical post-alveolar (retroflex), V - laminal post-alveolar (alveolo-palatal), VI - palatal, VII - velar; segments in parentheses are marginal (limited to recent Russian loans).

In this paper we focus on voiceless and voiced coronal stops, affricates, and fricatives (given in bold in Table 1). Some words illustrating the place contrasts in stops/affricates and fricatives in word- (or syllable)-initial position are given in Table 2. (Note that the palatal stops /c ɟ/ in word-initial position occur mainly in onomatopoeic forms and loans.) All these consonants are also contrastive word-finally and word-medially before consonants [2]. The question of primary interest is the following: What acoustic durational and spectral parameters are used to differentiate the places of articulation (1) among the coronal stops and affricates and (2) among the coronal fricatives? This

[1] It should be noted that laminal post-alveolars /t̠ɕ d̠ʑ ɕ ʑ/ are often listed together with palatal consonants [2, 3]. This might reflect the fact that they pattern as a natural class with respect to certain phonological processes. Acoustic and perceptual evidence, however, suggests that, at least some of them, /t̠ɕ d̠ʑ/, are likely to be articulated more to the front than the "true palatals" /c ɟ/ [4].

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question is addressed in our acoustic experiment.

a.	[t]ak 'thus,' [t̪ʂ]ak 'mushroom,' [c]ak (suvtnɨ) 'to be startled,' [t̠ɕ]ak (kernɨ) 'to chatter (teeth)'
b.	[d]aɟ 'sledge,' [d̪ʐ]ad̪ʐ 'shelf,' [ɟ]aɟ 'uncle,' d̠ʑo[d̠ʑ]og 'goose'
c.	[s]ar 'tsar,' [ʂ]ar 'ball,' [ɕ]ar 'to be seen'
d.	[z]aptɨnɨ 'to store,' [ʐ]əv (kerɕɨnɨ) 'to grow quiet,' [ʑ]ac 'son-in-law'

Table 2. Some words with voiceless stops/affricates (a), voiced stops/affricates (b), voiceless fricatives (c), voiced fricatives (c).

3 METHODOLOGY

The data for the experiment were collected in Perm', Russia from 6 speakers — 2 males and 4 females. All of the speakers were students of Perm' Pedagogical University, born and raised in Kudymkar, Komi-Permyak Autonomous District. The recordings were made directly to a laptop computer using a noise canceling head-mounted microphone. The sampling rate was 22.05 kHz with 16-bit resolution. The stimuli included words with voiceless and voiced stops/affricates (/t t̪ʂ t̠ɕ c/; /d d̪ʐ d̠ʑ ɟ/) and fricatives (/s ʂ ɕ/; /z ʐ ʑ/) in word-initial position (shown in Table 2) as well as the same voiceless consonants in word-final position (vo[t] 'here', la[t̪ʂ] 'a spinning-wheel part,' ma[t̠ɕ] 'ball,' ʑa[c] 'son-in-law;' kə[s] 'drought,' kə[ʂ] 'scoop,' gə[ɕ] 'guest'). The stimuli were randomized and presented in a carrier phrase (ˈɛta ____ ˈaʂin 'I see ____ in the morning') as a list in Komi-Permyak orthography. Each stimulus was presented twice.

The acoustic analysis of the data (using *Praat*) involved durational and spectral measurements: The durational measurements were made from a waveform with the assistance of a spectrogram and included the duration of the closure and the period of release burst/frication for stops/affricates; the closure-to-burst ratio was calculated based on these measurements. For fricatives, the overall duration of frication noise was measured. The spectral characteristics measured for stops/affricates and fricatives included the low frequency cutoff of the noise spectrum (*the cutoff frequency*), the intensity of the noise period, and the formant frequencies (F1 and F2) at the offset of the VC transition and at the onset of the CV transition. These measurements were made from a spectrogram, and LPC spectra were consulted in determining cutoff frequencies. Due to the relatively short and weak burst periods of /t d/ it was not possible to obtain accurate measurements of intensity for these consonants. Differences between voiceless and voiced consonants in terms of VOT were not investigated.

There was a total of 192 tokens with stops/affricates: 32 tokens (2 repetitions of 12 items with voiceless and 4 items with voiced consonants) per person. There was a total of 108 tokens with fricatives: 18 tokens (2 repetitions of 6 items with voiceless and 3 items with voiced consonants) per person. The results were evaluated statistically by running separate repeated-measures ANOVAs with the within-subject factors of Consonant (separately for stops/affricates and fricatives), Voicing, and Position (for voiceless obstruents only). A separate test was designed to examine the variability between the two groups of speakers (Gender). The dependent variables corresponded to the above-mentioned measurements. The variables of formant transitions were considered only in the environment of the vowel /a/. In each case, Tukey HSD post-hoc tests were performed to investigate significant interactions.

It should be noted that in a number of tokens (10% of all word-initial tokens), measurements of closure duration and VC transitions were not possible due to occasional pauses before word-initial obstruents. A frequent glottal stop insertion between word-final obstruents and the following vowel (56% of all word-final tokens) limited the number of measurements of CV transitions.

4 RESULTS

The results are presented separately for stops/affricates and for fricatives, with the results for each grouped according to their durational and spectral characteristics.

4.1 STOPS AND AFFRICATES: DURATIONAL PROPERTIES

The results showed a main effect for all durational parameters – closure duration ($F(3, 120) = 13.2$, $p < 0.001$), burst/frication ($F(3, 141) = 137.8$, $p < 0.001$), and closure-to-burst ratio ($F(3, 120) = 38.0$, $p < 0.001$). The results of post-hoc tests, however, indicated that all four places of articulation were consistently different only with respect to burst-to-closure ratio. They showed a continuum of distinct values from the "true" stops /t d/ with the lowest ratios (see Table 3) to the "true" affricates /t̠ɕ d̠ʑ/ with the highest ratios; the other two consonants, /c ɟ/ and /t̪ʂ d̪ʐ/, represented intermediate cases. It should be noted that the ratios for /c ɟ/ were relatively high for stops (0.41/0.46), indicating that they were substantially affricated.

Voiced stops/affricates were found to differ significantly from their voiceless counterparts primarily in the duration of the closure period (shorter for voiced consonants; $F(2, 120) = 14.8$, $p < 0.001$). Significant differences between the consonants in burst/frication and ratio values were limited to affricates only (shorter for voiced affricates). Voiceless stops/affricates in word-final position were found to have shorter closures than the same consonants in word-initial position ($F(1, 120) = 40.5$, $p < 0.001$). These differences ranged from 9 ms (/t/) to 32 ms (/c/). Unlike the closure, the burst/frication properties of the consonants remained relatively invariant. Given this, stops/affricates in word-final position were more affricated than the same consonants in word-initial position (based on burst-to-closure ratio; F(1, 120) = 11.7, p < 0.01).

Female speakers showed a significantly longer duration for the closure and burst periods than male speakers; burst-to-closure ratio was not significantly different.

	[t]/[d]	[ʈʂ]/[ɖʐ]	[tɕ]/[dʑ]	[c]/[ɟ]
closure, ms	99/91	85/80	76/56	93/71
burst/frication, ms	16/14	69/41	74/49	36/30
burst-to-closure ratio	0.18/ 0.16	0.9/ 0.53	1.03/ 0.94	0.41/ 0.46
cutoff frequency, Hz	1700/ 2200	1900/ 1900	2100/ 2000	3000/ 3000
intensity, dB	--	67/64	67/64	56/57
F1 (VC), Hz	550	609	494	498
F2 (VC), Hz	1555	1631	2039	2158
F1 (CV), Hz	662	630	615	534
F2 (CV), Hz	1535	1352	1880	2157

Table 3. Mean values for word-initial voiceless/voiced stops/affricates (formant values are for voiceless consonants only).

4.2 STOPS AND AFFRICATES: SPECTRAL PROPERTIES

In terms of spectral parameters, we found main effects of cutoff frequency of the noise spectrum (F(3, 134) = 88.9, p < 0.001), spectrum intensity (F(2, 102) = 26.4, p < 0.001), as well as VC (F1: F(3, 115) = 24.4, p < 0.001; F2: F(3, 110) = 50.8, p < 0.001) and CV transitions (F1: F(3, 109) = 9.4, p < 0.001; F2: F(3, 107) = 40.4, p < 0.001).

The consonants were thus found to differ in the quality of the burst/frication: While the burst of denti-alveolar stops /t d/ was characterized by weak noise at a wide range of frequencies above 1700 Hz, the burst/frication of palatal stops /c ɟ/ was manifested in a somewhat higher intensity noise at high frequencies, above 3000 Hz. The frication periods of post-alveolar affricates showed strong concentrations of energy in the mid-range, at somewhat lower frequencies for apicals /ʈʂ ɖʐ/ than for laminals /tɕ dʑ/ (p < 0.02). Both post-alveolars and palatals could be described auditorily as having strident frication.

Voiced stops/affricates did not differ significantly from their voiceless counterparts in the spectral properties of burst/frication. They did, however, show some differences in formant values during vowel transitions, namely, lower F1 for voiced consonants during the VC and CV transitions (p < 0.01). Voiceless stops/affricates in word-final position showed somewhat lower cutoff frequencies than the same consonants in word-initial position (F(3, 134) = 88.9, p < 0.001). Other differences between the two groups were not significant.

Unsurprisingly, female speakers showed higher cutoff frequencies, and higher F1 and F2 formant transitions than male speakers.

4.3 FRICATIVES: DURATIONAL PROPERTIES

The results showed only a marginal main effect for fricative duration (F(2, 71) = 3.3, p < 0.05). According to the post-hoc test, this effect was due to the difference between denti-alveolars /s z/ and laminal post-alveolars /ɕ ʑ/; thus, while the duration of the /s/ frication was 141 ms, it was only 128 ms for /ɕ/.

Voicing was found to be significant for fricatives (F(5, 71) = 53.2, p < 0.001): voiced fricatives were shorter than their voiceless counterparts by more than 30 ms. The significant differences, however, were limited to denti-alveolars (/s/ vs. /z/) and laminal post-alveolars (/ɕ/ vs. /ʑ/). Voiceless fricatives in word-final position were found to be shorter in duration than the same consonants in word-initial position (F(1, 71) = 35.9, p < 0.001). The mean difference between word-initial and word-final variants was more than 20 ms.

As for stops/affricates, the production of fricatives showed a substantially longer duration of frication noise for female speakers.

4.4 FRICATIVES: SPECTRAL PROPERTIES

In terms of spectral parameters, we observed main effects of the cutoff frequency (F(2, 71) = 81.9, p < 0.001), the intensity of noise spectrum (F(2, 70) = 30.0, p < 0.001), and VC (F1: F(2, 64) = 10.0, p < 0.001; F2: F(2, 61) = 36.0, p < 0.001) and CV transitions (F1: F(5, 52) = 5.6, p < 0.05; F2: F(5, 50) = 29.3, p < 0.001). In terms of the noise patterns, /s z/ produced by female speakers were characterized by weak energy almost uniformly distributed at high frequencies (above 3800 Hz). The same consonants produced by male speakers showed a pronounced spectral peak at around 4400 Hz. /ʂ ʐ/ showed noise above 1900 Hz, with particularly high spectral peaks at around 3500 Hz; /ɕ ʑ/ were characterized by high intensity noise at above 2500 Hz, and particularly around 4000 Hz. The laminal post-alveolars /ɕ ʑ/ consistently showed a lower F1 and a higher F2 during transitions, when compared to the denti-alveolars /s z/ and the apical post-alveolars /ʂ ʐ/.

	[s]/[z]	[ʂ]/[ʐ]	[ɕ]/[ʑ]
duration, ms	141/85	129/124	128/128
cutoff freq., Hz	3800/4000	1900/2500	2500/2800
intensity, dB	48/47	67/65	66/61
F1 (VC), Hz	647	628	491
F2 (VC), Hz	1548	1524	2099
F1 (CV), Hz	591	596	515
F2 (CV), Hz	1449	1412	2052

Table 4. Mean values for word-initial voiceless/voiced fricatives (formant values are for voiceless consonants only).

Compared to their voiceless counterparts, voiced fricatives were characterized by higher cutoff frequencies ((F(5, 71) = 10.3, p < 0.01) and higher F1 values of transitions (VC: F(4, 46) = 16.5, p < 0.001; CV: (F(2, 59) = 4.7, p < 0.05). Note that the contrast between /ʂ/ and /ʐ/ was not

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represented in the results for transitions, due to the difference in vowel quality (/a/ vs. /ə/). The differences between word-initial and word-final voiceless fricatives were not significant.

In addition to the differences in the spectral shape of /s z/, overall higher cutoff frequencies and higher F1 and F2 formant transitions were found for female speakers than male speakers.

5 DISCUSSION

The results show that Komi-Permyak coronal obstruents are well differentiated in terms of both temporal and spectral acoustic characteristics. As would be expected, the main durational differences are between stops and affricates. However, there are important differences within these two classes. Among the affricates, /ʈʂ ɖʐ/ show less affrication than /t̠ɕ d̠ʑ/ ("true" affricates); among the stops, /c ɟ/ are significantly more affricated than /t d/ ("true" stops). The relatively high degree of affrication of palatal stops is not uncommon across languages [5]. However, note that the stops /c ɟ/ are still substantially less affricated than the "true affricates" /t̠ɕ d̠ʑ/.

Among the consonants characterized by relatively long frication, namely affricates and palatal stops, the differences are in the shape and intensity of their noise spectra (primarily between the more back /c ɟ/ and the two more front affricate articulations). Although the differences in cutoff frequencies between /t̠ɕ d̠ʑ/ and /ʈʂ ɖʐ/ are relatively small (but significant), the latter tend to show peaks of energy at somewhat lower frequencies than the former (cf., a similar contrast in Standard Chinese and Polish [5]).

In terms of the transition differences, the main distinction is between the articulations that involve tongue body raising (/c ɟ t̠ɕ d̠ʑ/; high F2) and those that don't (/t d ʈʂ ɖʐ/; mid F2). Within these groups there are additional significant differences, most apparent during CV transitions. The fact that the affricates /ʈʂ ɖʐ/ show a substantial drop in F2 values at the onset of the following vowel (compared to the offset of the preceding vowel) suggests a possible adjustment in the constriction of these complex consonants or secondary lip rounding at their release. Overall, place distinctions in Komi-Permyak are always supplemented by manner (stop vs. affricate) differences, an observation that appears to hold cross-linguistically [1, 5].

Unlike the stops/affricates, durational characteristics do not play a major role in distinguishing sibilant fricatives. Only /s z/ and /ɕ ʑ/ are differentiated by duration. In terms of the fricative spectral shape, the main difference is between /s z/ (often weak energy at high frequencies) and the other two fricative places (strong concentrations of energy at mid frequencies). The formant transition values show a robust difference between laminal post-alveolars /ɕ ʑ/ (high F2) on the one hand, and denti-alveolar and apical post-alveolars (mid F2) on the other. The relevance of F3 values in contrasting apical post-alveolars /ʈʂ ɖʐ/ has not been explored. The laminal post-alveolars /ɕ ʑ/ show a higher cutoff frequency and higher F2 than their affricate counterparts /t̠ɕ d̠ʑ/; the values are, in fact, more similar to the palatal stops /c ɟ/. Overall, the production of fricatives shows substantial inter-speaker variation in both durational and spectral characteristics.

The acoustic parameters involved in the stop/affricate and fricative contrasts vary in terms of voicing as well as word position. The production of these consonants also shows some significant gender-based variation.

6 CONCLUSION

This study investigated the acoustic properties of relatively marked phonological contrasts between coronal stops/affricates and sibilant fricatives in Komi-Permyak. Although rather complex, the set of obstruent contrasts examined is well differentiated acoustically, as a combined result of their differences in place and manner of articulation. Overall, the results suggest that in order to maintain a complex inventory of contrastive units, a language has to exploit non-linear articulatory/acoustic mappings by selecting ranges of gestural specifications that have sufficiently salient perceptual consequences [6].

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