ULTRASOUND ANALYSIS OF POSTALVEOLAR AND PALATAL AFFRICATES IN CROATIAN: A CASE OF NEUTRALISATION

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ABSTRACT

The phonetic status of Croatian affricates /ʧ/ and /ʨ/ is uncertain. Traditionally, affricate /ʧ/ is classified as postalveolar and /ʨ/ as palatal, but there is no physiological data to support this classification. Several studies show that postalveolar and palatal affricates are being neutralised in modern Standard Croatian, but the evidence of the neutralisation process is limited. Motivated by the possible existence of a sound change and by the relative lack of articulatory data, our aim was to use ultrasound to investigate midsagittal tongue contours in Croatian affricates /ʧ/ and /ʨ/. Nine typically speaking Croatian participants were included in the study. The results did not support the traditional classification of the affricates, but they also did not support the claims about the complete neutralisation. The analysis showed that /ʨ/ had higher position of the tongue blade/dorsum and less variability when compared with /ʧ/. Speaker specific differences were found and discussed.

Keywords: affricates, neutralisation, ultrasound tongue imaging (UTI), Croatian.

1. INTRODUCTION

Previous research showed that affricates /ʧ/ and /ʨ/ as well as their voiced counterparts /ʤ/ and /ʥ/ might be undergoing a process of neutralisation or merger in modern Standard Croatian [13, 14]. Traditionally, affricates /ʧ/ and /ʤ/ were classified as apical postalveolars, while /ʨ/ and /ʥ/ as dorsal palatals [3, 6, 12]. However, these classifications were based mainly on listener judgements with no instrumental evidence to support these claims. Several relatively recent perceptual and acoustic studies showed that increasingly large percentage of Croatian speakers and listeners failed to produce an audible contrast and/or identify these two sets of affricates correctly [13, 14], and in those studies it is claimed that postalveolar and palatal affricates had been neutralised or merged completely in modern Croatian, especially in young speakers from major urban areas. These claims were somewhat weakened by the fact that methods and analysis procedures were not reported [14] or that the procedures applied were crude (e.g. one part of the speech material was obtained by recording speakers reading word lists and another part was extracted from television and radio broadcasts) [13]. With limited perceptual and acoustic evidence and no physiological articulatory data, this issue of the merger between the postalveolar and palatal affricates is still unresolved.

The only instrumental physiological study on the subject used electropalatography (EPG) [7] and showed that the difference in the place of articulation between the so called postalveolar and palatal affricates was not statistically significant, but that listeners identified these affricates successfully in 86% of the cases. Further analysis showed that one of the differences between the two affricates was in the amount of tongue-to-palate contact at the place of articulation, i.e. /ʨ/ and /ʥ/ had significantly more tongue-to-palate contact at the place of articulation than /ʧ/ and /ʤ/. The evidence from the EPG study seemed to suggest that these affricates were not completely neutralised, but that the process of near merger (incomplete neutralisation) [1, 5] might be taking place. The difference in the amount of contact was interpreted as an indication of the difference in tongue shape (apical vs. laminal). However, this could not be confirmed based on the EPG analysis alone, because EPG did not provide data on tongue shape and position. Physiological techniques such as ultrasound tongue imaging (UTI) or electromagnetic articulography (EMA) would perform much better at analysing tongue shapes and positions during speech.

In order to further investigate this issue and to check whether these affricates are completely merged or not, it is our aim to analyse articulatory and coarticulatory characteristics of Croatian affricates /ʧ/ and /ʨ/ using UTI in quasi-spontaneous speech. UTI will enable us to investigate midsagittal tongue contours during affricate productions and potentially to fill the gaps that exist in studies using techniques such as EPG [16]. A sample of quasi-spontaneous speech provides an opportunity to analyse these affricates in a more natural communicative situation than reading sentence lists. Therefore, there are two main research questions in the present study: 1. Do these affricates differ in their midsagittal tongue configuration? and 2. Do these affricates differ in their coarticulatory variability and resistance?

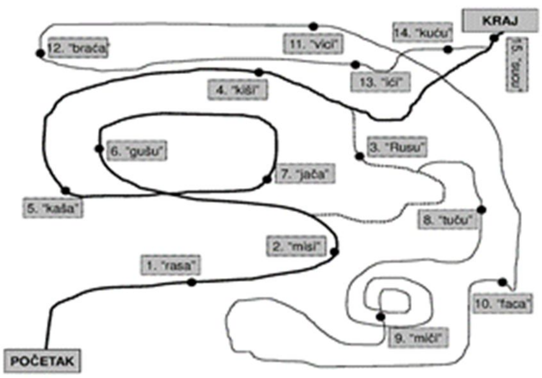
2. METHOD

2.1. Participants and speech material

Speech material was extracted from the CROCO corpus [4]. Nine speakers (five female: S2, S3, S7, S8, S9; four male: S1, S5, S6) of Standard Croatian with no speech and hearing impairments were included in this investigation, ranging in age between 21 and 24 (mean 22.4). Their speech was rated by five trained phoneticians and those nine speakers received the best scores for speech sound production and overall speech intelligibility among 105 candidates. The average score for affricate productions on the scale from 1 (poor) to 7 (excellent) for these 9 speakers was 6.2. Speakers were originally from different parts of North-Western Croatia but they had lived in Zagreb at least two years prior to recording.

Speech material was obtained through a dialogue situation, whereby each speaker was asked to describe the path through a maze and read signs at 15 check-points marked throughout the path (Fig 1). They had to explain to the experimenter where each sign was placed at the map, because the experimenter had the same map, but signs were not marked. The goal was to explain to the experimenter where to draw each sign. Each sign contained a two-syllable C_1VC_2V word, where C_2 was either /ʧ/ or /ʨ/ and V was one of the corner vowels of the Standard Croatian (/i, a, u/) (e.g. "miči", /miʧi/, English translation: move). Each speaker repeated each affricate four times.

Figure 1: An illustration of the map description exercise for the elicitation of the quasi-spontaneous speech in this investigation.



2.2. Instrumentation

UTI and acoustic data were recorded simultaneously using Micro ultrasound system for speech research with a convex ultrasound transducer and Ultrasound Stabilisation Headset developed by Articulate Instruments Ltd. UTI frame rate was 90 Hz and acoustic signal frame rate was 44100 HZ. Ultrasound probe was stabilised in the headset and fitted so that shadows of the hyoid bone and lower jaw were visible for all speakers.

2.3. Data preparation and annotation

Data recording, annotation and data analysis were done in the Articulate Assistant Advanced (AAA) software [2]. Tongue curves were traced automatically with manual correction. Affricates were annotated according to acoustic signal. The beginning of the affricate was the point where F2 of the previous vowel stopped and the silence of the affricate occlusion started. The end of the affricate was marked at the point where frication noise ended and the laryngeal vibrations of the following vowel started. Data for each affricate were calculated at one third of the annotation duration in order to capture the data during the occlusion phase. The occlusion phase and the frication phase in Croatian affricates are always homorganic [3].

2.4. Data analysis

Raw data for tongue splines of each affricate averaged for each speaker (mean and standard deviation (SD)) were exported for subsequent analysis and visualisation. The AAA software uses a fan grid with 42 equally spaced axes (Fig 2) and each tongue spline is defined by a crossing point at each axis. Splines for each affricate and each speaker were plotted in the AAA software for visual inspection of the data. Differences between the two affricates for each speaker were calculated by subtracting the tongue spline for /ʨ/ from the tongue spline for /ʧ/ resulting in the "zero" line and the difference [2]. The difference was also visualized by Spline Workspace tool available in the AAA software [2], where the size of the vertical bars along the spline indicated the amount of the difference between the affricates. Thick dark vertical bars indicated statistically significant areas of difference at the confidence level of 95% (Fig 3). The AAA uses a 2-tailed t-test assuming unequal variances and unequal sample sizes and applies the Welch-Satterthwaite equation [2]. Vertical bar positioned below the zero line indicates that the tongue spline in /ʨ/ was higher than in /ʧ/ at that particular fan axis, while vertical bars above the "zero" spline show areas where tongue spline in /ʧ/ was higher than in /ʨ/. Average variability (v) of each affricate was calculated by averaging standard deviations at each crossing point at each axis. The difference in variability between the two affricates was calculated using Repeated Measures ANOVA in SPSS software. Speakers were experimental units, while affricate type and vowel context were factors varying within each speaker (repeated measures).

Figure 2: An illustration of 42 axes overlaid over the ultrasound image of the tongue in S3. Tongue tip is oriented to the right in all figures.

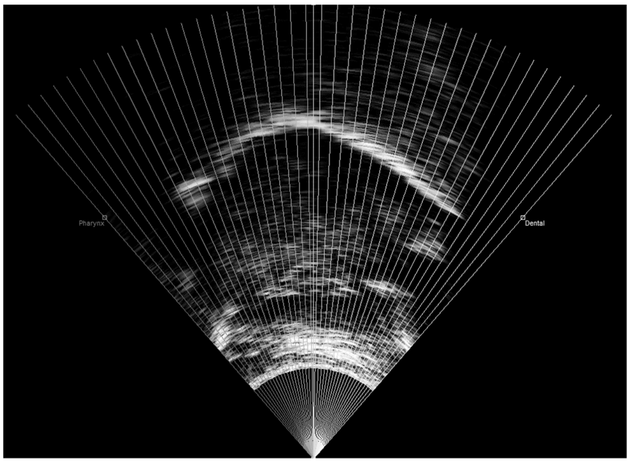
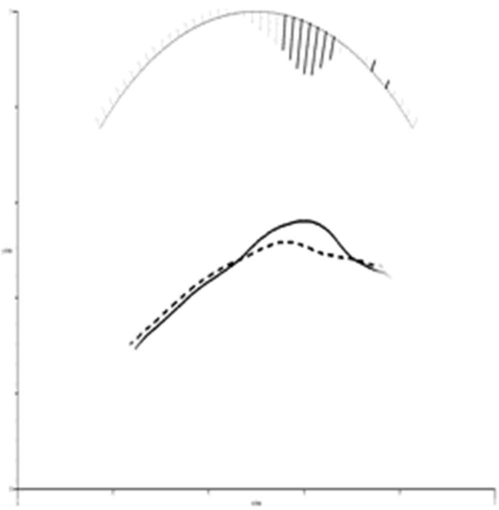


Figure 3: Average splines for affricate /tɕ/ (solid line) and /ʧ/ (dashed line) and the difference between them in symmetrical vowel context /a/. In this and all subsequent figures the difference between the splines is plotted above the average splines, whereby the vertical bars around the "zero" spline show areas where the two affricates differ in their tongue curves. Thick dark vertical bars indicate areas where the difference is statistically significant at the confidence level of 95%. Vertical bars below the "zero" line indicate higher position of the tongue for /tɕ/. Axes are normalised and ranging in value from 0 to 1 [2].



3. RESULTS

The results show that the overall tongue shapes for the two affricates are similar in all speakers (Fig. 4). However, speaker specific strategies can be observed, whereby some speakers show virtually no difference between the two affricates (S2, S5, S9), while speakers who show differences in the tongue shape between these two affricates do not follow the same trend (e.g. S1 vs S3, S4, S6, S7, S8). Speaker S1 produces /tɕ/ with the tip/lamina raised when compared with /ʧ/, while speakers S3, S4, S6, S7 and S8 produce /tɕ/ with the front of the tongue raised and bunched more forward, while the tip is lowered. It is worth keeping in mind that the tongue tip and the tongue root can often be obscured by the acoustic shadows from the lower jaw and the hyoid bone on the ultrasound image [15, 16, 17], so the tongue tip in S1 might be advanced and hidden in the acoustic shadow of the lower jaw.

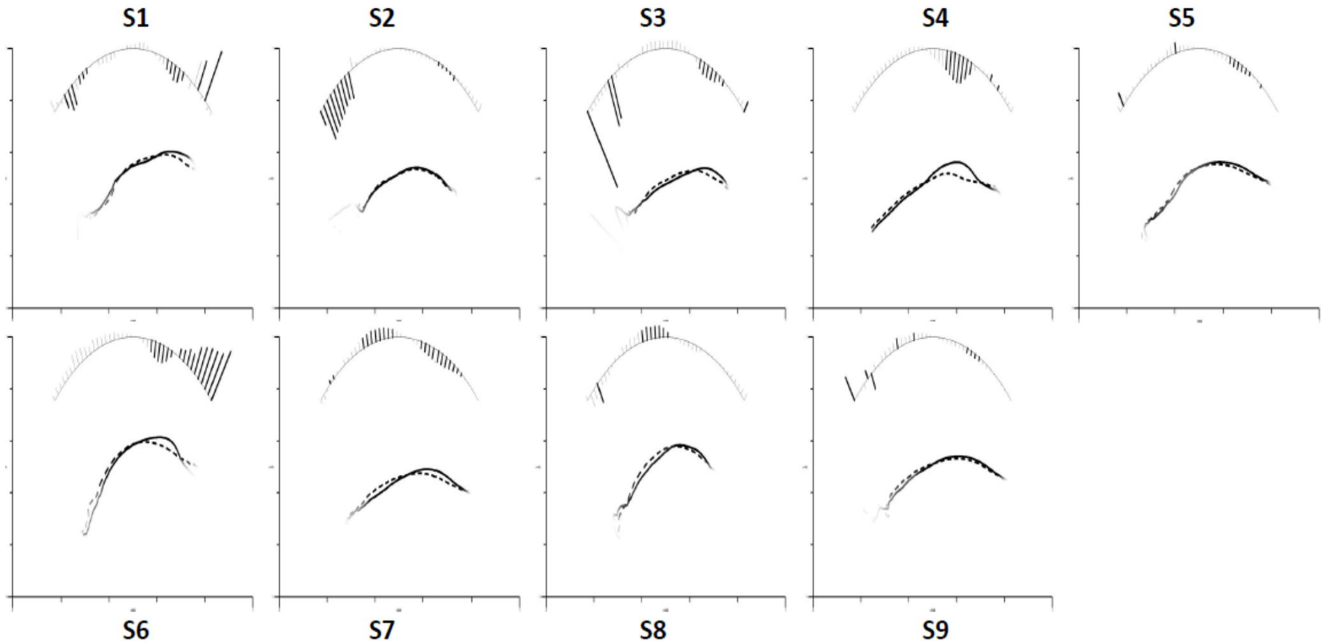
The analysis of differences between average splines for /tɕ/ and /ʧ/ (Fig 4) shows that differences between splines are significant at different sections of the tongue, but also that there are some consistencies across speakers. All speakers except S8 show significantly higher position of the tongue in /tɕ/ in the area between the initial fan axes on the right and the middle vertical fan axes. This falls within the area between the tongue tip and mid-dorsum in most speakers. Increased difference at the first and the last fan axes should be ignored due low confidence of the spline tracking algorithm in those areas of the tongue (e.g. S2, S3, S6). Some speakers also show more advanced position of (the back of) the tongue in /tɕ/ when compared with /ʧ/ (e.g. S4, S6, S7, S 8).

The analysis of the tongue shape variability (v) in different vowel contexts for each affricate shows that the splines are less variable in the affricate /tɕ/ (mean v: 2.93, SD 1.04) than /ʧ/ (mean v: 3.36, SD 1.21) and this difference is statistically significant ($F(1, 8)=6.268$, $p=0.03$). This tendency can be observed in each speaker except in speaker S1, whose /tɕ/ is more variable than /ʧ/ (Tab 1). The difference in variability is minimal in S7 (0.01) and it is maximal in S3 (1.1).

Table 1: Average variability (v) of tongue splines for /tɕ/ and /ʧ/ in each speaker.

	/ʧ/	**/tɕ/**
S1	3.10	3.73
S2	3.21	2.37
S3	4.58	3.48
S4	2.87	2.34
S5	2.52	2.09
S6	5.77	5.06
S7	1.83	1.82
S8	3.85	3.22
S9	2.47	2.25

Figure 4: Average tongue splines for the affricate /tɕ/ (solid line) and the affricate /ʧ/ (dashed line) for each speaker (S1-S9). The difference between the affricates is shown above the tongue splines.



4. DISCUSSION

The analysis shows that the tongue shapes in the two affricates are similar. Inter-speaker differences can be observed, whereby some speakers produce the two affricates with nearly identical tongue shapes, while other speakers produce differences by bunching the front of the tongue and advancing the tongue body for /tɕ/ as opposed to /ʧ/. Despite the observed inter-speaker differences, almost all speakers show one common tendency revealed by the analysis of tongue spline differences - consistently and significantly higher position of the tongue blade/dorsum in /tɕ/ when compared with /ʧ/ (as observed in S1, S3, S4, S5, S6, S7 and to some degree S2 and S9). This result does not support the claim that these two affricates are completely neutralised [13, 14], but it also does not completely support the claim that /tɕ/ is dorsal palatal as opposed to apical postalveolar /ʧ/ [3, 6, 12]. The results from this study are compatible with the results from the EPG study on these two affricates [7], which showed that /tɕ/ and /dʑ/ covered more than one place of articulation (alveolar and (pre)palatal) due to their increased amount of EPG contact when compared with /ʧ/ and /ʤ/. Speech sounds produced with “a simultaneous closure or constriction at the alveolar and palatal zones with a primary articulator which encompasses the blade and the tongue dorsum” are often referred to as alveolopalatals [11].

Alveolopalatals are also characterised by increased coarticulatory resistance as opposed to (post)alveolars, because of the higher articulatory demands placed on the tongue dorsum [8, 9]. The results of the coarticulatory effects of the three corner vowels on the tongue splines for /ʧ/ compared to /tɕ/ are statistically significant and consistent. In all speakers except in S1 /tɕ/ is more resistant to coarticulatory effects (i.e. less variable) than /ʧ/. A relatively high and bunched front of the tongue in /tɕ/ seems to constrain the tongue dorsum more than the tongue configuration in /ʧ/, which is flatter in the front section of the tongue in most speakers. This is consistent with the DAC model of coarticulation which states that increased tongue dorsum constraint causes speech sounds and articulatory gestures to be more resistant to coarticulation (i.e. less variable) [10].

Based on the data presented in this investigation it can be concluded that affricates /tɕ/ and /ʧ/ are not completely neutralised. Based on the finding that some speakers produce these affricates with almost identical tongue contours, it is reasonable to conclude that the process of neutralisation might be in progress. However, the difference between the two affricates is still consistently found in a more bunched and coarticulatorily resistant tongue gesture for /tɕ/. It should be noted that this sample of speakers was selected based on their intelligibility of speech.

The results presented here should be considered with the limitations of the study in mind. The number of speakers is small and data were calculated at a single point during the affricate. Larger samples and the analysis of the articulatory and coarticulatory dynamics could reveal individual speaker strategies and coarticulatory patterns more clearly.

5. ACKNOWLEDGEMENTS

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