An electropalatographic and acoustic study of the Greek rhotic in /Cr/ clusters

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ABSTRACT

Rhotic production has been reported to show variation in several languages as a function of factors such as context, position, and speech rate. The present study examines electropalatographic and acoustic data during the production of the Greek rhotic in /Cr/ clusters (C=/p, t, k, f, θ, x/). Data were recorded from five Greek speakers producing the rhotic in real words embedded in a carrier phrase. Results on the acoustic duration of the rhotic are reported. Articulatory analyses included examination of the place and degree of constriction of the rhotic as well as variability due to speaker and context. A significant influence of these factors on place and manner of articulation was found. The rhotic in /Cr/ clusters is frequently produced as an approximant while production varies from front anterior to retracted alveolar or postalveolar. Examination of coarticulatory effects shows that both the tongue tip/blade and dorsum adapt to the gestures of the neighbouring phonetic segments.

Keywords: rhotic, clusters, Greek, duration, electropalatography.

1. INTRODUCTION

Previous research on the Greek rhotic has identified interesting variation in its production. In standard phonetic descriptions of the Greek consonantal inventory, the rhotic is typically classified as an alveolar tap, e.g. [1]. Articulatory data have shown that its place of articulation can vary between alveolar and retracted alveolar [2]. In addition, articulatory and acoustic studies have shown that it is very frequently produced as an approximant [2, 3]. Further variation as a function of context has been documented, i.e. tap productions are typical in initial or intervocalic position while in /Cr/ and /rC/ clusters production typically includes the presence of a vocoid between the /r/ and the consonant. These realizations have been interpreted differently by researchers, i.e. as manifestations of trill production in clusters [4] or as tap productions involving a vowel-like transition possibly due to timing constraints between the two consonantal gestures [5].

Variation in rhotic production has also been reported for other languages as a function of context, position, speech rate and dialect, e.g. [6, 7]. Frequently variation both in place and manner has been reported in these studies.

The present study is part of a larger ongoing acoustic and articulatory investigation of the Greek tap produced in different positions, contexts and speaking rates. The current paper reports articulatory and acoustic data on tap production in /stop-r/ and /fricative-r/ clusters. It focuses on the examination of tongue-palate contact data at the frame of maximum contact/constriction during the tap aiming to report the variation in place and manner of articulation that is present in these clusters. It addresses the following questions: (a) are different degrees of constriction evident during the production of the rhotic in /Cr/ clusters? (b) is there an influence of the place and manner of articulation of the preceding consonant on the rhotic? (c) is there an influence of the vocalic environment on the rhotic? (d) are the different regions of the tongue relatively free or constrained to adapt to the gestures of the neighbouring phonetic segments? (e) is there evidence suggesting a tap vs trill production in /Cr/ clusters?

2. METHODOLOGY

2.1. Speech material and speakers

The speech material consisted of words containing a VCrV sequence, where C = /p, t, k, f, θ, x/ and V= /i, e, a, o, u/. Only symmetrical sequences were recorded in words containing up to 4 syllables. Stress placement varied so that the majority of words were real. Words were embedded in the carrier phrase [I 'leksi _ 'ine a'pli] 'The word _ is simple' and were repeated five times by each of five Greek adult speakers (three female and two

male) at a comfortable speaking rate. In total, 750 words (6 Cs x 5 Vs x 5 repetitions x 5 speakers) were recorded.

2.2. Data recording and analysis

Acoustic and EPG data were simultaneously recorded using the British EPG system marketed by Articulate Instruments. The artificial palate used in this system has 62 electrodes on its surface that record lingual contact with the palate in continuous speech. The electrodes are distributed in eight rows: the front four correspond to the alveolar zone and the back four to the palatal zone. The alveolar zone is subdivided to the alveolar and postalveolar regions (rows 1 to 2 and 3 to 4 respectively). The first two columns on the left and right side of the palate are characterized as lateral and the four remaining columns as central [8].

Measurement of the duration of the rhotic was based on the acoustic data. Onset was identified at the end of the preceding obstruent (end of noise at stop burst or fricative) and offset at the beginning of the formants of the following vowel. The rhotic typically involved a vocoid following the obstruent and a constriction phase; these were measured separately. For the articulatory analysis, the first EPG frame of maximum contact/constriction in the front four rows was identified during each rhotic. EPG data reduction methodology was based on the calculation of: (a) the percentage frequency of electrode activation of the entire palate over five repetitions, (b) the total number of contacts for the anterior four rows (front total), (c) the total number of contacts for the posterior four rows (back total), (d) the Centre of Gravity for the front four rows (front COG), (e) the mean lateral measure for the front four rows, (f) a variability index for the entire palate. The totals measures and contact indices are described in [8]. The former were ratios of the number of contacted electrodes over the total number of electrodes in the region. The Front COG index expresses the location of the main concentration of activated electrodes in the front four rows. The mean lateral measure was used to show if there was more contact near the midline or the lateral sides of the palate in the front four rows. For both indices the front four rows were selected for calculation because the place of articulation of the rhotic always occurred in the alveolar zone (i.e. front four rows). The variability index quantifies the degree of variability in EPG patterns across repetitions. Factorial analyses of variance on the different measures were carried out including subject, consonantal manner, consonantal place and vowel context as factors. All main effects and interactions were tested.

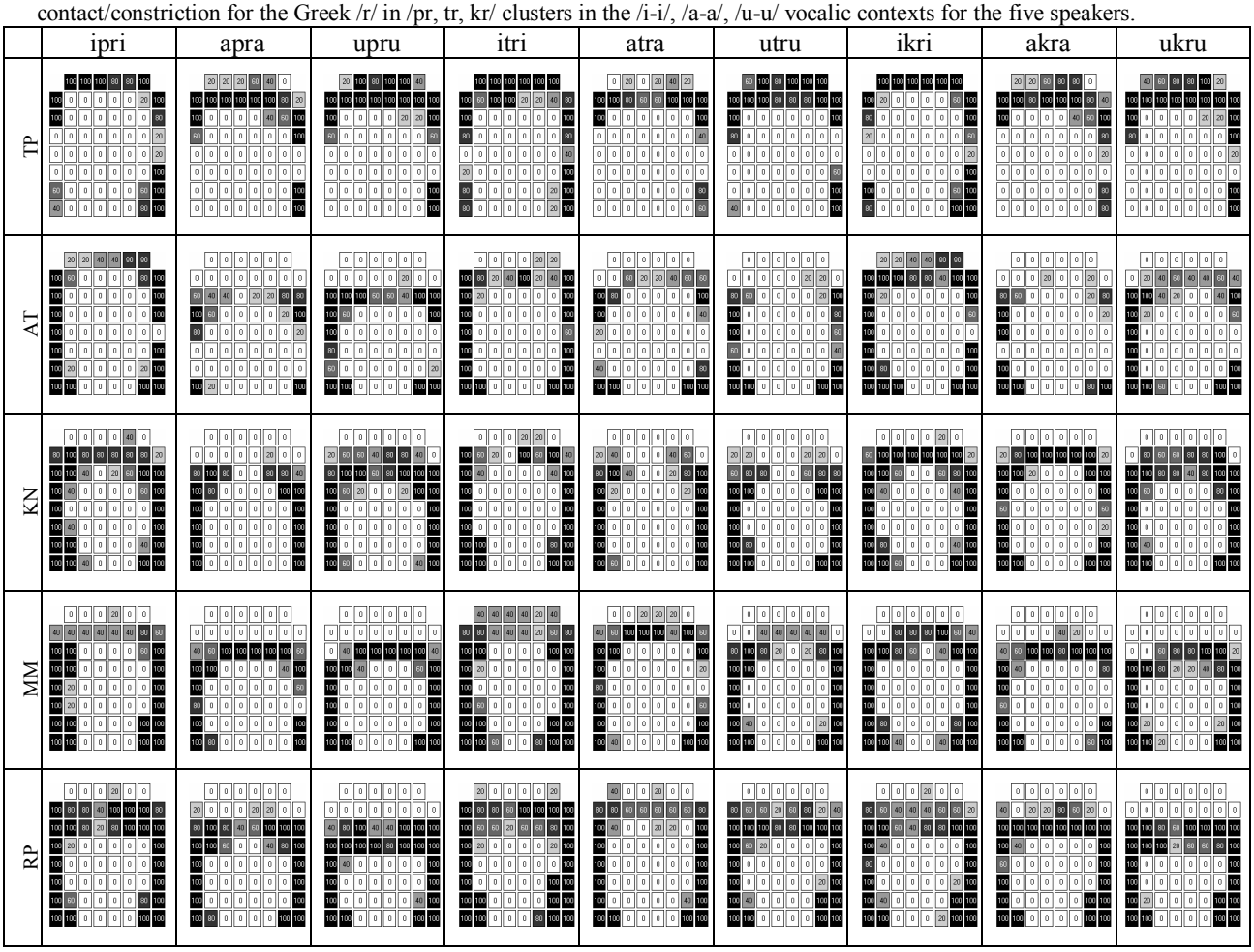
3. RESULTS

The duration of the constriction phase of the rhotic varied between 11 and 50 ms (average 24ms, standard deviation 8.7) and that of the vocoid between 11 and 55 ms (average 25ms, standard deviation 11). The vocoid was in general longer in duration than the constriction (sometimes longer than the neighbouring vowel). No more details of the acoustic characteristics of the phases of the rhotic are reported here due to limitations in space.

Figure 1 shows EPG palatograms for /stop-r/ clusters in the environment of /i/, /a/, /u/ for the five speakers. Percentage of contact over five repetitions is displayed in the palatograms. Interesting variation both in the location and the degree of constriction is evident during the production of the rhotic. Place of articulation varied including (a) contact in only the first row of electrodes indicating a front alveolar articulation (e.g. /ipri/ by TP), (b) contact in both the first two rows or only the second row indicating an alveolar production (e.g. /upru/ by TP, /akra/ by KN), (c) contact in the second and third rows or only the third row suggesting a retracted alveolar or advanced postalveolar production (e.g., /upru/ by KN and MM), (d) contact in the third and fourth rows indicating a postalveolar production (e.g. /upru/ by RP). Degree of constriction also varied including (a) full contact across a row of electrodes (e.g. /itri/ by TP), (b) incomplete contact for one up to four electrodes across the central four electrodes in the front four rows of the palate (e.g. /itri/, /atra/ by MM), (c) incomplete contact involving a relatively open production showing a discontinuous pattern with contact at the lateral sides of the palate and on one or more electrodes across the central front region (e.g. /itri/ by AT) (d) very open productions involving contact exclusively on just the first or second lateral columns on either side of the artificial palate (e.g. most productions of /akra/ by AT).

Analysis of the totals measures showed significant subject variability in the total amount of contact in the front region of the palate ($F(4, 747)=51.970$, $p<0.0001$). Speakers TP and RP had the greatest amount of contact while AT the least. Greater amount of contact was also found in the

Figure 1: Percentage frequency of electrode activation over five repetitions at the first frame of maximum contact/constriction for the Greek /r/ in /pr, tr, kr/ clusters in the /i-i/, /a-a/, /u-u/ vocalic contexts for the five speakers.



context of /i/, /u/ and least in /a/ ($F(4, 747)=12.720$, $p<0.0001$). At the back region of the palate, there was significantly more contact by speakers RP and KN and less contact by AT and TP. The last subject showed very little amount of contact in the back region ($F(4, 747)=1245.644$, $p<0.0001$). Significantly less contact was found in the context of the labial in /stop-r/ clusters ($F(2, 373)=29.364$, $p<0.0001$). In /fricative-r/ clusters there was variability between speakers with less contact in the context of the alveolar for three speakers (subject by C_place: $F(8, 373)=3.198$, $p<0.002$). Finally, significant differences due to the vowel context were found with contact generally decreasing in the order i>u>e, o>a ($F(4, 747)=295.531$, $p<0.0001$).

Results on the front COG showed that there was significant speaker variation in place of articulation with TP showing the most anterior productions followed by AT, KN and MM. The most retracted rhotics were produced by RP ($F(4, 747)=222.162$, $p<0.0001$). Manner of articulation of the consonantal context did not induce significant variation. Significantly more fronted productions were evident in the environment of the front vowels /i, e/ compared to the back vowel contexts ($F(4,747)=36.578$, $p<0.0001$). Within the /stop-r/ clusters, the rhotic was significantly more anterior in the environment of a preceding alveolar consonant followed by the velar and the labial ($F(2,373)=46.439$, $p<0.0001$). Some variation was however evident for two speakers in the degree of fronting between the alveolar and velar context (subject by C-place: $F(8, 373)=8.501$, $p<0.0001$). Within the /fricative-r/ clusters, the rhotic was also significantly more anterior in the environment of the alveolar compared to the velar or labiodental ($F(2,373)=254.679$, $p<0.0001$).

Results on the front mean lateral measure showed greater amount of contact in the central region of the palate for speaker TP and more lateral contact for speakers AT and KN in both /stop-r/ and /fricative-r/ clusters (stops: $F(4, 373)= 48.534$, $p<0.0001$; fricatives: $F(4, 373)=45.512$,

p<0.0001). This suggests the presence of more instances of complete constriction by speaker TP and more open articulations for AT and KN. More lateral contact was also found in the fricative context suggesting more open articulations (F (1, 747)=136.657, p<0.0001). Variability was evident between speakers in the influence of consonantal place of articulation and of the vocalic context on the mean lateral measure.

Table 1 shows the number of rhotics produced with incomplete constriction. In total, 351 out of 748 tokens analysed were produced with incomplete constriction (47%). Speakers KN, AT and RP show considerably more instances of open productions compared to MM and TP; over 50% of their tokens had incomplete closure.

Table 1. Number of rhotics produced with incomplete constriction in /stop-r/ and /fricative-r/ clusters for all speakers

	KN	AT	RP	MM	TP
stop-r	48	53	29	24	12
fric-r	54	43	51	29	8
Total	102	96	80	53	20

Finally, the analysis of token-to-token variability showed that none of the factors included in the model were significant. Differences in rate of speech may contribute to token-to-token variability and need to be investigated further.

4. DISCUSSION

Typically, an alveolar tap involves a very rapid ballistic action of the tongue tip/blade against the alveolar ridge lasting on average between 18-40 ms [6]. Our durational data are in general agreement with this. Our articulatory data have shown that this rapid movement can involve differential degree of constriction ranging from complete contact across one of more rows in the alveolar zone to very open articulations. Thus, the rhotic frequently involves approximation of the lingual gesture to the palate (c.f. [2] where over 80% of rhotics in a smaller sample were produced with incomplete constriction in spontaneous speech). Approximant production of the rhotic was also reported in acoustic studies [3, 5]. In addition, variation in place of articulation was evident in our data ranging from very front alveolar to retracted alveolar or postalveolar productions, similarly to findings in [2]. Finally, just one constriction was found in the data typically occurring after the vocoid which followed the obstruent. Only five tokens showed a possible second very open approximation (one electrode contacted on the second lateral column) suggesting that /Cr/ clusters typically involve the presence of a tap and not a trill.

A significant source of variation in place, degree of constriction and total amount of contact in the front and back regions of the palate during the rhotic is the speaker. Rhotic production in the same consonantal and vocalic context ranged between front anterior and retracted alveolar for different speakers; it also involved full constriction or open articulations for different speakers. Significant variation due to coarticulatory effects from the environment was also evident. More fronted productions were generally evident in the environment of a preceding alveolar stop or fricative compared to the labial or velar contexts. In addition, the rhotic was more fronted in the environment of the front vowels /i, e/. Evidence of C-to-r and V-to-r contextual effects in fronting together with findings indicating more contact in the alveolar and palatal zones in the environment of the close vowels compared to the mid and open ones suggests that the tongue tip/blade and dorsum adapt to the gestures for adjacent phonetic segments. These findings agree with data reported for other languages, e.g. tap production in Catalan shows variation in place and constriction degree and coarticulatory effects from the vocalic context in the alveolar and palatal zones [6, cf. 9].

5. REFERENCES

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