The many faces of /r/

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Abstract

Acoustic and articulatory (EPG) examination of the Greek rhotic in several prosodic positions (singleton phrase initially, word initially and word medially, also in /Cr[1]/ clusters and /rC/ sequences) revealed a single constriction of short duration suggesting a tap articulation. This contained a vocalic part in /Cr/ and /rC/ contexts, but interestingly, also in phrase initial position when the rhotic was followed by a vowel. The constriction phase had a fairly stable duration and was shorter than the vocalic part, whose duration depended on prosodic position and context: it was longest phrase initially, next longest in /rC/ sequences and shortest in /Cr/ clusters. Finally, the vocalic interval's formant structure was typically similar to that of the nuclear vowel, but with more centralized formant values. We hypothesize a vocalic gesture upon which the rhotic is superimposed. Articulatorily, the place and degree of constriction of the tap varied as a function of prosodic position, context and speaker.

1. Introduction

The phonetic variability of rhotics across and within languages has been noted repeatedly (e.g. Lindau 1985; Ladefoged & Maddieson 1996; Catford 2001). This variability in realization has been the sole subject of the *r-atics* conference, now in its 3rd occurrence, contributing a large body of evidence on the many faces of /r/ in language after language (e.g. Demolin 2001; Docherty & Foulkes 2001, among others). Apart from sociolinguistic context, variation has been reported, from a more phonetic viewpoint, as a function of phonetic context, prosodic position and speech rate (Lindau 1985; Inouye 1995; Recasens & Espinosa 2007). This paper follows the phonetic-oriented rather the sociolinguistic methodology in reporting on the Greek rhotic variability as spoken in Standard Modern Greek.

[1] Throughout the paper, the symbol /r/ is used for the Greek rhotic for practical reasons.

Part of
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In the Greek literature, recent laboratory studies describe the rhotic as a tap in intervocalic position (Nicolaidis 2001; Baltazani 2005, 2009) or in initial and intervocalic position (Arvaniti 1999). All studies have reported considerable variability in its acoustic and articulatory characteristics. Both a tap and an approximant realization have been observed (Nicolaidis 2001; Baltazani 2005, 2009) and its place of articulation has been reported to vary across alveolar, retracted alveolar, and postalveolar positions (Nicolaidis 2001).

The most recent studies have documented the presence of a vocoid between the rhotic and the consonant in /Cr/ clusters and /rC/ sequences, and more interestingly, in phrase initial position when /r/ is followed by a vowel (Nicolaidis & Baltazani 2011, 2013; Baltazani & Nicolaidis 2013, collectively referred to henceforth as N&B). While no other study, to our knowledge, has reported a vocoid accompanying a singleton /r/ in phrase initial position in other languages, several studies have detected a vocoid in /Cr/ clusters and /rC/ sequences, in Catalan, several Spanish dialects, in Romanian, and Hungarian (e.g. Bradley & Schmeiser 2003; Bradley 2004; Recasens & Espinosa 2007; Vago & Gósy 2007; Savu 2013).

Arvaniti (2007) claims that this more complex articulation of /r/ in Greek indicates trill production in clusters while Baltazani (2005, 2009) interprets it as a tap with a vowel-like transition. The electropalatographic data reported in N&B typically show one constriction present, providing evidence of a tap articulation.

There are two types of cross-linguistic accounts for /r/, especially in consonant clusters. Both assume that the vocoid is part of the nuclear vowel which underlies the whole syllable and is briefly exposed between the consonants: one accounts for this as the result of gestural overlap between the two consonantal gestures (Romero 1996; Bradley 2004; Recasens & Espinosa 2007) and the other, in a slightly different vein, hypothesizes that the unmasking is due to the tongue movement trajectory of the tap, which cocks back to gain momentum before tapping (Inouye 1995). On the other hand, Blecua (2001) argues that the vocoid is an inherent part of the rhotic based on the observation that the formant structure of the vocoid is similar but not identical to that of the tautosyllabic vowel.

The former two types of account mentioned above are not supported by our results which document a vocoid even for /r/ in vocalic environments, e.g. in phrase initial position (##rV). Instead, in line with literature on coarticulation (e.g. Öhman 1966), we hypothesize that the vocalic gesture is an integral part of the rhotic upon which the tap constriction is superimposed.

This study compares the rhotic acoustic and articulatory realization across positions explored in previous studies in N&B. It attempts a synthesis of the previous results, offering a unified interpretation of the Greek rhotic production on the basis of an analysis that studies the rhotic across several prosodic positions

using a consistent experimental and methodological design. It addresses two main issues: first, the effect of context and prosodic position on the rhotic duration, articulation and the vocoid formant structure; second, on a more theoretical level, an explanation for the vocoid based on our empirical data.

2. Our experimental data

2.1 Method

The N&B experiments examined /r/ in real words, where possible, in the environment of all five Greek vowels, /i, e, a, o, u/[2]; test words were up to four syllables long. Five adult speakers, AT, TP (male) and MM, KN, RP (female), repeated the material five times at a comfortable speaking rate. Apart from phrase initial position, where the test word was uttered in isolation, test words were embedded in the carrier phrase [i 'leksi 'ine ___a'pli] 'The word _ is simple'. We examined /r/ in five positions: phrase initial (/##rV/), word initial within a phrase (/i#rV/, henceforth 'word initial'), word-internal intervocalic (/arV/, 'intervocalic'), in /Cr/ clusters and in /rC/ sequences (henceforth 'C-contexts' will refer to both /Cr/ and /rC/ unless only one of them is discussed). C-contexts contained symmetrical VCrV and VrCV sequences, with C = /p, t, k, f, θ, x/. In singleton /r/ conditions the /rV/ syllable was stressed but C-contexts words had variable stress. The cross experiment total was 1875 tokens.

In all experiments we simultaneously collected acoustic and EPG data using the British EPG system marketed by Articulate Instruments. The artificial palate used in this system has 62 electrodes on its surface, which are distributed in eight rows. The front four correspond to the alveolar zone, which is further subdivided to the alveolar region (rows 1 to 2) and the postalveolar region (rows 3 to 4). The back four rows of electrodes correspond to the palatal zone (Recasens et al. 1993). In addition, a separate recording of acoustic data was made on a digital recorder (Marantz PMD 660) with a Røde NT1-A cardiod condenser microphone. Acoustic data were analysed using PRAAT.

We measured the durations of the rhotic constriction phase and of the vocoid, as well as the F1 and F2 formants of the vocoid and of the flanking vowel(s) to detect possible environment influences on the vocoid. The onset of the constriction phase – together with the onset of the voicebar – was marked at the offset of silence, preceding vowel or vocoid, depending on prosodic position. The offset of constriction was marked at the beginning of the formants for the following vowel or vocoid. The beginning and end of the vocoid was marked at the onset and offset

[2] For a description of the Greek vowels, see Arvaniti (1999, 2007).

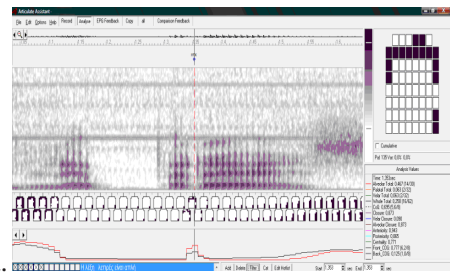
of its formant structure respectively (see e.g. Figures 8 and 10). The duration and formant measurements were automatically obtained through a PRAAT script.
For the articulatory analysis, the first EPG frame of maximum contact/constriction in the four front rows was annotated (Figure 1a, b) as constriction always occurred in the alveolar zone. The frame of maximum contact typically coincided with the frame of maximum constriction; in the few instances that it did not, the frame of maximum constriction was annotated. The percentage frequency of electrode activation of the entire palate, i.e. all eight rows, over five repetitions was then calculated at the frame of maximum contact/constriction for the rhotic in each test word.

2.2 Results

2.2.1 Articulatory results

The articulatory analysis showed that the Greek rhotic is produced with a single constriction of short duration, both in C-contexts and in singleton /r/ positions suggesting a tap articulation (Figures 1a, b, 8). Some tokens involving trill production were found but they were very few across contexts/positions (for details see N&B).

a.



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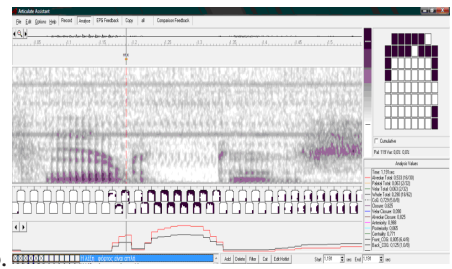
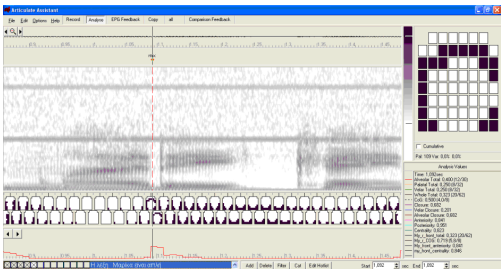


Figure 1(a, b) – Acoustic and electropalatographic data for the rhotic in [le'pres] above and ['fortos] below (speaker TP). The annotation line corresponds to the first frame of maximum contact/constriction in the alveolar zone and the corresponding palatogram is shown at the top right of the display. A single tap gesture is evident for the rhotic in both tokens (see also palatograms and contact totals displays below the spectrograms).

However, variability in the articulation of the tap was evident across the data as there were tokens with complete constriction and tokens with incomplete constriction. The latter ranged from very constricted to very open articulations. These patterns related to variability in the acoustic signal. For tokens with complete constriction, there was evidence of a stop-like pattern frequently with a burst present (Figure 2a). For tokens with incomplete constriction, undershoot was manifested variously: a stop-like pattern but with no abrupt discontinuity at release, i.e. no burst (Figure 2b), noise/breathiness during constriction (Figure 2c), or formant structure indicating approximant production of the rhotic (Figure 2d).

a.



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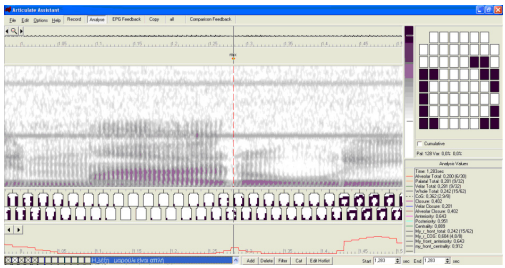

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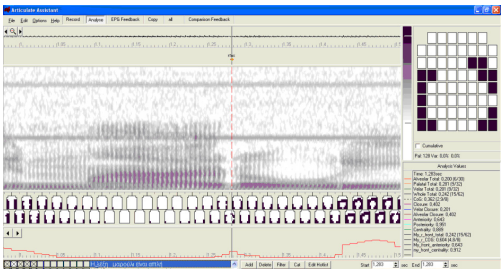


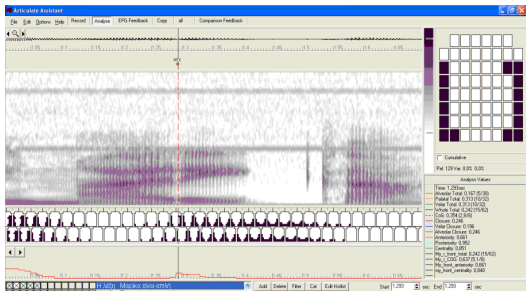
d. 

Figure 2(a-d) – Differences in the degree of constriction of the rhotic. Complete constriction in [ma'rika] (a) and incomplete constriction in [ma'ruli], ['rama] and [ma'rika] (b, c, d), and variation in the acoustic signal (see text for details).

The degree of constriction was influenced by several factors. First, an effect of singleton vs. cluster/sequence production was found, as most tokens with incomplete constriction were found for singleton /r/ (63%, 236 out of 375). Second, there were more tokens with incomplete constriction in heterosyllabic /rC/ (57%, 426 out of 749) than tautosyllabic /Cr/ contexts (47%, 351 out of 748).

Third, for singleton /r/, prosodic position had an effect on degree of constriction. More tokens with incomplete constriction were present for word initial position, i.e. 78% in comparison to 57% for phrase initial and 54% for word medial (Table 1, see also Figure 6).

Finally, for /r/ in C-contexts, overall more tokens were produced with incomplete constriction in the context of a fricative compared to a stop, i.e. /fricative-r/ 49% and /r-fricative/ 67% compared to /stop-r/ 44% and /r-stop/ 47% (see Figure 5; note speaker variation in Table 1).

Table 1 presents the numbers of tokens produced with incomplete constriction for singleton /r/ and C-contexts for all speakers. In addition to the variation noted above, large speaker variability is evident. For instance, for speakers KN, AT and RP more productions involved incomplete constriction systematically across conditions compared to MM and TP. This suggests different speaker strategies in rhotic production.

Singleton /r/	KN	AT	RP	MM	TP	
Phrase initial	*14*	*21*	*21*	*7*	*8*	
Word initial	*23*	*25*	*22*	*17*	*11*	
Word initial	*18*	*17*	*21*	*8*	*3*	
Total	*55*	*63*	*64*	*32*	*22*	*375*
/Cr/ clusters						
Stop-r	*48*	*53*	*29*	*24*	*12*	
Fricative-r	*54*	*43*	*51*	*29*	*8*	
Total	*102*	*96*	*80*	*53*	*20*	*748*
/rC/ sequences						
r-Stop	*59*	*41*	*34*	*14*	*28*	
r-Fricative	*71*	*62*	*48*	*30*	*39*	
Total	*130*	*103*	*82*	*44*	*67*	*749*

Table 1 – Number of tokens showing incomplete constriction for singleton /r/ and C-contexts.

These values should be considered with caution, as it is possible that complete contact may have not been registered for some tokens due to the sampling rate of the EPG system (10 ms). Observation of the EPG and acoustic data indicates that, if this has occurred, it involves a very limited portion of the data (tokens involving very constricted productions) as there were clear differences in the acoustic waveform among tokens produced with complete and incomplete constriction. Further analysis can estimate such cases more precisely. Such a shortcoming is expected to affect /r/ production to a similar degree in all contexts, as it is random. Thus although it may result in less accurate absolute values, it is not expected to affect the accuracy of the differences reported across conditions.

With reference to the place of articulation of the rhotic, the constriction location in the alveolar zone, i.e. the four front rows of electrodes, was found to vary as a function of context, prosodic position and speaker.

Figure 3 illustrates the influence of the vocalic context on the place of articulation of the rhotic. Overall, more advanced production was evident in the front vowel contexts /i, e/. More retracted articulation was generally present in the rest of the contexts with several tokens showing greatest retraction in the context of /a/ and/or /o/. The data showed therefore articulation in the alveolar zone but the precise place of rhotic articulation varies from alveolar, retracted alveolar, advanced postalveolar to postalveolar depending on the vocalic context.

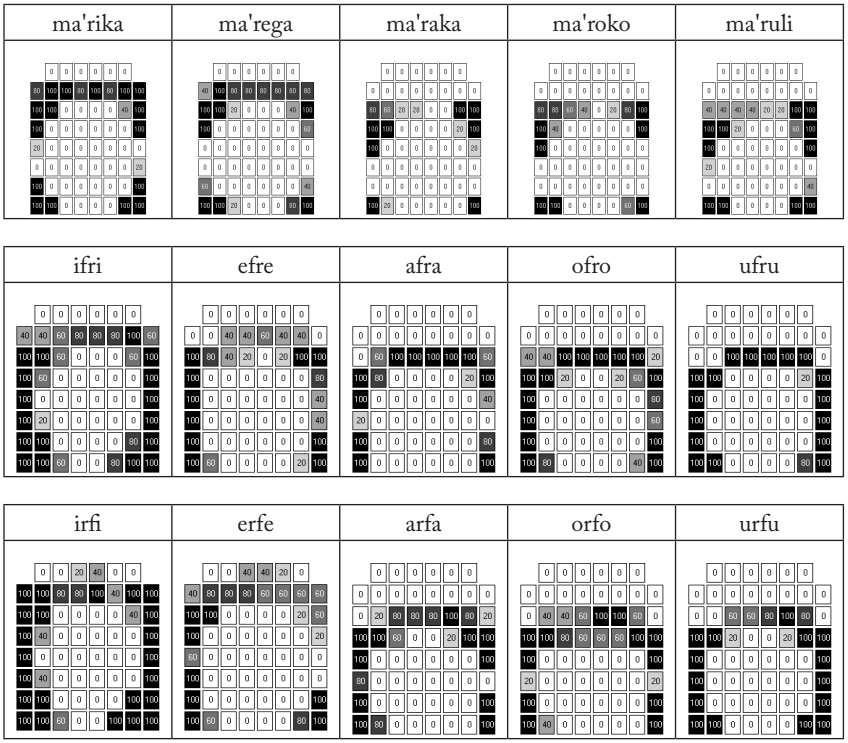
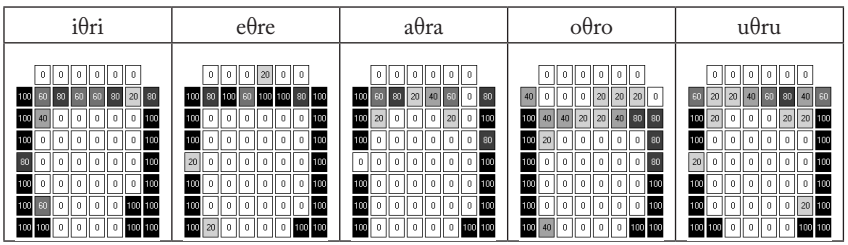


Figure 3 – EPG palatograms displaying percentage frequency of electrode activation over five repetitions during the production of the /r/ in word-internal intervocalic position (top) by speaker AT, in /Cr/ clusters (middle) and /rC/ sequences (bottom) by speaker MM.

The consonantal context also influenced /r/ production in C-contexts. More fronted production was overall evident in the context of the dentals (Figure 4).



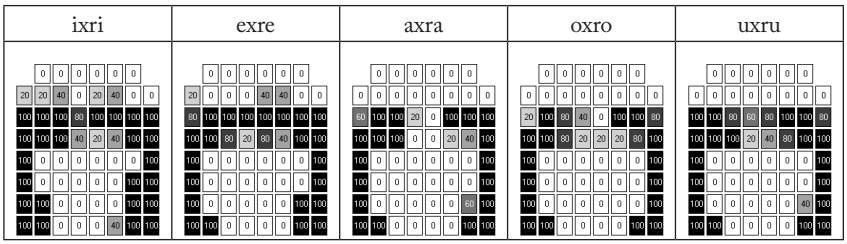


Figure 4 – Production of /r/ in /θr/and /xr/ clusters by speaker RP.

As noted above, context also had an effect on the degree of /r/ constriction in C-contexts. Overall, more open articulations were present in the context of fricatives (Figure 5).

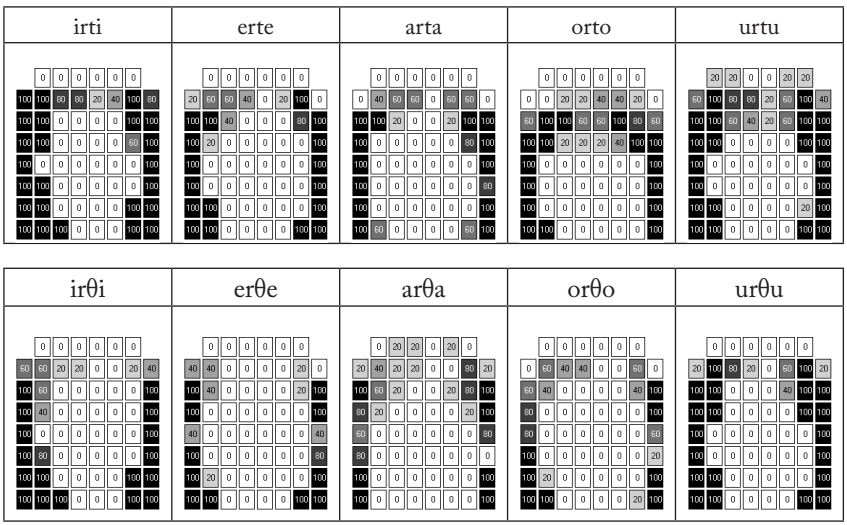


Figure 5 – Production of /r/ in /rt/and /rθ/ clusters by speaker KN.

Figure 6 illustrates variation in the degree of constriction for singleton /r/ in phrase initial and word initial position. As noted previously, more open productions were evident in the latter position.

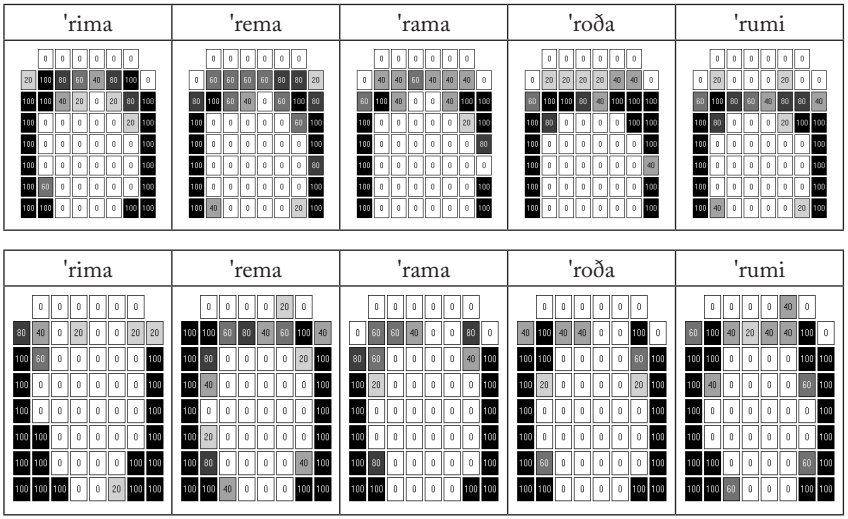


Figure 6 – Production of /r/ in phrase initial (top) and word initial position (bottom) by speaker KN.

Finally, the speaker was an important source of variation. Inter- and intra-speaker differences in degree of contact, place of articulation and degree of constriction were found. Figure 7 illustrates such differences: /r/ is produced at a more retracted place of articulation, with more instances of incomplete constriction and greater amount of contact in the palatal zone by speaker RP compared to TP.

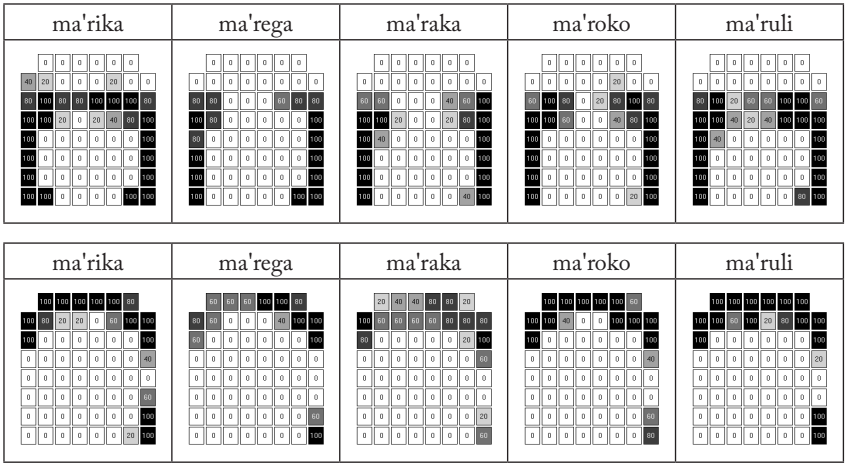


Figure 7 – Production of /r/ intervocalically by speakers RP (top) and TP (bottom).

2.2.2 Acoustic results

In C-contexts, but more importantly phrase initially where /r/ is not part of a cluster, the rhotic structure typically involves a vocoid (Figure 8).

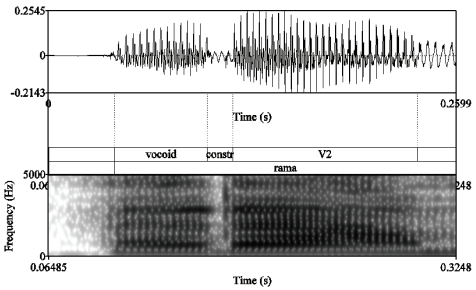


Figure 8 – Phrase initial tap in ['ɾama]. Notice the long vocoid duration (60 ms).

The vocoid was clearly evident in phrase initial position where it had the longest duration, while in word initial and intervocalic positions, it was not as easy to discern due to the flanking vowel environment. Thus in these last two positions no measurements were made. However, acoustic evidence, like discontinuities and/or an abrupt change in amplitude and formants during the pre-rhotic vowel (V1) (Figure 9), suggest the presence of a vocoid adjacent to V1 and to some degree overlapping with it even in these positions (cf. Savu 2013 for similar evidence in /VrV/ contexts in Romanian; Willis 2006 for another interpretation of these acoustic characteristics). For more details see Baltazani & Nicolaidis (2013). A possible alternative interpretation may account for such acoustic manifestations during the vowel as solely resulting from coarticulatory influence from the flanking vowel. Still it is interesting to note that there are frequently abrupt discontinuities present resulting in a vocalic interval that is relatively separate and of a remarkably similar duration to the vocoids found in other prosodic positions.

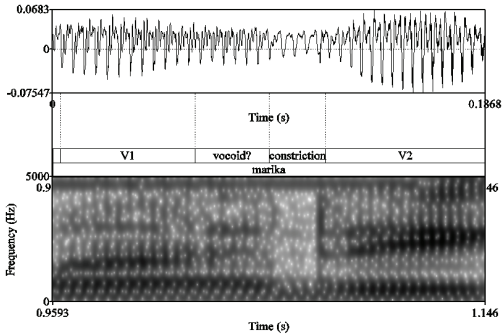


Figure 9 – Acoustic evidence for a vocoid in intervocalic position. The last 1/3 of V1 in [ma'rika] shows a discontinuity and a change in formants.

The acoustic measurements revealed variability in the vocoid production, which ranged from a modal vowel to a breathy/whispered one (top and bottom of Figure 10). Finally, there was a tendency for more tokens with whispered/breathy vocoids or frication noise during the constriction phase in heterosyllabic /rC/ sequences than in tautosyllabic /Cr/ clusters. This suggests more assimilatory effects of the following voiceless obstruent in /rC/ sequences.

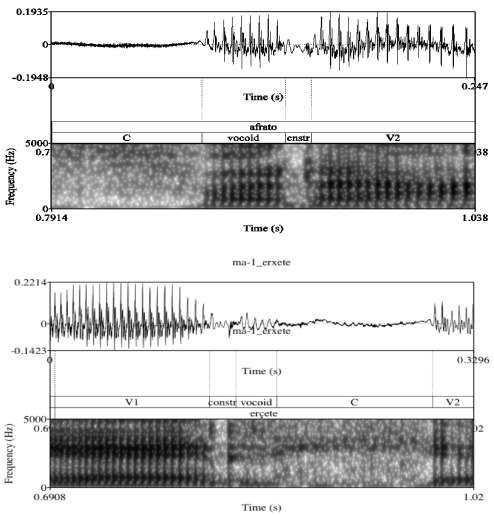


Figure 10 – Modal vowel quality for the vocoid in [a'frato] (top) and breathy vowel quality in ['erçete], (bottom).

A comparison across positions shows that the vocoid has longer average duration than the constriction (Figure 11). Similar results have been found for Spanish (Bradley & Schmeiser 2003).

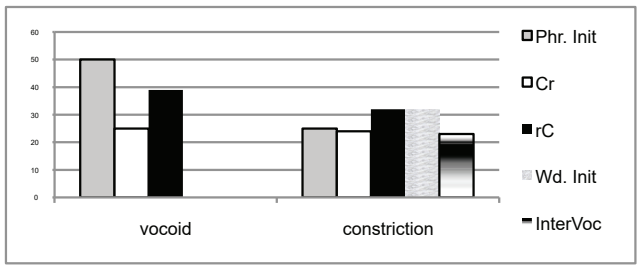


Figure 11 – Vocoid and constriction duration in different positions. Note that constriction duration was measured in all contexts, while the vocoid duration was measured in phrase initial and C-contexts only.

Furthermore, among the positions where the vocoid duration could be measured, shown in Figure 11, the longest occurred phrase initially, almost twice as long as that in /Cr/ clusters and considerably longer than that in /rC/ sequences. We attribute the long vocoid duration in phrase initial duration to the effect of initial strengthening. Differences in vocoid duration in C-contexts are attributed to differences in syllabic affiliation, as /Cr/ are tautosyllabic and /rC/ heterosyllabic and thus the spatio-temporal coordination of gestures may differ in the latter (see also Recasens & Espinosa (2007) for a review of similar findings for vocoid duration in /Cr/ and /rC/ contexts in Spanish and Catalan). The consonantal constriction was longest for word initial and /rC/ sequences and shorter for phrase initial, intervocalic and /Cr/ clusters (Figure 11). Note, furthermore, that, unlike the vocoid, the differences in the duration of the constriction across prosodic positions are small, with only 8.5 ms difference between the average longest and shortest duration.

These comparisons indicate that the different positions/contexts exert an asymmetric influence on the two components of the rhotic. One possible reason for such asymmetries relates to their articulatory nature. The tap, which has been described as a short ballistic gesture in the literature (Lindau 1985; Ladefoged & Maddieson 1996; Recasens & Espinosa 2007), is not as free to lengthen as the vocoid.

A comparison of the vocoid quality in the singleton vs. C-contexts revealed that across prosodic positions the vocoid formants (measured in Hz) are similar to those of the nuclear tautosyllabic vowel and somewhat more centralized

(Figure 12). The amount of centralization varied across prosodic positions, vowels and gender. In phrase initial position female speakers showed a smaller degree of centralization than males, while in /Cr/ clusters the opposite trend was observed. In /rC/ sequences, on the other hand, the amount of centralization was relatively similar across genders. On the whole, centralization was more pronounced across genders and vowels for /rC/ sequences, probably because /rC/ sequences are heterosyllabic.

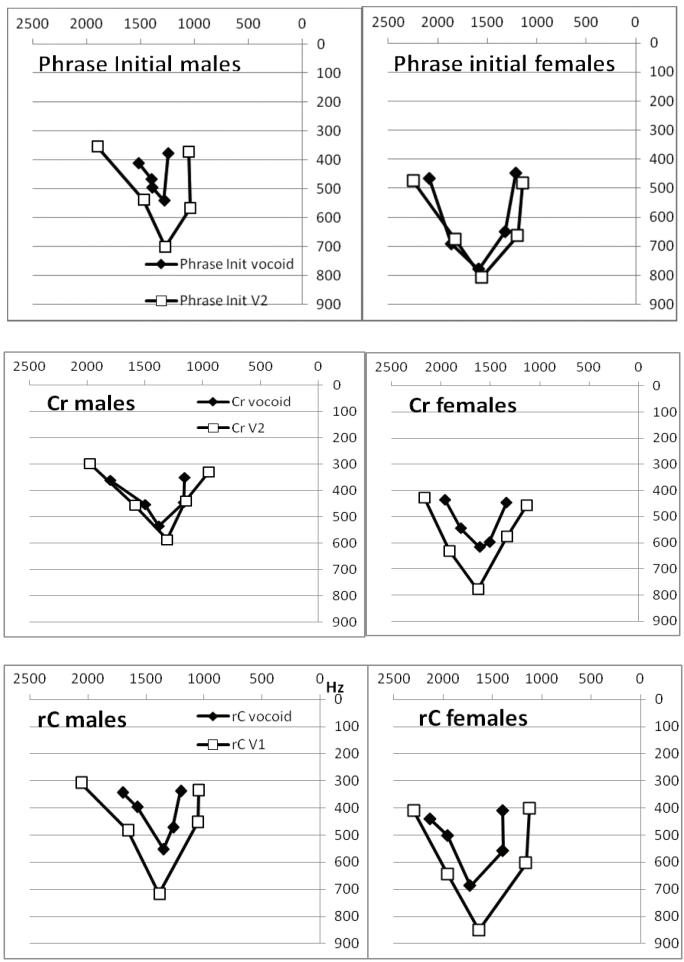


Figure 12 – Comparison of vocoid formants (in Hz) to the nuclear V in different contexts for male (left panels) and female speakers (right).

Figure 13 shows considerable variability in the Euclidean distance between the vocoid and the nuclear vowel across speakers and vowels. On average, across vocalic environments, the vocoid in /Cr/ clusters has the closest formant values to the nuclear vowel.

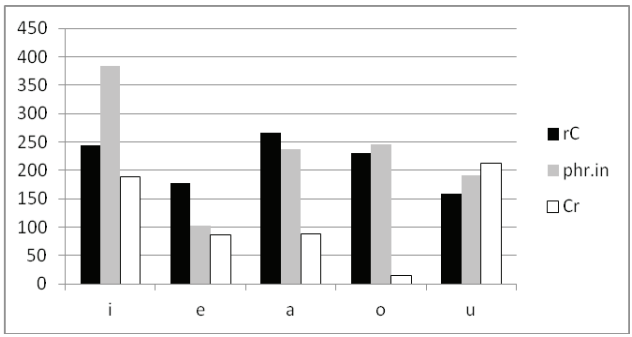


Figure 13 – The Euclidean distance between the vocoid and the nuclear vowel across speakers and vocalic contexts.

3. Discussion

Across contexts, articulation of the rhotic typically involved one short constriction (ranging between 11-57 ms) suggesting a tap articulation. Similar durations for taps have been reported for several languages previously (see Recasens & Espinosa 2007 and references therein). While single contact trills have also been reported before, in the case of utterance initial position they typically involve a much longer constriction phase (around 100 ms) than the one reported in the present study (see Recasens & Espinosa 2007). An interesting finding of the research reported in this study, is the presence of a vocoid during rhotic production in different contexts. On the basis of this finding, two main questions addressed in this paper are: "is there a vocoid present in all different contexts?" and "why is there a vocoid?". While the presence of the vocoid has been documented in C-contexts before, useful insights can be gained from the study of phrase-initial /r/ where /r/ articulation is not affected by an adjacent consonant. Establishing the existence of a vocoid before the constriction phase corroborates the view of the vocoid as an essential articulatory component of the rhotic in singleton contexts. If phrase initial /r/ is the 'canonical' production, then the vocoid can be explained along the same articulatory principles in other contexts. The evidence above, together with the indications provided for a vocoid in word initial and intervocalic position manifested through abrupt discontinuities

in amplitude and formant structure, cast doubt on an exclusively gestural overlap account (see section 1) since a vocoid is attested even without another consonant adjacent to the /r/. Instead, we propose that the rhotic is superimposed on a rhotic-specific vocalic gesture, which is necessary for the execution of the ballistic gesture (cf. Blecua 2001), i.e. the brevity/ballistic nature of the tap gesture requires an undelying vocalic gesture for its execution. Coarticulatory effects are expected in different contexts, which can account for the spatial and temporal variability present during the vocoid and constriction phases of the rhotic.

Further corroborating evidence for our proposal can be found in word-final /r/ which is produced with a vocoid after the constriction (Stolarski 2011 for Polish; Recasens & Espinosa 2007; but see Romero 2008 for a gestural coordination account). Figure 14 shows at the top panel the palindromic word [re'ver], as produced in the phrase [re'ver mu] "my cuffs" by the second author. The word-final vocoid is clear before the segment /m/ (the initial vocoid and constriction duration is 48 ms and 19 ms respectively; the final vocoid and constriction duration is 26 ms and 23 ms respectively). The bottom panel in Figure 14 shows /r/ produced in isolation with one vocoid on either side of the constriction; the initial and final vocoid duration is 36 ms and 54 ms respectively while the constriction itself, which ends with a burst followed by frication noise, lasts 28 ms (cf. Stolarski 2011 for Polish /CrC/ clusters).

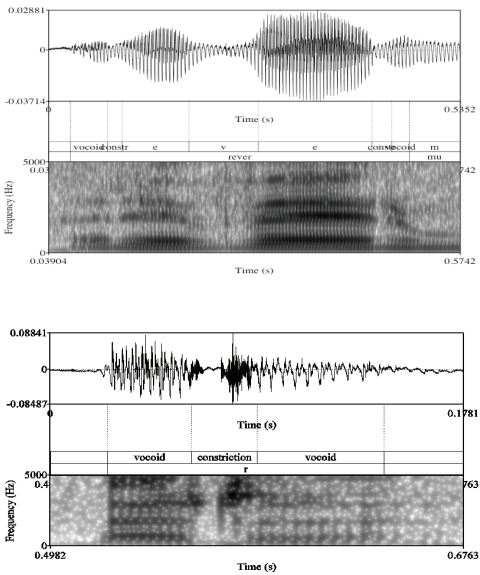


Figure 14 – Top: mirror images of vocoid+constriction in [re'ver]. Bottom: /r/ in isolation.

In line with the above interpretation, i.e. that the rhotic is superimposed on a rhotic-specific vocalic gesture, the variation observed in the position of the vocoid in relation to the consonantal context in /Cr/ vs. /rC/ sequences is expected and can be uniformly explained. If the rhotic is superimposed on a vocalic gesture then the vocoid is expected to precede the rhotic constriction in /CrV/ sequences and follow it in /VrC/ contexts.

Furthermore, the formant structure of the vocoid was more centralised than the nuclear vowel, which was an expected outcome: the V-to-V gesture upon which the rhotic is superimposed includes a vocoid which is influenced through V-to-V coarticulation by the nuclear vowel in to different degrees depending on the context (singleton, C-context). The influence of the adjacent vowel, especially in C-contexts, has been documented for other languages as well (e.g. Blecua 2001; Ramírez 2006).

More specifically, there was a difference between the heterosyllabic /rC/ sequences and all the other prosodic positions: in /rC/ sequences, which lack syllable coherence, both the vocoid and the constriction are longer than in /Cr/ clusters and the vocoid formants are more centralized suggesting less temporal compression and reduced spatial V-to-V overlap. However, there is C-to-r anticipatory coarticulatory influence across the vocoid both in place and degree of constriction. Interestingly, despite the longer vocoid and constriction duration, there were more tokens with incomplete constriction than in /Cr/ clusters. More C-to-r anticipatory than carryover effects, i.e. more tokens with incomplete constriction in /rC/ than in /Cr/ contexts, may relate to the more centralized quality of the vocoid in /rC/ sequences.

On the other hand, the longest vocoid duration was observed for the singleton rhotic phrase initially and the shortest for /Cr/ clusters. These findings can be interpreted as initial strengthening for the rhotic in phrase initial position, realised temporally in the vocoid but not in the constriction duration. The shortest vocoid and short constriction duration were found in tautosyllabic /Cr/ clusters suggesting temporal compression due to the closer co-ordination relations. Carryover C-to-r effects were also found across the vocoid affecting both the place and degree of constriction of the rhotic.

Our data showed variation in place and degree of constriction, duration and vocoid formants as a function of speaker, context and prosodic position. In addition, the vocoid was typically longer than the constriction. While the vocoid length showed considerable variation as a function of prosodic position and context, smaller differences were found for the constriction, something we interpret as lack of freedom for lengthening the tap constriction.

Across experiments, more than 50% of the tokens were produced with incomplete constriction, ranging from very constricted to very open articulations. A smaller percentage of productions with incomplete constriction was found in C-contexts than for singleton /r/, which suggests influence from the consonantal context. Interestingly, more tokens with reduced contact were found in word initial and /rC/ sequences where the constriction is longer. For the former, this suggests that more factors, in addition to boundary strength, regulate the amount of contact. In particular, more tokens with incomplete constriction in word-initial than word-medial position may relate to contextual influence and related gestural coordination patterns, i.e. word-initial tokens were preceded by the high vowel /i/ of the word *'leksi'* in the carrier phrase while word-medial rhotics were preceded by the open vowel /a/. A more open tongue position during /a/ may allow for a more complete ballistic gesture reaching the target for the tap. Note that difficulty in attaining closure during taps in the environment of a following /i/ has been reported in Recasens & Espinosa (2007) due to the nature of the gestures involved. More investigation is necessary for a comprehensive account of spatio-temporal variation.

Finally, the results on the contextual influence, in particular, V-to-r and C-to-r effects, indicate that the tongue coarticulates with neighbouring gestures during the production of the rhotic in Greek, in line with evidence from other languages (e.g. Recasens 1991). While the analysis presented has aimed towards a uniform explanation of /r/ production, it should be noted that further work is needed so that current and alternative interpretations can be tested and firm conclusions can be drawn. This includes statistical analyses of the different measures across positions and further qualitative analyses. These are currently underway.

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