Acoustic characterization of the Greek rhotic in clusters

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Abstract: This paper presents the results of a production experiment which examines the acoustic characteristics of the Greek rhotic sound in consonant clusters. The experimental results suggest that in this position the Greek rhotic has a different realization from the intervocalic rhotic: while in intervocalic position this sound is realized as a tap, in consonant clusters the tap closure is accompanied by a short vowel-like transition between the tap closure and the second consonant of the cluster. The presence of the vowel-like transition was systematic, appearing in 79.5% of the tokens, and is discussed in reference to similar realizations found in many other languages.

Key words: rhotic, tap, vowel-like transition, consonant cluster, trill.

1. Introduction

Cross-linguistically, rhotics exhibit phonetic variability (Lindau 1985; Inouye 1995; Ladefoged & Maddieson 1996) and have a wide range of realizations—from glide to fricative to stop—and for that reason they are difficult to classify. In addition to the cross-linguistic variability of rhotics, there is also considerable phonetic variability of these sounds within languages and different phonetic contexts have been found to affect their realization (Recasens 1991; Recasens et al 1993). While we know that Greek has only one rhotic phoneme, we do not yet have enough information on its phonetic realization in different contexts, thus not enough information to decide whether this phoneme has any allophones.

In the Greek literature, older phonological impressionistic descriptions assumed this sound is a trill (Φίλιππάκη-Warburton 1992; Nespor 1996). Recent phonetic studies which have examined this sound in intervocalic position have revealed that it is a tap in that position (Arvaniti 1999; Nicolaidis 2001)—that is, a very short alveolar stop, classifying it in the natural class of obstruents. Despite these results, the phonetic nature of the Greek rhotic is not yet widely acknowledged in phonological analyses, which treat it as a sonorant sound (e.g. Malikouti-Drachman 1999; Πετρούνιας 2002). In this paper I investigate the acoustic characteristics of the Greek rhotic when it is found in consonant clusters for two reasons: First, to consolidate the fact that this sound is an obstruent, and second, to understand its behaviour in different environments a little better. As we will see, in Greek too there is variability in its realization depending on the phonetic environment, which is systematic.

The present paper reports on an instrumental, acoustic study of the Greek rhotic sound in Cr and rC clusters and shows that in this environment its nature is more complex than a mere tap. Taps are very short voiced alveolar stops, that is, acoustically they are characterized by a single short closure with a mean duration of 20 ms (Ladefoged & Maddieson 1996). From the articulatory point of view, a tap is a brief contact between the articulators which is made by moving the tongue tip to a contact location in the alveolar region (see Nicolaidis 2001). In consonant clusters, as we will see in Section 3, this sound is realized as a combination of a tap and a vowel-like transition which occurs between the rhotic and the second member of the consonant cluster. This realization is not unique to Greek. Similar realizations have been reported
in Spanish (Quillis, 1970, 1993; Guirao & García Jurado, 1991; Bradley & Schmeiser, 2003; Colantoni & Steele, 2005), French (Rochette, 1973; Colantoni & Steele, 2005), Finnish (Harms 1976), and Hamburg German (Jannedy 1994), among many others (see Hall 2006 for further references).

In the remainder of this paper I present the production experiment I conducted to examine the acoustic characteristics of the rhotic in consonant clusters. I explain the experimental method in section 2, give the results in section 3 and discuss these results in section 4.

2. Experimental method
This production experiment explored the Greek rhotic in Cr and rC word internal clusters, with the same V flanking the cluster. The consonants chosen were voiced and voiceless stops and fricatives, varying among the following 12: [p, t, k, b, d, g, f, θ, x, v, δ, γ], therefore creating 24 possible Cr and rC clusters. The vowel flanking the cluster varied among [i, e, a, o, u], thus resulting in a corpus of 120 words (24 clusters X 5 vowels). To give one example, the group of words for the [dr] cluster were [madra, sedres, idriga, xodros, budrumi]. These words were embedded in the sentence *I leksi ___ ine apli* ‘The word ___ is simple’ and six speakers repeated the experimental sentences, for a total of 720 tokens. Notice that in Cr clusters [ɾ] is in onset position and in rC clusters it’s in coda position, as for example in the words *a.kra.ta* and *mar.ka*.

The speakers were all first year university students who participated for class credit. They were recorded in a quiet room after being checked through a short chat for traces of dialectal influence in their speech.

As was mentioned in Section 1, there was a vowel-like transition between the two consonants which, as we will see, was systematic. For that reason, in addition to the duration of the tap closure, I measured the characteristics of this vowel-like transition as well. More specifically, the measurements made were:

A. duration of the tap closure, to compare with that of the intervocalic tap, as well as to investigate possible differences between Cr and rC.
B. duration of the vowel-like transition
C. formant structure of the vowel-like transition, (a) to determine its quality, (b) investigate possible differences between Cr and rC, and (c) explore whether there are any influences of the vowels flanking the cluster on it.

The next section reports the results of the production experiment.

3. Experimental results
The results revealed that the Greek rhotic is realized differently in consonant clusters than when it is found between vowels. Specifically, there is systematic insertion of an extremely short vowel between the rhotic and the second consonant (cf. Navarro Tomás 1918; Quillis 1993; Bradley & Schmeiser 2003; Colantoni & Steele 2005 for a similar process in Spanish and French). The next section (3.1) presents some examples of rhotics both in intervocalic position and in consonant clusters. Section 3.2 gives the details of duration of the closure and of the vowel-like transition and formant measurements of the vowel-like transition.

3.1 Examples of the Greek rhotic realization
The following figures give representative examples of the acoustic realization of the Greek rhotic both in intervocalic position and in Cr and rC clusters. In addition, examples of such clusters in Spanish and French are given for comparison.
Figure 1 shows the waveform and spectrogram of an intervocalic tap flanked by the vowel [o] in the word /γριγόρο/ ‘fast’ in Greek. Only part of the word is shown. One of the most common acoustic characteristics among most types of rhotics, as reported in Ladefoged & Maddieson 1996, is F3 lowering, which is evident in this figure (arrow in the spectrogram). The tap itself is a brief voiced closure, lasting only 24 ms. Nicolaidis 2001 in an articulatory study of several consonants in spontaneous speech reports an average duration of 25 ms for the tap, while Arvaniti 1999 in a comparison between Cypriot and Greek segments reports an average duration of 20-25 ms for the Greek tap. The token presented in Figure 1 comes from an unpublished study of the Greek intervocalic tap (Baltazani 2005) where the average duration of [ɾ] was 24 ms.

**Figure 1.** The Greek intervocalic tap, shown here in the word /γριγόρο/ ‘fast’.

Figure 2 shows the rhotic in a Cr cluster in the Greek word /κράμα/ ‘alloy’. The structure of the tap closure in this figure is similar to the one in Figure 1: it is brief, 24 ms, and voiced, resembling the closure of a voiced stop. Between the stop [k] and the rhotic there is a vowel-like transition with formant structure which is similar to the nuclear vowel of this syllable. While this vowel-like transition is much shorter than the nuclear vowel, its duration is a little longer than that of the tap closure, 29 ms. It is conceivable that one could describe this type of rhotic as a short trill, however, I argue (see section 4) that the Greek rhotic in this position should not be called a trill.
Figure 2. The Greek rhotic in a Cr cluster in the word /krama/ ‘alloy’.

For comparison, Figure 3 shows the rhotic in a consonant cluster in the word crema /kRema/ ‘cream’ in Spanish (Colantoni & Steele 2005: 9). Here, too, a vowel-like transition with formant structure which is similar to the nuclear vowel of this syllable is present between the rhotic and the voiceless stop, [k]. Just like in Greek, the duration of this vowel-like transition is much shorter than the nuclear vowel but a little longer than that of the tap closure.

Figure 3. A Spanish Cr cluster in the word /kRema/ ‘cream’ (Colantoni & Steele 2005: 9). Notice the similarity between the Greek and Spanish rhotic.

Figure 4 shows an rC cluster in the Greek word /aγarba/ ‘clumsily’. Again the tap closure in this figure is brief and voiced and there is a vowel-like transition between the rhotic and the stop. The formants of the vowel-like transition in this token are lower
than in the vowels flanking the consonant cluster. While this vowel-like transition is much shorter than the nuclear vowel, its duration is a little longer than that of the tap closure, 29 ms.

Figure 4. The Greek rhotic in an rC cluster in the word /aγarba/ ‘clumsily’.

To compare with the Greek rC clusters, Figure 5 shows shows an rC cluster in the Spanish word muerte ‘death’ (Bradley 2001:95), which looks very similar to the Greek rC cluster.

Figure 5. An rC cluster in the word in the Spanish word muerte ‘death’ (Bradley 2001:95).

3.2 Measurements

The results show that in the clusters the speakers produced, 79.5% of the tokens had a brief vowel between the tap closure and second consonant of the cluster. All six speakers produced approximately the same percentage of this type of rhotic (78%, 79%, 79%, 83%, 80%, 78% for speakers 1 – 6 respectively). In the remainder of the tokens
the rhotic was mostly realized as an approximant without any vowel transition, and there were also very few tokens produced as trills (13 tokens, or 1.8%). Clusters with the tap in coda position (rC) had a slightly lower percentage of brief vowels than clusters with the tap in onset position (70% versus 88% respectively).

As already mentioned, I measured the duration of the closure portion and the vowel-like portion of the rhotic. The duration of the whole rhotic, tap plus vowel, is short, 55-60 ms. On average, the sum of the durations of the closure plus the brief vowel is slightly longer in coda than in onset position: 58 ms and 55.6 ms respectively. Examined a little closer, the position of the rhotic in the syllable—whether it is onset or coda—seems to play a role: the difference in duration between the tap constriction and the brief vowel is greater for codas (13.2 ms) than for onsets (5.3 ms). When [r] is in onset position, the V duration is longer than the closure duration for 82% of the tokens. When [r] is in coda position, the V duration is longer for 94% of the tokens. Table 1 presents the average durations of the closure and the vowel-like transition in onset and coda position.

Table 1. The brief vowel is longer than the tap constriction. Their difference is greater in coda position.

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<th>ONSET</th>
<th>CODA</th>
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<tbody>
<tr>
<td>CLOSURE</td>
<td>25.1</td>
<td>22.4</td>
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<tr>
<td>V</td>
<td>30.4</td>
<td>35.6</td>
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The duration of the vowel-like transition was longer than the tap constriction regardless the vowel flanking the cluster. Figure 6 shows the tap and V durations separately for each vowel flanking the cluster. The white and grey bars show the V duration in onset and coda position respectively. The horizontal stripes show the tap duration in onset position and the vertical stripes show the tap duration in coda position. Regardless of the vowel flanking the cluster, the makeup of the rhotic is consistent: the open portion (the brief V) is longer than the closed portion (the tap). Furthermore, the open portion is longer in coda position for all vowels flanking the cluster—except [u] where the open portion is equal in length both in onset and in coda position.

The spectral characteristics of the vowel-like transition were also measured, in order to (a) determine its quality, (b) investigate possible differences between Cr and rC, and (c) explore whether this quality is influenced by the vowel flanking the cluster. Measurements of the vowel-like transition were taken for the clusters in onset position (Xs) and coda position (white squares) and they are compared with the average values of the five Greek vowels from two studies, Baltazani (2006) (circles) and Sfakianaki (2002) (black squares).

The results show that, in general, the vowel-like transition has similar quality to the vowel flanking the cluster. This is especially true for the brief vowels in rC clusters whose average formant values are very close to average formant values for the Greek vowels reported in Baltazani (2006). On the other hand, the brief vowels in Cr clusters were found to have average formant values which were more central: [i] is lower and more back, [e] is more back, [a] is higher and both [o] and [u] are more front. This difference might be due to the duration difference between the vowel-like transition in onset and coda position: in onset position this brief vowel was found to be shorter than in coda position and therefore it might be a case of target undershoot.
4. Conclusion
In this paper I examined the phonetic properties of the Greek rhotic when it is found in consonant clusters with an obstruent. One of the goals of this paper, apart from establishing its acoustic realization in this environment, was to consolidate the fact that this sound is an obstruent. Rhotics are traditionally described as sonorants and liquids. However, a sonorant is produced without turbulent airflow, with only a partial closure and an unimpeded oral or nasal escape of air. Acoustically, it is a periodic sound. The Greek /r/, both in intervocalic position and in clusters with other consonants, has stop characteristics so it cannot be labelled sonorant. Instead, it is a voiced, coronal, non-continuant segment.

Another issue in connection with the phonetic realization of this segment in clusters has to do with the way we interpret it: Is this rhotic a tap or a short trill? It could be argued that in Cr clusters, the high-pressure air after the stop can set the tongue tip (which is in position for the tap) into a short trilling motion, thus explaining the
presence of the vocalic part. However, this aerodynamic explanation cannot cover rC clusters (where the vowel-like transition is also present): in that case there is no build-up of air, as the consonant follows the rhotic.

Furthermore, as has been repeatedly shown in the phoetic literature, whereas the tap involves a ballistic tongue tip gesture, the trill requires a tensed, controlled, and precise gesture in order to initiate passive vibration of the articulator by virtue of the Bernoulli effect (Catford 1977, Ladefoged & Maddieson 1996). Catford (1977) maintains that the duration of each tap is longer than that of each trill cycle: while for a trill 30 cycles per second can be produced, only five or six taps can be produced per second. Furthermore, Ladefoged & Maddieson 1996 describe short trills as “…two to five periods…”, whereas the segments described in this paper did not exhibit more than one constriction. For all the above reasons, in this paper I have described the rhotic in consonant clusters as a tap accompanied by a brief vowel and not a trill.

Regardless of the term used to describe these segments, however, the fact remains that they are systematically different from the rhotics in intervocalic position. This in turn permits us to have a more precise description of the phonological status of the rhotic. In other words, the Greek rhotic phoneme has at least two allophones: the tap in intervocalic position and the tap plus vowel-like transition in consonant clusters. It remains to be seen whether still more allophones exist for the Greek rhotic and what their distribution is.

The vowel-like transition between the /r/ and the second member of the cluster has been accounted for in other languages as a result of retiming of the two existing consonantal gestures—there is less overlap between the two consonantal gestures, leaving space between them for the realization of this brief vowel. Romero (1996:106) observes that in the realization of lateral-obstruent Spanish clusters, there is an overlapping of the two consonantal gestures, whereas rhotic-obstruent clusters are realized as a sequence, permitting the presence of the vowel-like transition between them. Since as we said the rhotic is an obstructive, while the lateral is a sonorant, there is greater probability of dissimilation via the intrusion of a brief vowel for the more similar segments and that is why we find a vowel transition in rhotic-obstruent clusters (cf. Hall 2006).

If we adopt such a hypothesis for Greek as well, several new questions are left open: If the brief vowel is a result of retiming of the existing consonantal gestures, is it affected by speech rate? We would expect shorter vowel-like transitions as the speech rate increases. Furthermore, if it is true that a brief vowel appears whenever the two members of a cluster are similar, we would expect such a brief vowel to appear in Greek for stop-stop or stop-fricative clusters, as well. These questions have not been explored yet for Greek as far as I know.

References
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