# Productive Palatalization in Romanian: An Acoustic Study

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## 1 Introduction

A consonant can be described as palatalized under the following circumstances: (1) if, when followed by a high vowel or glide, in its articulation the tongue is placed at a different (more palatal) position as compared to articulation in the absence of such vowels (referred to as contextual fronting by Keating and Lahiri 1993); (2) if, as a result of assimilation (feature-spreading) from a following high vowel or glide, the consonant in question has changed its primary place of articulation toward the palatal region; (3) finally, if its underlying description includes a secondary specification for a palatal articulation. Such consonants have been called ‘soft’ (for Slavic languages) or ‘slender’ (for Celtic languages) (Kochetov 2002) and, along with plain or [+back] consonants (either lacking a secondary articulation or having a velarized secondary articulation, Keating & Lahiri 1993) can be used contrastively as part of phonemic inventories such as that of Russian.

Palatalized consonants have been reported to exist in Romanian (Petrovici 1956, Schane 1971, Chitoran 2001, Iscrulescu 2003), but no acoustic or articulatory study has determined which of the above descriptions is the most adequate for them, or if they are indeed palatalized. In a previous study aimed at investigating the perceptual reality of palatalized consonants for native speakers of Romanian it was found that palatalization is perceived to differing degrees based on primary place of articulation (Spinu 2006). To better understand the phonological/phonetic status of Romanian palatalized consonants and their differing perceptibility we examine 3 acoustic aspects of Romanian palatalized consonants as well as their corresponding consonants in a fronting environment; specifically their release spectra, effect on neighboring vowels and their duration.

## 2 Palatalization in Romanian

The set of Romanian palatalized consonants includes all consonants in the phonemic inventory, with the exception of [s] and [d]. They are taken to be morphologically predictable (Chitoran 2001), being restricted to word-final position and generally associated with the presence of two suffixes: the plural for nouns (1a)[1] and adjectives (1b), and the 2nd person singular in the present indicative of verbs (1c). Closer examination reveals the existence of monomorphemic words exhibiting the same pattern[2] (2) as well as, with few exceptions, the lack of word-final consonant-unstressed [i] sequences in the language. It may be the case that palatalized consonants are not only morphologically, but also phonologically predictable in word-final position.

| | | | |
|---|---|---|---|
| (1) | a. *lupi* | [lup$^j$] | ‘wolves’ |
| | b. *albi* | [alb$^j$] | ‘white-M.pl’ |
| | c. *sari* | [sar$^j$] | ‘you jump’ |
| (2) | a. *unghi* | [ung$^j$] | ‘angle’ |
| | b. *puşti* | [puʃti] | ‘kid’ |
| | c. *baremi* | [barem$^j$] | ‘at least’ |

[1] Orthography is shown in italics.
[2] Chitoran (2001) also notes the existence of words ending in palatalized segments in the singular form, but limits her discussion to the case of velar palatalized consonants, taken to be the result of a phonological process, distinct from morphological palatalization.

Contrasts in meaning are thought to arise between the inflected forms, ending in a palatalized consonant, and the ones ending in a plain consonant (singular nouns and adjectives, or 1st person singular for verbs), thus resulting in minimal pairs (1a-3a, 1b-3b, 1c-3c).

| | | | |
|---|---|---|---|
| (3) | a. *lup* | [lup] | 'wolf' |
| | b. *alb* | [alb] | 'white-M.sg' |
| | c. *sar* | [sar] | 'I jump' |

Root-final consonants are sometimes further affected in the presence of these affixes by changing their primary place and/or manner of articulation (4), in a way very similar to the second type of palatalization described in the introduction.

| | | | |
|---|---|---|---|
| (4) | a. *rac* | [rak] | 'crawfish' |
| | b. *rac* | [ratʃʲ] | 'crawfish-pl' |
| | c. *pas* | [pas] | 'step' |
| | d. *paşi* | [paʃʲ] | 'step-pl' |

This study focuses on the cases where the primary place of articulation of the root-final consonant remains unaffected. While changes such as those in (4) might be described as morphologically-conditioned processes, palatalization as the superimposition of a secondary palatal feature to the primary POA of a consonant may be illustrative of a more general phonological/phonetic process in the language. Although Chitoran's feature-geometric account (Chitoran 2001) provides a unified perspective of the two palatalization processes, not all of the previous accounts discuss them in conjunction with each other.

It should be emphasized at this point that, though we refer to them as palatalized consonants, different descriptions exist in the literature with respect to the phonetic characteristics of these structures, and this situation may be regarded as one of the reasons underlying the present study. Though not supported by acoustic studies, two main opinions prevail regarding the surface realizations of the word-final structures orthographically represented as 'Ci': either as *palatalized consonants, with a secondary palatal feature* simultaneous with the primary place of articulation, as can be found in neighboring Slavic languages, or as *sequences of consonant-glide.* Since the term 'palatalized consonants' in the sense of a secondary palatal feature has been more frequent in recent years, we also refer to them as such. Even more disagreement is found with respect to their underlying representation: palatalized consonants are considered part of the phonemic inventory by Petrovici (1956), while Schane (1971) does not take them to be underlying, but grants the native speaker a special level of awareness at which surface contrasts can be phonemic. Other linguists take palatalization or the final glide to be underlyingly represented as a glide or semi-vowel (Agard 1958, Avram 1991), or an archiphoneme, sharing features of both /j/ and /e̯/ (Vasiliu 1990). Finally, there is the view according to which surface palatalized consonants or word-final, post-consonantal glides correspond to an underlying /i/ (Stan 1973, Ruhlen 1973, Steriade 1984).

## 3 Previous Accounts

In this section we first provide a more detailed overview of the different accounts that have been offered on Romanian palatalization and then go on to discuss some of the perceptual differences that have been found.

### 3.1 Varying Views

As previously mentioned, two descriptions have been provided for the word-final structures spelled as 'Ci' in Romanian, where the 'i' does not stand for a syllabic segment (as shown by auditory observation and native speakers' intuitions).

a) *Palatalized consonants.* While their opinions with regard to the phonological status of these structures differ, Petrovici (1956), Schane (1971), Chitoran (2001) and Iscrulescu (2003) describe their surface manifestation as consonants having any primary place of articulation, but with a secondary palatal articulation present simultaneously. This description is also encountered for palatalized consonants in Slavic. One related point is that for Schane, the consonants which also change their primary place of articulation, by becoming palatal (as in 5 above), are taken to go through consecutive processes of palatalization and subsequent depalatalization and thus do not exhibit a secondary feature on the surface.

b) *Sequences of consonant-glide.* On the other hand, Ruhlen (1973) treats the word-final orthographic 'Ci' sequences as consonants followed by glides. The glides result from a process of high vowel reduction in word-final position, and are taken to delete completely when preceded by a palatal consonant (as in (4) above. In her study of Romanian glides and vowels, Steriade (1984) also takes these word-final structures to be consonants followed by glides, resulting from a rule of high vowel desyllabification.

From (a) and (b) above we can conclude that there is no general agreement on the phonetic aspect of Romanian palatalization. Related to this issue, the subset of palatal consonants also receives different treatments regardless of the general approach to these consonants: either they are followed by a glide or else there is a secondary feature on them, or not (their form in the plural is taken to be identical, on the surface, to that in the singular).

## 3.2 Perceptual differences

If we follow the claims according to which the surface structures are indeed palatalized consonants, a conflict seems to arise between their (morpho-)phonological predictability, which would imply an allophonic status, and their potential ability to signal differences in meaning, which is more indicative of phonemic behavior. Given this situation, a perceptual study (Spinu 2006) sought to determine the extent to which native speakers actually utilize the functional load with which these (complex) segments are associated. The study examined the perceptual properties of these word-final structures with three different places of articulation, more specifically root-final labials, dentals, and post-alveolars. Stimuli were presented in matched and mismatched singular/plural contexts with and without palatalization (palatalization signaling the plural). While native speakers were found to be very sensitive to both singular and plural forms of roots ending in labials and dentals, a significant decrease in perceptibility was reported in the case of post-alveolars. This finding provides a perceptual basis for Schane and Ruhlen's differential treatments of post-alveolars as opposed to the other consonants with respect to palatalization, and may add a perceptual motivation for the crosslinguistic rarity of contrastively palatalized post-alveolars. For the other two places of articulation speakers were found to differentiate between minimal pairs ending in either a plain or palatalized consonant, thus it can be concluded with enough certainty that palatalization in Romanian is perceptually salient. However, other studies on palatalized consonants (Padgett 2001, Kochetov 2002) report a perceptual asymmetry in the case of labials versus coronals, with labials being perceived less accurately than coronals in both onset and coda position for both native speakers of Russian and Japanese. This asymmetry was found to correlate with articulatory and acoustic factors, as well as with frequency distributions and neutralization patterns cross-linguistically. Under these circumstances, it is interesting that the perceptual study of Romanian palatalization do not replicate these findings, and in fact found the labials tended to be more salient than the dentals; the question thus arises of whether the term 'palatalized consonants' is the most accurate description for the phenomenon occurring in Romanian and in what ways is Romanian articulation distinct from languages which show differing perceptual asymmetry.

# 4 Acoustic Description of Romanian Palatalization

Following the perceptual study (Spinu 2006), voiceless labial, dental and postalveolar consonants were selected for acoustic investigation. Labial and dental consonants have been well documented in the palatalization literature and thus serve best for a comparison with palatalization in other languages. Palatalized post-alveolars were included as they are considered to be crosslinguistically rare and thus this study would constitute a description. We will begin by summarizing the articulatory and acoustic properties that are involved in these consonants, namely a secondary palatal constriction coupled with the primary articulators [lips] or [tongue blade], as well as the properties of a primary palatal constriction.

## 4.1 Description of Palatalization

In his study of Russian contrastive palatalization Kochetov (2002) found palatalized coronals to show a raising (15-22mm) and fronting (although fronting was not contrastive) of the tongue body beginning earlier than 30ms before primary closure, and coinciding with closure. The palatalized coronal is described with the gestural specifications [palatal,closed]. In previous work Kochetov (2001) found that plain/palatalized distinction was manifested in coronals in the primary articulator as well, plain being gesturally [dental,apical], and palatalized being [alveolar,laminal]. Acoustically palatalized coronals are longer and have a more noisy strident like release which Kochetov attributes to the laminal contact. In the same study Kochetov found palatalization in labial stops was realized as a raising (16/18mm) and fronting (24/26mm) of the tongue body beginning less than 30ms before primary closure and coinciding with release of the primary articulator. He notes that the peaks of the fronting and raising were not always simultaneous and confirms earlier reports that the Russian plain consonants are velarized. The gestural specifications are summarized as [velar, mid] for plain and as [palatal, narrow] for palatalized. Acoustically palatalized labials were longer than plain labials with weak energy at the higher frequencies. Kochetov found the timing of the primary [lips] and secondary [tongue body] articulations as well as tongue rise and tongue fronting varied by speaker and by syllabic position. In coda position the achievement of the secondary target is found to be earlier (20-70ms) than in onset position (Kochetov 2006). In another paper Kochetov (1998) compares 4 dialects of Polish and finds palatalized labials have four distinct realizations which differ in the timing and degree/place of constriction of the secondary articulation. The palatalized labials range from the secondary articulation described above, to a sequence of labial stop followed by palatal strident.

Post-alveolars usually pattern with either plain or palatalized consonants but not both (Kochetov 2002). Some loan words in Polish show palatalization of (retroflex) post-alveolar fricatives before the high front vowel /i/ to palatalized laminal post-alveolar fricatives which contrast acoustically with alveolo-palatal fricatives (Zygis & Hamann 2003), although this is disputed. Zygis & Hamann find the Center of Gravity of the palatalized post-alveolar before the vowel /a/ to be around 3500Hz for one speaker and 4500Hz for another.

As palatalization consists of a secondary palatal constriction it maybe useful to describe palatal constrictions. Keating & Lahiri (1993) discuss the palate in terms of four areas; the corner of the alveolar ridge, the diagonal behind it, the roof, and the soft palate. They define the tongue blade as the front 2-3 centimeters of the tongue corresponding to the anterior section of the tongue based on Stone's (1990) analysis of the tongue into 4 functionally independent sagittal sections. Keating & Lahiri refer to the other sections as the tongue body. Palatal stops involve both the tongue blade and the tongue body, with the contact being mostly lateral, similar to non-low front vowels /i,e/ which generally have lateral contact. Palatal stops and glides in Czech are described as a laminal tongue blade non-anterior constriction, as well as a lateral tongue body constriction, with the stop having the tongue blade as the primary articulator and glides having the tongue body. Hungarian palatal fricative and glide show longer lateral contact than stops, with an open passage in the center of the tongue. Keating & Lahiri found the main spectral peak in palatal stops to align with the following vowel's F4. They note that in the context of unrounded vowels the spectrum of palatals slopes up to 3500hz and does not have a dominate peak but a cluster, whereas the spectra of palatal stops before round vowels are more compact and show a main peak between 2500-3000hz.

## 4.2 Data Collection

Using an inverse dictionary (http://dexonline.ro/), 4 words in the masculine paradigm with a stressed /o/ preceding the target consonant were chosen for the three places of articulation: labial, dental, and post-alveolar. Due to limitations of the Romanian lexicon a fricative series or stop series were unavailable, thus a labial stop, dental affricate and post-alveolar fricative, were chosen for investigation. While this differs from previous studies of palatalization which focus primarily on voiceless stops, the fricated consonants were chosen to track changes in articulation and thus obtain a better understanding of where the secondary gesture is realized. As the palatalized consonants under debate appear only word-finally in Romanian, both syllable position (onset and coda) and frontness of the environment (back and front) were controlled for. To determine whether palatalization was different from contextual fronting, palatalized consonants were compared with controls in the onsets of /i/ high [front] and /u/ high [back] vowels. To determine the effects of syllable structure, palatalized consonants are compared with non-palatalized controls in coda position (we will refer to these as [plain]). For simplicity, we will use the descriptive labels [palatalized], [plain], [front] and [back] to refer to the four conditions.

A minimal quadruplet formed the four conditions:

(5) Coda Position

| | | | |
|---|---|---|---|
| a. [plain] | *cocoş* | [ko.ˈkoʃ] | ‘rooster’ |
| b. [palatalized] | *cocoşi* | [ko.ˈkoʃʲ] | ‘roosters’ |

Onset Position

| | | | |
|---|---|---|---|
| a. [back] | *cocoşul* | [ko.ˈkoʃul] | ‘the rooster’ |
| b. [front] | *cocoşii* | [ko.ˈko.ʃii] | ‘the roosters’ |

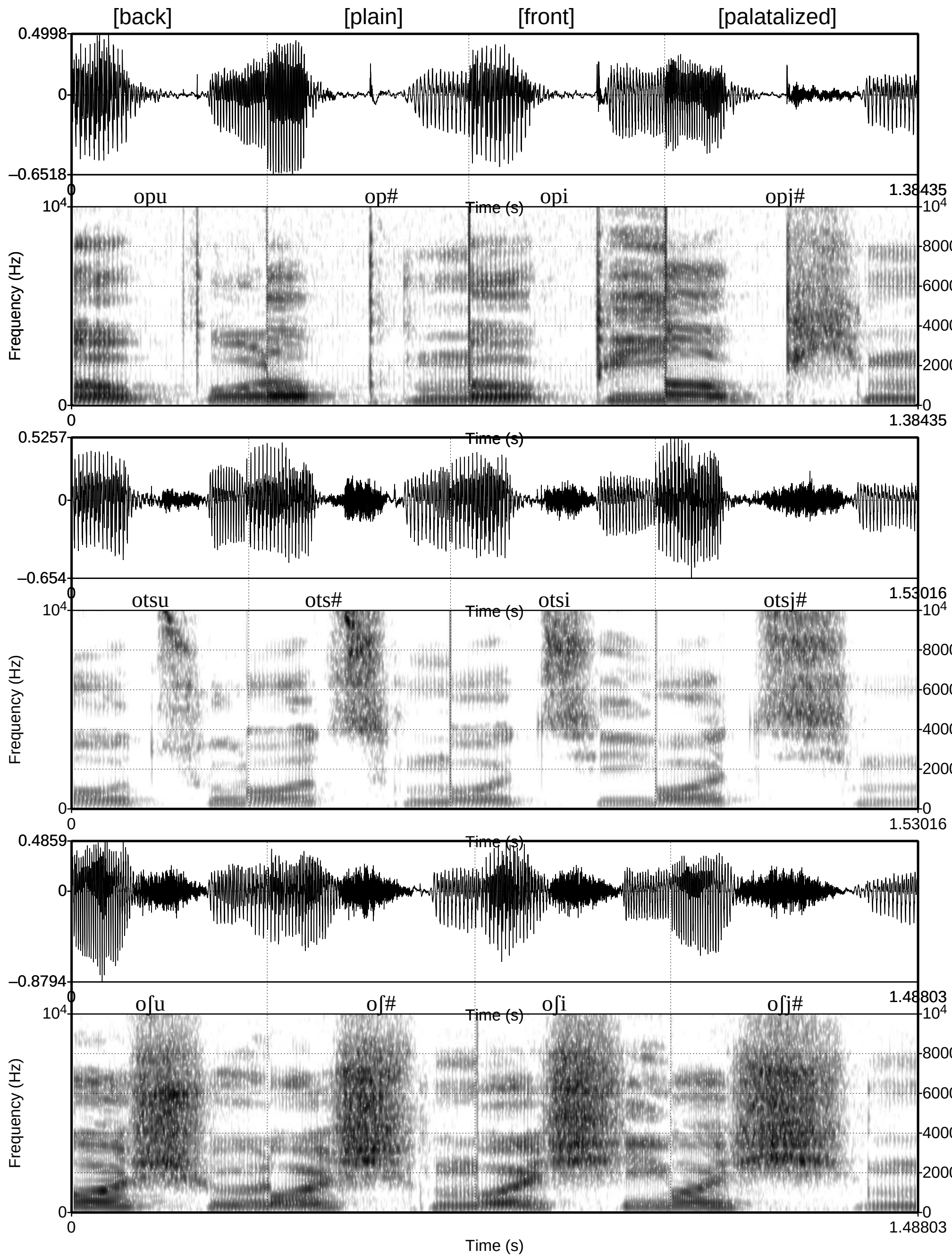
Stimuli were recorded at a 22 kHz sample rate by a 30 year old male speaker. The 4 target words for 3 places of articulation were repeated 3 times in each of the 4 contexts with an equal number of filler items, for a total of 288 items (4x3x3x4x2). The items were randomized and presented in the carrier phrase: *Aş vrea să văd* _____ *mâine când vin prietenii mei.* (“I’d like to see ____ tomorrow when my friends arrive.”)

## 4.3 Description of Results

For all places of articulation, consonants in both the [front] and [palatalized] conditions showed a higher F2 in the offset of the preceding vowel than consonants in the [plain] and [back] conditions. The F2 was higher in [palatalized] conditions than in the [front] conditions. Consonants in the [front] and [palatalized] condition showed a spectral prominence around 2600Hz in the later part of the frication, as well as what visually appear to be rather consistent formant-like spectral peaks. The frication was longer in the [palatalized] condition. The labial stop showed the largest acoustic difference in the [palatalized] condition, where there was an additional frication with a spectral peak around 2600hz, no frication was present in the labials of the other three conditions ([front], [back] and [plain]). We expect this additional frication to have contributed to the labial’s increased perceptibility in Romanian, instead of the reduced perceptibility found crosslinguistically. The additional frication found in the labial stops maybe similar to that found in palatalized labials of Polish spoken in Mragowo and Jabłonka which are realized as a labial stop followed by a palatal fricative or strident (Kochetov 1998).[3] Waveforms and spectrograms of the consonants in the four conditions are provided in Figure 1. Of interest are the fricated release in the [front] and [palatalized] segments, as well as the F2 transitions in the preceding vowels. (The “Cj” notation is used for the [palatalized] condition.)

[3] Kochetov derives their sequence realization from an underlying palatalized labial through an OT constraint grammar.

**Figure 1 Waveforms and Spectrograms of the four conditions**

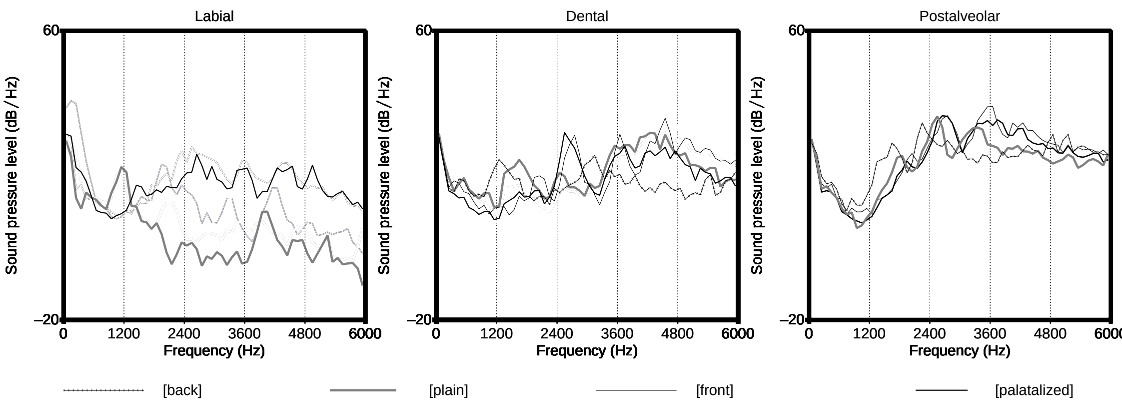



## 4.4 Release Spectra

FFT spectra were generated over a 512 (25.6ms) point window aligned with the offset of the fricated release. Only conditions displaying fricated releases were compared to maintain consistency (thus excluding labial stops in onset position). Figure 2 displays the mean spectra of the [back], [front], [plain] and [palatalized] conditions for the dentals and post-alveolars, and the [plain], [palatalized] condition for the labials.

Dispersion and spectral prominence were examined in the release of the consonants to determine the place of final constriction. Dispersion is taken to be a measure of the ratio of front cavity resonance to that of the back cavity. When the volume in the front cavity is low compared with the back (as is the case with front constrictions such as dentals) the energy in the low and mid ranges is more disperse. When the ratio is reversed (in the case of relatively back constrictions such as palatals and velars) the spectra is more compact with a prominent peak (Keating & Lahiri 1993, Gordon & Maddieson 1999). The area of spectral prominence is often described in terms of its frequency or the natural resonances of a tube modeled on the length of front cavity (F1, F2 etc) (Keating & Lahiri, 1993; Stevens 2003); thus the further front the constriction, the higher the spectral prominence.

**Figure 2 Release Spectra**




The most pronounced shift in spectral prominence is found in labials. The release of the [plain] labial shows a mean spectral prominence around 1200Hz while the release of the labials in the [palatalized] condition showed a mean spectral prominence of 2600Hz.

Dentals in the [plain] condition show a cluster of peaks between 3500-4500Hz, dentals in both the [front] and [palatalized] conditions are more compact and also show a prominent peak around 2600Hz as well as significantly lower amplitude in the frequencies below 2000Hz. As the dental peaks are the least clear with respect to spectral prominence, the amplitudes of the dental peaks are shown in detail in Figure 3, the peaks are referred to with their average values in hertz shown in the legend. In the [plain] condition the peaks at 3600Hz and 4500Hz are the most prominent, with the peak at 2600Hz being the least prominent. In the [palatalized] condition the peaks at 3600Hz and 4500Hz are reduced in amplitude with a trend for the peak at 2600Hz to be the most prominent.

Post-alveolars in the [front] and [palatalized] conditions showed a shift to higher frequencies in both of their characteristic peaks of 2500Hz (+100Hz) and 3300Hz (+200Hz), although slight, the difference was statistically significant ($p < 0.05$). As the spectral differences between post-alveolars in the [plain] and [palatalized] conditions are not as pronounced as those found in labials and dentals, we expect this to have been a factor in their reduced perceptibility found in the perceptual study discussed earlier (Spinu 2006).

No statistically significant differences were found between the [front] and [palatalized] conditions in dentals and post-alveolars. Labials lacked a fricated release in the [front] condition and thus were too different spectrally to compare.

While it is clear that the three consonants investigated are articulated differently in front contexts ([front] and [palatalized] conditions) than in non-front contexts ([back] and [plain] conditions), it is not clear what the increased prominence around 2600Hz implies as such a spectral prominence is not mentioned in the studies of palatalization or palatal constriction surveyed. According to Stevens (2003) a spectral prominence between 2000 and 2900Hz (F3) is attributed to a front cavity length around 3.5cm. However, the closest candidate found in the palatalization literature was that of the voiceless fronted velar found before front non-low vowels /i,e/ in Czech and Hungarian, where there are two peaks which fall 2500-2700 and 2800-3000 (Keating & Lahiri 1993:96). We leave the nature of this articulation for a broader study including more consonants in varying vowel contexts.

**Figure 3 Amplitude of Peaks in Dentals**

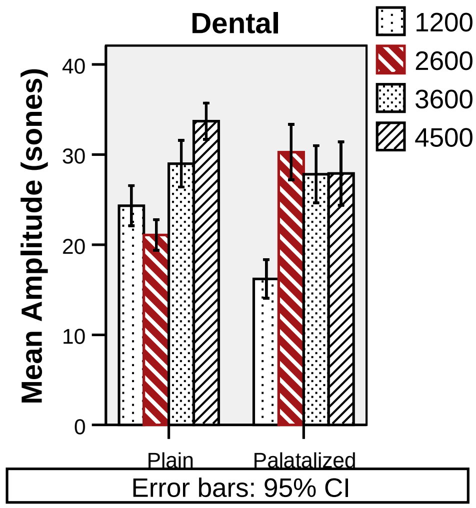
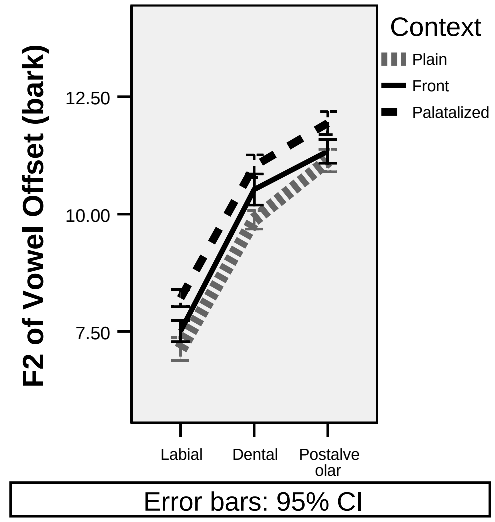



**Figure 4 F2 at Offset of Preceding Vowel**




## 4.5 F2 of Preceding Vowel

Perceptual studies using the cross-splicing technique have shown that transitions in surrounding vowels are usually more informative than spectral characteristics of the burst (Andreeva et al. 1999). To determine acoustic cues which might have led to the differences in perceptibility reported in Spinu (2006) we compared the F2 at offset of the preceding vowel in the [plain], [palatalized] and [front] conditions. Transitions following the consonants, commonly considered the most informative, were not available due to the consonant's position at the end of a prosodic word. There was an expected main effect of place of articulation on the height of F2 with labials causing F2 to fall, dentals showing a rise and post-alveolars showing a greater rise. The F2 was significantly higher in both frequency (hertz) and human perceptibility (bark)[4] in the [palatalized] condition than in the [plain] for all three places of articulation.

Although the spectral properties of the release in [front] and [palatalized] consonants do not appear to differ as suggested in Section 4.4, the [front] and [palatalized] consonants appear to have differing effects on the F2 of the preceding vowel. F2 offset for labials and post-alveolars was significantly higher in the [palatalized] condition than the [front] condition; this was a clear trend in dentals as well although it did not reach statistical significance, as shown in Figure 4.

The raise in F2 in the offset of the preceding vowel is commonly taken to be indicative of an earlier front target. As the [front] and [palatalized] consonants differed with respect to syllabification we cannot be certain that the earlier articulation is not due to the consonant forming the coda of the vowel in the [palatalized] condition. In his articulatory study of Russian palatalization mentioned earlier Kochetov found secondary palatal articulations were articulated earlier in coda position than in onset position (Kochetov 2006).

## 4.6 Duration

While consonants in the fronting environments do not appear to differ spectrally with consonants in the [palatalized] condition, a difference was observed in their duration. In order to determine whether this difference in duration is due to syllabic position, we compared the duration of the dental and post-alveolar consonants in the onset conditions [back] and [front] with those in the coda conditions [plain] and [palatalized] (shown in Figure 5). The consonants in the [plain] condition patterned with those in

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[4] Bark values are calculated on a roughly linear scale for values less than 1000Hz and on a logarithmic scale above 1000Hz to more closely model human perception of higher frequencies.

the onset conditions. The consonants in the [palatalized] condition were significantly longer (40-50ms)[5] we expect this to have been an additional cue in the perceptual study. In the fronted conditions [front] and [palatalized] we found the [palatalized] condition to show significantly longer frication with the spectral properties described in Section 4.4, which is referred to as 'Palatalized' frication in Figure 6.

**Figure 5 Consonant Duration**

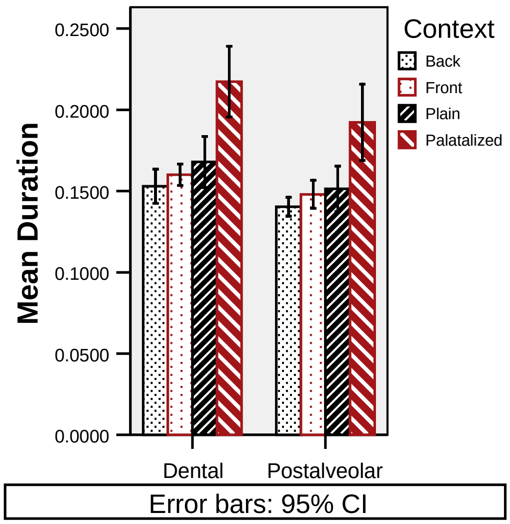
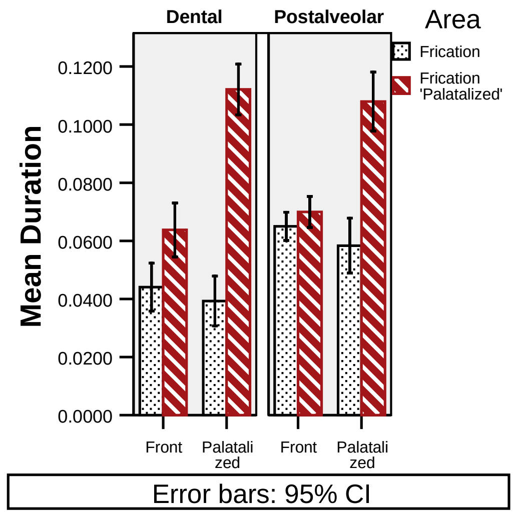



**Figure 6 Duration of 'Palatalized' Frication**




## 5 Conclusion

The current study compared the acoustic properties of palatalized consonants in three places of articulation, labial, dental and post-alveolar, to their 'plain' counterparts in coda position and in environments conducive to contextual fronting. Dentals and post-alveolars in the fronting conditions ([front] and [palatalized]) showed increased spectral prominence around 2600Hz in the later part of the release. The labial stops showed a lengthy fricated release in the [palatalized] condition which also showed a spectral prominence around 2600Hz.

All palatalized consonants caused significantly higher F2 (fronting) in the offset of the preceding vowel than did fronted consonants. This far reaching difference must be due to differences in articulation; however the source of the differing articulation could be attributed to a number of processes at different stages in the production. On the phonological side, higher F2 may indicate a closer palatal target such as those found in languages with contrastive palatalization (Kochetov 2002). On the more phonetic side, the effect on preceding vowels may be due differing syllabic structure, as palatalized consonants are in coda position and thus are tauto-syllabic with the preceding vowel, while fronted consonants are hetro-syllabic. Secondary palatal gestures have been shown to be earlier in to coda position (Kochetov 2006). To understand more of the effect that prosodic position has on palatalized consonants, the palatalized consonants were compared with their plain counterparts in word final position. The palatalized consonants were found to be longer, with the added duration consisting of frication showing a spectral prominence around 2600Hz.

The extra frication found in labials, dentals and post-alveolars is suggestive of a sequence of consonant + fricative/glide which is later co-articulated. This supports proposals which retain an underlying suffix consisting of a high front vowel /i/ or glide /j/ (Ruhlen 1973; Steriade 1984). A comparison of monomorphemic palatalized consonants with the "productively" palatalized consonants analyzed in this study may provide more information, but was beyond the scope of this investigation. As the sample size was small (one speaker) and an articulation which gives rise to a prominence

[5] Palatalized segments are commonly longer than plain (Kochetov 2002).

around 2600Hz is undocumented in the palatalization literature surveyed, we have no conclusive answer as to the derivation of 'productively palatalized' consonants in Romanian. However we hope to have shown that despite differing perceptual reality they are distinct from plain consonants in their production, and that perhaps they are closer to their origin of front high vowels than previously considered.

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