Spectral properties of Estonian palatalization

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ABSTRACT

This paper studies Estonian palatalization by describing the spectral centre of gravity (COG) of palatalized and non-palatalized Standard Estonian consonants [l t n s].

43 subjects were asked to read carrier sentences in which palatalization differentiated meaning in minimal pairs. COG was measured from the beginning and middle of the consonant.

When compared to non-palatalized [s], the COG of palatalized fricative was lower in the beginning; by the midpoint the values were similar. For palatalized [t] and [n] the COG was lower than in non-palatalized productions in both of the measurement points. Palatalized [l] had higher COG values throughout the consonant. There was a significant gender and vocalic context effect on the COG of the palatalized consonant.

Keywords: palatalization, spectral moments, segmental phonetics, Estonian, consonants

1. INTRODUCTION

The aim of this paper is to study the realization of Estonian palatalization by describing the spectral properties of palatalized Standard Estonian [lʲ tʲ nʲ sʲ] and non-palatalized [l t n s] consonants. Palatalization is a process of assimilation that is triggered by a high vowel or a glide in which a consonant acquires a secondary place of articulation on the palatal region of the mouth [1].

Palatalization can be used to differentiate meaning in Estonian. On the other hand it is in some cases optional and the degree of palatalization can vary regionally and idiomatically [2,3]. Estonian has a rich inventory of words which are differentiated only by palatalization (palk ’wage’ [pɑlkː] ~ palk ’log’ [pɑlʲkː], nutt ’cry’ [nutː] ~ nutt ’smarts’ [nutʲː]). This phonemic distinction is not expressed in orthography and palatalization can only be recognized from the context.

Some of the minimal pairs might not have a counterpart in the same grammatical case, but because of the apocope (loss of [i] from the end of the word), the palatalization still realizes, although the vowel that follows is not [i]. For example, kaste ’sauce’ sg. nom. [kɑste] ~ kaste ’boxes’ pl. part. [kɑsʲːte]. And, because of the apocope, monosyllabic nominative nouns with an i-stem can be palatalized at the end of the word even though they are not followed by [i]. For example, kont ’bone’ sg. nom [konʲtː]: kondi ’bone’ sg. gen. [konʲti]. In some cases, the word can be e-stemmed (sulg ‘feather’ [sulʲːk]) but still be palatalized. This is thought to be also because of the apocope [2].

Palatalization in Estonian occurs after a vowel on the first primary stressed and second unstressed syllable boundary or after a vowel in a monosyllabic word [2,4] and is acoustically [5,6] and perceptually [7] defined by an [i]-like transition, from the preceding vowel to the palatalized consonant. It has been said [2,5,7,8] that palatalization only affects the quality of the first part of the consonant.

Research on the acoustic features of palatalization in Russian [9–13], Greek [14], Afrikaans [15], Romanian [16], Connemara Irish [17] and Estonian [2,4,7,8,18,19] have shown that the transition to the palatalized consonant has a higher F2 value and lower F1 value than in non-palatalizing contexts. The magnitude of the transition is dependent on the vowel. This F2 rise in vowels also affects consonants.

Palatalized [l] is described as having a higher F2 value compared to non-palatalized [l] [5,8,18,19]. Compared to non-palatalized [n], the oral cavity for palatalized [n] is narrower and has lower energy in the higher frequencies because of the anti-formant that forms in the nasal cavity [8]. Labial and alveolar palatalized stops have a higher frequency in the spectral burst [11,13,14,17]. A study in Octoepec analyzed the COG values of palatalized and non-palatalized [s]. There was some intraspeaker variability, but palatalized [s] tended to have a lower COG [20]. There is no data on the quality of Estonian palatalized [t] and [s], only the vowels preceding them.

Based on previous studies it is hypothesized in this study that COG should be higher for palatalized [t n l] because of a higher place of articulation. COG for palatalized [s] should be lower than non-palatalized [s]. The study addresses the following questions:

(1) How does palatalization affect the spectral features of consonants [l t n s]?

(2) Which part of the consonant is affected?

2. MATERIALS AND METHODS

A reading task experiment was conducted in the University of Tartu and Tallinn University of Technology. The participants were 43 native Estonian speakers (20 male, 23 female; age 20-78, average 31 years).

The subjects were recorded reading the stimuli in a soundproof room after they had read those same stimuli with an articulograph. The sentences were presented to the subjects on computer screen in random order using Speech Recorder software [21]. Sound was recorded with AKG 414 and Audiotechnica ATM33a microphones using Sound Devices Mixpre 6 or M-Audio Fast Track Pro USB sound cards.

The stimuli consisted of 60 carrier sentences in which the palatalization differentiated meaning of the test words in minimal pairs. Palatalized consonant was in a mono- or disyllabic word following the first vowel. The data consisted of 2132 consonant tokens (Table 1). Test words were in the middle of the utterance following a comma and a word starting with mi-. For example: Järgmine aasta tõuseb keskmine **palk** [pɑlkː], mis on hea uudis kõigile. 'The mean **wage** will rise next year, which is good news for everyone'; Tee peale kukkus suur **palk** [pɑlʲkː], mis häiris liiklust. 'A big **log** fell on the road which interfered the traffic'.

Table 1: Number of tokens of consonants.

Vowel	[s]	[t]	[l]	[n]	Total
[ɑ]	258	258	516	84	1116
[u]	84	258	334	172	848
[y]	-	84	-	-	84
[o]	-	-	-	84	84
Total	342	600	850	1190	2132

The recordings were automatically segmented using ASR based force alignment software created in the Tallinn University of Technology [22]. The segmentation was manually checked for errors and corrected if needed.

COG was used to measure the quality of consonants, because based on previous research [23–26] it has been proven to be a good characteristic in describing the quality of the fricatives and plosives. It will also be used to describe the quality of [n] and [l] in this study.

For [l n s] COG was measured from a 40ms window from the beginning and middle of the consonant. To avoid overlapping of the measurement points, all productions below 80ms were excluded. For [t], COG was measured from a 10ms window from the beginning and the middle of the release burst. As the burst duration is very short, all productions below 15ms were excluded. In this case, the overlapping of the measurement points could not always be avoided. Before the analysis, a 200Hz cepstral smoothing was applied to all of the consonants. This prevents short spectral peaks and removes unnecessary outliers [27].

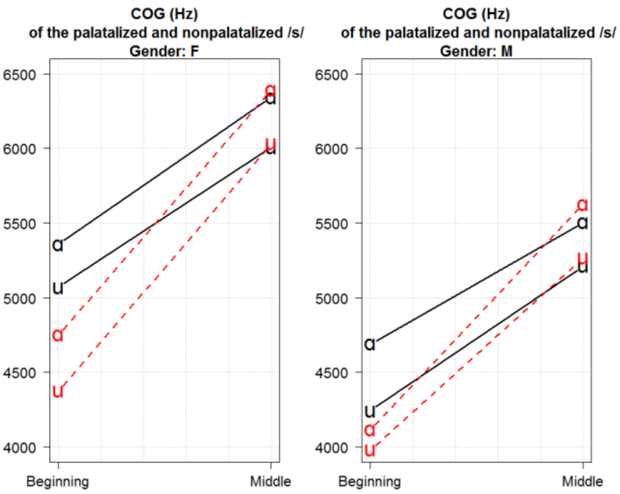
A Generalized Linear Mixed Model (GLMM) was used for statistical analysis which was conducted in R [28]. In the model, the dependent variable was the spectral moment measured from the beginning and from the middle of the consonant. The independent variables were the vowel ([ɑ o u y]), palatalization ("y" for yes or "n" for no) and gender ("M" for male or "F" for female). The test subject was used as a random effect. Post-hoc analysis was done with glht (multcomp package in R).

3. RESULTS

3.1. COG of [s]

The results showed (Fig. 1) that palatalized [s] had lower COG values in the beginning of the fricative for both genders.

Figure 1: Centre of gravity of the palatalized and non-palatalized [s] of female and male speakers. Dashed line represents palatalized, solid line non-palatalized productions.



For females, COG in the beginning of palatalized [s] in the context of [ɑ] was 603Hz lower ($p<.001$) and 695Hz lower in the context of [u] ($p<.001$). By the midpoint of [s], the differences leveled out. Palatalized [s] in the context of [ɑ] was 49Hz ($p<.005$) higher than non-palatalized counterpart. Although palatalized [s] in the context of [u] was 26Hz higher, this rise was not statistically significant ($p<.9$).

For male speakers the palatalized fricative in the context of [ɑ] was 574Hz lower (p<.001) and with [u] 262Hz lower (p<.001) than non-palatalized [s]. By the middle of the fricative, [s] in the context of palatalized [ɑ] was 122Hz higher (p<.001) than non-palatalized [s]. In the context of [u] palatalized [s] was 57Hz higher but again, this rise was not statistically significant (p<.13).

3.2. COG of [t]

The results showed (Fig. 2) that for female speakers when compared to non-palatalized productions, the COG values for palatalized [t] in the context of [u] were 622Hz higher (p<.001) and in the context of [y] 399Hz higher (p<.001). In the context of the vowel [ɑ], palatalized [t] was 466Hz lower (p<.001) than non-palatalized [t].

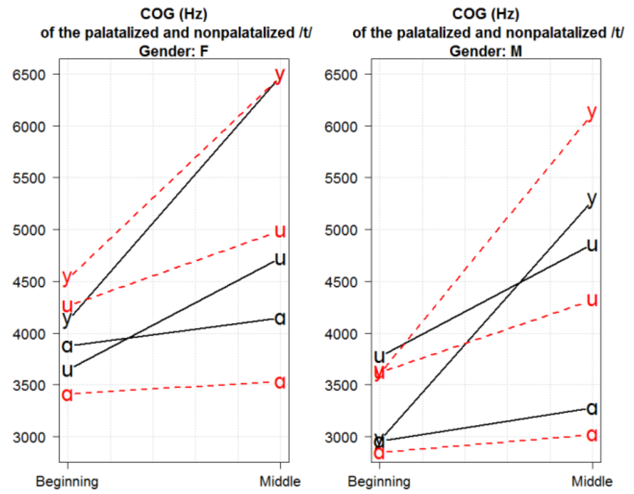


Figure 2: Centre of gravity of the palatalized and non-palatalized [t] of female and male speakers. Dashed line represents palatalized, solid line non-palatalized productions.

In the midpoint of [t] the COG for palatalized plosive in the context of [u] was 264Hz higher than non-palatalized [t] (p<.001). In the context of [y] the COG values were the same for both contrasts. Palatalized [t] in the context of [ɑ] was 613Hz lower than non-palatalized [t] (p<.001).

For male speakers the COG values in the beginning of the burst of palatalized [t] were lower compared to non-palatalized [t]. In the context of [ɑ] the palatalized [t] was 108Hz (p<.001), in the context of [u] 151Hz (p<.001) and in the context of [y] 651Hz (p<.001) lower. In the midpoint of [t] in the context of [ɑ], palatalized [t] was 257Hz lower (p<.001) and in the context of [u] 534Hz lower (p<.001) than non-palatalized counterpart. In the context of [y] the COG value of palatalized [t] rose and was 834Hz higher (p<.001).

3.3. COG of [l]

The results for [l] showed (Fig. 3) that when compared to non-palatalized lateral the COG values for female speakers were higher with palatalized lateral.

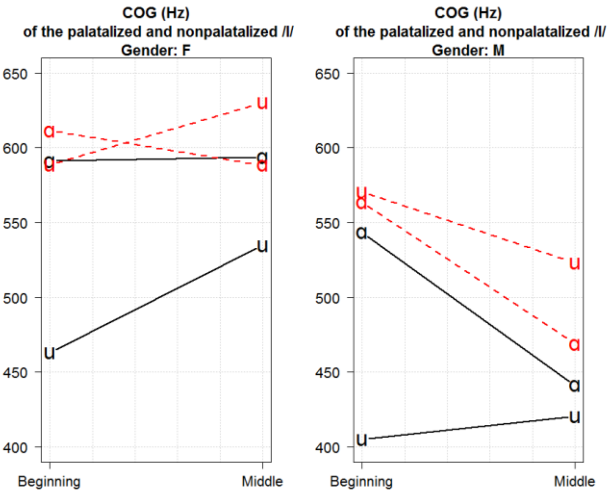


Figure 3: Centre of gravity of the palatalized and non-palatalized [l] of female and male speakers. Dashed line represents palatalized, solid line non-palatalized productions.

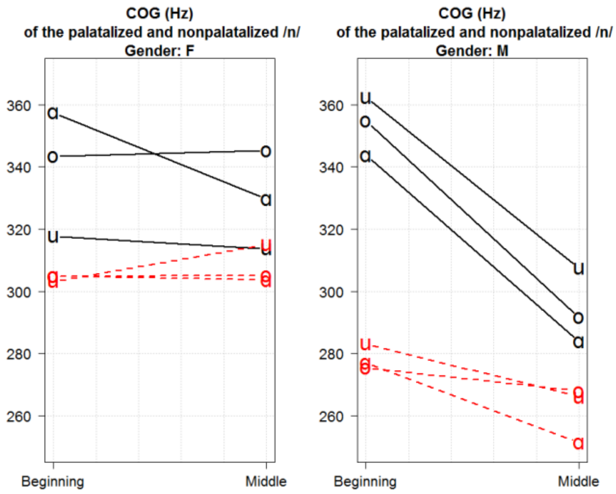
COG values of the palatalized [l] in the context of [ɑ] were 20Hz higher than in non-palatalized context, but this difference was not statistically significant (p<.94). In the context of [u] the values were 126Hz higher (p<.001). In the midpoint of [l] in context of [ɑ] the palatalized and non-palatalized [l] had similar values and the difference was not significant (p<.001). Palatalized [l] in the context of [u] was 95Hz higher (p<.001) than non-palatalized counterpart.

For male speakers the COG values were higher in the palatalized contexts in both measurement points of [l]. In the context of [ɑ] the COG of palatalized [l] was 21Hz higher (p<.001) and in the context of [u] 102Hz higher (p<.001) when compared to non-palatalized counterpart. In the midpoint, palatalized [l] in the context of [ɑ] was 28Hz higher (p<.001) and in the context of [u] 102Hz higher (p<.001).

3.4. COG of [n]

The results for the nasal [n] showed (Fig. 4) that the COG values for female speakers were lower for palatalized productions. In the context of [ɑ] 52Hz (p<.01), [o] 34Hz (p<.01) and in the context of [u] 15Hz lower, but this difference was statistically not significant (p<.13). In the midpoint of palatalized and non-palatalized [n] in the context of [u] the values were similar and the difference between them was not statistically significant (p=.809). In the context of [ɑ] the palatalized [n] was 26Hz lower (p<.01) and in the context of [o] 40Hz lower (p<.01) than non-palatalized [n].

Figure 4: Centre of gravity of the palatalized and non-palatalized [n] of female and male speakers. Dashed line represents palatalized, solid line non-palatalized productions.



For male speakers, in the context of [ɑ] the values of palatalized [n] were 67Hz lower (p<.01), in the context of [o] 80Hz lower (p<.01), in the context of [u] 79Hz lower (p<.01). When measured from the midpoint, palatalized [n] in the context of [ɑ] was 33Hz lower (p<.01), in the context of [o] 24Hz lower (p<.01) and in the context of [u] 41Hz lower (p<.01).

4. DISCUSSION

It was hypothesized that when compared to non-palatalized contexts, COG should be higher for palatalized [t n l] and lower for palatalized [s].

As predicted, COG for palatalized [s] was lower than for non-palatalized [s]. According to palatographic studies in Estonian [29,30] the tongue is relatively flat with non-palatalized [s], the air can flow freely over the tongue. Palatalized [s] has a higher place of articulation with a bigger lateral contact. With this tongue configuration the air flows through a narrow passage over the middle of the tongue which lowers the mean energy of the spectrum. This only occurred in the beginning of [s].

Contrary to the prediction, the pronunciation of palatalized [t] generally showed that COG was lowered. It decreased in the context of back vowels [ɑ] and [u] and increased in the context of [y]. The pronunciation of palatalized [t] in the context of [u] varied with gender. For females the COG was higher, for male speakers it was lower than in non-palatalized context. In the midpoint of [t] the effects stayed the same, only female [y] had similar values as non-palatalized [t].

As predicted, [l] showed a regular rise in the COG for palatalization in the beginning of the consonant. With the exception of [ɑ] measured from the midpoint of palatalized [l] for females, all the COG values were higher. As the most sonorous palatalized consonant, the place of articulation of [l] has been shown to be more anterior with higher F2 values of the preceding vowel [31,32].

Contrary to the prediction COG values for palatalized [n] were lower in the beginning of the test word for males and females alike. As the articulation of palatalized [n] raises the tongue body and reducing the volume of oral cavity, a lot of the energy gets absorbed into the nasal cavity resulting in lower COG values for palatalized [n] [33]. In the middle of the nasal, the COG values for female palatalized [n] in the context of [u] were similar to non-palatalized [n].

5. CONCLUSIONS

The spectral properties of palatalization in Estonian consonants were observed in this paper. The results showed that palatalization had a tendency to lower the COG values of [s t n] and raise the values of [l].

With the exception of [s], palatalization affected the quality of the consonants in the beginning and also middle of the consonant. There was a significant gender and vocalic context effect on the COG of the palatalized consonant.

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