COMPARING PALATOGRAPHY PATTERNS OF ESTONIAN CONSONANTS ACROSS TIME

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ABSTRACT

The few known palatographic studies on Estonian consonants date back to the 1970s, and no research in articulatory phonetics has been practised throughout the following four decades. Recently, the Estonian EPG corpus was recorded using a contemporary EPG system.

In the paper we introduce first results on contemporary palatography patterns of Estonian sonorants and compare these to results from Arvo Eek's seminal studies in the 1970s.

Keywords: Estonian, electropalatography, consonant articulation, coarticulation

1. INTRODUCTION

Palatography as a method to measure the tongue contact with the hard palate has been in use for more than 100 years. Since the 1960s, electropalatography (EPG) [12] [15] [14] has been developed, enabling researchers to study the timing and location of tongue contact with the hard palate during speech. The few known articulatory studies on Estonian vowels and consonants were carried out in the beginning of the 1960s and 1970s. Georg Liiv studied articulatory features of Estonian vowels [13] using several techniques such as roentgenography, filming of lip movements, and static palatography; in a series of publications in 1970-71 Arvo Eek examined the articulation of Estonian sonorant consonants [3], [4], [5], [6], [7] using the same techniques. In 1973, a study on Estonian palatalization [8] followed, exploiting an EPG system built in Estonia in 1972 [9].

The consonants covered in Eek's publications are:

- nasal [n] and lateral [l] (1970: Part I)
- tremulant [r] (1970: Part II)
- palatalized [n^{j}] and [l^{j}] (1971: Part III)
- nasal [m] (1971: Part IV)
- nasal [ŋ] (1971: Part V)
- palatalized [l^{j}, n^{j}, s^{j}, t^{j}] *versus* non-palatalized [l, n, s, t] (1973)

The consonants' quantity varied in the context of bisyllabic words containing aCa in short (Q1), long (Q2) and overlong (Q3) quantity degrees, and additionally the consonant is also produced with Q3 in word-final position (aC::).

No further articulatory research was carried out in Estonia for the forty years to follow.

In recent years, several tools for articulatory research (electropalatography, electroglottography (EGG), electromagnetic articulography (EMA)) became available and the Estonian EPG corpus was recorded. It includes EPG data of two native Estonian subjects (one male, one female) reading lists of isolated VCV structures that are also recorded synchronously as audio and EGG signals. In the corpus, all Estonian consonants occur in the context of all Estonian vowels, representing the word structures in three quantity degrees, i.e. VCV, VCCV, VC:CV.

The goal of this paper is to provide first results on sonorant articulation in contemporary Estonian using EPG data from one native speaker and compare these to the results from the 1970s studies.

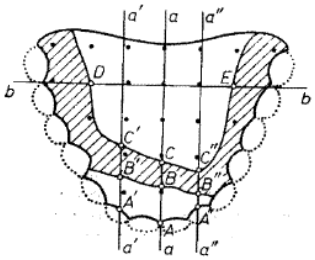
2. PALATOGRAPHIC DATA IN EARLY STUDIES

In the studies from 1970-71, static palatography with an artificial palate was used and the contact surfaces of the tongue were transferred to blank images of the artificial palate. The location and extent of linguopalatal contact has been derived from the palatograms using the coordinate system shown in Figure 1. To quantify the palatogram observations the following distance measures were employed:

- AB, the distance of the anterior boundary of the contact area from the front
- AC, the distance of the posterior boundary of the contact area from the front
- BC, the length of the alveolar contact, and
- DE, the width of the contact-free palatal area

The first three measures were used to determine the size and the placement of the alveolar contact area, while DE was employed as an index of the palatal contact area.

Figure 1: Coordinate system for measuring palatograms [3]. Linguopalatal contact area is cross-hatched; measusrement points A, B, C, D, and E are explained in text.



The distances AB, AC, and BC were measured along the median line of the palate a — a; in the case of an obvious asymmetry of the contact pattern, the same distances were measured along the lines a'— a' and b'— b' (see Figure 1). Table 1 is provided as an example of measured distances for nasal [n] and lateral [l] and their palatalized counterparts in three quantity degrees.

Table 1: Mean distances (mm) measured from palatograms of non-palatalized [n] and [l] (subject R.T., data from Table 1 [3]), palatalized [n^{j}] and [l^{j}] (subject A.S., data from Table 1 [5]), and [r] (subject K.K., data from Table 1 [4]).*

Subject	VCV	AB	AC	BC	DE
R.T.	ana	11.8	18.3	6.5	48.8
	anːa	9.7	19.5	9.8	46.6
	anːːa	9.0	19.6	10.6	46.1
	ala	11.9	22.8	10.9	60.0
	alːa	11.9	26.0	14.1	54.9
	alːːa	10.3	23.3	13.0	53.5
A.S.	an'a	11.5	20.7	9.1	48.4
	an'ːa	7.6	19.3	11.6	35.2
	an'ːːa	4.5	18.2	13.6	32.1
	al'a	12.3	21.3	8.9	55.9
	al'ːa	10.8	20.3	9.5	43.0
	al'ːːa	7.8	18.6	10.8	40.8
K.K.	ara	11.0	13.0	2.0	44.8
	arːa	10.2	12.8	2.7	43.7
	arːːa	10.1	12.7	2.6	42.4

* In addition to mean values, the confidence intervals, range of variation, and standard deviation for all measures are given in the original tables.

In all palatographic studies the same four subjects participated, however, the results for different consonants are not reported for all subjects, e.g. Part I reports the full set of data for non-palatalized [n] and [l] for subject R.T. only, Part III for palatalized versions of the same sonorants for subject A.S., and Part II for tremulant [r] for subject K.K. only. This makes the systematic comparison of inter- and intra-speaker variability of studied consonants impossible. However, the data in the papers from 1970-71 has served as the main source of articulatory characteristics of Estonian sonorants. Therefore, we find it important to compare this historical data with contemporary EPG data.

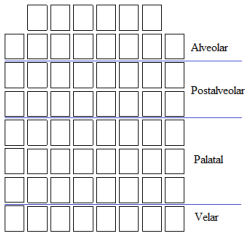
3. MATERIALS AND METHODS

3.1. Corpus description

The Estonian EPG corpus includes isolated VCV structures in three quantity degrees (VCV, VCCV, VC:CV), such that all Estonian consonants occur in the context of all Estonian vowels. Each VCV word is repeated three times. In addition, the most frequent consonant clusters occurring in word initial, medial, and final positions were recorded. The recording setup involved the WinEPG system by Articulate Instruments [1], the Laryngograph Processor by Laryngograph [10], and a digital audio recorder (close-talk microphone Sennheiser ME3, sampling at 22.1 kHz, 16 bit). The corpus is manually segmented and labelled at word and phoneme levels and integrated into EMU/R [2].

The palates used in the recordings were the "Reading"-type palates with 62 electrodes arranged in eight horizontal rows corresponding to phonetically relevant areas, as shown in Figure 2. To quantify the EPG contact profiles, measures such as anteriority index (AI), centrality index (CI), dorsopalatal index (DI), and center of gravity index (COG) [11] are used.

Figure 2: Phonetic zones for the "Reading"-type EPG palate.

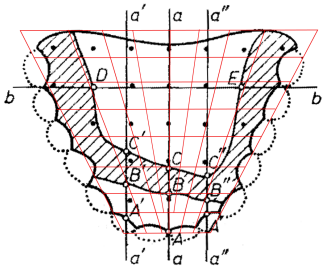


For the comparison of the old data with present-day EPG data we use a subset of the EPG corpus including aCa words, where C = [n], [l], [n^{j}], [l^{j}], and [r], produced by one female subject.

3.2. Converting EPG patterns

To make the palatograms comparable, we had to operationalize Eek's measuring concepts for palatography patterns in a way suitable for our EPG data. First of all, we had to compensate for the relative imprecision of the EPG data – eight rows and eight columns of electrodes versus the possibility to continuously measure distances in Eek's static palatograms. The obvious solution is to exploit the temporal dimension of our data to enrich its spatial resolution; we did this by calculating means of electrode contact counts over the whole time of consonant articulation. As opposed to Eek, we evaluate only the central area of front-back alveolar contact along Eek's *a*-line for back-front measurements. The approximation of EPG electrode areas with Eek's coordinate system is shown in Figure 3.

Figure 3: Eek's coordinate system with pattern of approximate EPG electrode areas overlayed as a red grid. Note that in Eek's diagram the front of the mouth is at the bottom, not at the top as in present-day EPG charts.



The distance measures are defined as follows:

- **AB** corresponds to the number of contact-free electrodes in columns 4-5 from line 1 up to the front boundary of alveolar contact,
- **AC** equals the highest row number with linguopalatal contact in the same range of rows and columns,
- **BC** equals the number of contacts in the center columns (4-5) of rows 1-5 (in agreement with the implementation of the anteriority index AI [11]; BC is inversely proportional to AI,
- **DE** is the number of contact-free electrodes in row 7. This correlates inversely with the dorsopalatal index DI; maximum value of DE = 8 (the number of electrodes in row 7).

4. RESULTS AND DISCUSSION

The general findings on linguopalatal contacts in [n] and [l], and in their palatalized counterparts [n^{j}] and [l^{j}], as presented in [3] and [5], are the following:

- Both alveolar and palatal contact areas are larger for the higher quantity degrees.
- Contact areas for Q2 and Q3 are close to each other and clearly distinct from those for Q1.
- Quantity-induced increases in alveolar contact area are mainly due to shifting the anterior contact boundary forward, however, for [n] it typically happens through a backward movement of the area's posterior boundary, as for [l], the anterior boundary of the alveolar contact often does not change between Q1 and Q2, but Q3 causes a retraction of the posterior boundary.
- The contrast between palatalized and non-palatalized sonorants lies mainly in two features: (1) the size of lateral contact, and (2) more forward place of articulation in palatalized sonorants.
- The place of articulation in nasals is more advanced than in laterals.

As for [r], the findings reported in [4] are in line with [n] and [l]: (1) quantity correlates with overall linguopalatal contact, (2) quantity-induced lengthening of the alveolar contact region is due to forward-shifting of its anterior boundary.

The measures calculated for contemporary EPG data are partially presented in Table 2. The anteriority index AI and dorsopalatal index DI correlate highly with the BC and DE measures adopted for our data from Eek's studies; CA is total contact area.

Table 2: Mean values of CA, AI, DI, BC and DE calculated for [n] and [l], palatalized [n^{j}] and [l^{j}], and [r].

VCV	CA	AI	DI	BC	DE
ana	20.9	0.9	0.108	2.17	6.68
anːa	12.7	0.971	0.012	1.34	7.73
anːːa	18.5	0.934	0.009	2.05	7.79
ala	15.7	0.917	0	1.79	8.0
alːa	14.8	0.976	0	1.21	8.0
alːːa	13.8	0.98	0	1.11	8.0
an'a	24.5	0.96	0.29	1.0	4.91
an'ːa	33.8	0.897	0.254	3.08	5.59
an'ːːa	31.2	0.976	0.258	2.19	5.43
al'a	21.8	0.927	0.187	1.64	5.52
al'ːa	30.1	0.951	0.342	1.69	4.22
al'ːːa	37.6	0.957	0.403	2.98	3.43
ara	8.9	0.367	0.147	2.0	6.72
arːa	9.9	0.731	0.119	1.0	7.15
arːːa	11.2	0.692	0.128	1.0	6.9

ANOVA and TukeyHSD are used to test which of the previous findings on articulatory patterns of Estonian sonorants hold true in present-day EPG data.

Figure 4: Palatograms for non-palatalized sonorants [n] and [l]: (a) superimposed palatograms for Q1 (green), Q2 (red), and Q3 (blue) reconstructed from [3]; color lines represent the anterior (upper) and posterior (bottom) boundaries of contact area, (b) EPG pattern for Q1, (c) EPG pattern for Q2, and (d) EPG pattern for Q3.

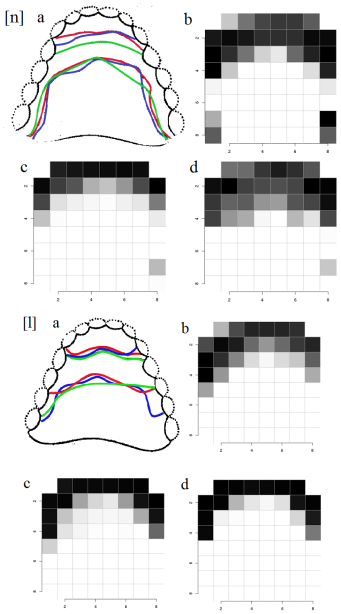
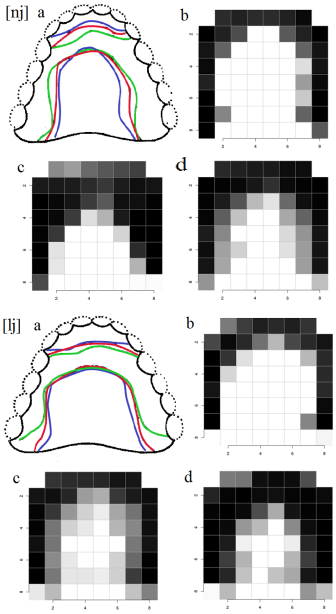


Figure 5: Palatograms for palatalized sonorants [n^j] and [l^j]: (a) superimposed palatograms for Q1 (green), Q2 (red), and Q3 (blue) reconstructed from [5]; color lines represent the anterior (upper) and posterior (bottom) boundaries of contact area, (b) EPG pattern for Q1, (c) EPG pattern for Q2, and (d) EPG pattern for Q3.



In general, CA, AI, CI, COG, and BC demonstrate larger values for the higher quantity degrees ($p<0.001$), DI and DE have no quantity-related effect ($p>0.1$). However, the role of quantity varies among different measures and sonorant groups, e.g., in [n] and [l] the measures related to the size of total contact area (CA and BC) decrease, and in [n^j], [l^j] and [r] increase with quantity degree. Eek's claim that contact areas for Q2 and Q3 are close to each other and clearly distinct from Q1 holds true for [l], [n^j], and [r], but not for [n] where Q2 is different from other quantities ($p<0.001$); for [l^j] all quantities are different ($p<0.001$) (see Figure 4 and 5).

In line with Eek's findings, the most salient feature distinguishing palatalized and non-palatalized sonorants is the size of lateral contact manifesting itself mostly as an increase of DI, CA, and BC and consequently resulting in decrease of COG and DE (all $p<0.001$). However, the more forward place of articulation of palatalized sonorants, as found by Eek, has not be confirmed in our data: AI has no difference in both non-palatalized-palatalized sonorant pairs ($p>0.1$). Also, current EPG measures do not provide clear information on the more forward place of articulation in nasals compared to laterals, and quantity-induced increase of the alveolar contact region due to forward-shifting of its anterior boundary described by Eek. In present-day palatograms the contact area involves the first row of electrodes in both nasals and laterals, and AI exhibits contradictory results: AI is larger for [l] than for [n] ($p<0.01$) whereas no difference is between [n^j] and [l^j]. Also, the adopted measure AB shows the difference ($p<0.01$) between nasals and laterals, but unlike Eek's data, the place of articulation of laterals is more forward.

5. SUMMARY

In the paper we compared contemporary EPG characteristics of intervocalic sonorants to the results reported by Arvo Eek in his seminal studies from 1970s. In general, the essential characteristics of Estonian sonorants have remained stable over time. However, several differences between old and present-day data were discovered.

6. ACKNOWLEDGEMENTS

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