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LOCUS EQUATIONS AND THE PLACE OF ARTICULATION FOR THE LATVIAN SONORANTS*

1. Introduction

Identifying effective acoustic cues for consonantal place of articulation that would overcome difficulties caused by the enormous acoustic variability in consonant production is a long-time issue in acoustic phonetics. It has been commonly regarded that not only the consonant spectrum itself but also the spectral properties of adjacent vowels provide relevant information on the quality of a consonant, and in particular cases these data may even stand for a primary consonantal place cue.

In this article, the sonorant consonants of Standard Latvian are investigated using locus equations — the approach introduced by Björn Lindblom (Lindblom 1963a) and promoted by a number of other scholars (see, for instance, Duez 1989; Fowler 1994; Fruchter, Sussman 1997; Everett 2008; Iskarous et al. 2010; Krull 1988; 1989; Sussman 1994; Sussman et al. 1991; 1997; Sussman, Shore 1997). The major goal of the present study is to examine whether locus equations can be considered as efficient descriptors of consonantal place of articulation both within the group of sonorants and across different manner classes in Standard Latvian.

2. Background

2.1. Locus theory

It has long been assumed that formant transitions seen in spectrogram "reflect the changes in cavity size and shape caused by the movements of the articulators", and second formant (F2 henceforth) transitions "rather directly represent the articulatory movements from the place of production of the consonant to the position for the following vowel" (Delattre et al. 1955,

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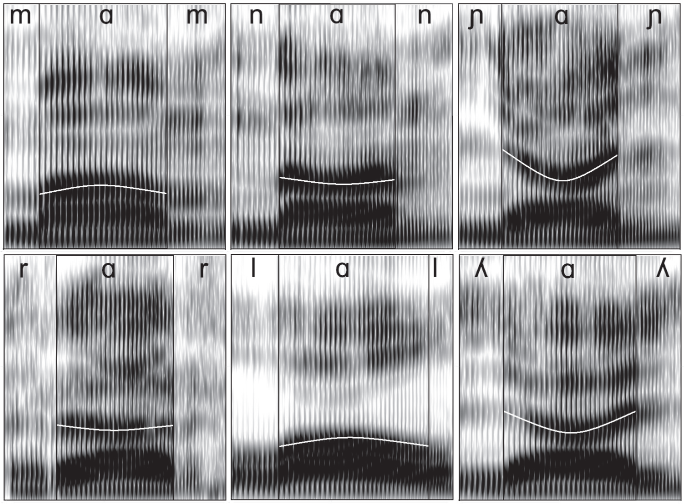

Figure 1. **The dynamic spectrograms of [mɑm], [nɑn], [ɲɑɲ], [lɑl], [ʎɑʎ] and [rɑr] produced by a male speaker of Standard Latvian** (the white lines indicate the trajectory of vowel's F2)

769; see also Figure 1 for changes of one and the same vowel's F2 trajectory in the context of sonorants in question).

F2 frequency is negatively related to the length of the oral cavity, which in case of consonants is associated chiefly with tongue position. Thus, a fronting tongue-body gesture induces the increase of the F2 frequency, while retracting tongue body results in generally low F2 (Iskarous et al. 2010, 2024).

The concept of F2 locus, earlier defined as an abstract and fixed frequency value approximately 50 ms before consonant release and treated as hypothetic starting point of the F2 of the following vowel (Delattre et al. 1955), was reinvented by B. Lindblom (Lindblom 1963a) who virtually upended both its abstractness and fixedness. He described changes in the trajectory of vowel's F2 in different consonantal environments using two values — its frequency measured at the onset ($F2_{onset}$) and at the steady state (i. e., approximately at the middle; $F2_{middle}$) of a vowel. By plotting these pairs of measurements for a range of different vowels produced with the same consonant on the Cartesian plane ($\mathrm{F2}_{\mathrm{middle}}$ on the x-axis, $\mathrm{F2}_{\mathrm{onset}}$ on the y-axis) a point locus was obtained. The data points exhibited a great amount of linearity, and thus could be approximated by a straight line according to the following equation:

$$F2_{onset} = k \cdot F2_{middle} + c,$$

where F2 frequency at vowel onset ($F2_{onset}$) is a function of F2 frequency at the middle of a vowel ($F2_{middle}$), k denotes the slope of a straight line approximation, and c is the point where the line intersects the y-axis (y-intercept henceforth). B. Lindblom discovered that the slopes of regression lines for the Swedish stops [b; d; g] in CVC syllables with eight different vowels varied systematically along with place of articulation, and thus could be used for distinguishing between those consonants. In accordance with this approach, the F2 locus can be defined as "the frequency of the formant at the first pulse of the vowel after consonant release" (Krull 1987, 44), which varies systematically under the influence of contextual vowels, therefore the so-termed locus equations enable one to calculate an ideal locus pattern for each consonant using data on formant transitions before several different vowels (Ladefoged 2003, 163).

Later it was also argued that the slope of a regression line is associated primarily with the degree of coarticulation between the vowel and the consonant (Krull 1987; 1989; Fowler 1994):

- High slope indicates variable consonantal locus and high degree of coarticulation between the vowel and the consonant (i. e., the vowel markedly affects the consonant).
- Low slope indicates stable locus and low degree of coarticulation between the vowel and the consonant (i. e., the vowel scarcely affects the consonant).

The relation between slope and the degree of coarticulation can be explained by a simple fact that greater slope suggests greater similarity between F2 frequencies at the onset and at the steady state of a vowel, which in turn indicates minimal changes in size and shape of oral cavity during the production of consonant-to-vowel transition. Y-intercept in its turn is considered to be "a complex measure, affected by several different articulatory phenomena: coarticulation resistance, C-to-V carryover coarticulation, and the average position of the tongue back and lips at the consonant release" (Iskarous et al. 2010, 2023).

While initially investigated mostly in respect of voiced stops, later on locus equations were also claimed to be a universal and invariant phonetic descriptors of phonological place distinction for consonants across varied manner classes (Sussman 1994; Sussman, Shore 1996), and rather fair distinction between labials, dentals/alveolars and velars was found. However, as Carol A. Fowler (Fowler 1994, 598) has rightfully mentioned, locus equations provide information for place indirectly, only insofar as variation in place contributes to variation in coarticulatory resistance — "the extent to which a phonetic segment blocks the coarticulatory influence of adjacent phonetic segments" (Recasens, Espinosa 2009, 2288) — since the latter has been also exposed to factors other than place of articulation (e. g., manner of articulation, syllable and/or phrasal position, speaking style and rate, etc.). This point will be discussed further using evidence from Standard Latvian.

2.2. Sonorants in the consonant system of Standard Latvian

In Table 1, the inventory of Latvian consonants arranged by place and manner of articulation is presented. According to Alise Laua (Laua 1997), there are twenty-six consonant phonemes in Standard Latvian, which include six sonorant phonemes:

- three nasals—bilabial /m/, dental /n/ and palatal /ɲ/;
- two laterals—alveolar (or dental, as the results of a recent EPG study suggest (Grigorjevs 2012, 275)) /l/ and palatal /ʎ/;
- one trill—alveolar /r/.

Table 1. **The consonantal inventory of Standard Latvian, in IPA** (sonorants indicated with grey color)

Place / **Manner**	**Labial**	**Dental**	**Alveolar**	**Palatal**	**Velar**
Stop	/p/ /b/	/t/ /d/		/c/ /ɟ/	/k/ /ɡ/
Fricative	/f/ /v/	/s/ /z/	/ʃ/ /ʒ/	/j̥/	/x/
Affricate		/ʦ/ /ʣ/	/ʧ/ /ʤ/		
Nasal	/m/	/n/		/ɲ/	[ŋ]
Lateral		/l/		/ʎ/	
Trill			/r/		

When the dental /n/ occurs before a velar stop /k/ or /ɡ/, it is articulated as the velar [ŋ] (e. g., *banka* [bɑŋkɑ] 'a bank' or *bungas* [buŋɡɑs] 'a drum'). The material for the study (see Section 3.1) was recorded to cover the whole group of sonorants including the velar allophone of /n/.

3. Method

3.1. Speakers, material and recording procedure

Speech recordings from 10 native speakers of Standard Latvian, five male (M1–M5 henceforth) and five female (F1–F5 henceforth), aged 19–39, without any disorders or dialectal traces in their pronunciation, were used for the analysis. The speakers were recorded using AKG C520 head-mounted condenser microphone and Edirol UA-25 (M1–M3, F1–F4) or Roland UA-55 (M4, M5, F5) sound capture device attached to a computer. The recording was performed at 44.1 kHz sample rate and 16 bit quantization using WavePad Sound Editor v5.40 (NCH Software 2013) or Audacity v2.0.3 (Audacity Team 2013) software.

Two-type sequences were analyzed:

- The CV part of isolated nonsense CVC syllables, where C is one of the sonorants [m; n; ɲ; l; ʎ; r] and V is one of the vowels [i(ː); e(ː); æ(ː); ɑ(ː); ɔ(ː); u(ː)].
- The V(ː)C part of isolated nonsense V(ː)CV (VCV for [ŋ]) structure utterances, where C is one of the nasals [m; n; ɲ; ŋ] and V is one of the vowels [i; e; æ; ɑ; ɔ; u].

For the nasals [m; n; ɲ], locus equations were generated both for CV and VC sequences to consider the possible effects of the consonant position on the degree of coarticulation for the velar [ŋ], which has a limited distribution, as mentioned in Section 2.2.

Each utterance was recorded in three repetitions by every speaker, thus 3420 items were analyzed in total.

3.2 Measurements

Vowel F2 frequencies were tracked using Praat v5.3.35 software (Boersma, Weenink 2012). Measurements were made using wideband spectrograms: the first measurement ($F2_{onset}$) was taken at the CV or VC transition starting point, and the second measurement ($F2_{middle}$) was taken at the steady state (i. e., approximately at the middle) of a vowel (Figure 2).

Then scattergrams were created to estimate a locus equation for every consonant in question: $F2_{middle}$ values were plotted along the x-axis, $F2_{onset}$ values were plotted along the y-axis, and a linear regression line was generated for each scattergram. Finally, slope (*k*) and y-intercept (*c*) values were derived from the regression equations generated, as well as the coefficient of determination (R^2)[1] was estimated for each equation. The scattergrams were created using Microsoft Excel v14.0.4760 software (Microsoft Corporation 2010).

Locus equations for overall data were calculated by creating a single chart with F2 measurements for all speakers' productions of every consonant. Locus equations for individual data were calculated by creating a separate chart with F2 measurements for each speaker's productions of every consonant.

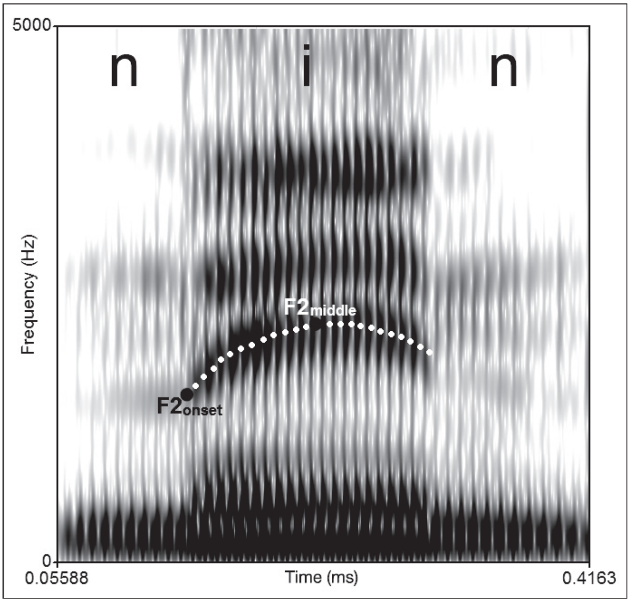

Figure 2. **The dynamic spectrogram of [**nin**] produced by a male speaker of Standard Latvian** (the white dotted line indicates the trajectory of the vowel's F2; the black dots indicate the onset and the middle of the vowel's F2)

Statistical analysis of locus equation slopes and y-intercepts both for the sonorants and for the whole consonant inventory of Standard Latvian was performed in order to test the relevance of these indices for discriminating places of articulation within the group of consonants in question and across different manner classes. For this purpose, several separate multi-way analyses of variability (ANOVA) for each of the two dependent variables were

[1] The coefficient of determination shows the percent of the variation which can be explained by the equation estimated.

carried out: (1) for prevocalic sonorants (Section 4.1) — a two-way (2 × 3) ANOVA with a two-level independent variable for gender (males vs. females) and a three-level independent variable for place of articulation (labial vs. dental/alveolar vs. palatal); (2) for postvocalic nasals (Section 4.2) — a three-way (2 × 2 × 4) ANOVA with a two-level independent variable for gender (males vs. females), a two-level independent variable for syllable position (prevocalic vs. postvocalic) and a four-level independent variable for place of articulation (labial vs. dental/alveolar vs. palatal vs. velar); (3) for the whole consonant inventory (Section 4.3) — a four-way (2 × 3 × 4 × 6) ANOVA with a two-level independent variable for gender (males vs. females), a three-level independent variable for voicing (voiceless vs. voiced obstruent vs. sonorant), a four-level independent variable for place of articulation (labial vs. dental/alveolar vs. palatal vs. velar) and a six-level independent variable for manner (stop vs. fricative vs. affricate vs. nasal vs. lateral vs. trill). The tests were performed using SPSS Statistics v21.0.0.0 software (IBM Corporation 2012).

4. Results and discussion

4.1. Locus equations for prevocalic sonorants

Data plots for the prevocalic sonorants [m; n; ɲ; l; ʎ; r] are shown in Figure 3. Each plot is supplemented with two locus equations (estimated separately for male and female pronunciation), slopes (*k*), y-intercepts (*c*) and coefficients of determination (R^2) for both equations. Table 1 contains slopes, y-intercepts and coefficients of determination both for overall and individual data compared with the results of the pilot study conducted by Juris Grigorjevs (Grigorjevs 2012).

Slope of a regression line usually varies between 0 and 1.0 when used to characterize coarticulatory effects on vowel F2 in CV or VC sequences (although it can also exceed 1.0 in particular cases). Y-intercept indicates the point where the line intersects the vertical axis. It can be observed (Figure 3, Table 1) that the labial [m] is characterized by the steepest regression line (k = 0.62 for males, k = 0.58 for females), the lowest y-intercept (c = 390 Hz for males, c = 359 Hz for females) and the highest coefficient of determination (87–88 per cent of variation in F2 onsets is predictable from the locus equations). The scattergrams for the palatals [ɲ; ʎ] demonstrate the lowest slopes (k = 0.22, k = 0.28 for males, k = 0.14, k = 0.29 for females, respectively), the highest y-intercepts (c = 1671 Hz, c = 1414 Hz for males,

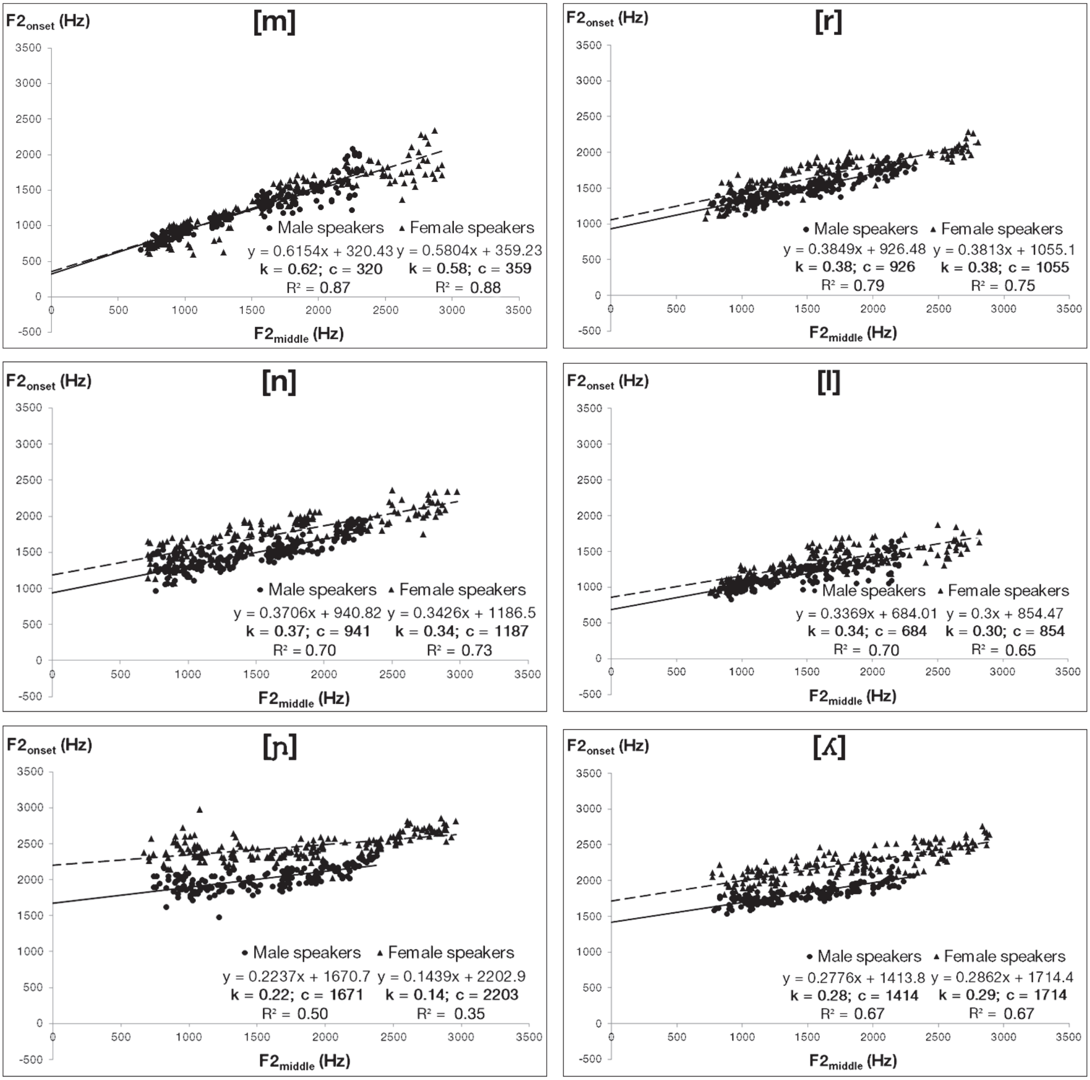

Figure 3. **Locus equations for prevocalic sonorants, overall data by gender** (linear regression fit for the male speakers' data shown by the solid line, linear regression fit for the female speakers' data shown by the dashed line)

c = 2203 Hz, c = 1703 Hz for females, respectively) and the lowest coefficients of determination (35–67 per cent of variation in F2 onsets is predictable from the locus equations). Finally, the locus equations for the dentals [n; l] and alveolar [r] are rather similar among themselves, as it is seen from the graphs, and demonstrate medium slopes and y-intercepts: (1) [l]—k = 0.33, c = 684 Hz for males, k = 0.30, c = 854 Hz for females; (2) [n]—k = 0.37, c = 941 Hz for males, k = 0.34, c = 1187 Hz for females; (3) [r]—k = 0.38, c = 926 Hz for males, k = 0.38, c = 1055 Hz for females. This group of consonants has also medium coefficients of determination with 65–79 per cent of variation in F2 onsets predictable from the locus equations.

Table 2. **Slopes, y-intercepts and coefficients of determination for prevocalic sonorants, overall and individual data compared with those obtained by J. Grigorjevs (Grigorjevs 2012)**

Consonant		[m]	[n]	[l]	[r]	[ɲ]	[ʎ]
Speaker	Index						
Male speakers	**k**	0.62	0.37	0.33	0.38	0.22	0.28
	c	320	941	684	926	1671	1414
	R^2	0.87	0.70	0.70	0.79	0.50	0.66
Grigorjevs (2012)	**k**	0.64	0.36	0.39	0.55	0.21	0.26
	c	285	875	578	639	1629	1387
M1	**k**	0.37	0.29	0.14	0.41	0.19	0.17
	c	595	1053	855	911	1711	1541
	R^2	0.83	0.83	0.49	0.92	0.50	0.74
M2	**k**	0.65	0.25	0.31	0.24	0.16	0.20
	c	242	1237	742	1139	1891	1567
	R^2	0.83	0.60	0.76	0.77	0.70	0.79
M3	**k**	0.56	0.24	0.44	0.46	0.22	0.21
	c	342	1050	567	744	1573	1495
	R^2	0.97	0.51	0.93	0.88	0.77	0.75
M4	**k**	0.77	0.54	0.38	0.55	0.29	0.43
	c	152	624	682	680	1529	1160
	R^2	0.97	0.95	0.86	0.92	0.64	0.84
M5	**k**	0.57	0.40	0.39	0.30	0.25	0.36
	c	395	885	618	1078	1677	1345
	R^2	0.92	0.88	0.86	0.89	0.87	0.79

Table 2 (continued).

Consonant		[m]	[n]	[l]	[r]	[ɲ]	[ʎ]
Speaker	Index						
Female speakers	**k**	0.58	0.34	0.30	0.38	0.14	0.29
	c	359	1187	854	1055	2203	1714
	$\mathbf{R^2}$	0.88	0.73	0.65	0.75	0.35	0.67
Grigorjevs (2012)	**k**	0.52	0.26	0.34	0.55	0.18	0.37
	c	544	1232	740	765	2123	1483
F1	**k**	0.52	0.29	0.30	0.30	0.05	0.31
	c	447	1340	794	1245	2383	1708
	$\mathbf{R^2}$	0.83	0.76	0.84	0.76	0.05	0.80
F2	**k**	0.45	0.31	0.34	0.29	0.19	0.24
	c	584	1220	918	1270	2087	1786
	$\mathbf{R^2}$	0.95	0.75	0.77	0.84	0.77	0.77
F3	**k**	0.61	0.32	0.32	0.43	0.14	0.31
	c	217	1295	797	945	2249	1708
	$\mathbf{R^2}$	0.87	0.81	0.78	0.83	0.52	0.73
F4	**k**	0.59	0.39	0.19	0.38	0.12	0.22
	c	378	1160	985	1121	2173	1697
	$\mathbf{R^2}$	0.91	0.86	0.41	0.81	0.20	0.68
F5	**k**	0.72	0.42	0.29	0.47	0.19	0.31
	c	201	892	860	762	2169	1743
	$\mathbf{R^2}$	0.99	0.96	0.74	0.95	0.53	0.80

Thus, according to overall data (both male and female productions),

- slopes decrease in the following order: [m] > [r] > [n] > [l] > [ʎ] > [ɲ];
- y-intercepts decrease in the following order: [ɲ] > [ʎ] > [n] > [r] > [l] > [m].

The data presented in Table 2 demonstrate that the general pattern varies to some extent in individual cases, and slopes exhibit greater variability than y-intercepts. The extreme members of the slope order are [m] and [ɲ] for most speakers' data (except for M1 who has the highest slope for [r] (k = 0.41) and the lowest for [l] (k = 0.14), and M3 who has the lowest slope for [ʎ] (k = 0.21)). The slope of the lateral [ʎ], which is close to [ɲ] in overall data with k = 0.28 for males and k = 0.29 for females, is rather variable across several speakers' data, namely,

- M4 (k = 0.43; [ʎ] > [l] > [ɲ]),
- M5 (k = 0.36; [ʎ] > [r] > [ɲ]),

- F1 (k = 0.36; [ʎ] > [r] = [l] >[n] > [ɲ]),
- F4 (k = 0.22; [ʎ] > [l] >[ɲ],
- F5 (k = 0.31; [ʎ] > [l] > [ɲ].

This variability in slope for [ʎ] is compensated by its consistently high y-intercept value (the lowest c = 1160 Hz for the productions by M4), therefore its contrast to the group of dentals and alveolars is well-pronounced both in overall and individual data, while the dentals and alveolars overlap among themselves both in terms of slopes and y-intercepts (Table 2). This is the reason why hereinafter in the paper these two places are merged under the joint category of dentals/alveolars, which in fact agrees with the previous assumptions concerning this group of consonants (see Sussman 1994).

In Figure 4, the plot of slope-by-intercept space for overall data of this study and those obtained by J. Grigorjevs (Grigorjevs 2012) is displayed to illustrate the distribution of slopes and y-intercepts more clearly. According to the plot, two major groups can be distinguished accurately by both indices — the group of palatals/dentals/alveolars and the group of labials. The

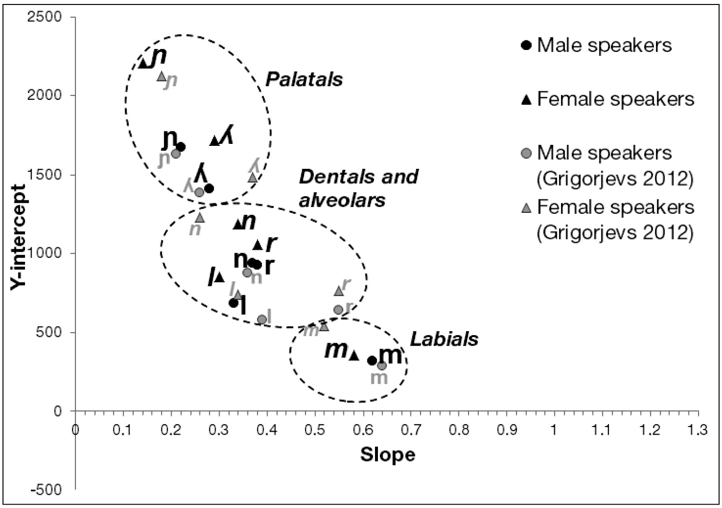

Figure 4. **The plot of slope-by-intercept space for prevocalic sonorants, overall data compared with those obtained by J. Grigorjevs (Grigorjevs 2012)** (dashed ellipses indicate the zones for different places of articulation; symbols without formatting denote male productions, symbols in italics denote female productions)

groups of palatals and dentals/alveolars can be discriminated by y-intercept in the vicinity of c ≈ 1250 Hz, while the difference in slopes seems not so pronounced.

Both the data of the present study and those reported by J. Grigorjevs generally follow the same pattern (Figure 4, Table 2, see also Grigorjevs 2012, 289–290) — in the sense that in both cases the contrast between the groups of palatals and dentals/alveolars (by y-intercept), as well as palatals/dentals/alveolars and labials (both by slope and y-intercept) is observed. However, there are still some differences that should be noted.

While the distribution of consonants by y-intercept values remains consistently the same with those highest for [ɲ; ʎ], lowest for [m] and medium for [n; r; l], the mean slopes follow distinct patterns in both studies. Specifically, the distribution of slope values adduced in the study by J. Grigorjevs is as follows (in descending order):

- [m] > [r] > [l] > [n] > [ʎ] > [ɲ] (for males);
- [r] > [m] > [ʎ] > [l] > [n] > [ɲ] (for females).

The first arrangement is somewhat common for the present study as well, since variability within the group of dentals/alveolars is observed in individual data. In this respect, it should be noted that [l] exhibits the most variable slope among the dentals/alveolars ($0.14 < k < 0.44$). This can be attributed to the amount of velarization in the context of back vowels which varies across speakers considerably and consequently results in volatile degree of coarticulation for [l]. The distribution of slopes observed in female data in its turn seems to be caused by the differences in speakers' samples rather than any relevant articulatory patterns, since the means obtained by J. Grigorjevs are calculated from the data of merely two speakers, and the order they form does not correspond to any observed in the present study.

Another pronounced difference between the two studies is the location of [r] in slope-by-intercept space (Figure 4) caused by the discrepancy between the slopes and y-intercepts estimated for [r] (Table 2). In the study by J. Grigorjevs, the results obtained are being related to the alveolar articulation of [r] as opposed to the group of dentals (Grigorjevs 2012, 289–290). However, in light of the current data this difference may be attributable either to inter-speaker variation or to the specific features of the material used for the research, or both. In the study by J. Grigorjevs, only CVC syllables with short vowels were examined, while for the present research both the contexts of short and long vowels were investigated. It is commonly known that shorter duration of a vowel usually results in greater formant target undershoot at its steady state (see, for instance, Lindblom 1963b; Stevens, House 1963; Lindgren, Lindblom 1996), therefore it is quite likely that the final results of the present study were affected by the measurements taken for long vowel contexts, and this is particularly true for slopes, since they indicate the relation between F2 frequency at the steady state and at the onset of a vowel.

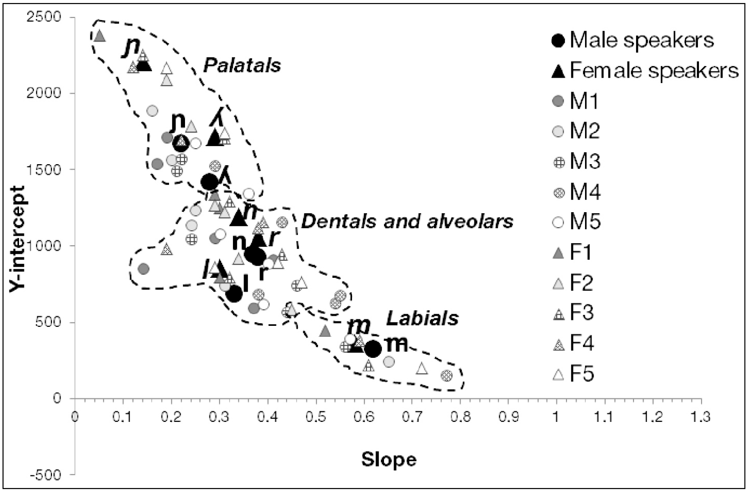

Figure 5. **The plot of slope-by-intercept space for prevocalic sonorants, overall and individual data** (dashed lines indicate the zones for different places of articulation; symbols without formatting denote male productions, symbols in italics denote female productions)

In Figure 5, the overall data are plotted along with those for individual productions by all speakers. It can be observed that, with the amount of data increasing, the place zones expand, overlap both in terms of slopes and y-intercepts, and become less distinguishable. Still, the pattern remains generally the same, and the contrast between the groups of palatals, dentals/alveolars and labials still persists except for some minor differences across speakers within place zones, especially that of dentals/alveolars (Table 2). Two separate two-way ANOVA's were performed in order to examine whether distinction in terms of slopes and y-intercepts is statistically significant across place categories and gender groups.

ANOVA revealed statistically significant difference in y-intercepts across gender groups ($df = 1$, $F = 11.805$, $p = 0.001$), while slopes were not influenced by gender ($df = 1$, $F = 0.609$, $p = 0.439$). The effect of the place factor was proved to be statistically significant both for slopes ($df = 2$, $F = 42.59$, $p = 0.000$) and y-intercepts ($df = 2$, $F = 165.605$, $p = 0.000$). Gender–place interaction was found to be not statistically significant in regard of slope ($df = 2$, $F = 0.113$, $p = 0.893$), while in case of y-intercept an opposite effect was revealed ($df = 2$, $F = 3.44$, $p = 0.039$).

As the results imply, all the place categories discussed so far can be distinguished efficiently both by slopes and y-intercepts. Gender effects on y-intercepts are not surprising, since this index is directly associated with absolute formant frequency values, which are known to be generally higher in female pronunciation than in male pronunciation due to the differences in the vocal tract length observed in men and women. The lack of relevant gender-related distinctions in slopes suggests uniform coarticulation patterns for the same consonant across gender groups. Gender-place interaction in terms of y-intercept makes itself evident in the fact that the discrepancy between gender groups differs across place categories: it is rather little for the labial (c = 320 Hz for males, c = 359 Hz for females), medium for the group of dentals/alveolars (684 Hz < c < 941 Hz for males, 854 Hz < c <1187 Hz for females), and the most pronounced for the palatals (1414 Hz < c < 1671 Hz for males, 1714 Hz < c < 2203 Hz for females).

The results in general agree both with those obtained in the pilot study of the Latvian sonorants (Table 2, see also Grigorjevs 2012, 289–290) and the data acquired for other manner classes in Standard Latvian (to be discussed in Section 4.3; see also Čeirane 2011; Čeirane, Indričāne 2012; Indričāne 2013). The consistent differences in slopes and y-intercepts observed across place categories can be explained in terms of articulation. Labial consonants are produced without a tongue constriction, so the tongue body can freely adjust to the position required for articulating the following vowel, which results in considerable degree of coarticulation indexed by high slope and low y-intercept values. For lingual consonants, i. e., dentals, alveolars and palatals, more precise tongue positioning is necessary, therefore they are more resistible to vowel coarticulatory effects than labials. Within the group of linguals, palatals are characterized by the most stable locus and the lowest degree of coarticulation.[2] According to Daniel Recasens (Recasens 1985), greater coarticulatory resistance in palatals stems from two factors: (1) they require high articulatory control over relatively large region of vocal tract (i. e., wide pharyngeal passage) with a large degree of dorsopalatal contact, which results in high F2 frequency at the onset of an adjacent vowel; (2) palatal articulation involves highly constrained gestures that override conflicting vocalic gestures (such as those needed for the production of low back vowels). This results in relatively stable F2 onset frequency that is scarcely affected by vowel quality.

Although the consonants in question can be distinguished in terms of place of articulation fairly using locus equation constants, there are still some relevant differences in these indices that can be observed among consonants within the same place category. Primarily it concerns the location of laterals in slope-by-intercept space (Figure 5). Firstly, in comparison with other dentals/alveolars, [l] is consistently characterized by lower y-intercepts and exhibits the most variable slopes, as it was already mentioned. This indicates volatile degree of coarticulatory resistance to vowel effects and in fact agrees with data across languages where the acoustic characteristics of [l] (especially F2 frequency) may vary considerably and exhibit different degrees of darkness/lightness depending on vowel context (Recasens, Espinosa 2005, 2–3). Secondly, it can be observed — both in the data of this study and those obtained by J. Grigorjevs — that the group of palatals is not homogeneous: [ʎ] has consistently higher slopes and lower y-intercepts than [ɲ] (Table 1), its location in slope-by-intercept space therefore differs considerably from that of [ɲ] and comes close to the zone of dentals/alveolars (Figure 5). This regularity accords with the findings of D. Recasens concerning the degree of coarticulatory resistance in the Catalan linguals [j; ɲ; ʎ; n] that was proved to be greater in [j] and [ɲ] than in [ʎ] (Recasens 1984). According to D. Recasens, [ʎ] showed larger coarticulatory effects from surrounding vowels than other palatals both in symmetric and asymmetric environments in the articulatory and acoustic domains. By comparing the acoustic and EPG data for [j; ɲ; ʎ; n] it was inferred that vowel-to-consonant coarticulation was dependent

[2] This can also be observed in Figure 1 (see Section 2.1) — in comparison with labial, dental and alveolar context, [ɑ] between palatals has considerably longer F2 transitions directed to higher frequency region; F2 frequency at the nucleus of the vowel is also notably affected by the palatal context.

on the amount of dorsopalatal contact, which was found to be less for [ʎ] than for [j] or [ɲ] (Ibid., 72).

It can be concluded so far that there are certain coarticulatory mechanisms associated with particular places of constriction for the Latvian sonorants that allow linking locus equation data to different place categories pretty surely when other possible influences are eliminated.

4.2. Locus equations for postvocalic nasals

Figure 6 demonstrates the scattergrams and locus equations estimated for the postvocalic nasals [m; n; ɲ; ŋ]. The measurements are plotted along with the data for prevocalic [m; n; ɲ] to see if there are any considerable position-

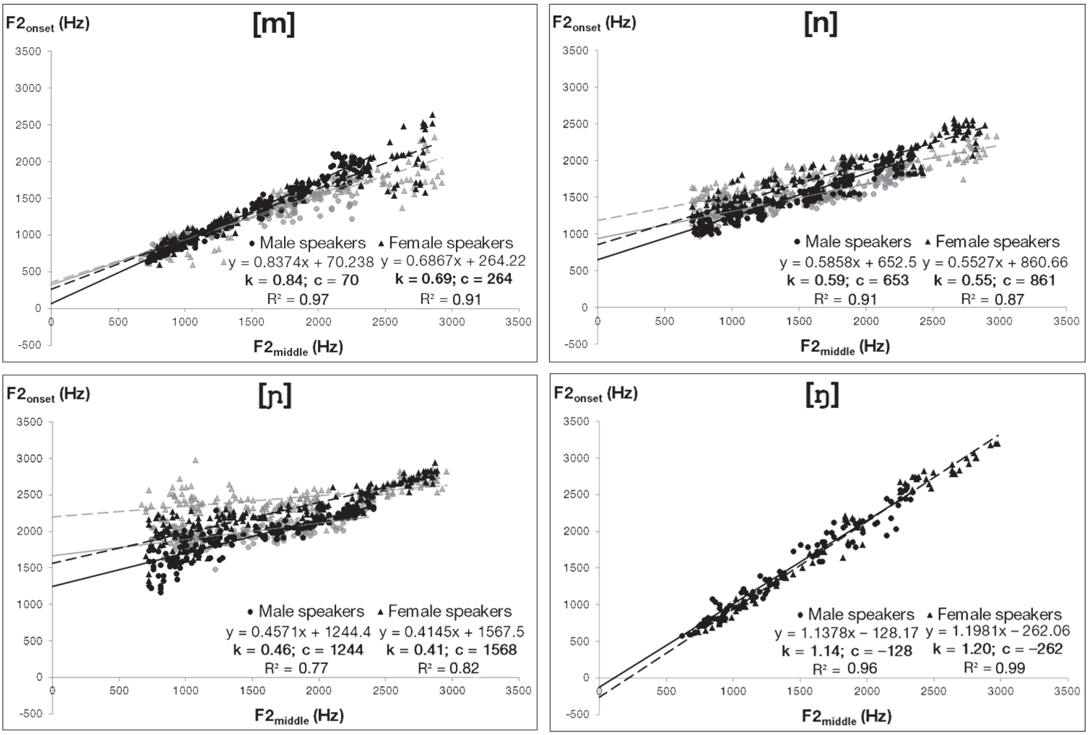

Figure 6. **Locus equations for postvocalic nasals, overall data by gender; data points and regression lines for the prevocalic** [m; n; ɲ] **are added to the plot for comparison** (the data for the prevocalic nasals indicated with grey color; linear regression fit for the male speakers' data shown by the solid line, linear regression fit for the female speakers' data shown by the dashed line)

related differences that should be taken into consideration when analyzing the properties of velar consonant. Table 3 contains slopes, y-intercepts and coefficients of determination for the postvocalic nasals calculated both for overall data and individual productions.

The first point that should be noted in respect of Figure 6 is the difference in locus equations for prevocalic and postvocalic consonants. It can be seen that postvocalic [m; n; ɲ] have considerably lower y-intercepts and higher slopes than corresponding prevocalic nasals (consult also Tables 2 and 3 for individual data) — an indication of decreased resistance to vowel coarticulatory effects. According to the results of ANOVA, position appears to be statistically significant factor both for slopes ($df = 1$, $F = 73.651$, $p = 0.000$) and y-intercepts ($df = 1$, $F = 68.819$, $p = 0.000$). The changes in slopes and y-intercepts are accompanied by notable increase of linearity as indexed by greater coefficients of determination for postvocalic nasals relative to prevocalic ones (the mean coefficient estimated for all three consonants changes from 67 to 88 per cent for prevocalic vs. postvocalic position). Figure 8, where the plot of the nasals in slope-by-intercept space is presented, fully reveals the distinction among the consonants caused by syllable position: all postvocalic consonants are shifted considerably towards lower regions of the acoustic space due to reduced y-intercepts and increased slopes.

Table 3. **Slopes, y-intercepts and coefficients of determination for postvocalic nasals, overall and individual data**

Consonant		[m]	[n]	[ɲ]	[ŋ]
Speaker	Index				
Male speakers	**k**	0.84	0.59	0.46	1.14
	c	70	653	1244	–128
	$\mathbf{R^2}$	0.97	0.91	0.77	0.96
M1	**k**	0.81	0.55	0.46	0.78
	c	41	761	1212	354
	$\mathbf{R^2}$	0.98	0.96	0.93	0.98
M2	**k**	0.89	0.63	0.35	1.16
	c	7	662	1472	–199
	$\mathbf{R^2}$	0.99	0.95	0.86	0.99
M3	**k**	0.74	0.52	0.50	1.21
	c	215	659	1162	–165
	$\mathbf{R^2}$	0.98	0.96	0.92	0.99

Table 3 (continued).

Consonant		[m]	[n]	[ɲ]	[ŋ]
Speaker	Index				
M4	**k**	0.96	0.69	0.54	1.29
	c	–51	474	1064	–307
	$\mathbf{R}^2$	0.99	0.94	0.71	0.98
M5	**k**	0.82	0.55	0.54	1.17
	c	105	761	1286	–189
	$\mathbf{R}^2$	0.99	0.96	0.72	0.99
Female speakers	**k**	0.69	0.55	0.41	1.20
	c	264	861	1568	–262
	$\mathbf{R}^2$	0.91	0.87	0.82	0.99
F1	**k**	0.79	0.59	0.39	1.18
	c	139	870	1648	–239
	$\mathbf{R}^2$	0.96	0.96	0.92	0.99
F2	**k**	0.56	0.45	0.41	1.21
	c	476	1133	1589	–263
	$\mathbf{R}^2$	0.86	0.93	0.81	0.99
F3	**k**	0.68	0.58	0.33	1.24
	c	218	845	1764	–320
	$\mathbf{R}^2$	0.95	0.97	0.86	0.98
F4	**k**	0.54	0.59	0.44	1.16
	c	425	780	1451	–233
	$\mathbf{R}^2$	0.86	0.93	0.82	0.98
F5	**k**	0.84	0.54	0.49	1.19
	c	47	683	1419	–241
	$\mathbf{R}^2$	0.98	0.93	0.86	0.99

The results turn out to be rather contradictory when compared with those for voiced stop consonants obtained in other studies. Harvey Sussman and colleagues who investigated position-related differences in locus equations for English voiced stops (Sussman et al. 1997) reported generally reduced degree of coarticulation and reduced linearity of locus equations in post-vocalic stops relative to prevocalic ones. The amount of reduction differed across place categories though — it was greater for [b] and less for [d]; the data for postvocalic [g] showed an increased slope in front vowel contexts, a decreased slope in back vowel contexts, and an increased slope when all contexts fit with a single regression line. In the original study of locus equations by B. Lindblom (Lindblom 1963), where Swedish stops produced by a single male speaker were examined, less vowel dependence for postvocalic [b] and greater vowel effects on [d] and [g] loci were observed. Later Diana Krull came up with different findings and reported slope values near to 1.0 for all four postvocalic Swedish stops (Krull 1988, 69). Although the position-induced changes in locus equation data reported in these studies are nearly opposite, the authors basically concur with conclusion that the separability of place categories diminishes significantly for consonants being in postvocalic position.

The degraded locus equation forms for postvocalic stops, as noted by H. Sussman and colleagues, can be attributed to greater articulatory precision needed for the production of prevocalic consonants as opposed to postvocalic ones. Particularly, locus equations reflect "the vowel normalization of the variable F2 transitions encoding stop place contrasts", which is more efficient in case of syllable-onset relative to final consonants (Sussman et al. 1997, 2837). The results acquired for the Latvian nasals, however, agree better with those obtained for the Swedish stops (Lindblom 1963; Krull 1988) showing the dominancy of vowel carryover coarticulatory effects over consonant anticipatory coarticulation.

Regarding place contrasts, it can be observed (Figure 6) that the velar nasal is characterized by the steepest regression line and the lowest y-intercept. This result is quite predictable considering the data for the Latvian obstruents (Čeirane 2011; Čeirane, Indričāne 2012; Indričāne 2013), as well as consonants in other languages (see, for instance, Everett 2008; Krull 1987; 1988; 1989; Sussman 1994), where the highest slope values for labials and velars are usually observed indicating the weakest coarticulatory resistance to vowel effects for these place categories. However, similar locus equations for labials and velars, as C. A. Fowler (Fowler 1994, 600) and Caleb Everett (Everett 2008, 194) note, are motivated by distinct factors, though. As it was mentioned before (see Section 4.1), the tongue is not involved in the production of labials, therefore it has freedom to adjust to the articulation of an adjacent vowel. Still, consonantal place is not affected by vowel, since there is actually no coarticulatory overlap between the main gestures needed for the production of these two segments due to distinct active articulators (lips and tongue). In case of velars, the position of their active articulator, i. e., tongue dorsum, changes under the influence of a neighboring vowel,

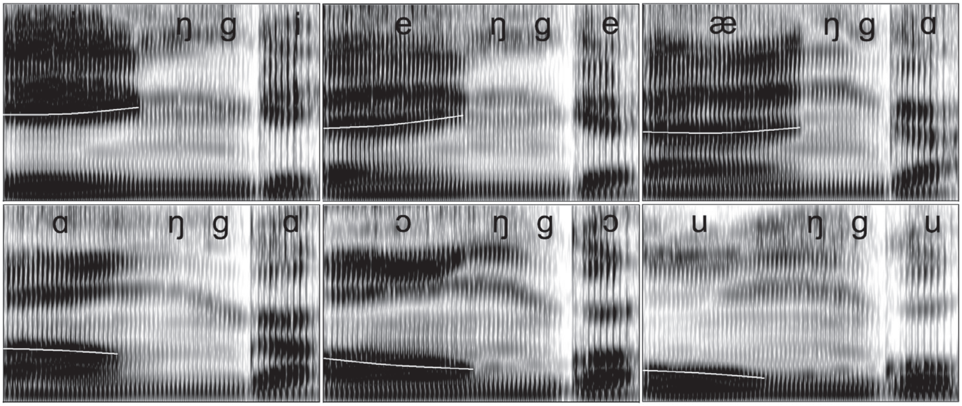

Figure 7. **The dynamic spectrograms of V[ŋg]V sequences produced by a male speaker of Standard Latvian** (the white lines indicate the trajectory of vowel's F2)

and this triggers the shift of consonantal place from velar in the context of back vowels to palatovelar in the context of front vowels.

The comparison of prevocalic and postvocalic [m; n; ɲ] helps to better understand the data obtained for the velar nasal [ŋ]. It can be concluded that the extremely high slopes far exceeding 1.0 (k = 1.14 for males, k = 1.20 for females, 0.78 < k < 1.29 in individual data) and negative y-intercepts (c = −128 Hz for males, c = −262 Hz for females, −320 Hz < c < 354 Hz in individual data) may be caused by the increased vowel coarticulatory effects typical of VC sequences. The extreme steepness of the regression line for [ŋ] is caused by vowel-determined changes in the trajectory of F2 (Figure 7): it can be observed that the F2's of front vowels move towards higher frequency regions, while in case of back vowels F2 frequency tends to decrease in the direction of VC boundary.

In the slope-by-intercept space (Figure 8), the distance is reduced among the postvocalic consonants in comparison with prevocalic ones, nevertheless all the place categories can be discriminated efficiently by both parameters. ANOVA revealed statistically significant place-related differences both in slopes (df = 3, F = 126.83, p = 0.000) and y-intercepts (df = 3, F = 341.048, p = 0.000). Differences across gender groups were found to be similar with prevocalic sonorants—significant for variationin y-intercepts (df = 1, F = 19.068, p = 0.000) and non-significant for variation in slopes

(df = 1, F = 1.274, p = 0.264). Gender–place interaction was found to be not statistically significant in regard of slope (df = 3, F = 1.938, p = 0.134), while in case of y-intercept an opposite effect was observed (df = 3, F = 7.388, p = 0.000).

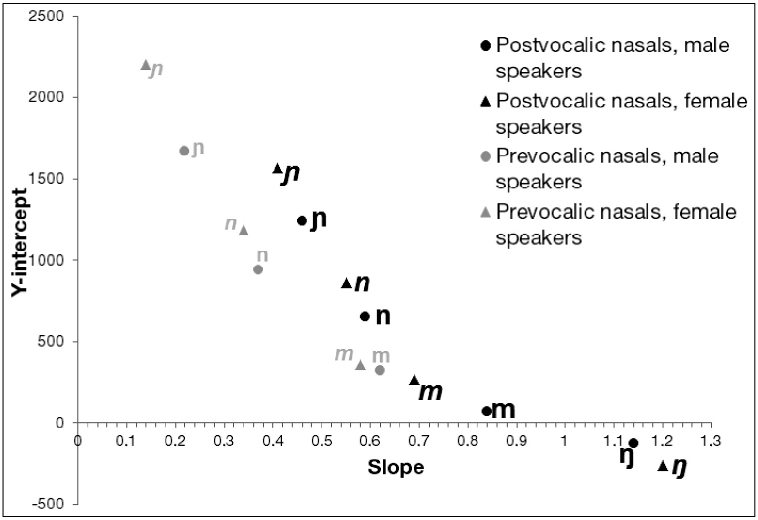

Figure 8. **The plot of slope-by-intercept space for postvocalic and prevocalic nasals, overall data by gender** (symbols without formatting denote male productions, symbols in italics denote female productions)

In case of nasals, vowel coarticulatory effects appear to be greater in VC sequences than in CV's according to locus equation data, and the separability of the consonants in slope-by-intercept space diminishes. However, differences both in slopes and y-intercepts as functions of place category remain relevant.

4.3. Locus equations for the whole consonant inventory

As it was mentioned before (see Section 2.1), locus equations should not be considered as direct indicators of consonantal place, since they primarily reflect the coarticulatory relations between the consonant and the vowel that are usually influenced by other factors apart from place of constriction.

The first factor that should be considered in respect of locus equation data is manner of articulation. According to D. Recasens, fricative and stop manners are rather likely to be characterized by distinct degrees of coarticulatory resistance (Recasens 1989). As C. A. Fowler suggests, locus equation indices for stops and fricatives of different place categories might overlap due to manner effects. Particularly, "the articulatory requirements for producing fricatives are considerably more delicate than they are for producing stops" (Fowler 1994, 600). There is a certain extent of articulatory variability possible during the creating of complete closure needed for producing a stop (e. g., variable amount of force), although it is not likely to result in somewhat significant changes in stop acoustics. In case of fricatives, narrow channel is created in the vocal tract, and it cannot be too narrow (otherwise the gesture will result in a stop) or too wide with no turbulent noise (otherwise the gesture will result in a vowel). The articulatory precision needed for producing fricatives, as noted by C. A. Fowler, might lead to shallower slopes as compared with those for stops of the same place category. Moreover, it is also possible that a stop and a fricative having different places might have similar slopes — one due to the degree of coarticulatory resistance derived from its place of articulation, and the other due to the same resistance associated with its manner (Ibid.).

Voicing should be considered as another factor of importance for estimating locus equations. In the literature (see References), this approach has been applied to voiced stops most frequently. The reason for that apparently is greater burst duration typical of voiceless stops as compared with voiced ones (Everett 2008, 195). The F2 transition therefore is usually more noticeable for vowels in the context of voiced rather than voiceless consonants, "since the values can be collected further apart, allowing for greater transition between them" (Ibid.), which in turn may lead to greater difference between F2 middle and onset and, consequently, lower slopes for voiced stops than for voiceless ones of the same place category.

Some of the possible manner-related differences in locus equations concerning the group of sonorants were discussed in Section 4.1. Let's now see whether (or how) manner and voicing affect the separability of place categories determined by locus equation data for the whole set of the Latvian consonants.

It should be noted first that the possible effects of inter-speaker variation can contribute to the final results to some extent, since the recordings from different informants were used for the analysis of each of three groups — sonorants, voiced obstruents (Čeirane 2011) and voiceless obstru-

Table 4. **Slopes and y-intercepts for prevocalic sonorants compared with those for the Latvian voiced and voiceless obstruents (Čeirane 2011; Indričāne 2013), overall data by gender**

Place	Consonant	Male speakers		Female speakers	
		k	c	k	c
Labial	[p]	0.82	144	0.80	204
	[b]	0.67	326	0.66	434
	[f]	0.83	185	0.81	201
	[v]	0.65	338	0.70	311
	[m]	0.62	320	0.58	359
Dental	[t]	0.57	744	0.61	781
	[d]	0.36	1020	0.45	1020
	[ʦ]	0.38	1061	0.39	1194
	[ʣ]	0.30	1073	0.32	1275
	[s]	0.39	1026	0.40	1185
	[z]	0.37	927	0.36	1142
	[n]	0.37	941	0.34	1187
	[l]	0.33	684	0.30	854
Alveolar	[ʧ]	0.35	1211	0.38	1364
	[ʤ]	0.29	1298	0.33	1424
	[ʃ]	0.50	905	0.47	1122
	[ʒ]	0.46	844	0.36	1257
	[r]	0.38	926	0.38	1055
Palatal	[c]	0.33	1367	0.34	1691
	[ɟ]	0.23	1537	0.34	1565
	[j]	0.20	1702	0.17	2123
	[ɲ]	0.22	1671	0.14	2203
	[ʎ]	0.28	1414	0.29	1714
Velar	[k]	1.00	96	1.00	69
	[g]	0.86	339	0.92	209
	[x]	0.99	86	0.98	128
	[ŋ]	1.14	–128	1.20	–262

ents (Indričāne 2013). However, despite the different data sources, slopes and y-intercepts for all Latvian consonants generally follow similar pattern (Table 4). According to the full set of data, two major groups can be distinguished in slope-by-intercept space quite clearly—palatals/dentals/alveolars and labials/velars (Figure 9). Labials and velars can be discriminated by slope (the boundary can be drawn at k ≈ 0.86); for palatals and dentals/alveolars, difference in terms of y-intercept is more pronounced, even though affected by gender (the boundary is found to be at c ≈ 1300 Hz for males and c ≈ 1500 Hz for females). In comparison with the plot for sonorants only (see Figure 4 in Section 4.1), separability among place zones is diminished, since the degree of coarticulation indexed by slopes and y-intercepts is affected by manner and voicing as well.

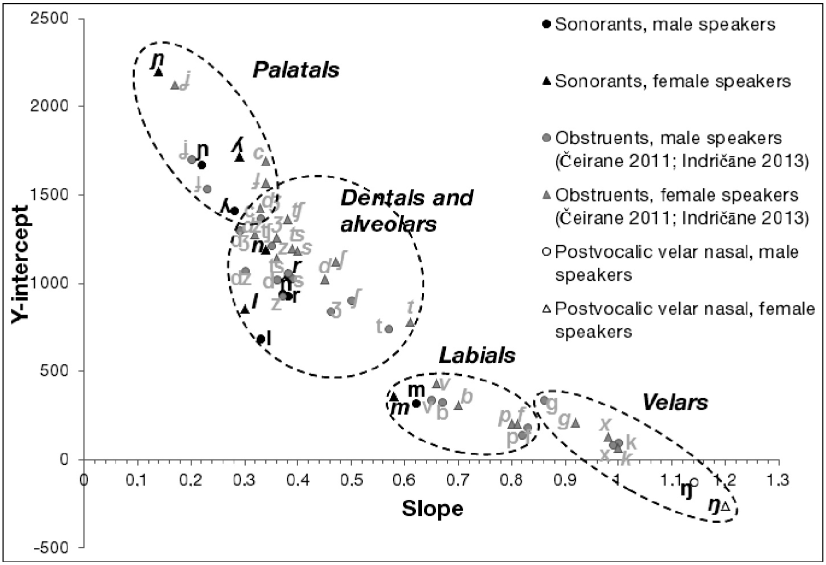

Figure 9. **The plot of slope-by-intercept space for all Latvian consonants, overall data by gender** (dashed ellipses indicate the zones for different places of articulation; symbols without formatting denote male productions, symbols in italics denote female productions)

To test the effects of gender, place, manner and voicing on locus equation data, two separate four-way ANOVA's for slope and y-intercept were performed. According to the results, there are statistically significant manner-related differences both in slopes ($df = 4$, $F = 12.881$, $p = 0.000$) and y-intercepts ($df = 4$, $F = 32.035$, $p = 0.000$). Post-hoc tests (Bonferroni correction) for slopes revealed significant difference among the groups of affricates, stops and fricatives ($p = 0.000$ for all cases) and no statistically significant distinctions between affricates and sonorants, i. e., nasals, laterals and trill ($p = 0.309$, $p = 1.000$, $p = 0.470$, respectively). There is also significant difference between nasals and laterals discussed previously (see Section 4.1). In respect of y-intercepts, no significant difference detected between fricatives and trill ($p = 1.000$), as well as among nasals, affricates and laterals ($p = 0.598$), nasals and laterals ($p = 1.000$), nasals and trill ($p = 0.151$). Voicing also affects locus equation indices both in regard to slopes ($df = 1$, $F = 47.709$, $p = 0.000$) and y-intercepts ($df = 1$, $F = 15.324$, $p = 0.000$). Gender effects are statistically significant only for y-intercept variation ($df = 1$, $F = 39.238$, $p = 0.000$) and does not affect slopes ($df = 1$, $F = 0.008$, $p = 0.927$). Gender-related differences in y-intercepts are greater for palatals and dentals/alveolars and less for labials and velars (consult Table 4 for figures). Despite the effects caused by manner and voicing, place distinction remains relevant between all four categories both for slopes ($df = 3$, $F = 396.581$, $p = 0.000$) and y-intercepts ($df = 3$, $F = 790.185$, $p = 0.000$).

The distribution of slope values is as follows (in descending order):

- [ŋ] > [k] > [x] > [ɡ] > [f] > [p] > [b] > [v] > [m] > [t] > [ʃ] > [ʒ] > [s] > [ʦ] = [r] > [z] = [n] > [d] > [ʧ] > [l] = [c] > [ʣ] > [ʤ] > [ʎ] > [ɟ] > [ɲ] > [ʝ] (for males);
- [ŋ] > [k] > [x] > [ɡ] > [f] > [p] > [v] > [b] > [m] > [t] > [ʃ] > [d] > [s] > [ʦ] > [r] = [ʧ] > [z] = [ʒ] > [n] = [c] = [ɟ] > [ʤ] > [ʣ] > [l] > [ʎ] > [ʝ] > [ɲ] (for females).

The distribution of y-intercept values is as follows (in descending order):

- [ʝ] > [ɲ] > [ɟ] > [ʎ] > [c] > [ʤ] > [ʧ] > [ʣ] > [ʦ] > [s] > [d] > [n] > [z] > [r] > [ʃ] > [ʒ] > [t] > [l] > [ɡ] > [v] > [b] > [m] > [f] > [p] > [k] > [x] > [ŋ] (for males);
- [ɲ] > [ʝ] > [ʎ] > [c] > [ɟ] > [ʤ] > [ʧ] > [ʣ] > [ʒ] > [ʦ] > [n] > [s] > [z] > [ʃ] > [r] > [d] > [l] > [t] > [b] > [m] > [v] > [ɡ] > [p] > [f] > [x] > [k] > [ŋ] (for females).

Although there are some minor differences in slopes between the gender groups, generally the same pattern remains unchanged across genders. There is no overlapping among the groups of velars, labials and dentals/alveolars, while the separability between dentals/alveolars and palatals is violated because of relatively low slopes for the alveolar [ʤ] and the dental [ʣ] and high slopes for the palatals [c]and [ɟ]. The differences caused by voicing are evident within place categories: slope values for voiceless consonants in most cases are greater than those for corresponding voiced consonants of the same place and manner of articulation (which agrees with the assumption by C. Everett

(Everett 2008, 195) mentioned previously). The slopes for fricatives and affricates are usually shallower than those for stops within the same place category indicating smaller degree of coarticulatory resistance for the latter. In case of y-intercepts, the overlap between labials and velars is observed due to relatively high y-intercept acquired for [g] and reduced y-interpcept estimated for the voiceless labials [p]and [f]. In general, lack of voicing results in reduced y-intercepts. It can be observed in Figure 9, where the locus patterns formed by slopes and y-intercepts are displayed, that the zones of dentals/alveolars and palatals overlap primarily due to the location of the alveolar fricative [ʒ] (in female pronunciation) and the alveolar affricate [ʤ] in slope-by-intercept space. This might be caused by the palatalization typical of the pronunciation of these consonants (Čeirane 2011, 109; Grigorjevs 2012, 290; Indričāne 2013, 117). The zones for labials and velars overlap chiefly due to reduced y-intercepts for the voiceless labials [p] and [f].

According to the results, Latvian sonorants with different places of articulation can be distinguished by locus equation constants most efficiently using small amount of data (e. g., within a single speaker's data or the same consonantal class). As the amount of data increases, place categories become less distinguishable in terms of locus equations, since the degree of coarticulation indexed by slopes and y-intercepts is affected by other factors apart from place of articulation, although the difference remains statistically significant in most cases. For more reliable results, the data from the same speakers should be considered to minimize the effects caused by inter-speaker variation.

5. Conclusion

Slope and y-intercept values of the sonorants generally follow the pattern similar to those obtained by J. Grigorjevs (Grigorjevs 2012) for the same group of consonants, as well as the data on voiced and voiceless obstruents (Čeirane 2011; Indričāne 2013). By plotting the data for the whole consonant inventory in slope-by-intercept space it is possible to distinguish between the groups of palatals/dentals/alveolars and labials/velars, while the results of statistical analysis show significant difference among all place categories.

Although place distinction appears to be statistically significant both within the group of sonorants and across manner classes, in the latter case other factors like voicing and manner (also syllable position — at least for one of the manner classes) contribute to the degree of coarticulation and thus affect locus equation indices. Nevertheless, place of articulation as a determinant of coarticulatory effects overrules these factors when other possible influences are excluded. Further research on the variability of locus equations as affected by syllable or phrasal position, stress, speaking style and other aspects should be carried out to evaluate their effect on the coarticulatory patterns observed across place categories. Parallel study of articulation would be beneficial to link acoustic data with articulation processes.

LOKUSA VIENĀDOJUMI UN LATVIEŠU VALODAS SKANEŅU ARTIKULĀCIJAS VIETA

Kopsavilkums

Rakstā, izmantojot lokusa vienādojumu analīzi, tiek aplūkoti latviešu standartvalodas skaneņi. Pētījuma mērķis ir noteikt, vai lokusa vienādojumu konstantes ir uzskatāmas par nozīmīgu līdzskaņa artikulācijas vietas rādītāju gan skaneņu grupā, gan artikulācijas veida ziņā atšķirīgiem latviešu standartvalodas līdzskaņiem.

Tika analizētas divu veidu vienības: (1) izolēti izrunātu *CVC* struktūras zilbju *CV* daļa, kur *C* ir viens no skaneņiem [m; n; ɲ; l; ʎ; r] un *V* ir viens no patskaņiem [i(ː); e(ː); æ(ː); ɑ(ː); ɔ(ː); u(ː)]; (2) izolēti izrunātu *V(:)CV* (*VCV* līdzskanim [ŋ]) vienību *V(:)C* daļa, kur *C* ir viens no nazālajiem slēdzeņiem [m; n; ɲ; ŋ] un *V* ir viens no patskaņiem [i; e; æ; ɑ; ɔ; u]. Materiālu ierunājuši 10 informanti (5 vīrieši un 5 sievietes). Katra vienība tika ierakstīta trijos atkārtojumos, tādējādi kopumā ir analizēti 3420 līdzskaņi. Lai pārbaudītu, vai lokusa vienādojumu konstantēm ir nozīme artikulācijas vietas grupu savstarpējā nošķiršanā, tika veikta regresijas koeficienta un regresijas taisnes un y ass krustpunkta vērtību statistiska analīze.

Visu latviešu valodas līdzskaņu datus attēlojot koordinātu plaknē, var nošķirt divas artikulācijas vietas grupas — palatālos/dentālos/alveolāros līdzskaņus un labiālos/velāros līdzskaņus —, lai gan statistiskas analīzes rezultāti liecina par nozīmīgām atšķirībām starp visām vietas kategorijām. Pētījuma rezultāti rāda, ka slēguma vai sašaurinājuma vieta līdzskaņa izrunas laikā lielā mērā nosaka līdzartikulācijas mehānismus, tāpēc dažādas artikulācijas vietas kategorijas var tikt nošķirtas pēc lokusa vienādojumu datiem, taču šos rādītājus ietekmē arī artikulācijas veids un balsīgums. Tomēr artikulācijas vieta kā līdzartikulācijas pakāpes noteicēja dominē pār šiem aspektiem, kad citi iespējamie ietekmes faktori ir izslēgti.

REFERENCES

Audacity Team 2013, *Audacity* v2.0.3 [Computer software], http://audacity.sourceforge.net/ (09 07 2013).

Boersma, Paul, David Weenink 2012, *Praat: Doing phonetics by computer* v5.3.35 [Computer software], http://www.fon.hum.uva.nl/praat/ (8 12 2012).

Čeirane, Solveiga 2011, *Latviešu valodas balsīgo troksneņu akustiskais raksturojums* [Acoustic characteristics of the Latvian voiced obstruents], Doctoral Thesis, University of Latvia.

Čeirane, Solveiga, Inese Indričāne 2012, Latviešu valodas troksneņu raksturojums pēc lokusa vienādojumiem [The description of Latvian obstruents via locus equations], *Baltistica* 47(1), 37–50.

Delattre, Pierre C., Alvin M. Liberman, Franklin S. Cooper 1955, Acoustic loci and transitional cues for consonants, *Journal of the Acoustical Society of America* 27(4), 769–773.

Duez, Danielle 1989, Second formant locus-nucleus patterns in spontaneous speech: some preliminary results on French, *PERILUS* 10, 109–114.

Everett, Caleb 2008, Locus equation analysis as a tool for linguistic fieldwork, *Language Documentation & Conservation* 2(2), 185–211.

Fowler, Carol A. 1994, Invariants, specifiers, cues: An investigation of locus equations as information for place of articulation, *Perception & Psychophysics* 55(6), 597–610.

Fruchter, David, Harvey M. Sussman 1997, The perceptual relevance of locus equations, *Journal of the Acoustical Society of America* 102(5), 2997–3008.

Grigorjevs, Juris 2012, Acoustic characteristics of the Latvian sonorants, *Baltistica* 47(2), 267–292.

IBM Corporation 2012, *SPSS Statistics* v21.0.0.0 [Computer software], http://www-01.ibm.com/software/analytics/spss/products/statistics/index.html (1 01 2013).

Indričāne, Inese 2013, *Latviešu valodas nebalsīgo troksneņu akustisks un auditīvs raksturojums* [Acoustic and auditory characteristics of the Latvian voiceless obstruents], Doctoral Thesis, University of Latvia.

Iskarous, Khalil, Carol A. Fowler, Douglas H. Whalen 2010, Locus equations are an acoustic expression of articulator synergy, *Journal of the Acoustical Society of America* 128(4), 2021–2032.

Krull, Diana 1987, Second formant locus patterns as a measure of consonant-vowel coarticulation, *PERILUS* 5, 43–61.

Krull, Diana 1988, Acoustic properties as predictors of perceptual responses: A study of Swedish voiced stops, *PERILUS* 7.

Krull, Diana 1989, Second formant locus patterns and consonant-vowel coarticulation in spontaneous speech, *PERILUS* 10, 87–108.

Ladefoged, Peter 2003, *Phonetic data analysis: An introduction to fieldwork and instrumental techniques*, Malden, MA: Blackwell Publishing Ltd.

Laua, Alise 1997, *Latviešu literārās valodas fonētika* [Phonetics of Standard Latvian], Rīga: Zvaigzne ABC.

Lindblom, Björn 1963a, On vowel reduction, Thesis for fil. lic. degree, *Speech Transmission Laboratory Quarterly Progress Report* 4(1), 5–9.

Lindblom, Björn 1963b, Spectrographic study of vowel reduction, *Journal of the Acoustical Society of America* 35(11), 1773–1781.

Lindgren, Rolf, Björn Lindblom 1996, Reduction of vowel chaos, *Speech Transmission Laboratory Quarterly Progress Report* 37, 1–4.

Microsoft Corporation 2010, *Microsoft Excel* v14.0.4760 [Computer software], http://office.microsoft.com/en-001/excel/ (23 12 2012).

NCH Software 2013, *WavePad Sound Editor* v5.40 [Computer software], http://www.nch.com.au/wavepad/index.html (10 05 2013).

Recasens, Daniel 1984, V-to-C coarticulation in Catalan VCV sequences: an articulatory and acoustical study, *Journal of Phonetics* 12, 61–73.

Recasens, Daniel 1985, Coarticulatory patterns and degrees of coarticulatory resistance in Catalan CV sequences, *Language and Speech* 28(2), 97–114.

Recasens, Daniel 1989, Long range coarticulatory effects for tongue dorsum contact in VCVCV sequences, *Haskins Laboratories Status Report on Speech Research* 99/100, 19–37.

Recasens, Daniel, Aina Espinosa 2005, Articulatory, positional and coarticulatory characteristics for clear /l/ and dark /l/: evidence from two Catalan dialects, *Journal of the International Phonetic Association* 35(1), 1–25.

Recasens, Daniel, Aina Espinosa 2009, An articulatory investigation of lingual coarticulatory resistance and aggressiveness for consonants and vowels in Catalan, *Journal of the Acoustical Society of America* 125(4), 2288–2298.

Stevens, Kenneth N., Arthur S. House 1963, Perturbation of vowel articulations by consonantal context: An acoustical study, *Journal of Speech, Language, and Hearing Research* 6(2), 111–128.

Sussman, Harvey M. 1994, The phonological reality of locus equations across manner class distinctions: Preliminary observations, *Phonetica* 51(1–3), 119–131.

Sussman, Harvey M., Helen A. McCaffrey, Sandra A. Matthews 1991, An investigation of locus equations as a source of relational invariance for stop place categorization, *Journal of the Acoustical Society of America* 90(3), 1309–1325.

Sussman, Harvey M., Nicola Bessell, Eileen Dalston, Tivoli Majors 1997, An investigation of stop place of articulation as a function of syllable position: A locus equation perspective, *Journal of the Acoustical Society of America* 101(5), 2826–2838.

Sussman, Harvey M., Jadine Shore 1996, Locus equations as phonetic descriptors of consonantal place of articulation, *Perception & Psychophysics* 58(6), 936–946.

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