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SPECTRAL FEATURES OF NASALS IN STANDARD LATVIAN[1]

1. Introduction

During the last decades, research in the field of acoustic phonetics has been held quite extensively in Latvia, however, there is still lack of comprehensive studies of the Latvian sound system performed using modern methods of speech analysis, and there are various gaps that need to be filled. The acoustic properties of vowels (both monophthongs and diphthongs) and obstruents have been investigated rather thoroughly (see, for instance, Grigorjevs 2008; 2009; 2012; 2013; Čeirane 2011; Čeirane, Indričāne 2012; Indričāne 2013; Indričāne 2014), but Latvian sonorants are less studied (Grigorjevs 2012a; 2012b; Čeirane et al. 2014; Taperte 2013; 2014a; 2014b).

Since 2013, the research project "Acoustic characteristics of the sound system of Standard Latvian by age groups (5–15, 16–39, 40–59, 60–80)" (No. 148/2012, funded by Latvian Council of Science, led by Juris Grigorjevs) has been carried out at the Latvian Language Institute of the University of Latvia, Riga. In the present paper, the midline results of the project have been discussed to find out if the acoustic properties of nasal murmur may be considered as efficient cues for distinguishing between nasal places of articulation.

2. Acoustics of nasals

The term "nasal" is associated with a special manner of articulation: it refers to sounds produced with lowered velum which allows air to come out through the nasal cavity (Figure 1), thus causing an audible effect called nasality. Both consonants and vowels can be pronounced this way.

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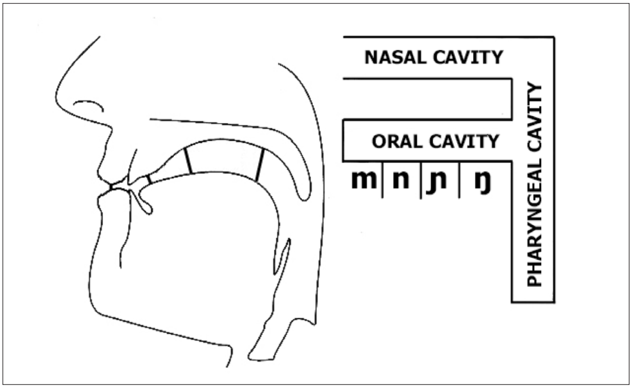


Figure 1. **Vocal tract configuration during the production of nasals (on the left) and its approximation (on the right)** (adapted from Johnson 2003, 154) **with the place of articulation indicated for the nasals** [m], [n], [ɲ], [ŋ]

Nasal consonants, or nasals (sometimes referred to as nasal occlusives or nasal stops (Johnson 2003, 151; Reetz, Jongman 2009, 15)), occur when there is a complete closure in the mouth and airflow therefore is redirected through the nasal cavity. They are nearly universal in human languages, and most common places of articulation for nasals are bilabial, alveolar and velar positions ([m], [n], [ŋ], respectively), although the latter occurs in fewer languages than [m] and [n] (Ladefoged 2001, 148). The palatal nasal [ɲ] appears still more rarely (for example, in Latvian, as well as in Catalan, Czech, Hungarian, etc. (CAIPA 1999)); nevertheless, it is more common than the palatal stop [c]. Other types of nasals which act as phonemic units (for instance, uvular [N], palatalized [m^{j}], [n^{j}], velarized [m^{ɣ}], [n̪^{ɣ}], aspirated [m^{h}], [n^{h}], [ɳ^{h}], etc.) are much less common.

The main feature which contributes to spectral characteristics of nasals is shape and size of the resonator system. It is considerably larger than the one for oral sounds and also rather complex, consisting of two branches (Figure 1): one represents the main resonator, i. e. pharyngeal and nasal cavities, while another stands for the side resonator, i. e. oral cavity, which is closed at one end, as an occlusion occurs there. While there is a closure in the mouth, vocal folds remain in a configuration for modal voicing and continue to vibrate in a normal manner, and the sound produced during this time is called the nasal murmur (Stevens 1998, 488).

In general, the main spectral features which mark nasals as a class can be derived from the spectra of nasal murmurs rather than from the transition segments of adjacent vowels, and they are as follows (see also Figure 2):

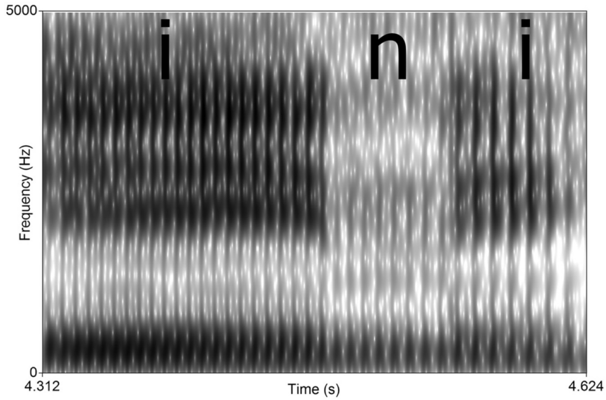


Figure 2. **The dynamic spectrogram of [**ini**] produced by a male speaker of Standard Latvian**

- Overall amount of acoustic energy considerably lower than that of vowels; low (about 250–300 Hz) first nasal formant (N1 henceforth) determined by the resonance occurring in the large nasal passages which are constricted by the small nostrils (Stevens 1998, 489);
- Damped upper formants with low intensity and broad bandwidths;
- The presence of anti-formants (also referred to as anti-resonances or spectral zeros — Z1, Z2, etc.).

There are two main reasons for the low intensity level and increased formant bandwidths, as Peter Ladefoged (2001) suggests: (1) during the production of nasals the vocal tract has side cavities, i. e. sinuses, and (2) the vocal tract is more constricted in nasals than in vowels (the constriction occurs at the nostrils).

Other manner cues — such as nasalization of the neighboring segments and vowel F1 transitions that are less pronounced than those for oral stops — can be regarded as less important (Recasens 1983, 1346).

It is known that murmur spectrum contains mainly nasal manner cues, while the primary information for indicating place of articulation regardless consonant manner is found in the formant transitions of the adjacent vowels (mostly F2) (Delattre et al. 1955, 769; Ladefoged 2003, 53). Still, as the results of perception studies suggest, murmur structure is relevant for distinguishing between nasal places as well and complements the cues encoded in the adjacent segments (Repp 1986; 1988).

One of the spectral traits associated with the place of articulation in nasals is the frequency of anti-formant Z1 — frequency component in nasal consonants that is actively subtracted from the spectrum because of the interaction between the main resonator and its side branch (Johnson 2003; Ladefoged 2001; Stevens 1998). The side resonator of the mouth cavity, where closure occurs, resonates at particular frequencies absorbing acoustic energy in the system and forming anti-formants which appear in the spectrum as pronounced spectral valleys (as opposed to formants which appear as spectral peaks). The closure in the mouth affects the size of the side resonator, which in turn has an effect on the spectrum of the nasal produced. Figure 1 demonstrates the places of articulation for the nasals of Standard Latvian. The longest oral resonator is the one for [m] (the occlusion is made by the lips), but the shortest one — the one for [ŋ] (the occlusion is made by the tongue body that is raised towards the velum). The length of the side chamber is inversely related to Z1 frequency, thus the latter is supposed to decrease in the following order: [ŋ] > [ɲ] > [n] > [m].

Since the constriction made in the oral cavity has minimal effect on the main resonator, the formant structure of nasals is less variable than the one of oral vowels and sonorants. Nevertheless, data analysis for several languages (German, Russian, Czech, Hungarian, etc.) revealed systematic differences in the frequency (N1) and bandwidth (B1) of the first nasal formant which might be determined by the place of articulation of nasals, as it is presumably associated with the size of the pharyngonasal tract and the coupling section of the velopharyngeal passage (Recasens 1983, 1346). According to these data, N1 is supposed to decrease in the following order: [ŋ] > [ɲ] > [n] > [m]; B1 in its turn decreases in the following order: [ŋ] > [ɲ; n; m] (Ibid.).

Hereafter in the article, the Latvian nasals have been analyzed using three above mentioned acoustic parameters of nasal murmur — anti-formant frequency, as well as frequency and bandwidth of the first nasal formant.

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 software (version 5.40, NCH Software 2013) or Audacity software (version 2.0.3, Audacity Team 2013).

Prevocalic nasals [m; n; ɲ] were analyzed in isolated CVC syllables, where C is one of the nasals and V is one of the vowels [i(ː); e(ː); æ(ː); ɑ(ː); ɔ(ː); u(ː)]. Since the velar [ŋ] — the allophone of the phoneme /n/ — appears only before a velar stop /k/ or /g/ (e. g., *banka* [bɑŋkɑ] 'a bank' or *bungas* [buŋgɑs] 'a drum') (Laua 1997), it was recorded in postvocalic position in [k]V[ŋks] structure units.

Each utterance was recorded in three repetitions by every speaker, thus 1260 items were analyzed in total.

3.2 Measurements

The analysis was performed with the help of Praat software (version 5.3.35, Boersma, Weenink 2012). Z1 frequencies were obtained using FFT and LPC spectra of the steady state of the nasals in question (see Section 4.1); N1 frequencies were tracked using FFT spectra; B1 frequencies were measured semi-automatically by selecting "Show formants" function under the "Formant" menu, then placing cursor at the center of the nasal segment and selecting "Get second bandwidth" under the "Formant" menu. Means and standard deviations were estimated using Microsoft Excel software (version 14.0.4760, Microsoft Corporation 2010). Boxplots representing the N1 and B1 data were created using SPSS Statistics software (version 21.0.0.0, IBM Corporation 2012).

The same software was used for further statistical analysis of Z1, N1 and B1 values in order to test the relevance of these indices for discriminating places of articulation within the group of nasals. For this purpose, three multi-way analyses of variance (ANOVA) were carried out: (1) a three-way ($2 \times 4 \times 2$) ANOVA for Z1 values with a two-level independent variable for gender (males vs. females), a four-level independent variable for place of articulation (labial vs. dental vs. palatal vs. velar) and a two-level independent variable for vowel context (front vs. back); (2) two separate two-way (2 × 4) ANOVA's for N1 and B1 values with a two-level independent variable for gender (males vs. females) and a four-level independent variable for place of articulation (labial vs. dental vs. palatal vs. velar).

4. Results and discussion

4.1. Anti-formants

To identify anti-formants, the spectral slice of the steady state of each nasal was analyzed. Two types of spectra — FFT and LPC — were obtained for each unit; then the FFT spectrum was plotted along with the LPC spectrum. In the spectral regions where anti-formants are located, the discrepancy between the FFT and LPC spectra is observed, since LPC analysis is based on the assumption that the vocal tract transfer function has no anti-formants (Johnson 2003, 157).

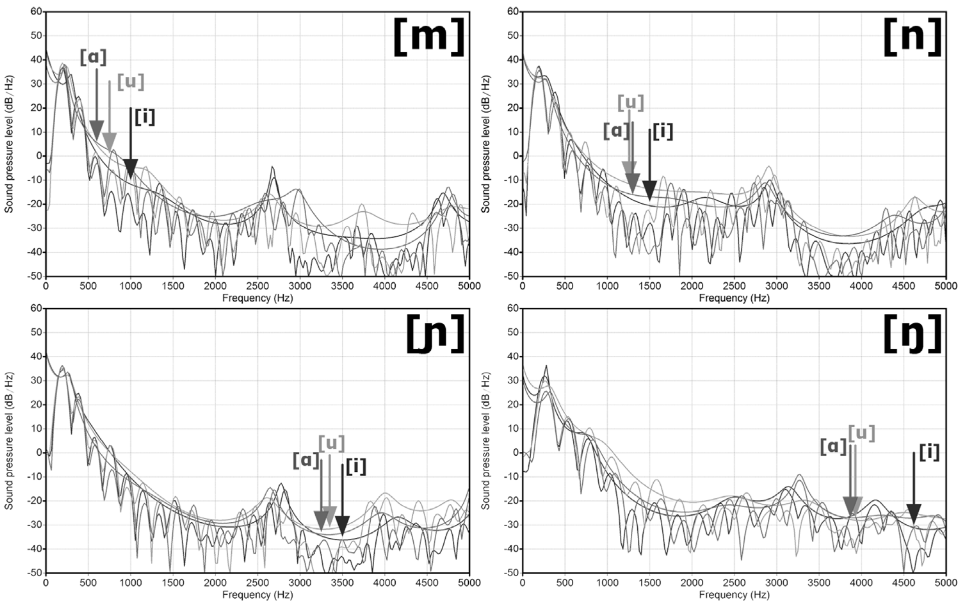


Figure 3. **The anti-formants of prevocalic nasals in the context of vowels** [i], [ɑ], [u] **produced by a male speaker of Standard Latvian** (the location of anti-formants is indicated by the arrows)

It can be observed in Figure 3, where the process of detecting anti-formants is shown, that Z1 frequency is affected both by the place of articulation of a nasal and the quality of an adjacent vowel: it is lower in the context of back vowels, while front vowel contexts usually cause the increase of Z1 frequency. As the data presented in Table 1 suggest, vowel context effect is more evident for [m] than for the rest of the nasals. The reason for that apparently is the specific articulation of labials: since the tongue is not involved in their production, it has freedom to adjust to the articulation of an adjacent vowel, thus affecting the size and shape of the resonator system. Still, as the results of ANOVA imply, the correlation between Z1 frequency and vowel frontness/backness is statistically significant for all the nasals examined ($df = 1$, $F = 23.623$, $p = 0.000$).

Table 1. **Anti-formant frequencies estimated for male and female speakers and vowel contexts in comparison with those obtained in previous studies of Latvian nasals** (Grigorjevs 2012; Taperte 2013) **and reported for other languages** (Johnson 2003, 157; Ladefoged, Maddieson 1998, 117; Raphael et al. 2007, 123; Recasens 1983, 1348)

Vowel	[m] (M | F)		[n] (M | F)		[ɲ] (M | F)		[ŋ] (M | F)	
[i(:)]	600–1050	700–1250	1200–1950	1250–2250	2400–3250	2600–3600	3100–4000	3250–4500
[e(:)]	700–1000	750–1000	1150–1900	1250–1900	2300–2950	2750–3400	3000–4500	3300–4500
[æ(:)]	750–1000	800–1000	1150–1850	1250–1800	2250–2900	2700–3500	3000–4500	3250–4300
[ɑ(:)]	650–800	700–900	1000–1950	1250–1750	2400–2950	2750–3500	3300–4750	3700–4450
[ɔ(:)]	550–700	650–850	1000–1800	1000–1700	2400–2900	2750–3300	3000–4300	3500–4400
[u(:)]	500–800	500–850	950–1800	1650–1750	2400–3000	2750–3500	3200–3950	3500–4250
Total range	**500–1250**		**950–2250**		**2250–3600**		**3000–4750**	
Previous studies	**500–1300**		**900–1700**		**1700–3600**		**3100–5200**	
In other languages	**500–1500**		**1400–3000**		**2100–2700**		**3000–5000**	

For all the nasals, the range of Z1 frequency is rather broad (Table 1), as it is influenced both by vowel context and speakers' anatomy and articulatory habits. In general, the results obtained in this study accord with those of the previous research of Latvian nasals and demonstrate the same overall trend: Z1 frequency increases, as the length of the oral resonator decreases. Although there is quite much overlap in Z1 frequencies observed between nasals with distinct places of articulation (in the region of 950–1250 Hz for [m] and [n] and in the region of 3000–3600 Hz for [ɲ] and [ŋ]), there is always at least 100–200 Hz difference for the nasals produced by the same speaker in the same phonetic context.

All in all, Z1 frequencies for the Latvian nasals correspond to those reported for other languages except for [n]: the frequency range observed both in the present research and in the previous studies is considerably lower than that of the same consonant in other languages. As J. Grigorjevs (2012, 279) points out, this can be explained by the dental articulation of the Latvian [n], while in most other languages it has been characterized as an alveolar consonant.

4.2. The frequency of the first nasal formant

In Table 2, the frequencies of the first nasal formant estimated for the prevocalic nasals are presented. As the results suggest, [ŋ] differs rather considerably from the rest of the nasals by this parameter (in most cases, although not for all speakers) varying in the range of 221–339 Hz, while the discrepancy between [m], [n] and [ɲ] is not so pronounced (196–271 Hz, 223–297 Hz, 204–281 Hz, respectively).

Figure 4 demonstrates the distribution of N1 values within the two gender groups. In general, both groups follow the same pattern with rather compact overall range (shorter boxplots) and lower median for [m], [n], [ɲ] and considerably higher range (taller boxplots) and higher median for [ŋ]. Female data distribution is characterized by generally higher interquartile range and uneven shape with more variable results above the middle quartile than those below the median.

Although the difference among N1 values for [m], [n] and [ɲ] is not very obvious, there is a rather constant pattern across speakers suggesting the increase of N1 frequency in the following order: m < [ɲ] < [n] < [ŋ]. The relevant difference among all the nasals is supported by the results of statistical analysis as well ($df = 3$, $F = 84.075$, $p = 0.000$). However, although the difference among [m], [n], [ɲ] is quite persistent, it is very small in most cases, often lower than 10 Hz, and therefore very unlikely to be perceptually significant, while the contrast between [m; n; ɲ] and [ŋ] is more pronounced.

Table 2. **Means and standard deviations estimated for N1 values** (overall and individual data)

	[m]		[n]		[ɲ]		[ŋ]	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Males	235	25	248	21	244	24	279	43
M1	249	12	262	12	252	9	309	22
M2	196	19	223	24	204	17	221	39
M3	256	15	259	16	252	11	312	22
M4	240	9	246	8	261	17	279	37
M5	235	11	249	12	252	11	277	17
Females	243	23	262	29	249	22	279	50
F1	271	19	297	21	281	16	339	20
F2	245	11	258	13	249	9	242	12
F3	218	9	235	17	232	20	284	39
F4	237	4	242	4	241	4	239	16
F5	246	24	276	29	241	15	291	61

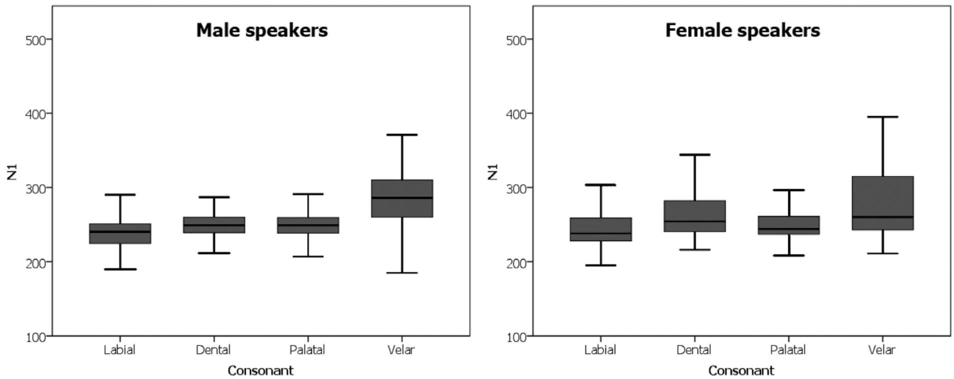


Figure 4. **Boxplots representing the distribution of N1 frequencies, data by gender** (interquartile ranges are indicated by the boxes; medians are indicated by the horizontal lines; the bottom whiskers show the range between the first quartile and the smallest non-outlier value; the upper whiskers show the range between the third quartile and the largest non-outlier value)

4.3. The bandwidth of the first nasal formant

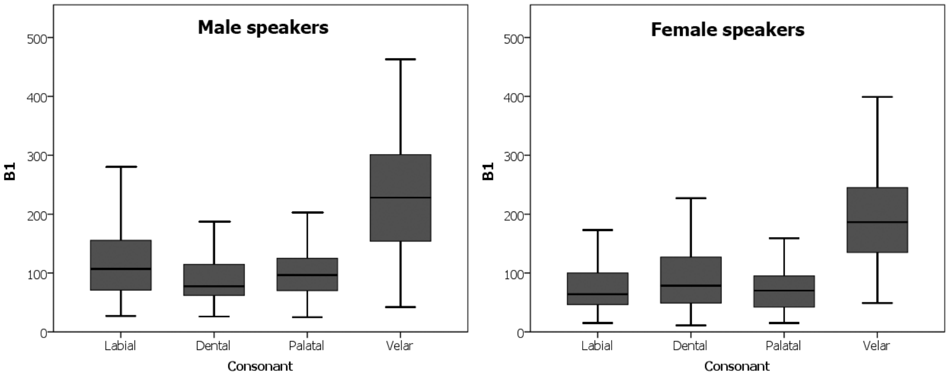
Table 3 shows the bandwidths of the first nasal formant estimated for the prevocalic nasals. It can be observed that the results for B1 exhibit high-scale variability both across speakers and within the data of the same speaker (see the high standard deviation scores in Table 3 in comparison with those for N1 values presented in Table 2). However, there is still a consistent pattern suggesting higher B1 values for [ŋ] (ranging between 142 and 318 Hz) as compared with those for [m], [n], [ɲ] (ranging between 45 and 169 Hz, 38 and 206 Hz, 32 and 201 Hz, respectively).

Table 3. **Means and standard deviations estimated for B1 values** (overall and individual data)

	[m]		[n]		[ɲ]		[ŋ]	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Males	119	63	101	64	107	56	237	102
M1	120	67	95	30	110	24	318	77
M2	136	53	81	24	98	30	254	126
M3	169	59	206	63	184	66	256	80
M4	92	35	68	14	87	24	187	53
M5	78	52	56	19	54	19	172	91
Females	84	61	89	50	88	74	195	86
F1	87	50	128	23	85	21	142	48
F2	55	14	63	14	55	14	154	54
F3	78	41	85	34	65	26	238	77
F4	45	38	38	13	32	10	153	59
F5	157	75	131	62	201	93	290	77

In Figure 5, the distribution of B1 values within the two gender groups is shown. It can be seen that generally both groups follow similar pattern with relatively high overall range for all the nasals and especially broad range in case of [ŋ]. Data distribution for both gender groups is characterized by rather even boxplot shapes with more variable results above the median than those below.

The results of ANOVA demonstrate statistically significant difference in B1 values ($df = 3$, $F = 159.152$, $p = 0.000$), while post hoc test using Bonferroni correction reveals relevant contrast only between [ŋ] and [m; n; ɲ] ($p = 0.000$) with $p = 1.000$ for other pairs. These results accord with those reported for other languages (Recasens 1983) suggesting higher B1 frequency for the velar nasal in comparison with other places of articulation.



F i g u r e 5. **Boxplots representing the distribution of B1 frequencies, data by gender** (interquartile ranges are indicated by the boxes; medians are indicated by the horizontal lines; the bottom whiskers show the range between the first quartile and the smallest non-outlier value; the upper whiskers show the range between the third quartile and the largest non-outlier value)

5. Conclusion

According to the results, the nasals of Standard Latvian can be distinguished by anti-formant frequencies rather efficiently, and the results generally agree with those obtained in previous research of Latvian as well as the data reported for other languages. The frequencies and the bandwidths of the first nasal formant are less informative regarding nasal place of articulation and can be used only for distinguishing between [ŋ] and [m; n; ɲ]. The inefficiency of N1 contradicts to some previous data reported for other languages (see Section 2).

Conducting perception tests to assess the auditory relevance of these acoustic features is necessary. It is thought that Z1 frequency — the only parameter in the present study proven to be effective in discriminating between all four nasals in question — is quite unlikely to be efficient for perception, especially in noisy environments when background noise tends to fill the spectral valleys caused by anti-formants.

LATVIEŠU STANDARTVALODAS NĀSEŅU SPEKTRĀLĀS ĪPAŠĪBAS

Kopsavilkums

Rakstā tiek aplūkotas latviešu standartvalodas nāseņu akustiskās īpašības. Pētījuma mērķis ir noteikt, vai, izmantojot nāseņa spektrālās īpašības (proti, antiformantu un pirmā nazālā formanta frekvenci, kā arī pirmā nazālā formanta joslas platumu), ir iespējams savstarpēji nošķirt artikulācijas vietas ziņā atšķirīgus nāseņus.

Analīzei tika izmantoti 10 informantu (5 vīriešu un 5 sieviešu vecumā no 19 līdz 39 gadiem) runas ieraksti. Visi informant ir latviešu standartvalodas runātāji bez manāmām dialektālām vai individuālām izrunas īpatnībām. Tika analizēti prevokāli nāseņi [m; n; ɲ] izolēti izrunātās *CVC* struktūras zilbēs, kur *C* ir viens no līdzskaņiem un *V* ir viens no patskaņiem [i(:); e(:); æ(:); ɑ(:); ɔ(:); u(:)]. Velārais [ŋ] — fonēmas /n/ alofons — tika analizēts postvokālā pozīcijā [k]V[ŋks] struktūras vienībās. Kopumā tika aplūkotas 1260 vienības.

Rezultāti rāda, ka latviešu standartvalodas nāseņi ir nošķirami pēc antiformanta frekvences, un gūtie dati kopumā saskan ar iepriekšējiem latviešu valodas un citu valodu pētījumiem. Pirmā nazālā formanta frekvence un joslas platums ir mazāk informatīvi rādītāji un var tikt izmantoti, lai nošķirtu [ŋ] no [m; n; ɲ]. Lai novērtētu aplūkoto akustisko parametru auditīvo nozīmi, ir nepieciešami arī uztveres eksperimenti.

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