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FORMANT FREQUENCIES OF VOWELS IN TONAL AND NON-TONAL STANDARD SLOVENIAN

The article presents formant frequencies of Standard Slovenian (SS) vowels as spoken by five tonal and five non-tonal speakers in citation form. The results and subsequent analysis of variance indicate two types of differences between both groups. In the tonal SS, [+ATR] mid vowels have higher F1, and short [a] has considerably lower F1. Secondly, acute, circumflex, and short vowels of all phonemes are more dispersed in the tonal SS, the differences being statistically significant in most cases. This is a by-product of fundamental frequency and intensity distinctions in the two tones, and of duration/centralization effects in quantity contrast. These phenomena do not occur in the non-tonal SS.

V članku so predstavljene formantne frekvence samoglasnikov standardne slovenščine, kot jih govori pet tonemskih in pet netonemskih govorcev v izoliranih besedah. Rezultati in statistična analiza kažejo na dve vrsti razlik med obema skupinama: (1) pri tonemskih govoricah imata srednja visoka samoglasnika višji F1, kratki [a] pa precej nižjega (je centraliziran). (2) Pri tonemskih govoricah se akutirani, cirkumfektirani in kratki samoglasniki posameznega fonema v večini primerov statistično razlikni. V akustičnem smislu je to predvsem posledica razlik v osnovni frekvenci in jakosti, deloma pa tudi trajanja oz. fonetične redukcije. Tega v netonemski standardni slovenščini ni.

Key words: acoustic phonetics, formant frequencies, suprasegmentals, tone, Slovenian

Ključne besede: akustična fonetika, formanti, formantne frekvence, nadsegmentne lastnosti, ton, tonem, slovenščina

1 Introduction¹

Phonetic studies of lexical tones in pitch-accented languages usually include acoustic analyses of fundamental frequency, intensity (or amplitude), duration, and phonation types. Spectral characteristics, most prominently formant frequencies, are considered non-significant or only marginally affected, and thus left aside, when tone is in question. On the other hand, formant frequencies, formant bandwidths, and spectral balance are the primary indicators of vowel quality (e.g., correspondence between openness and F1), and also prone to phonological and phonetic influence of stress (cf. Sluijter and Van Heuven 1996). The dependence of formant frequencies on vowel duration, phonetic reduction, or undershoot effect, speaking rate and style (e.g., Lind-

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blom 1963, Gay 1978, Tuller idr. 1982, Miller 1989, Engstrand 1988, Bakran 1989, Fourakis 1991, Van Son and Pols 1992, Moon and Lindblom 1994, Fourakis idr. 1999, Pitermann 2000, Erickson 2002, and Jurgec 2005c, for Slovenian), speaker's gender and fundamental frequency (Murry and Singh 1980, Assmann and Nearey 1987, Childers and Wu 1991, Wu and Childers 1991, Simpson 2001, and Jurgec 2005b) have been researched extensively. Moreover, studies of formant frequencies in pitch-accented languages usually represent each prosodic combination individually, cf., vowel charts of Croatian in Bakran 1989, or Lehiste and Ivič 1963: 84.

In the present study however, the interaction between tonal features (i.e., phonological features primarily encoded as fundamental frequency oscillations) and formant frequencies is addressed. The hypothesis is that in tonal languages, formant frequencies can be affected by tonal differences to a certain degree. This can be viewed primarily as a by-product of fundamental frequency and intensity. In respect to tonal features, Slovenian has two types of dialects, pitch-accented² and stress-accented, and is therefore very appropriate for this task. Furthermore, in contemporary Standard Slovenian (SS) both tonal and non-tonal varieties are permitted.

In Slovenian,³ the majority of central dialects, i.e., those of the Upper and Lower Carniola regions, are tonal. Additionally, Carinthian dialects in Austria and Italy are tonal, as well as the Littoral dialects of Ter, Nadiža, and Upper Soča Valley. In Rovtarsko dialects, only Horjul and parts of Tolmin dialects are tonal. Tonal speech is found in Bela Krajina as well. Other dialects (most of the Littoral dialects, all of Styrian and Pannonian dialects, and Carinthian dialects in Slovenia) are non-tonal (cf. Rigler 1968). Srebot Rejec (1988) disputed the tonal contrast in educated speech of Ljubljana, believed to be the most important in contemporary standardization processes. She concludes: »The lexical (phonological) function of the two accents is on the wane, while the phonetic characteristics, the sing-song effect, is retained.« (Srebot Rejec 2000: 66.) Relatively recent tone loss has also been documented in Eastern Haloze (Lundberg 2003). – Slovenian has two lexical tones, acute and circumflex. For acoustic analyses of tones in Slovenian, see Vodušek 1961, Toporišič 1967, 1968, Neweklowsky 1973, and Srebot Rejec 1988, 2000. Phonetically, the acute is realized as a rising tone (or low on the stressed and high on the post-stressed/final syllable), the circumflex as the opposite. Phonologically, both tones can occur only in traditionally (i.e., diachronically) long vowels, while short vowels are considered circumflex (unmarked) in SS. In contrast to phonological limitations of better known pitch-accent languages, like Swedish and Serbo-Croatian, the contrast is preserved also in words with final stress (e.g., *pot* /*po:t* – acute 'path', circumflex 'sweat'). A total of less than 100 morphologically non-related minimal pairs in tone exist (e.g., *kila*, *kura*, *mula*, *šibica*, *šalica*), while morphologically related pairs are abundant.

In comparing the tonal and the non-tonal varieties of SS, other issues, such as inherent phonetic distinctions in vowel height, not limited to a certain prosodic feature,

² In the present article, the term tonal (language) is used in reference to lexical tones, i.e., in this meaning of the pitch accent (as opposed to non-tonal). The term tonal is preferred to the term pitch-accented.

³ This paragraph and the corresponding references do not appear in the Slovenian version of the article.



may arise. These are to be acknowledged as well, although these are not the main aim of the study. The sole nature of the linguistic material used (see section 2 for further details) renders it impossible to exclude such variables.

2 Method

The present study of SS vowels is based on the extensive corpus of 241 one-, two-, and three-syllable words, compiled according to the suprasegmental criteria (stress, tone, duration).⁴ The list was exported to PowerPoint program and randomized manually, so that each word appeared twice non-consecutively. Speakers were instructed to read the words in citation form as they appear on the computer screen. 10 native speakers of Slovene were chosen, representative by sex (5 female and 5 male), tone contrast (5 non-tonal in origin, and 4 tonal), and age (35 years on average). The geographical criteria (i.e., the origin of the speakers) were in favour of central Slovenia. Recordings took place in the studio of the Department of Phonetics in Zagreb (Croatia) in April 2004 and in the studios of Radio Slovenia in June 2004 (1 speaker only). Sampling frequency was 44.1 kHz, at a 16-bit rate. F1–F4 of the total of 5,960 vowels were measured using *Praat* LPC-analysis software (ver. 4.2–4.2.14) under default settings. Typically, the individual formant steady state was measured, if possible. Alternatively, the central point or averaged value of the transient formant was measured. Altogether, 21,220 readings (of stressed and unstressed vowel formants) were acknowledged, and 4.59 % of the readings were discarded. Data were averaged and analyzed statistically (ANOVA) separately for both groups of speakers. – For a more detailed description of the speakers, method, procedures and more general results see Jurgec 2005b.

3 Results

The measurements of formant frequencies were grouped into prosodic combinations (or accent types), i.e., acute, circumflex and short vowels,⁵ separately for both tonal and non-tonal SS. For each, mean value, standard deviation (SD), sample size, and confidence interval were calculated. One needs to note that sample size varies considerably, which is a consequence of (1) phonological distribution or constraints, (2) lexical realization, and (3) discharged cases due to nature of pronunciation. These data are presented in Table 1–2 below. Here, F1–F4 values are presented, while in the rest of the article only F1 and F2 are discussed.

Generally, several types of differences between the tonal and the non-tonal speakers can be observed. Mean values of individual phonemes differ substantially in high-mid vowels /e/ and /o/, which have lower F1 in the tonal SS, while /ε/ has somewhat higher F1. Short [a] is considerably centralized (i.e., has lower F1) for the tonal speakers, and this phenomenon is much higher than in other vowels. In /u/, the mean values of F1 are only slightly lower for the tonal speakers.

⁴ The complete list of words can be obtained from the author.

⁵ For discussion on this matter and its implications to the traditional grammar (e.g. Toporišič 2000 and the predecessors), see Jurgec 2005b: 128–131.

	/i/	/e/	/ɛ/	/a/	/ɔ/	/ɔ/	/o/	/u/
F1								
Acute	274	357	564	731	492	587	393	304
	31.92 120 5.71	32.97 80 7.23	60.91 68 14.48	77.64 110 14.51	41.22 50 11.43	67.01 58 17.24	41.84 90 8.65	54.78 90 11.32
Circumflex	274	373	573	725	500	608	411	304
	26.57 120 4.75	41.48 120 7.42	69.34 108 13.08	75.35 120 13.48	39.19 118 7.07	56.52 80 12.38	41.49 120 7.42	42.66 119 7.67
Short	283	/	591	661	/	623	/	327
	37.85 50 10.49		66.97 60 16.95	97.13 50 26.92		45.10 60 11.41		47.80 20 20.95
F2								
Acute	2317	2310	1969	1262	1383	1004	769	827
	248.19 114 45.56	244.61 75 55.36	311.36 68 74.00	110.42 110 20.63	118.48 50 32.84	83.10 58 21.39	92.00 90 19.01	141.08 90 29.15
Circumflex	2293	2318	1850	1233	1350	1020	803	890
	274.94 117 49.82	235.07 116 42.78	291.94 108 55.06	103.17 120 18.46	143.67 118 25.92	76.49 80 16.76	83.75 120 14.98	156.97 118 28.32
Short	2299	/	1819	1268	/	1042	/	857
	271.78 48 76.89		257.95 59 65.82	117.94 50 32.69		60.67 60 15.35		93.56 20 41.00
F3								
Acute	2947	2839	2680	2650	2431	2689	2678	2533
	355.81 120 63.66	274.39 78 60.89	305.04 68 72.50	197.99 107 37.52	206.01 50 57.10	217.01 58 55.85	303.61 89 63.08	238.34 89 49.52
Circumflex	2916	2848	2640	2668	2554	2723	2706	2519
	340.42 117 61.68	261.70 116 47.62	329.12 108 62.07	194.19 120 34.75	195.58 118 35.29	241.68 79 53.29	243.38 118 43.91	253.81 119 45.60
Short	2858	/	2607	2581	/	2627	/	2506
	335.77 47 95.99		225.99 60 57.18	283.17 49 79.29		190.75 59 48.67		211.68 20 92.77
F4								
Acute	3836	3828	3884	3825	3719	3733	3591	3661

Table 1. Average values of formant frequencies (in Hz) of tonal speakers, according to phoneme, formant, and prosodic combination. Below the mean values, standard deviation, sample size, and confidence interval (\pm of mean value, $\alpha = .05$) are listed.

SD is similar in both varieties of SS, on average. Coefficient of SD is 11.22 % for the non-tonal and 10.55 % for the tonal variety, although the individual SDs for several phonemes and prosodic combinations vary. This is further discussed in section 4.

On the other hand, comparison of prosodic combinations within their phonemic domain reveals fundamental differences between the two varieties of SS. Acute, circumflex and for most phonemes also short vowels are clearly much more dispersed in the tonal SS. This is clearly visible from Fig. 1, where the more dispersed accent types of the tonal SS are depicted with empty symbols (as opposed to the full symbols of the non-tonal variety). To evaluate the statistical significance of the differences among prosodic combinations a single-factor ANOVA was performed for each of the combinations. In F1, there are no statistically significant ($p < .05$) differences between the accent types, for all phonemes in the non-tonal variety of SS. In the tonal SS however, accent types are statistically distinct for /e/ and /o/. For /a/ the difference between long and short is highly significant (but no difference between acute and circumflex). The distinctions in /ɛ/ and /ɛ/ are marginal, as there is statistical significance only between

	/i/	/e/	/ɛ/	/a/	/ə/	/ɔ/	/o/	/u/
F1								
Acute	274	357	564	731	492	587	393	304
	31.92 120 5.71	32.97 80 7.23	60.91 68 14.48	77.64 110 14.51	41.22 50 11.43	67.01 58 17.24	41.84 90 8.65	54.78 90 11.32
Circumflex	274	373	573	725	500	608	411	304
	26.57 120 4.75	41.48 120 7.42	69.34 108 13.08	75.35 120 13.48	39.19 118 7.07	56.52 80 12.38	41.49 120 7.42	42.66 119 7.67
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	37.85 50 10.49		66.97 60 16.95	97.13 50 26.92		45.10 60 11.41		47.80 20 20.95
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	335.77 47 95.99		225.99 60 57.18	263.17 49 79.29		190.75 59 48.67		211.68 20 92.77
F4								
Acute	3836	3828	3884	3825	3719	3733	3591	3661
	380.30 111 70.75	363.90 78 80.76	450.37 66 108.65	371.66 108 70.09	348.04 50 96.47	309.98 58 79.78	379.54 88 79.30	407.23 88 85.08
Circumflex	3846	3846	3878	3853	3703	3772	3617	3629
	424.67 114 77.96	412.27 115 75.35	437.27 106 83.24	351.46 119 63.15	329.46 118 59.44	278.42 79 61.40	363.69 119 65.34	429.93 117 77.90
Short	3796	/	3799	3763	/	3692	/	3573
	397.22 49 111.22		411.82 60 104.20	353.38 47 101.03		298.32 60 75.48		468.80 20 205.37

Table 2. Average values of formant frequencies (in Hz) of non-tonal speakers, according to phoneme, formant and prosodic combination. Below the mean values, standard deviation, sample size and confidence interval (\pm of mean value, $\alpha = .05$) are listed.

most distinct prosodic combinations, i.e., acute and short (but not between acute and circumflex, and circumflex and short).

In F2, statistical significance is attested for both accent types of /o/ in the tonal SS. Acute and circumflex difference is significant also in [ɛ], [a], [u], circumflex vs. short in [a], and acute vs. short in [ɛ] and [ɛ]. In [a], significance is only marginal. In sum, the accent types of [a] and of both tense mid vowels [e], [o] differ significantly, while in [ɛ] and [ɛ] this effect is only marginally significant. There is no statistical significance only among the accent types of the high vowel [i] and central vowel [ə]. Detailed results of the analysis for both F1 and F2 are presented in Table 3.

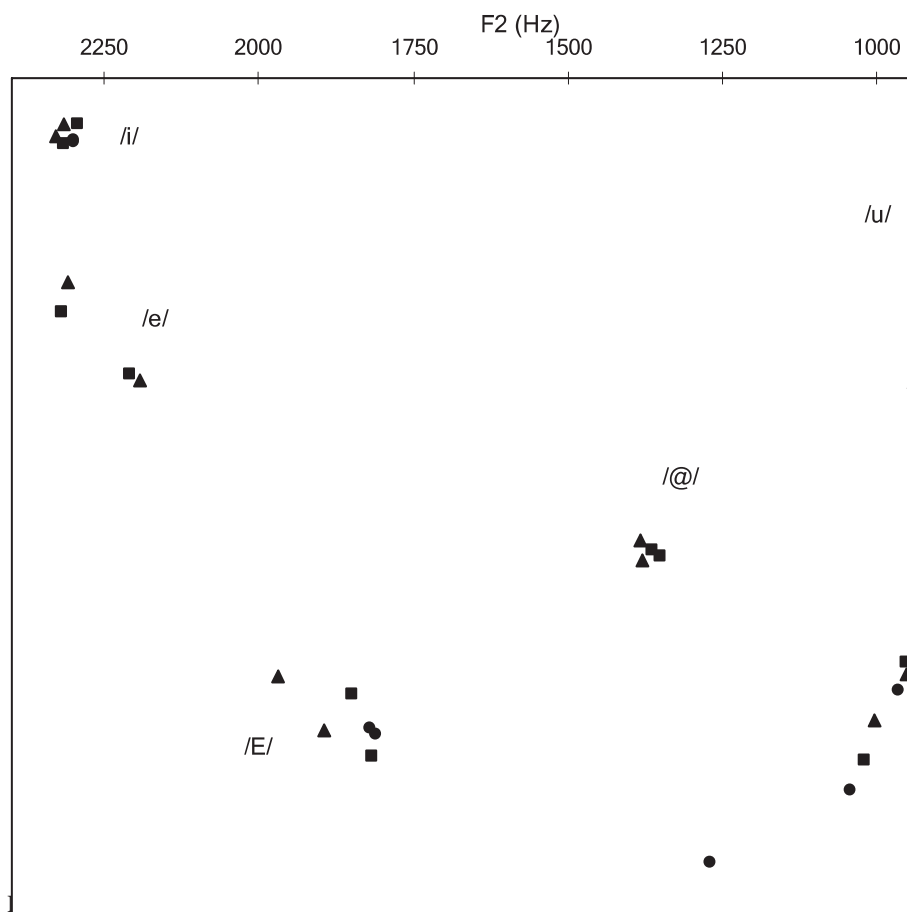


Table 3. *F1x F2 vowel space of tonal and non-tonal varieties of SS.*

This is not the case in non-tonal SS, where no variability is attested in F1. In F2 however, a marginal statistical significance is found in [ɛ], [a] and [u] (see Table 4 for further results). This fact is explained in Section 4.

4 Discussion and conclusion

Previous section revealed several differences between the groups of tonal and non-tonal speakers, either related to purely acoustic phonetic factors of tone itself or not. As regards the latter, one could say that in the tonal variety, low-mid and high-mid vowels are less central. [e] and [o] are therefore more tense perceptually, or higher articulatorily in the tonal SS than in the non-tonal, while [ɛ] is lower. The only exception is [ɛ], which exhibits no such tendency. Generally, in Slovenian spoken in central

Phoneme	F1				F2			
	Accent types	df	F	p ($\alpha=.05$)	Accent types	df	F	p ($\alpha=.05$)
/i/	Acute vs. circumflex	1, 238	.005	.942	Acute vs. circumflex	1, 229	.497	.481
	Acute vs. short	1, 168	2.30	.131	Acute vs. short	1, 160	.156	.694
	Circumflex vs. short	1, 168	2.68	.103	Circumflex vs. short	1, 163	.022	.882
/e/	Acute vs. circumflex	1, 198	8.43	<u>.004</u>	Acute vs. circumflex	1, 189	.055	.814
/ɛ/	Acute vs. circumflex	1, 174	.852	.357	Acute vs. circumflex	1, 174	6.67	<u>.011</u>
	Acute vs. short	1, 126	5.64	<u>.019</u>	Acute vs. short	1, 125	8.65	<u>.004</u>
	Circumflex vs. short	1, 166	2.48	.177	Circumflex vs. short	1, 165	.461	.498
/a/	Acute vs. circumflex	1, 228	.400	.528	Acute vs. circumflex	1, 228	4.21	<u>.041</u>
	Acute vs. short	1, 158	23.71	<u><.00001</u>	Acute vs. short	1, 158	.118	.731
	Circumflex vs. short	1, 168	21.01	<u><.00001</u>	Circumflex vs. short	1, 168	3.84	<u>.052</u>
/ə/	Acute vs. circumflex	1, 166	1.41	.237	Acute vs. circumflex	1, 166	2.04	.155
/ɔ/	Acute vs. circumflex	1, 136	4.04	<u>.047</u>	Acute vs. circumflex	1, 136	1.40	.239
	Acute vs. short	1, 116	12.16	<u>.0007</u>	Acute vs. short	1, 116	8.41	<u>.004</u>
	Circumflex vs. short	1, 138	3.01	.085	Circumflex vs. short	1, 138	3.54	.062
/o/	Acute vs. circumflex	1, 208	9.29	<u>.003</u>	Acute vs. circumflex	1, 208	7.86	<u>.006</u>
/u/	Acute vs. circumflex	1, 207	.000	.992	Acute vs. circumflex	1, 206	9.07	<u>.003</u>
	Acute vs. short	1, 108	2.87	.093	Acute vs. short	1, 108	.791	.376
	Circumflex vs. short	1, 137	4.55	<u>.035</u>	Circumflex vs. short	1, 136	.876	.351

Table 4. Single-factor ANOVA results for separate phonemes and prosodic combinations of the tonal SS. The default Alpha factor is used (.05). Statistically significant values are underlined; marginally significant p-values (0.035–0.055) are marked with a dashed line.

dialects, including Ljubljana, the feature [+ATR] has greater effect on vowel quality, decreasing F1 of high-mid vowels. This is complemented by the increased F1 of low-mid, but the effect is rather limited. The above-mentioned phonetic property is consistent with experimental data from non-central Slovenian in Ozbič 1998ab for SS as spoken in Trst (Trieste) and in Jurgec 2005a, for speech of Ovčja vas (Valbruna).

One should also take into account the gender of both groups of speakers: 3 females and 2 males are tonal (the situation is reversed for the non-tonal speakers). Average F0 of females is higher than that of males, and there is a positive correlation between average F0 and formant frequencies. Therefore, the increased F2 of tonal speakers in /ɛ/, /e/, and /i/ can be attributed to this, but no such effect should be present in F1.

Moreover, certain phonological variables influence formant frequencies of the tonal variety. Quantity contrast in SS stressed vowels is at least questionable (Srebot Rejec 1988, Petek et al. 1996), if not already completely neutralized, at least for speakers of Ljubljana, as well as for most speakers in southwest and northeast Slovenia. On the other hand, these oppositions are still present on dialectal level and

Phoneme	F1				F2			
	Accent types	df	F	p (α=.05)	Accent types	df	F	p (α=.05)
/i/	Acute vs. circumflex	1, 238	1.81	.179	Acute vs. circumflex	1, 237	.279	.598
	Acute vs. short	1, 168	.371	.543	Acute vs. short	1, 168	.695	.406
	Circumflex vs. short	1, 168	.211	.647	Circumflex vs. short	1, 167	.220	.640
/e/	Acute vs. circumflex	1, 195	.141	.708	Acute vs. circumflex	1, 194	.189	.665
/ɛ/	Acute vs. circumflex	1, 174	.483	.488	Acute vs. circumflex	1, 173	6.59	<u>.011</u>
	Acute vs. short	1, 116	.012	.914	Acute vs. short	1, 116	6.11	<u>.015</u>
	Circumflex vs. short	1, 154	.275	.600	Circumflex vs. short	1, 153	.043	.836
/a/	Acute vs. circumflex	1, 228	.009	.924	Acute vs. circumflex	1, 228	7.45	<u>.007</u>
	Acute vs. short	1, 158	.321	.572	Acute vs. short	1, 158	.018	.893
	Circumflex vs. short	1, 168	.308	.580	Circumflex vs. short	1, 168	4.77	<u>.030</u>
/ɔ/	Acute vs. circumflex	1, 159	.309	.579	Acute vs. circumflex	1, 159	.372	.543
/ɔ/	Acute vs. circumflex	1, 113	.340	.561	Acute vs. circumflex	1, 113	.0006	.980
	Acute vs. short	1, 91	.559	.456	Acute vs. short	1, 91	.671	.415
	Circumflex vs. short	1, 108	1.72	.192	Circumflex vs. short	1, 108	.670	.415
/o/	Acute vs. circumflex	1, 206	.216	.643	Acute vs. circumflex	1, 206	1.07	.303
/u/	Acute vs. circumflex	1, 208	1.06	.304	Acute vs. circumflex	1, 207	7.60	<u>.006</u>
	Acute vs. short	1, 108	3.46	.066	Acute vs. short	1, 107	.0005	.994
	Circumflex vs. short	1, 138	1.78	.184	Circumflex vs. short	1, 136	2.20	.140

Table 5. Single-factor ANOVA results for separate phonemes and prosodic combinations of the non-tonal SS. The default Alpha factor is used (.05). Statistically significant values are underlined; marginally significant p-values (0.035–0.055) are marked with a dashed line.

in the sub-standard speech as qualitative changes, i.e., phonological reduction processes. Thus when speaking SS, speakers tend to avoid these processes, and since they are unable to produce any quantity contrasts, diachronically short vowels merge with unreduced long vowels (Rigler 1968). Present data confirm only marginally significant contrast between short and long vowels, limited to the tonal SS, namely to the phonemes /ɛ/ and /ɛ/, in F1 and F2 (see Table 3–4). The only exception is /a/, where phonologically short [a] is considerably centralized. The average F1 of short [a] is 67 Hz lower than the average F1 in long [a]. This is highly significant ($p < 0.0001$), although the coefficient of SD is moderately increased (14.7 % in F1). This unique phenomenon, not attested in other phonemes, can be corroborated by the data in Petek et al. 1996, where /a/ was the only phoneme that exhibited (some) durational differences. This inconsistency has not been explored yet and has had no influence on normative practice so far.

As regards the influence of phonological tone on formant frequencies, the results prove a positive correspondence. To confirm the research hypothesis, one should first

prove that there are differences in formant frequencies of the tonal SS and that they are statistically significant. Furthermore, that no such differences exist in the non-tonal SS, and that this situation cannot be explained otherwise, for example as a consequence of other phonetic features.

Suprasegmental (phonological) variables are statistically significant in majority of phonemes in the tonal SS (Fig. 1). Upon further inspection (ANOVA, cf. Table 3–4), only /i/ and /ə/ exhibit no significant differences between the accent types. /ə/ is a phonetically neutral vowel and attested differences should not be contraindicative to the research hypothesis. On the other hand, the same situation in /i/ cannot be explained in terms of general phonetics. However, other data from Slovenian and its formant frequencies (Jurgec 2005bc), posit an interesting property of Slovenian /i/, being the least subjected to influences of stress and word-position. In contrast, another high vowel, /u/, is subjected to much greater degree of variance, while the influence of tone is only marginal.

In the non-tonal SS, individual accent types of each phoneme are clearly less dispersed. This is evident from Fig. 1 (e.g., phonemes /e/, /o/, /ɛ/, and /a/), and corroborated by statistical analyses in Tables 3–4. In F1, no prosodic differences are statistically significant. In F2 however, there are a few exceptions: acute [ɛ] is distinctive of circumflex and short, as it is circumflex [a]. There is also statistical significance in acute or circumflex [u].

Dispersion in [ɛ] could be attributed to the problematic distribution of both front mid vowels, which are morphologically connected, and the distribution in SS differs greatly from the contemporary dialectal and sub-standard realization. When unstressed, both phonemes are neutralized and merged into a single archiphoneme (Lehiste 1961, Srebot Rejec 1988, 1998), which is realized as [e] in the pre-stressed and as [ɛ] in the post-stressed position (see Jurgec 2006 for further data and discussion). This is corroborated by the increased coefficient of SD, which is exhibited in both front mid vowels of the non-tonal SS; in F1 of [ɛ] the coeff. is 20.1 %, almost twice the average, in [e] it is 15.3 % (F2 of both vowels is too close to influence SD). Although erroneous cases of pronunciation were discharged (see the drop in sample size of both phonemes in Table 2), a partial overlap in formant frequencies is a possible and also probable explanation. The increase is also noticeable in back mid vowels (yet lower than in front vowels) and in [ɛ] of the tonal SS (but not in front vowels and [e]) and exhibits a general phonological tendency of contemporary Slovenian. To sum up, the data of the non-tonal [ɛ] should be regarded highly inconclusive.

The increased coefficient of SD is observed in [u] as well, both tonal and non-tonal (on average, well above 15 % in F2). The fact that circumflex [u] is statistically distinct from the acute and short is also surprising. In most vowels, circumflex is more similar to short than the acute, which is in accordance with the traditional theory that considers phonologically short vowels circumflex in tone. As the significance is similar in both varieties of SS, one can say that the analysis is dubious: [u] must also be influenced by other variables. For example, the difference between word-final and initial vs. medial position of the two high vowels, documented in certain sources (e.g., Toporišič 2000: 50). The present analysis, based on linguistic material of the existing

and generally known words in Slovene, cannot answer this problem satisfactorily. This will be done in the future work.

The phoneme /a/ has a moderately increased coefficient of SD as well, under acute tone more than under circumflex and as short. One reason for this could be a considerable backness of the low vowel in Styrian and Pannonian dialects, where three of our speakers originate.⁶ If this is true, only the acute is being influenced and is statistically significantly differs from circumflex and short [a]. This cannot be caused by the phonetic factors per se, but by dialectal phonetic influences and should therefore be disregarded.

All things considered, vowel formant frequencies of the tonal SS are affected by phonological tone. The differences may not be large (as opposed to influence of consonantal environment, stress, and certain extralinguistic factors), but they are still significant, and, as a rule, not present in the non-tonal speech. Whether this is directly related to the distinctions in fundamental frequency or intensity attested in Slovene acute vs. circumflex tone, remains unknown. However, F0 and formant frequencies show a positive correlation (via stress, gender or speaking style), and the correspondence grows exponentially, higher formants exhibiting much larger increase than the lower ones if F0 rises. Intensity (via duration, stress or speaking style) also corresponds to formant frequencies, i.e., vowels with greater intensity have higher formant frequencies (either via duration, stress, or speaking style), all other things being equal. – The design of the present experiment itself renders it impossible to account for all acoustic and articulatory factors and to determine their extent. It proves, however, that such differences occur.

REFERENCES

- Peter F. ASSMANN and Terrance M. NEAREY, 1987: Perception of front vowels: The role of harmonics in the first formant region. *The journal of the Acoustical society of America* LXXXI/2. 520–534.
- Juraj BAKRAN, 1989: Djelovanje naglasaka i dužine na frekvencije formanata vokala. *Govor* VI/2. 1–12.
- D. G. CHILDERS and Ke WU, 1991: Gender recognition from speech. Part II: Fine analysis. *The journal of the Acoustical society of America* XC/4. 1841–1856.
- Olle ENGESTRAND, 1988: Articulatory correlates of stress and speaking rate in Swedish VCV utterances. *The journal of the Acoustical society of America* LXXXIII/5. 1863–1875.
- Donna ERICKSON, 2002: Articulation of extreme formant patterns for emphasized vowels. *Phonetica* IL/2–3. 134–149.
- Marios FOURAKIS, 1991: Tempo, stress, and vowel reduction in American English. *The journal of the Acoustical society of America* XC/4,1. 1816–1827.
- Marios FOURAKIS, Antonis BOTINIS in Maria KATSAITI, 1999: Acoustic characteristics of Greek vowels. *Phonetica* LVI/1–2. 28–43.
- Thomas GAY, 1978: Effect of speaking rate on vowel formant movements. *The journal of the Acoustical society of America* LXIII/1. 223–230.

⁶ There were no cases of non-standard rounded back vowel [ɒ], which differs from SS low vowel considerably, and would subsequently be excluded from further analysis.



- Peter JURGEC, 2005a: Fonetični opis govora Ovčje vasi. *Ovčja vas in njena slovenska govorica / Valbruna e la sua parlata slovena*. Kanalska dolina: Slovensko kulturno središče Planika, ZRC SAZU. 60–84.
- 2005b: Formant frequencies of standard Slovenian vowels. *Govor* XXII/2. 127–144.
- 2005c: Položaj v besedi in formantne frekvence samoglasnikov (standardne slovenščine), I. Naglašeni samoglasniki. *Jezikoslovni zapiski* XI: 1. 121–132.
- 2006: O nenaglašeni /e/ in /o/ v standardni slovenščini. *Slavistična revija* LIV/2. 173–185.
- Ilse LEHISTE, 1961: The phonemes of Slovene. *International journal of Slavic linguistics and poetics* IV. 48–66.
- Ilse LEHISTE and Pavle Ivič, 1963: *Accent in Serbo-Croatian: An experimental study*. Ann Arbor: University of Michigan (Michigan Slavic Materials 4).
- Björn LINDBLOM, 1963: Spectrographic study of vowel reduction. *The journal of the Acoustical society of America* XXXV/11. 1773–1781.
- Grant H. LUNDBERG, 2003: Typology of tone loss in Haloze, Slovenia: An acoustic and autosegmental analysis. *Slovenski jezik / Slovene linguistic studies* III. 169–189.
- James D. MILLER, 1989: Auditory-perceptual interpretation of the vowel. *The journal of the Acoustical society of America* LXXXV/5. 2114–2134.
- Seung-Jae MOON and Björn LINDBLOM, 1994: Interaction between duration, context, and speaking style in English stressed vowels. *The journal of the Acoustical society of America* XCVI/1. 40–55.
- Thomas MURRY and Sadanand SINGH, 1980: Multidimensional analysis of male and female voices. *The journal of the Acoustical society of America* LXVIII/5. 1294–1300.
- Gerhard NEWEKLOWSKY, 1973: *Slowenische Akzentstudien [...]*. Vienna: Verlag der Österreichischen Akademie der Wissenschaften.
- Martina OZBIČ, 1998a: Akustična spektralna FFT-analiza samoglasniškega sistema slovenskega jezika: formanti slovenskih samoglasnikov. *Jezikovne tehnologije za slovenski jezik: Zbornik konference*. 55–59. <http://nl.ijs.si/isjt98/zbornik/sdjt98-Ozbic.pdf>.
- 1998b: Razmerja med formanti samoglasnikov matične in tržaške slovenščine. *Uporabno jezikoslovje VI: Jezikovne tehnologije*. 124–135.
- Bojan PETEK, Rastislav ŠUŠTARŠIČ and Smiljana KOMAR, 1996: An acoustic analysis of contemporary vowels of the Standard Slovenian language. *Proceedings ICSLP 96: Fourth International Conference on Spoken Language Processing, October 3–6, 1996, Philadelphia, PA, USA*. 133–136. <http://www.asel.udel.edu/icslp/cdrom/vol1/820/a820.pdf>.
- Michel PITERMANN, 2000: Effect of speaking rate and contrastive stress on formant dynamics and vowel perception. *The journal of the Acoustical society of America* CVII/6. 3425–3437.
- Jakob RIGLER, 1968: Problematika naglaševanja v slovenskem knjižnem jeziku. *Jezik in slovstvo* XIII/6. 192–199.
- Adrian P. SIMPSON, 2001: Dynamic consequences of differences in male and female vocal tract dimensions. *The journal of the Acoustical society of America* CIX/5.1. 2153–2164.
- Agaath M. C. SLUIJTER and Vincent J. VAN HEUVEN, 1996: Spectral balance as a acoustic correlate of linguistic stress. *The journal of the Acoustical society of America* C/4.1. 2471–2485.
- Tatjana SREBOT REJEC, 1988: *Word accent and vowel duration in Standard Slovene: An acoustic and linguistic investigation*. Munich: Otto Sagner (Slavistische Beiträge, 226).
- 1998: O slovenskih samoglasniških sestavih zadnjih 45 let. *Slavistična revija* XLVI/4: 339–346.
- 2000: Ali je današnja knjižna slovenščina še tonematična? *Razprave II. razreda SAZU* XVII. 51–66.
- Jože TOPORIŠIČ, 1967: Pojmovanje tonemičnosti slovenskega jezika. *Slavistična revija* XV/1–2. 64–108.

- – 1968: Liki slovenskih tonemov. *Slavistična revija* XVI. 315–393.
– – 2000: *Slovenska slovnica*. Maribor: Obzorja.
- Betty TULLER, Katharine S. HARRIS and J. A. Scott KELSO, 1982: Stress and rate: Differential transformations of articulation. *The journal of the Acoustical society of America* LXXI/6. 1534–1543.
- R. J. J. H. VAN SON and Louis C. W. POLS, 1992: Formant movements of Dutch vowels in text, read at normal and fast rate. *The journal of the Acoustical society of America* XCII/1. 121–127.
- Božo VODUŠEK, 1961: Grundsätzliche Betrachtungen über den melodischen Verlauf der Wortakzente in den zentralen Slowenischen Mundarten, *Linguistica* IV. 20-38.
- Ke WU and D. G. CHILDERS, 1991: Gender recognition from speech. Part I: Coarse analysis. *The journal of the Acoustical society of America* XC/4. 1828–1840.

POVZETEK

Članek predstavlja formantne frekvence samoglasnikov tonemske in netonemske različice standardne slovenščine (SS).

Upoštevajoč fonološko distribucijo in nadsegmentne lastnosti je bil sestavljen obsežen korpus eno-, dvo- in trizložnic. 241 besed je v naključnem vrstnem redu izolirano bralo deset govorcev, enakomerno porazdeljenih po spolu, izvoru in tonemskosti. Pet jih je bilo tonemskih (3 ženske in 2 moška govorca), pet netonemskih. Snemanje je bilo digitalno, pri standardnih pogojih, tj. frekvenci vzorčenja 44,1 kHz in 16-bitni kvantizaciji. F1–F4 skupno 5.960 samoglasnikov so bili izmerjeni z LPC-analizo v programu Praat, pri standardnih nastavitvah. Izmerjene vrednosti so bile razvrščene v skupine in izračunana povprečja. Sledila je statistična analiza, vključno z analizo variance (ANOVA). Za podrobnejše podatke gl. Jurgec 2005b.

Povprečne vrednosti (skupaj s standardnim odklonom, številom meritev in intervalom zaupanja) obeh različic SS so v prikazih 1 in 2 (Table 1 in 2). V prikazu 3 (Figure 3) je akustični diagram F2/F1 za tonemske (prazni simboli) in netonemske (polni simboli) govorce. V prikazih 4 in 5 (Table 3 in 4) pa so rezultati analize variance (najprej za tonemske, potem za netonemske govorce).

Rezultate lahko razdelimo v dve skupini, ki so bodisi (nad)narečni v fonetičnem in fonološkem smislu ali strogo akustični. V prvi skupini so tako razlike v F1 [+ATR] srednjih samoglasnikov [e] in [o], ki je v tonemski slovenščini nižji, kratki [a] je pri tonemskih govorcih občutno centraliziran, česar ni pri drugih samoglasnikih tonemskih ali netonemskih govorcev.

Razlike med akutiranimi, cirkumflektiranimi in kratkimi samoglasniki posameznega fonema so pričakovano večje v tonemski SS in povečini tudi statistično značilne v F1 in/ali F2. Ni pa take razlike pri [ə] in [i]. Pri [u] so očitno pomembnejše druge segmentne spremenljivke, saj se F1 in F2 obeh skupin tu bistveno ne razlikujejo. Sicer so v netonemski SS statistično značilne razlike redke; tako lahko F2 pri [a] pojasnimo z narečnimi vplivi, pri [ε] pa je problematična distribucija.

Razpršenost skupin akutiranih, cirkumflektiranih in kratkih samoglasnikov ter njihovih formantnih frekvenc v tonemski SS lahko razložimo (tudi) kot posledico osnovne frekvence in jakosti na eni ter jakosti in fonetične redukcije oz. učinka podhranjenosti (undershoot) na drugi.