Formant frequencies of standard Slovene vowels

Peter Jurgec

Inštitut za slovenski jezik Frana Ramovša ZRC SAZU

Novi trg 2, 1000 Ljubljana

+386-1-4706-169, +386-31-339-075

peter.jurgec@guest.arnes.si

Formant frequencies in Slovene

FORMANT FREQUENCIES OF STANDARD SLOVENE VOWELS

ABSTRACT

Formant frequencies of standard Slovene have already been analysed by several phoneticians (Lehiste, 1961; Toporišič, 1975; Petek et al., 1996; Ozbič, 1998; Tivadar, 2004a). The aim of this study is to present a more in-depth view of stressed vowels and their formant frequencies, in order to address some of the problems that have not yet been considered. A 241-word corpus of one- to three-syllables was compiled according to suprasegmental criteria (stress, tone, duration). Ten subjects were chosen, representative by sex, tone contrast, dialect of origin, etc. F1–F4 of a total of 5,960 vowels were measured using Praat LPC-analysis software. A total of 21,220 readings, or 95.41% were acknowledged. Data were averaged and analysed statistically (ANOVA). The measurements confirm that lexical tone does not influence formant frequencies of most vowels to any statistical significance (see F1×F2 vowel space in Fig. 3). However, there are statistically significant differences among accent types of /ɛ/, /a/, /ɔ/, and /u/. While dispersion of /u/ is most probably induced by segmental variables, the differentiation of /ɛ/, /a/ and /ɔ/ can be explained by comparing two varieties of SS, the tonal and the non-tonal. In the latter, the contrast between the tones is statistically insignificant (forthcoming-a). Separate vowel spaces and values are given for female and male speakers (Fig. 4).

Key words: Slovene, formant frequencies, acoustic phonetics, vowel space.

1. INTRODUCTION

Formant frequencies of standard Slovene (SS) vowels have been one of the more researched fields in 20th century Slovenian acoustic phonetics. Recently, these studies were presented in

detail by Toporišič (2003) and Tivadar (2004a). Therefore, only issues of a methodological value will be discussed in this section.

Lehiste (1961) introduced the topic of SS formant frequencies. Her study of SS phonemes included a detailed analysis of formant frequencies for both stressed and unstressed vowels, paying particular attention to the phonetic realization of unstressed /e/ and /o/, or alternatively, /ɛ/ and /ɔ/.[1] Interestingly enough, she did recognize the phonological value of quantity in stressed vowels, only to be complemented by a phonetic notion of simple and compound (i.e. double-peaked) stress. Unfortunately, her formant measurements were limited to one female speaker possessing a non-central dialect in origin, which failed to make the extensive pre-digital spectrographic analysis (425 spectrograms from approx. 50 hours of recordings) fully representative. A later spectrographic analysis by Toporišič (1975) offered more precise data. A 174-item corpus (i.e. 700 words, approx.) was compiled. Seven male speakers of both tonal and non-tonal variety of SS were instructed to pronounce words in citation form (2–54 items per speaker). The author offered more representative values of formant frequencies, but the study failed to address the possible influence of tone and position of the vowel in the word. The results were not analysed statistically. Srebot Rejec (1988b) organised Toporišič's data in a vowel space chart and compared Slovene and English vowel systems. Petek and associates (1996) were the first to analyze formant frequencies of SS vowels digitally. The authors recorded three speakers (two male and a female), each reading 96 one- and two-syllables in a frame sentence (approx. 4 minutes per speaker), and only the average values of F1–F3 were presented. Ozbič (1998a) used FFT in her analysis of SS formant frequencies. Eleven female informants from central Slovenia were recorded and one instance of each vowel per prosodic combination was measured. From the description of the digital analysis procedure (p. 56), it is obvious that only the harmonic closest to F1 (i.e. A1) was actually measured, and averaged. This was not the case in Tivadar's studies (2004a; cf.

2003ab, 2004b), where FFT readings were estimated manually on the basis of the relative amplitude of harmonics closest to F1 (2004a: 39–40). Particular attention was paid to the selection of speakers, who were mainly professional radio announcers. Formant frequencies of 6 speakers of the non-tonal variety of SS were analysed, or approximately 600 items. Only the measurements of stressed vowels' F1 and F2 were averaged separately for male and female speakers.

In summary, previous studies did offer a general overview of formant frequencies that enabled vowel space to be constructed, and the values of individual vowel phonemes. Whereas, phonological variables of stress and quantity (Lehiste, 1961; Toporišič, 1975; Tivadar, 2004a) and the extra-linguistic variable of the speaker's sex (Tivadar 2004a) were considered, other linguistic variables, such as tone, position in the word/phrase/prosodic unit remained unanswered. The averaged values are not to be considered representative for the entire Slovene speaking area, or either tonal or non-tonal variety of SS. In this paper, formant frequencies are measured on the basis of a controlled experiment with 10 speakers, chosen to represent contemporary SS and originating from various dialects, both tonal and non-tonal.[2] Values are given separately for male and female speakers. A subsequent statistical analysis determined significance of stress, lexical tone and word-position. Here only basic characteristics of SS vowel system are presented; others will be published elsewhere (Jurgec, 2005; forthcoming-a, forthcoming-b).

2. METHOD

2.1 Corpus

A 241-word corpus was compiled using electronic editions of *Slovene Orthography* (SP 2003) and the *Dictionary of Standard Slovene* (SSKJ 1998). The corpus consists of one-, two- and three-syllable words, according to suprasegmental criteria (stress, quantity and tone). The

following phonological criteria were considered: number of syllables, position of the stressed vowel, stress, position of the unstressed vowel, quantity of the stressed vowel and tone of the long (also stressed) vowel.[3]

Two words per combination per vowel were chosen. Homonyms, as well as doublets were heavily disfavoured, although it was not possible to omit them entirely due to the strong morphological nature of Slovene.[4] Words more frequent in use and basic forms were preferred. Of the ideal number of 282 combinations that would be possible according to the phonological distribution of vowels in SS,[5] not all were realized lexically. For example, non-epenthetic /ə/ is frequently substituted by [ˈɛː] in a stressed position or unstressed [e], possibly due to the influence of the spelling. According to Slovene orthoepy, these cases are (still) considered non-standard, while many others are already a standard doublet (*sestaviti* /səˈstáːʊiti/ ↔ /seˈstáːʊiti/, *čebula* /ʧəˈbèːla/ ↔ /ʧeˈbèːla/) or even the sole pronunciation (20th century SS *steklo* /ˈstéːklo/ < Proto-Slavic *stьklò). Examples from the corpus: *dežek* ‘rain, dimm.’ /ˈdəʒək/ → /ˈdèːʒək/, *dežnik* ‘umbrella’ /dəˈʒníːk/ → /deˈʒníːk/, *jazbečar* ‘dachshund’ /ˈjàːzbəʧaɾ/ → /ˈjàːzbeʧaɾ/. Furthermore, acute tone is rarely realized lexically in words with final stress, the fact being conditioned diachronically (cf. Rigler, 1980). Long and stressed [ˈɛː] and [ˈɔː] in the word-final position are limited to words of foreign origin, which are predominantly circumflex in tone (cf. Jurgec, 2004), etc.

2.2. Speakers

Ten speakers were selected, five female and five male. Five of the speakers came from central Slovenia, i.e. born and living in Ljubljana, others had lived there for at least the last 4 years. Educated speakers from Ljubljana are believed to be most prominent in the contemporary standardisation process (Srebot Rejec, 1988; 2000), although 20th century Slovene orthoepy is

largely diachronically based (cf. Rigler, 1968; 1970; see Šekli, 2004: 45ff., for discussion). The speakers were aged 35 years, on average, at the time of recording.

Insert Figure 1 Here.

Five of the speakers have lexical tone contrasts, although at least three (one generally considered to be tonal and two non-tonal) are doubtful, i.e. their tonal contrast is impaired. It seems there are many independent and seemingly unrelated processes of tone loss in Slovene. Lundberg (2003) examines tone loss in Eastern Haloze dialect experimentally. Tone loss is also reported in the extreme western part of the Slovene speaking area (R. Dapit, personal communication) and in the eastern Dolenjska region (V. Smole, personal communication). Detailed analysis by Srebot Rejec also confirms progressive tone loss in Ljubljana. She concludes: "The lexical (phonological) function of the two accents [i.e. acute and circumflex] in on the wane, while the phonetic characteristics, the sing-song effect, is retained." (Srebot Rejec, 2000: 66.) It is this kind of tone contours that were frequent in our recordings, also conditioned by sentence intonation as words were isolated. Relevant characteristics of the speakers are summarized in Table 1 with their geographical origin represented in Fig. 1.

Insert Table 1 Here.

2.3. Procedure

Corpus material was randomized manually; each word was used twice non-consecutively. The list was exported to the PowerPoint program; words were put on separate slides on a white background. A short introduction and instructions were added initially. Speakers were instructed to read each word once (i.e. in citation form), but were encouraged to correct themselves, if they found their pronunciation imperfect, regardless of the reason. Basic forms were added for morphological dependent ones: *kipi* → *trije kipi* 'statue, pl.', *kepate* → *vi kepate* 'to snowball, 2nd pers. pl. praes.', *sob* → *brez sob* 'room, gen. pl.' Speakers were instructed to read only the second word in these cases.

Recordings took place in the studio of the Department of Phonetics in Zagreb during March–April 2004. One speaker (namely 08mt) was recorded in the studios of Radio Slovenija in Ljubljana. Sampling frequency was 44.1 kHz, at a 16-bit rate. Recordings were stored on digital storage devices and later transferred to a computer for acoustic analysis. The first four formant frequencies were measured using a Praat software program (ver. 4.2–4.2.14). Typically, individual formant steady state was measured, where possible. Alternatively, the central point or averaged value of transient was measured. Standard Praat settings of LPC based formant estimates were used. Doubtful cases[6] (4.59%) were dismissed as irrelevant. Altogether, 21,220 readings were acknowledged. Statistical analysis followed; average values, standard deviation (SD) and confidence intervals were calculated. Analysis of variance (ANOVA) was performed using Excel and SPSS programs.

3. RESULTS

Vowels were averaged according to suprasegmental criteria. Although traditional grammar (Toporišič, 2000) classifies vowels into three groups, i.e. long stressed, short stressed and unstressed, the author proposes an alternative classification. Instead, circumflex, acute, short

and unstressed groupings are more appropriate.[7] These are represented systematically in Fig. 2.

Insert Figure 2 Here.

Statistical analysis followed. The average values of F1–F4 and corresponding sample size, SD and confidence interval are represented in Table 2. It is worth noticing that sample size varies between individual combinations, which is a consequence of phonological, lexical, combinatory, and phonetic reasons. Confidence intervals are relatively narrow, conditioned by a large enough sample size, and are somewhat higher for short vowels, perhaps mirroring the ongoing loss of quantity contrast in the present-day SS (Srebot Rejec, 1998b). The average SD is approx. 11.2% of the mean value. Relative differences among the speakers in regard to their dialect of origin and their voice characteristics (most prominently the difference in their average fundamental frequencies) contributes to the relatively high SD (see Table 1 for an overview). However, the coefficient of SD does not differ significantly among accent types and phonemes. The exceptions with relatively high coefficient of SD are F1 of /e/, /ɛ/, /o/ and /u/ (14.4%, 16.5%, 14.1% and 14.0%) and F2 of /o/ and /u/ (14.1%, 17.4%).

Insert Table 2 Here.

These results can be represented as a two-dimensional vowel space of standard Slovene (Fig. 3). The largest difference between any accent type of the same phoneme is attested in short vs. long (acute and circumflex) [a]. The degree of centralization is not attested elsewhere in phonemic system of standard Slovene, except perhaps for /u/, but there are other (segmental) variables to consider (see section 4 below). Differences among various accent types are not statistically significant ($p >> 0,05$) in /i/, /e/, /ə/ and /o/, i.e. in all high, high-mid and mid vowels with the exception of /u/.

Insert Figure 3 Here.

Interestingly enough, there are no statistically significant differences between acute and circumflex F1 in any vowel. This also contributes to the fact of why phonemes /e/, /o/ and /ə/ show no contrast. Elsewhere, at least one accent type is distinct from the other two. In F1, only short vs. long contrasts are attested (in /a/, /ɔ/, and /u/), while inF2, the situation is considerably more complex - the following differences are statistically significant: acute vs. circumflex and short /ɛ/, acute vs. short /ɔ/, acute vs. circumflex /u/, and circumflex vs. acute and short /a/. Altogether, all accent types are contrastive in /a/, /ɔ/, and /u/. These results are further commented in section 4.

Insert Table 3 Here.

The data can be represented separately for female and male speakers. Apart from generally greater values in all formants, conditioned by a gender dependent F0 difference, minor, yet statistically significant differences in some of the vowels exist, e.g. in /u/. These can be partially explained by influences of a dialectal and sub-standard nature. Vowel space of both female and male speakers are depicted in Fig. 3. Data is presented in Appendixes 1 and 2.

Insert Figure 4 Here.

On average, female formant frequencies are higher in comparison to male by 26 Hz or 5.5% in F1, 126 Hz or 8,6% in F2, 246 Hz or 9.2% in F3, and 582 Hz or 15.8% in F4. The difference increases exponentially. Lower SD would be expected in formant frequencies of speakers of one gender only, but the current data do not support it. This is connected to average F0 variability among speakers.

4. DISCUSSION AND CONCLUSION

In general, average values of formant frequencies do not differ considerably from the those previously established in Lehiste, 1961; Toporišič, 1975; Petek et al., 1996; Ozbič, 1998a; Tivadar, 2004a. The differences present, of course, can be explained by speakers characteristics, i.e. most prominently their gender and geographical origin. It is fair to conclude, that current findings do not contradict the findings of previous studies done.

A more important question needs to be addressed. Why do some accent types differ from others of the same phoneme significantly, while others do not? These differences are limited to low-mid and low vowels /ɛ/, /a/, /ɔ/, and the high vowel /u/ on the other hand.

As regards the phoneme /u/, the dispersion attested is far greater that would be expected, if conditioned by accent type (i.e. tone and durational) differences alone. This notion is corroborated by the considerably increased coefficient of SD, in comparison to the other vowels. One should also acknowledge the relative infrequency of the phoneme /u/ and its distributional constraints, resulting in accidental gaps in vocabulary. For example, words with a final stress on the short [u] are monosyllables only, although polysyllables could be possible phonologically. Comparison of the tonal and non-tonal SS confirms this hypothesis (forthcoming-a). If both variants, tonal and non-tonal were taken into consideration and analysed statistically, the result would be an average value of both variants. If only the tonal was presented, differences between suprasegmentals would be considerably higher (i.e. predominantly statistically significant), while the non-tonal SS would exhibit a poor amount of statistical significance in the prosodemes (see forthcoming-a for further discussion and results). This finding is in accordance to Croatian data (e.g. Bakran, 1989).

The higher coefficient of SD in mid vowels can be explained by the fact, that speakers' realization in standard speech differs much more in mid vowels than in low or high ones. The dialectal distribution of /e/ vs. /ɛ/ and /o/ vs. /ɔ/ is inconsistent with the situation in SS, thus greater variability, hesitations etc. is present in the speech of many Slovenes, when speaking in the standard form (cf. Srebot Rejec, 1998b for further consequences, and Ozbič, 1998b for the contrastive analysis of formants in Slovene as spoken in Trst/Trieste vs. standard Slovene). All these factors contribute to occasional statistical significance in mid vowels, with the exception of /ɔ/, for which only contrast between long (acute and circumflex) and short ones is statistically significant. This is a likely situation, as vowels similar in quantity tend to

have more similar formants; long vowels are more resistant to reduction processes, universally (see data for Croatian in Bakran, 1989).

Regardless of all the above mentioned facts, /a/ remains a structural curiosity. The short [a] is believed to be greatly influenced by the reduction process and is much more central in comparison to other vowels. This is also true with regard to its duration. While other short vs. long contrasts are mainly statistically insignificant in duration, the opposite is attested in /a/ (Srebot Rejec, 1988b; Petek et al., 1996). In SS, the reduction processes otherwise apparent in non-standard speech seem to be avoided in other vowels, i.e. /i/ and /u/ especially, by the speakers themselves (Rigler, 1968).

These are the reference values for SS formant frequencies. In the future, the results should be complemented by contrastive studies of SS in general and of more local, dialectal, and sub-standard or standardised varieties of SS, both tonal and non-tonal. Furthermore, several new questions arise. For example, the phonological status of /a/ should be re-evaluated, and complemented by an extensive study of duration.

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REFERENCES

Bakran, J. (1989). Djelovanje naglaska i dužine na frekvencije formanata vokala. *Govor* **VI**, 2, 1–12.

Fant, C. G. M. (1956). On the predictability of formant levels and spectrum envelopes from formant frequencies. *For Roman Jakobson* (eds. M. Halle, H. Lunt, & H. MacLean). The Hague: Mouton.

Jurgec, P. (2004). Fonološke značilnosti novejšega slovenskega besedja. *40. seminar slovenskega jezika, literature in kulture: Moderno v slovenskem jeziku, literaturi in kulturi, Zbornik predavanj* (ed. M. Stabej), 179–181.

Jurgec, P. (2005). Položaj v besedi in formantne frekvence samoglasnikov (standardne slovenščine): I. Naglašeni samoglasniki. *Jezikoslovni zapiski* XI, 1, ???–???.

Jurgec, P. (forthcoming-a). Does tone affect formant frequencies? The case of standard Slovene. Submitted.

Jurgec, P. (forthcoming-b). O nenaglašenih /e/ in /o/ v standardni slovenščini. Submitted.

Lehiste, I., (1961). The phonemes of Slovene. *International journal of Slavic linguistics and poetics* **IV**, 48–66.

Lundberg, Grant H. (2003). Typology of tone loss in Haloze, Slovenia: An acoustic and autosegmental analysis, *Slovenski jezik/Slovene linguistic studies* **III**, 169–189.

Ozbič, M. (1998a). Akustična spektralna FFT-analiza samoglasniškega sistema slovenskega jezika: formanti slovenskih samoglasnikov. *Jezikovne tehnologije za slovenski jezik: Zbornik konference* (eds. T. Erjavec & J. Gros), 55–59. Http://nl.ijs.si/isjt98/zbornik/sdjt98-Ozbic.pdf.

Ozbič, M. (1998b). Razmerja med formanti samoglasnikov matične in tržaške slovenščine. *Uporabno jezikoslovje* **VI**: *Jezikovne tehnologije*, 124–135.

Petek, B., Šuštaršič R., & Komar, S. (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.

Potter, R. K., & Steinberg, J. C. (1950). Toward the specification of speech. *Journal of the Acoustical Society of America* **XXII**, 1, 807–820.

Rigler, J. (1968). Problematika naglaševanja v slovenskem knjižnem jeziku. *Jezik in slovstvo* **XIII**, 6, 192–199.

Rigler, J. (1970). Akcentske variante I. *Slavistična revija* **XVIII**, 1, 4–15.

Rigler, J. (1980). Nekaj opažanj pri akutu na zadnjem zlogu v slovenščini, Slavistična revija **XXVIII,** 1–4, 219-222.

SP 2001: *Slovenski pravopis*. Ljubljana: SAZU in ZRC SAZU, 2001.

SP 2003: *Slovenski pravopis: Elektronska izdaja, v1.0*. Ljubljana: SAZU in ZRC SAZU, 2003.

Srebot Rejec, T. (1988a). Kakovost slovenskih in angleških samoglasnikov (kontrastivna analiza obeh sestavov po njihovi kakovosti s stališča akustične, artikulacijske in avditivne fonetike). *Jezik in slovstvo* **XXXIV**, 3, 57–64+128a.

Srebot Rejec, T. (1988b). *Word accent and vowel duration in Standard Slovene: An acoustic and linguistic investigation*. München: Otto Sagner (Slavistische Beiträge, 226).

Srebot Rejec, T. (1998). O slovenskih samoglasniških sestavih zadnjih 45 let. *Slavistična revija* **XLVI**, 4, 339–46.

Srebot Rejec, T. (2000). Ali je današnja knjižna slovenščina še tonematična? *Razprave II. razreda* **XVII**, 51–66.

SSKJ 1998: *Slovar slovenskega knjižnega jezika: Elektronska izdaja, v1.0*. Ljubljana: ZRC SAZU in DZS, 1998.

Šekli, M. (2004). Jezik, knjižni jezik, pokrajinski oz. krajevni knjižni jezik: genetskojezikoslovni in družbenojezikoslovni pristop k členjenju jezikovne stvarnosti (na primeru slovenščine). *Aktualizacija jezikovnozvrstne teorije na Slovenskem: Členitev jezikovne resničnosti* (ed. E. Kržišnik), 41–58.

Tivadar, H. (2003a). *Govorjena podoba slovenskega knjižnega jezika – pravorečni vidik: Magistrsko delo.* Ljubljana.

Tivadar, H. (2003b). Kontrastivna analiza slovenskih i hrvatskih vokala (mogući izgovorni problemi sa slovenskog aspekta). *Govor* **XX**, 1–2, 449–467.

Tivadar, H. (2004a). Fonetično-fonološke lastnosti samoglasnikov v sodobnem knjižnem jeziku. *Slavistična revija* **LII**, 1, 31–48.

Tivadar, H. (2004b). Priprava, izvedba in pomen perceptivnih testov za fonetično-fonološke raziskave (na primeru analize fonoloških parov). *Jezik in slovstvo* **IL**, 2, 17–36.

Toporišič, J. (1975). Formanti slovenskega knjižnega jezika. *Slavistična revija* **XXIII**, 2, 153–196.

Toporišič, J. (2000). *Slovenska slovnica*. Maribor: Obzorja.

Toporišič, J. (2003). Eksperimentalnofonetične raziskave slovenskega knjižnojezikovnega glasovja in tonemskosti. *Slavistična revija* **LI**, Posebna številka, 119–140.

Figure 1

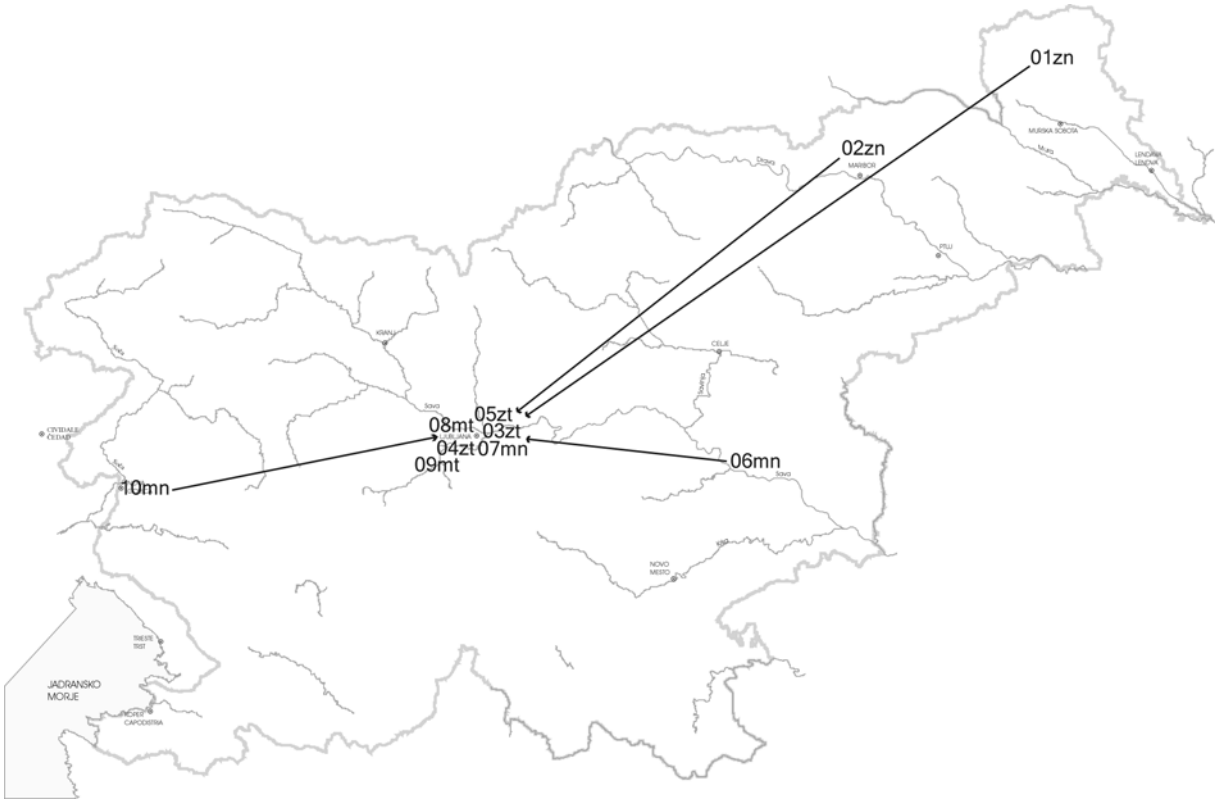

Figure 1. Geographical origin of the speakers.

Slika 1. Izvor ispitanika.

Table 1

Label	Origin	Dialect	Age (years)	F0 mean and SD (Hz)	Characteristics		
					Acoustic	Linguistic (phonetic/phonological)	Para-/Extralinguistic
01zn	Otovci	Prekmurje	25	247 ± 42	Unclear F3 and F4	Problematic distribution of mid vowels	Student
02zn	Maribor/Spodnja Kungota	South Pohorje	24	182 ± 32	Difficult reading of F3 and F4 for front vowels	Problematic distribution of mid vowels	Intensity decreasing throughout the recording; student
03zt	Ljubljana	LJ Urban	24	212 ± 30	Creaky voice	Problematic realization of lexical tone; reduction	Student
04zt	Ljubljana	LJ Urban	56	163 ± 24	Problematic F1 and F2 of back vowels, and F2 and F3 of front vowels		Overall low intensity
05zt	Ljubljana	LJ Urban	27	204 ± 44	Very high F3 and F4	Rising intonation regardless of the tone	
06mn	Blanca/Sevnica	Posavje	36	107 ± 14	Unclear F4		Living in Ljubljana for 12 years
07mn	Ljubljana	LJ Urban	35	132 ± 20	Even F3	Problematic realization of lexical tone	Father non-Slovene
08mt	Ljubljana	LJ Urban	36	100 ± 19	Very low pitch, creaky voice	Hypercorrectness	Professional speaker
09mt	Vnanje Gorice	Mixed	63	135 ± 27		U-kanje	Linguist, university professor
10mn	Nova Gorica	Kras (Carst)	23	134 ± 19		Problematic realization of lexical tone; problematic distribution of mid vowels	Student

Table 1. Speakers' characteristics.

Tablica 1. Karakteristike informanata.

Figure 2

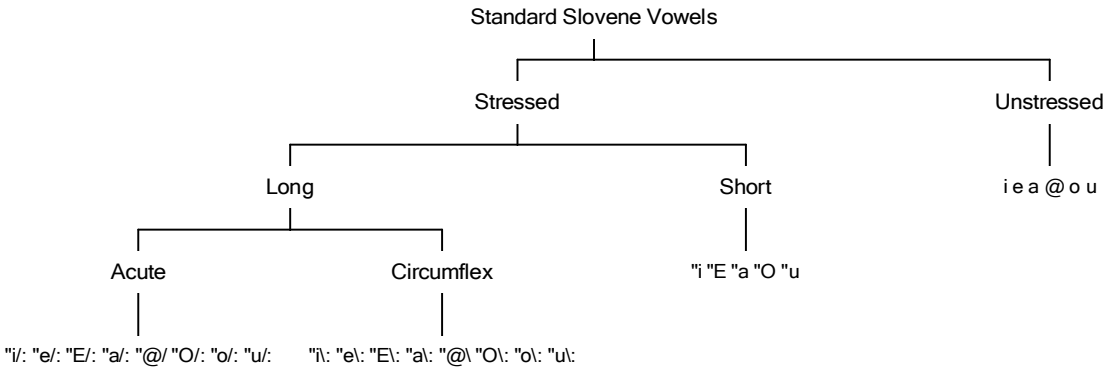

Figure 2. An alternative model of standard Slovene vowels.

Slika 2. Alternativni model za samoglasnike standardnoga slovenskoga jezika.

Table 2

Accent type	/i/			/e/			/ɛ/			/a/			/ə/			/ɔ/			/o/			/u/		
										F1														
Acute	277			382			578			732			497			576			419			313		
	31.82	240	4.03	55.87	158	8.71	98.65	137	16.52	94.52	220	12.49	52.98	100	10.38	62.97	107	11.93	60.67	178	8.91	48.12	180	7.03
Circumflex	280			389			589			728			499			584			426			316		
	26.90	240	3.40	54.91	239	6.96	100.99	215	13.50	85.42	240	10.81	45.11	229	5.84	64.86	146	10.52	58.52	240	7.40	42.02	239	5.33
Short	283			/			592			692			/			601			/			334		
	31.85	100	6.24				89.74	109	16.85	100.67	100	19.73				52.79	104	10.15				44.02	40	13.64
Average	280			386			586			717			498			587			423			321		
	30.19	193	4.56	55.39	199	7.84	96.46	154	15.62	93.53	187	14.34	49.05	165	8.11	60.21	119	10.87	59.59	209	8.16	44.72	153	8.67
										F2														
Acute	2324			2250			1932			1265			1380			979			810			826		
	236.44	234	30.29	241.87	153	38.32	262.56	137	43.97	104.94	220	13.87	142.51	100	27.93	83.88	107	15.89	126.05	178	18.52	146.32	180	21.38
Circumflex	2304			2263			1833			1233			1356			989			818			890		
	241.59	236	30.82	244.56	234	31.33	249.50	214	33.43	100.97	240	12.77	147.66	229	19.12	86.91	146	14.10	102.95	240	13.03	169.49	237	21.58
Short	2299			/			1815			1269			/			1010			/			841		
	238.74	98	47.27				218.89	108	41.28	115.67	100	22.67				84.88	104	16.31				128.86	39	40.44
Average	2309			2257			1860			1256			1368			993			814			852		
	238.92	189	36.13	243.21	194	34.83	243.65	153	39.56	107.19	187	16.44	145.08	165	23.53	85.23	119	15.44	114.50	209	15.77	148.22	152	27.80
										F3														
Acute	2949			2795			2695			2567			2480			2665			2634			2575		

	330.24	238	41.96	270.96	156	42.52	274.18	137	45.91	222.97	217	29.67	214.19	100	41.98	234.99	106	44.73	300.54	176	44.40	243.76	173	36.32
Circumflex	2906			2802			2632			2605			2572			2679			2684			2560		
	300.19	235	38.38	268.04	235	34.27	291.67	215	38.99	212.31	239	26.92	186.29	229	24.13	238.21	144	38.91	276.79	237	35.24	255.83	234	32.78
Short	2872			/			2607			2531			/			2563			/			2547		
	303.39	96	60.69				229.67	109	43.12	254.45	97	50.64				217.81	102	42.27				240.37	40	74.49
Average	2909			2798			2645			2567			2526			2636			2659			2561		
	311.27	190	47.01	269.50	196	38.39	265.17	154	42.67	229.91	184	35.74	200.24	165	33.05	230.33	117	41.97	288.66	206.5	39.82	246.65	149	47.86
										F4														
Acute	3781			3735			3864			3753			3685			3592			3514			3613		
	398.64	226	51.97	395.85	156	62.12	428.00	131	73.29	385.16	209	52.22	362.37	99	71.38	361.18	104	69.41	371.96	175	55.11	409.43	175	60.66
Circumflex	3776			3752			3791			3791			3655			3642			3555			3567		
	432.27	231	55.74	440.34	232	56.66	445.10	211	60.06	374.52	229	48.51	344.62	227	44.83	324.87	138	54.20	371.21	237	47.26	432.15	236	55.14
Short	3744			/			3724			3714			/			3630			/			3573		
	407.04	98	80.59				412.52	107	78.16	361.84	92	73.94				353.39	101	68.92				398.60	40	123.52
Average	3767			3743			3793			3753			3670			3622			3534			3585		
	412.65	185	62.77	418.10	194	59.39	428.54	150	70.50	373.84	177	58.22	353.49	163	58.11	346.48	114	64.18	371.58	206	51.18	413.39	150	79.77

Table 2. Average values of measured formant frequencies in Hz according to phoneme, formant and accent type. Below the mean values (boldface), standard deviation, number of samples and confidence interval are given.

Tablica 2. Srednje vrijednosti formanata u Hz po fonemu, formantu i tipu akcenata. Dodane su standardna deviacija, broj odčitavanja i interval vjernosti.

Figure 3

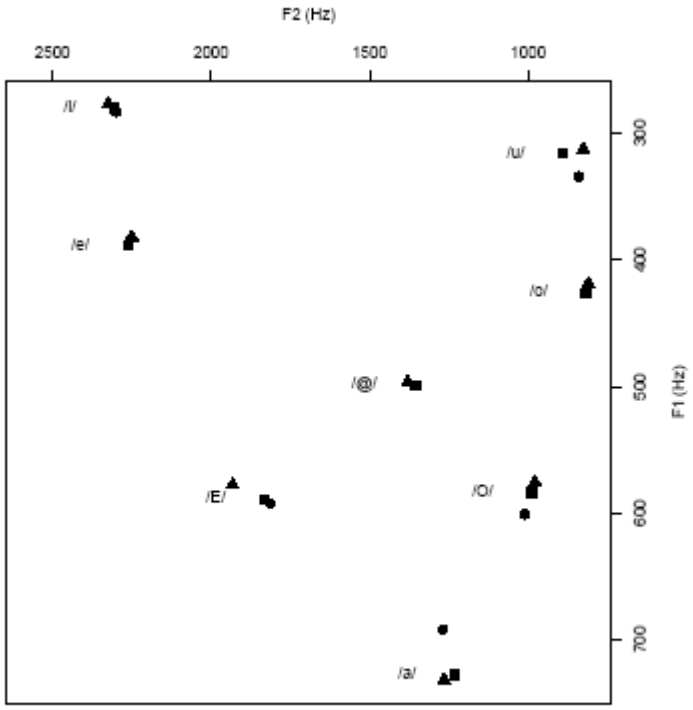

Figure 3. Vowel space of standard Slovene, according to the accent type. Legend: ▲– acute, ■ – circumflex, ● – short.

Slika 3. Samoglasnički prostor standardnoga slovenskoga jezika. Znakovi: ▲– akut (uzlazni), ■ – cirkumfleks (silazni), ● – kratki.

Table 3

Phoneme	F1				F2			
	Accent types	df	F	p (α=.05)	Accent types	df	F	p (α=.05)
/i/	Acute vs. circumflex	1, 478	.980	.323	Acute vs. circumflex	1, 468	.789	.375
	Acute vs. short	1, 338	2.38	.124	Acute vs. short	1, 330	.723	.396
	Circumflex vs. short	1, 338	.880	.349	Circumflex vs. short	1, 332	.026	.872
/e/	Acute vs. circumflex	1, 395	1.35	.246	Acute vs. circumflex	1, 385	.237	.627
/ɛ/	Acute vs. circumflex	1, 350	1.05	.307	Acute vs. circumflex	1, 349	12.56	.0004
	Acute vs. short	1, 244	1.39	.240	Acute vs. short	1, 243	13.91	.0002
	Circumflex vs. short	1, 322	.076	.783	Circumflex vs. short	1, 320	.427	.514
/a/	Acute vs. circumflex	1, 458	.209	.648	Acute vs. circumflex	1, 458	11.34	.0008
	Acute vs. short	1, 318	11.84	.0007	Acute vs. short	1, 319	.119	.730
	Circumflex vs. short	1, 338	11.38	.0008	Circumflex vs. short	1, 338	8.61	.004
/ə/	Acute vs. circumflex	1, 327	0.064	.800	Acute vs. circumflex	1, 327	1.99	.159
/ɔ/	Acute vs. circumflex	1, 251	1.15	.284	Acute vs. circumflex	1, 251	.738	.391
	Acute vs. short	1, 209	10.01	.002	Acute vs. short	1, 209	6.80	.010
	Circumflex vs. short	1, 248	4.62	.033	Circumflex vs. short	1, 248	3.59	.059
/o/	Acute vs. circumflex	1, 416	1.40	.238	Acute vs. circumflex	1, 416	.540	.463
/u/	Acute vs. circumflex	1, 417	.412	.521	Acute vs. circumflex	1, 415	16.55	.00006
	Acute vs. short	1, 218	5.91	.016	Acute vs. short	1, 217	.351	.554
	Circumflex vs. short	1, 277	5.74	.017	Circumflex vs. short	1, 274	3.01	.084

Table 3. Single factor ANOVA analysis results for each phoneme and accent type combination. The default Alpha factor was used (.05). Statistically significant values are underlined.

Tablica 3. Rezultati analize ANOVA za pojedinačne foneme i tipe naglasaka. Alfa faktor je 0,05. Statistički signifikantne vrjednosti su podcrtane.

Figure 4

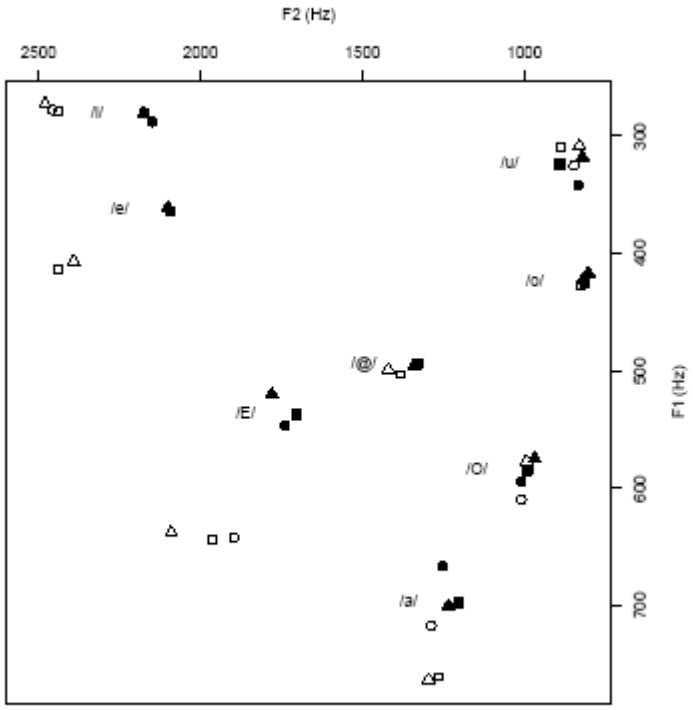

Figure 4. Vowel space for female and male speakers of standard Slovene, according to the accent type. Legend. Female speakers: Δ – acute, □ – circumflex, ○ – short. Male speakers: ▲– acute, ■ – circumflex, ● – short.

Slika 4. Samoglasnički prostor ženskih i muških govornika standardnoga slovenskoga jezika. Znakovi. Ženske: Δ – akut (uzlazni), □ – cirkumfleks (silazni), ○ – kratki. Muški: ▲– akut (uzlazni), ■ – cirkumfleks (silazni), ● – kratki.

APPENDIX 1

Average values of measured formant frequencies in Hz for female speakers according to phoneme, formant and accent type. Under the mean values (boldface), standard deviation, number of samples and confidence interval are given, respectively.

Accent type	/i/			/e/			/ɛ/			/a/			/ə/			/ɔ/			/o/			/u/		
												F1												
Acute		273			407			638			763			499			577			422			309	
	35.84	120	6.41	64.82	80	14.20	103.61	67	24.81	106.37	110	19.88	57.87	50	16.04	71.19	49	19.93	72.06	88	15.06	58.61	90	12.11
Circumflex		279			414			643			758			503			585			427			309	
	31.05	120	5.56	57.05	120	10.21	108.96	106	20.74	93.71	120	16.77	46.03	114	8.45	62.34	69	14.71	68.25	120	12.21	42.78	120	7.65
Short		278			/			642			717			/			609			/			325	
	35.89	50	9.95				97.51	53	26.25	121.66	50	33.72				48.63	49	13.62				49.11	20	21.52
Average		277			410			641			746			501			590			425			314	
	34.26	97	7.31	60.94	100	12.21	103.36	75	23.93	107.25	93	23.46	51.95	82	12.24	60.72	56	16.09	70.15	104	13.63	50.17	77	13.76
												F2												
Acute		2480			2392			2091			1296			1420			993			818			830	
	194.96	114	35.79	270.46	75	61.21	272.14	67	65.16	122.16	110	22.83	147.91	50	41.00	100.89	49	28.25	140.31	88	29.31	160.62	90	33.18
Circumflex		2441			2438			1966			1264			1382			992			825			890	
	232.26	116	42.27	201.62	115	36.85	261.41	106	49.76	113.78	120	20.36	165.05	114	30.30	110.54	69	26.08	110.18	120	19.71	170.43	120	30.49

Short	2457			/			1897			1287			/			1009			/			847		
	221.86	48	62.76				264.82	52	71.98	109.72	50	30.41				82.57	49	23.12				149.95	20	65.72
Average	2459			2415			1984			1282			1401			998			822			855		
	216.36	93	46.94	236.04	95	49.03	266.12	75	62.30	115.22	93	24.53	156.48	82	35.65	98.00	56	25.82	125.24	104	24.51	160.33	77	43.13
										F3														
Acute	3095			2956			2837			2653			2547			2804			2795			2681		
	340.59	120	60.94	244.25	78	54.20	280.81	67	67.24	215.22	107	40.78	245.90	50	68.16	246.36	48	69.69	285.16	87	59.92	210.06	83	45.19
Circumflex	3039			2976			2775			2672			2653			2774			2874			2706		
	310.40	117	56.24	214.90	116	39.11	323.72	106	61.63	218.33	120	39.06	190.22	114	34.92	268.80	67	64.36	227.56	117	41.23	204.86	117	37.12
Short	3042			/			2697			2624			/			2649			/			2653		
	303.53	47	86.78				252.02	53	67.85	289.11	48	81.79				207.67	47	59.37				139.82	20	61.28
Average	3059			2966			2770			2650			2600			2742			2835			2680		
	318.18	95	67.99	229.58	97	46.66	285.52	75	65.57	240.89	92	53.88	218.06	82	51.54	240.94	54	64.48	256.36	102	50.58	184.92	73	47.86
										F4														
Acute	4078			4049			4227			4019			3987			3871			3795			3925		
	252.99	116	46.04	258.61	87	54.34	261.10	78	57.94	252.96	109	47.49	150.95	50	41.84	265.98	49	74.47	239.78	86	50.68	158.41	89	32.91
Circumflex	4080			4079			4164			4015			3947			3845			3827			3909		
	304.06	116	55.33	298.90	118	53.93	260.31	104	50.03	247.49	120	44.28	169.38	113	31.23	283.34	68	67.34	205.46	119	36.91	238.18	119	42.79
Short	4072			/			4053			3961			/			3798			/			3833		
	243.24	49	68.10				314.83	52	85.57	231.03	48	65.36				245.99	49	68.87				311.07	20	136.33
Average	4077			4064			4148			3998			3967			3838			3813			3889		
	266.76	94	56.49	278.75	103	54.14	280.00	98	55.94	243.83	92	52.38	160.16	82	36.54	265.10	55	70.23	222.62	103	43.80	235.89	76	70.68

APPENDIX 2

Average values of measured formant frequencies in Hz for male speakers according to phoneme, formant and accent type. Under the mean values (boldface), standard deviation, number of samples and confidence interval are given, respectively.

Accent type	/i/			/e/			/ɛ/			/a/			/ə/			/ɔ/			/o/			/u/		
											F1													
Acute	**281**			**361**			**520**			**700**			**496**			**575**			**417**			**318**		
	26.79	120	4.79	36.48	79	8.04	44.70	70	10.47	67.79	110	12.67	48.15	50	13.35	55.72	58	14.34	47.25	90	9.76	34.30	90	7.09
Circumflex	**281**			**364**			**537**			**697**			**494**			**584**			**425**			**324**		
	22.07	120	3.95	39.34	119	7.07	55.01	109	10.33	63.11	120	11.29	43.93	115	8.03	67.45	77	15.07	47.08	120	8.42	40.04	119	7.19
Short	**288**			/			**546**			**666**			/			**594**			/			**342**		
	26.56	50	7.36				47.38	56	12.41	65.88	50	18.26				55.68	55	14.72				37.50	20	16.43
Average	**283**			**362**			**534**			**688**			**495**			**584**			**421**			**328**		
	25.14	97	5.37	37.91	99	7.56	49.03	78	11.07	65.59	93	14.07	46.04	83	10.69	59.62	63	14.71	47.17	105	9.09	37.28	76	10.24
											F2													
Acute	**2176**			**2100**			**1780**			**1234**			**1341**			**968**			**802**			**821**		
	167.16	120	29.91	150.60	79	33.21	130.58	70	30.59	72.64	110	13.57	126.51	50	35.07	65.01	58	16.73	110.57	90	22.84	131.24	90	27.11
Circumflex	**2172**			**2094**			**1703**			**1201**			**1329**			**986**			**810**			**890**		
	165.08	120	29.54	142.13	119	25.54	149.50	108	28.20	74.12	120	13.26	123.19	115	22.52	58.84	77	13.14	95.05	120	17.01	169.25	117	30.67
Short	**2148**			/			**1739**			**1252**			/			**1010**			/			**834**		
	133.34	50	36.96				126.28	56	33.07	119.84	50	33.22				87.65	55	23.17				105.99	19	47.66

Average	2165			2097			1740			1229			1335			988			806			848		
	155.19	97	32.13	146.37	99	29.37	135.45	78	30.62	88.87	93	20.02	124.85	83	28.79	70.50	63	17.68	102.81	105	19.92	135.49	75	35.15
										F3														
Acute	2801			2628			2559			2483			2414			2551			2477			2477		
	243.03	118	43.85	194.32	79	42.85	185.48	70	43.45	197.99	110	37.00	152.24	50	42.20	148.25	58	38.15	222.47	89	46.22	232.32	90	48.00
Circumflex	2774			2631			2494			2537			2492			2595			2499			2415		
	222.79	118	40.20	195.35	119	35.10	165.45	109	31.06	183.16	119	32.91	143.44	115	26.22	170.23	77	38.02	177.02	120	31.67	216.79	117	39.28
Short	2708			/			2522			2439			/			2490			/			2441		
	195.18	49	54.65				168.10	56	44.03	173.82	49	48.67				200.51	55	52.99				274.35	20	120.24
Average	2761			2630			2525			2486			2453			2545			2488			2444		
	220.33	95	46.23	194.84	99	38.97	165.83	75	38.86	184.99	93	39.53	147.84	83	34.21	172.99	63	43.05	199.75	105	38.95	241.15	76	69.17
										F4														
Acute	3469			3421			3516			3463			3377			3344			3240			3291		
	261.94	110	48.95	216.28	79	47.69	249.19	67	59.67	281.32	100	55.14	231.07	49	64.70	230.33	55	60.87	250.72	89	52.09	332.67	86	70.31
Circumflex	3469			3414			3429			3544			3365			3446			3280			3219		
	307.44	115	56.19	277.31	114	50.91	240.25	107	45.52	333.47	109	62.60	198.51	114	36.44	228.15	70	53.45	288.91	118	52.13	279.86	117	50.71
Short	3415			/			3412			3445			/			3472			/			3314		
	234.72	49	65.72				192.09	55	50.77	276.59	44	81.73				367.75	52	99.95				295.91	20	129.68
Average	3451			3418			3452			3484			3371			3421			3260			3275		
	268.03	91	56.95	246.79	97	49.30	227.18	76	51.99	297.13	84	66.49	214.79	82	50.57	275.41	59	71.42	269.82	104	52.11	302.81	74	83.57

SAŽETAK: FRENKVENCIJE FORMANATA SAMOGLASNIKA U STANDARDNOM SLOVENSKOM JEZIKU

Mjerenja frekvencija formanata samoglasnika u standardnom slovenskom jeziku (SS) u prošlosti su bila nedostatna. Mjerenja prije digitalnih nisu bila dovoljno reprezentativna u smislu veličine govornog korpusa. Lehiste (1961) je navela prosjek formanata jedne govornice (425 pojavnica). Toporišič (1975) je analizirao 174 pojavnice kod 6 govornika. To vrijedi i za poluatomatiski mjerene frekvencije formanata u posljednjem desetljeću. Petek i suradnici (1996) predstavili su frekvencije formanata izmjerene LPC analizom triju govornika (1 žena), te ukupno 288 pojavnica. Ozbič (1998a) je izmjerila 11 pojavnica po samoglasniku (1 po govorniku) putem FFT analize. Tivadar (2004a) je predstavio svoje nalaze na temelju 10 govornika. Utjecaj leksičkog tona na frekvencije formanata svi su odbacili kao nerelevantan.

Ova studija o SS samoglasnicima temelji se na opsežnom korpusu od 241 jednosložne, dvosložne i trosložne riječi, prikupljene prema suprasegmentalnim kriterijima (naglasak, ton, trajanje). Odabrano je 10 ispitanika (reprezentativnih prema spolu, tonskom kontrastu, izvornom dijalektu itd.). Prva četiri formanta od ukupno 5960 samoglasnika izmjerena su s pomoću Praat softwarea za LPC analizu. Izračunat je prosjek i izvršena statistička analiza podataka (ANOVA).

Mjerenja potvrđuju da leksički ton nije razlikovan u frekvenciji formanata kod većine fonema (vidi F1×F2 samoglasnički prostor na slici 1). Međutim, postoji statistički značajna razlika ($p \leq 0,05$) kod /a/, /ɛ/, /ɔ/ i /u/. Osim kod /u/, ove se fonetske razlike mogu objasniti usporedbom dviju varijanti SS-a, tonalne i netonalne. U potonjoj je kontrast između tonova statistički beznačajan (cf. Jurgec, forthcoming-a).

[1] The problem was later re-evaluated in the works of T. Srebot Rejec (1988b, 1998).

[2] The general concept of formants is not discussed further in the text. Rather, we presume a purely technical acoustical definition of formant frequency from Potter and Steinberg 1950: 811, i.e. $F = \frac{\Sigma \omega_i f_i}{\Sigma \omega_i}$, where »$f_i$ = frequency of the *i*th component, and ω_i = a weighting factor dependent on the number of dB and that the *i*th component is below the dominant or maximum component«, or alternative view in Fant, 1956: 110: »The frequency of a formant is the position on the frequency scale of the peak of the specturm envelope drawn to enclose the peaks of the harmonics.«

[3] The complete list of the words analysed can be obtained from the author.

[4] Examples of homonyms from the corpus: *karate* [kaɾaˈtèː] 'karate' (in the corpus) vs. [ˈkàːɾate] 'to blame, 1st pers. pl. praes.', *izrazit* [izɾaˈzìːt] 'distinctive, adj.' vs. [iˈzɾáːzit] 'to express, supp.'. The word used in the experiment is much more frequent in use. The speakers pronounced the non-targeted word in pairs only very infrequently (≤10% of all cases).

[5] According to traditional grammar, the main distributional laws are as follows: (1) Stress is free, but predictable in Slovene. (2) Long vowels are always stressed. (3) If there are no long vowels, the last is stressed = Short vowels can be normally stressed only word-finally. (4) /ə/ is always short and can be stressed, regardless of the previous rule. (5) /e/ and /o/ cannot be short, and to some authors (cf. Toporišič, 2000: 71–72; see Srebot Rejec, 1988b, for a review) also not stressed. (6) Long vowels and non-final /ˈə/ distinguish two tones, the so called *acute* (labelled ´) and *circumflex* (`).

[6] These are instances of words pronounced incorrectly, i.e. in contradiction to the standard, e.g. *ukanje*, hypercorrection or reduction processes, or irregularities because of phonetic reasons, e.g. formant characteristics. However, no words were discharged due to vowel quantity (cf. Petek et al., 1996; Srebot Rejec, 1988b, 1998) or lexical tone.

[7] /ə/ is considered acute or circumflex, rather than short, although it is inherently short, according to the traditional grammar (e.g. Toporišič, 2000).