Peter Jurgec, Inštitut za slovenski jezik Frana Ramovša v Ljubljani
peter.jurgec@guest.arnes.si

Does tone affect formant frequencies? The case of Standard Slovene

Abstract

The article presents formant frequencies of Standard Slovene (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.

Key words: acoustic phonetics, formant frequencies, suprasegmentals, tone, Slovene.

1 Introduction

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). Formant frequencies' dependence on vowel duration, phonetic reduction, or undershoot effect, speaking rate and style (e.g. Lindblom 1963, Gay 1978, Tuller idr. 1982, Miller 1985, Engestrand 1988, Bakran 1989, Fourakis 1991, Van Son and Pols 1992, Moon and Lindblom 1994, Fourakis idr. 1999, Pitermann 2000, Erickson 2002, and Jurgec 2005ab, for Slovene), 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, forthcoming-b) 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 Ivić 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, Slovene has two types of dialects, pitch-accented[1] and stress-accented, and is therefore very appropriate for this task. Furthermore, in contemporary Standard Slovene (SS) both tonal and non-tonal varieties are permitted.

In Slovene,[2] majority of central dialects, those of Gorenjska and Dolenjska regions, are tonal. Additionally, Carinthian dialects in Austria and Italy are tonal, as well as Primorska 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 Primorska dialects, all Štajerska, and Panonsko 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). – Slovene has two lexical tones, acute and circumflex. For acoustic analyses of tones in Slovene, see Vodušek 1961, Toporišič 1967, 1968, Neweklowsky 1973, and Srebot Rejec 1988, 2000. Phonetically, acute realizes as rising tone (or low on the stressed and high on the post-stressed syllable), circumflex vice versa. Phonologically, both tones can occur only in traditionally (i.e. diachronically) long vowels, short vowels are considered circumflex (unmarked), in SS. In contrast to phonological limitations of better-known pitch-accent languages as Swedish and Serbo-Croatian, contrast is preserved also in words with final stress (e.g. *pot* /ˈpoːt/ – acute ‘path’, circumflex ‘sweath’). In total, less than 100 morphologically non-related minimal pairs in tone exist (e.g. *kila*, *kura*, *mula*, *šibica*, *šalica*), while morphologically related pairs are abundant.

---

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

[2] This paragraph and the corresponding references do not appear in the Slovenian version of the article.

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, 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 extensive corpus of 241 one-, two- and three-syllable words, compiled according to the suprasegmental criteria (stress, tone, duration).[3] 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), 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 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, individual formant steady state was measured, if possible. Alternatively, central point, or averaged value of transient formant was measured. Altogether, 21,220 readings (of stressed and unstressed vowels' 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, forthcoming-b.

3 Results

The measurements of formant frequencies were grouped into prosodic combinations (or accent types), i.e. acute, circumflex and short vowels,[4] separately for both tonal and non-tonal SS. For each, mean value, standard deviation (SD), sample size, and confidence interval were

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

[4] For discussion on this matter and its implications to the traditional grammar, see Jurgec, forthcoming-b.

calculated. Do 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 Tab. 1–2 below. Here, F1–F4 values are presented, while in the rest of the article only F1 and F2 are discussed.

Insert Table 1 here.

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 (± of mean value, α = .05) are listed.

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 /ɔ/ 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.

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.

Insert Table 2 here.

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 (± of mean value, α = .05) are listed.

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 /ɔ/ are marginal, as there is statistical significance only between most distinct prosodic combinations, i.e. acute and short (but not between acute and circumflex, and circumflex and short).

Insert Figure 1 here.

FIGURE 1. F1×F2 vowel space of tonal and non-tonal varieties of SS.

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 [ɛ], and acute vs. short in [ɔ]. In [a] significance is only marginal. In sum, accent types of [a], and of both tense mid vowels [e], [o], differ significantly, while in [ɛ] and [ɔ] this effect is only marginally significant. There is no statistical significance among the accent types of high vowels [i] and [u] (for the latter, there is only marginal significance), and for central vowel [ə]. Detailed results of the analysis for both F1 and F2 are presented in Tab. 3.

Insert Table 3 here.

TABLE 3. 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.

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

Insert Table 4 here.

TABLE 4. 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.

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 [ɔ] is lower. The only exception is [ɛ], which exhibits no such tendency. Generally, in Slovene, spoken in central 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 consistent with experimental data from non-central Slovene in Ozbič 1998ab, for SS as spoken in Trst (Trieste), and in Jurgec, fortcoming-a, 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 vice versa for the non-tonal speakers). Average F0 of females is higher than that of males, and F0 influences the formant frequencies increasingly. 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 in the sub-standard speech as qualitative changes, i.e. phonological reduction processes. Thus when speaking SS, speakers tend to avoid these processes, and being 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 /ɔ/, in F1 and F2 (see Tab. 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 Srebot Rejec 1988 and Petek et al. 1996, where /a/ was the only phoneme that exhibited (some) durational differences. This inconsistency has not been explored yet, and had no influence on prescriptive praxis 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. Tab. 3–4), only /i/ and /ə/ exhibit no significant differences between the accent types. /ə/ is 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 by terms of general phonetics. However, other data from Slovene and its formant frequencies (Jurgec 2005ab, forthcoming-b), posit an interesting property of Slovene [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 Tab. 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 problematic distribution of both front mid vowels, which are morphonologicaly bounded, and the distribution in the standard differs greatly from contemporary dialectal and sub-standard realization. When unstressed, both phonemes neutralize 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, fortcoming-c, 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 Tab. 2), 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 Slovene. 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 (well above 15% in F2, on average). The fact that circumflex [u] is statistically distinct from acute and short is also surprising. For 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 be influenced by other variables more. For example, the difference between word-final and initial vs. medial position of the two high vowels, documented in prescriptive sources (e.g. Toporišič 2000: 50). The present analysis, based on linguistic material of 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 can be a considerable backness of the low vowel in Štajerska and Panonsko dialects, from where three of our speakers are.[5] If so, acute being the only influenced, is statistically significant to circumflex and short [a]. This cannot be conditioned by the phonetic factors proper, but dialectal phonetic influences. Therefore, it should be disregarded.

All in all, 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

[5] 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.

certain extralinguistic factors), but still significant, and by rule not present in the non-tonal speech. Either this is directly connected to distinctions in fundamental frequency or intensity, attested in Slovene acute vs. circumflex tone, remains unknown. However, F0 influences formant frequencies (via stress, gender or speaking style) considerably, and the correspondence rises exponentially, higher formants exhibiting much larger increase than lower, if F0 rises. Intensity (via duration, stress or speaking style) also has a positive correspondence to formant frequencies; vowels greater in 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 present, and their extent. It proves however, that such differences occur.

Acknowledgements

The author would like to thank Vesna Mildner and Mateja Blas for their valuable contributions to this work. Any remaining errors are, of course, the author's. Earlier versions of the article (or parts thereof) have been presented at *Between Stress and Tone Conference* in Leiden (June 16–18, 2005) and the *International Conference of Language Variation in Europe* in Amsterdam (June 23–25, 2005). The ZRCola font, used in this text, was developed by Peter Weiss at The Scientific Research Centre of the Slovenian Academy of Sciences and Arts in Ljubljana (http://www.zrc-sazu.si).

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, 1990: Gender recognition from speech. Part II: Fine analysis. *The journal of theAacoustical 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* LXXX/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.

Peter JURGEC, 2005a: Položaj v besedi in formantne frekvence samoglasnikov (standardne slovenščine), I. Naglašeni samoglasniki. *Jezikoslovni zapiski* XI: 1. 121–132.

— —, 2005b: Položaj v besedi in formantne frekvence samoglasnikov (standardne slovenščine), II. Nenaglašeni samoglasniki. *Jezikoslovni zapiski* XI: 2. ???–???.

— —, forthcoming-a: Fonetični opis govora Ovčje vasi. In print.

— —, forthcoming-b: Formant frequencies of Standard Slovenian vowels. Submitted.

— —, forthcoming-c: O nenaglašenih [e] in [o] v standardni slovenščini. Submitted.

Ilse LEHISTE, 1961: The phonemes of Slovene. *International journal of Slavic linguistics and poetics* IV. 48–66.

Ilse LEHISTE and Pavle IVIĆ, 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/11. 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* [...]. Wien: 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, Pt. 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*. München: 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: Grudsätzliche Betrachtungen über den melodischen Verlauf der Wortakzente in den zentralen Slowenichen Mundarten, *Linguistica* IV. 20-38.

Ke WU and D. G. CHILDERS, 1990: Gender recognition from speech. Part I: Coarse analysis. *The journal of the Acoustical society of America* XC/4. 1828–1840.

Summary

There are two varieties of Standard Slovene (SS), the pitch-accented (or tonal) and the stress-accented. The article presents vowel formant frequencies of both varieties.

Extensive corpus of one- to three-syllables was compiled, acknowledging distribution of suprasegmentals in SS. 241 words in random order were read twice in citation form by 10 speakers, representative by gender, dialect of origin, and tone. 5 of them were tonal (3 females and 2 males) and 5 non-tonal. Digital recording was performed under standard conditions (44.1 kHz sampling frequency, at a 16-bit rate). The first four formants of the total of 5,960 vowels were measured using *Praat* LPC-based analysis software. Data were grouped and averaged. Statistical analysis, including analysis of variance (ANOVA) followed. More detailed information on the method of the expement can be found in Jurgec-forhcoming-b.

The average values (with corresponding standard deviation, sample size, and confidence interval) of the tonal and non-tonal SS vowels are in Tab. 1–2, respectively ("Prikaz 1" and "Prikaz 2"). Fig. 1 ("Prikaz 3") is F1×F2 plot presenting suprasegmentals of the tonal (depicted with empty symbols) and the non-tonal variety (full symbols). In Tab. 3–4 results of ANOVA for both groups can be found.

The results fall in two domains, either conditioned by primarily dialectal phonetic and phonological variables, or purely acoustic. The former includes the difference of F1 in [+ ATR] mid vowels [e] and [o]. In the tonal variety, these have lower F1 than in the non-tonal variety. Furthermore, in the tonal SS vowel [a] is considerably centralized (i.e. has lower F1), when unstressed. Other vowels have no such short realizations, neither in the tonal or non-tonal SS.

On the other hand, the tonal SS has clearly more dispersed suprasegmentals than the non-tonal. In most cases, the differences are statistically significant, in F1 and/or F2. However, no

differences were observed in [ə] and [i]. For [u] one can say variables other than tone are in question, as the same significance is attested in the non-tonal SS. Statistically significant suprasegmentals in the non-tonal SS are exceptional. Both F2 of [a] and [u] can be explained with influences of dialectal nature, and in [ɛ] the problematic distribution (in connection with [e]) is observed.

The variability between accent types in formant frequencies of the tonal SS vowels can be seen as a by-product of fundamental frequency and intensity on one hand, and duration, phonetic reduction/undershoot etc. on the other.

Table 1

	/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
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		
	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				468.60	20	205.37

Table 2

	/i/			/e/			/ɛ/			/a/			/ə/			/ɔ/			/o/			/u/		
F1																								
Acute		280			408			592			732			502			563			446			322	
	31.58	120	5.65	62.27	78	13.82	124.17	69	29.30	109.18	110	20.40	62.62	50	17.36	55.70	49	15.60	65.55	88	13.70	38.63	90	7.98
Circumflex		285			405			605			731			497			556			441			328	
	26.28	120	4.70	61.80	119	11.10	123.40	107	23.38	94.64	120	16.93	50.79	111	9.45	63.27	66	15.26	68.52	120	12.26	38.10	120	6.82
Short		283			/			594			722			/			571			/			340	
	24.84	50	6.88				112.25	49	31.43	95.61	50	26.50				47.46	44	14.02				39.97	20	17.52
F2																								
Acute		2330			2194			1895			1268			1378			950			852			824	
	225.55	120	40.36	226.47	78	50.26	198.89	69	46.93	99.55	110	18.60	164.25	50	45.53	75.91	49	21.25	141.89	88	29.64	152.16	90	31.44
Circumflex		2316			2208			1816			1232			1361			951			833			889	
	204.12	119	36.67	242.49	118	43.75	197.12	106	37.53	99.16	120	17.74	152.24	111	28.32	84.13	66	20.30	117.51	120	21.03	181.72	119	32.65
Short		2299			/			1810			1271			/			965			/			824	
	204.88	50	56.79				162.37	49	45.46	114.54	50	31.75				92.95	44	27.47				158.84	19	71.42
F3																								
Acute		2951			2751			2711			2486			2530			2637			2589			2619	
	303.54	118	54.77	261.80	78	58.10	241.22	69	56.92	217.06	110	40.56	212.68	50	58.95	254.44	48	71.98	292.24	87	61.41	242.97	84	51.96
Circumflex		2896			2757			2624			2542			2591			2625			2662			2603	
	255.20	118	46.05	267.61	119	48.08	249.55	107	47.28	211.81	119	38.06	174.71	111	32.50	224.26	65	54.52	305.76	119	54.94	252.05	115	46.07
Short		2885			/			2607			2479			/			2476			/			2588	
	271.64	49	76.06				236.45	49	66.20	212.31	48	60.06				224.34	43	67.05				264.92	20	116.11

F4

Acute	3729			3641			3843			3677			3651			3415			3437			3565		
	410.34	115	75.00	406.59	78	90.23	406.49	65	98.82	386.47	101	75.37	376.93	49	105.54	345.39	46	99.81	349.48	87	73.44	408.38	87	85.81
Circumflex	3707			3660			3703			3723			3602			3469			3492			3507		
	430.46	117	78.00	449.10	117	81.38	437.68	105	83.72	388.39	110	72.58	354.36	109	66.52	302.25	59	77.12	369.57	118	66.68	427.54	119	76.82
Short	3691			/			3627			3663			/			3539			/			3573		
	414.09	49	115.94				397.12	47	113.53	367.36	45	107.33				408.21	41	124.95				326.40	20	143.05

Figure 1

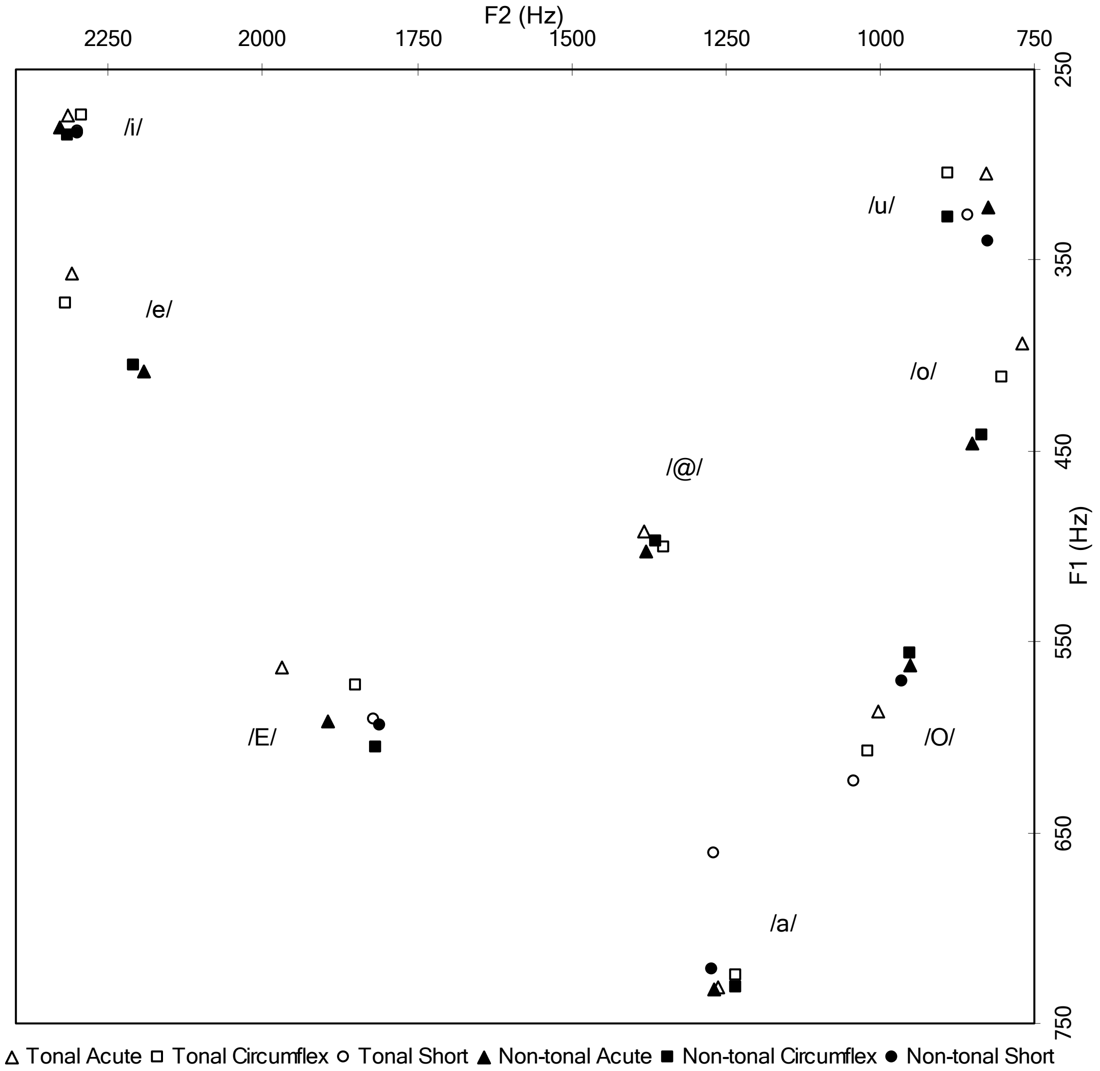
F2 (Hz)
2250
2000
1750
1500
1250
1000
750
250
350
450
550
650
750
F1 (Hz)
/i/
/e/
/E/
/@/
/a/
/O/
/o/
/u/
Tonal Acute
Tonal Circumflex
Tonal Short
Non-tonal Acute
Non-tonal Circumflex
Non-tonal Short

Table 3

Phoneme	F1 Accent types	df	F	p (α=.05)	F2 Accent types	df	F	p (α=.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	.004	Acute vs. circumflex	1, 189	.055	.814
/ɛ/	Acute vs. circumflex	1, 174	.852	.357	Acute vs. circumflex	1, 174	6.67	.011
	Acute vs. short	1, 126	5.64	.019	Acute vs. short	1, 125	8.65	.004
	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	.041
	Acute vs. short	1, 158	23.71	<.00001	Acute vs. short	1, 158	.118	.731
	Circumflex vs. short	1, 168	21.01	<.00001	Circumflex vs. short	1, 168	3.84	.052
/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	.047	Acute vs. circumflex	1, 136	1.40	.239
	Acute vs. short	1, 116	12.16	.0007	Acute vs. short	1, 116	8.41	.004
	Circumflex vs. short	1, 138	3.01	.085	Circumflex vs. short	1, 138	3.54	.062
/o/	Acute vs. circumflex	1, 208	9.29	.003	Acute vs. circumflex	1, 208	7.86	.006
/u/	Acute vs. circumflex	1, 207	.000	.992	Acute vs. circumflex	1, 206	9.07	.003
	Acute vs. short	1, 108	2.87	.093	Acute vs. short	1, 108	.791	.376
	Circumflex vs. short	1, 137	4.55	.035	Circumflex vs. short	1, 136	.876	.351

Table 4

Phoneme	F1 Accent types	df	F	p (α=.05)	F2 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>
/ə/	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