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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, Engstrand 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-accented¹ 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* /po:t/ – 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 (\pm of mean value, $\alpha = .05$) 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 (\pm of mean value, $\alpha = .05$) 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 /ε/ 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 [ε], [a], [u], circumflex vs. short in [a] and [ε], 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 [ε] 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, forthcoming-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 morphologically 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, forthcoming-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 [ɔ], 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.

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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 experiment can be found in Jurgec-forthcoming-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			

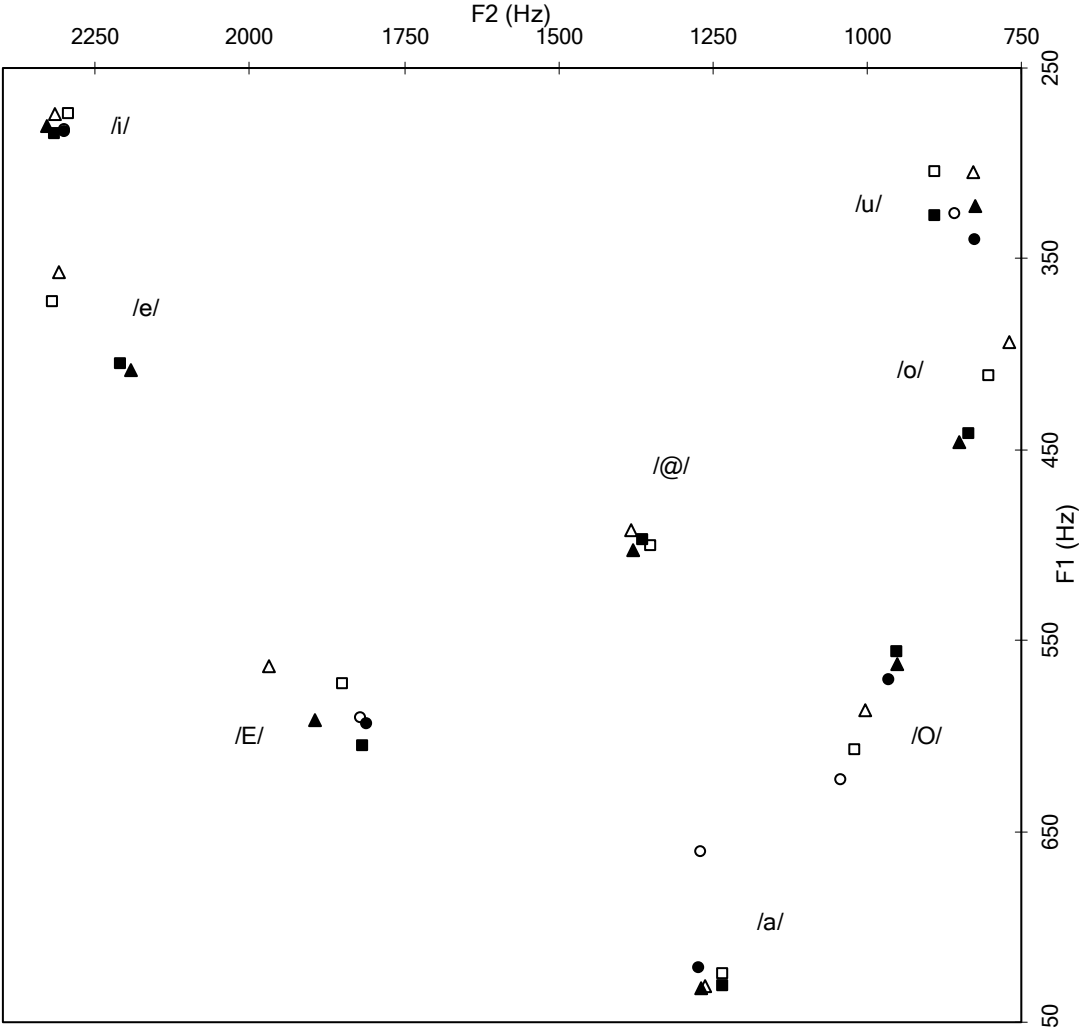
Table 2

	/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



△ Tonal Acute □ Tonal Circumflex ○ Tonal Short ▲ Non-tonal Acute ■ Non-tonal Circumflex ● Non-tonal Short

Table 3

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

Phoneme	F1				F2			
	Accent types	df	F	p ($\alpha=.05$)	Accent types	df	F	p ($\alpha=.05$)
<i>/i/</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
<i>/e/</i>	Acute vs. circumflex	1, 195	.141	.708	Acute vs. circumflex	1, 194	.189	.665
<i>/ɛ/</i>	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
<i>/a/</i>	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>
<i>/ə/</i>	Acute vs. circumflex	1, 159	.309	.579	Acute vs. circumflex	1, 159	.372	.543
<i>/ɔ/</i>	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
<i>/o/</i>	Acute vs. circumflex	1, 206	.216	.643	Acute vs. circumflex	1, 206	1.07	.303
<i>/u/</i>	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