

Spectral Tilt as a Cue to Word Stress in Polish, Macedonian, and Bulgarian

Katherine Crosswhite

University of Rochester

E-mail: crosswhi@ling.rochester.edu

ABSTRACT

Word stress in strongly stress-timed languages like Dutch and English is known to be associated with changes in spectral tilt, which are plausibly linked to both increases in glottal effort and increases in perceived loudness [1], [2]. In this paper, I show that this is also true for Polish, Macedonian, and Bulgarian, a group of languages that are prosodically distinct from Dutch and English. Polish and Macedonian are both syllable-timed languages with predictable stress, and Bulgarian is weakly stress-timed with lexical stress [3]. An acoustic measure linked to spectral tilt (*phons-dB*) was significantly affected by stress in all three languages, an effect that held for all phonemic vowel heights of the languages studied. It is further hypothesized that measures of spectral tilt may therefore be useful in word segmentation in languages with predictable stress.

1. INTRODUCTION

In [1], Sluijter and van Heuven argue that although word stress is often impressionistically described as involving an increase in loudness, it may not be the case that sound intensity level is a direct acoustic correlate of word stress. They point out that perceived loudness is affected not only by intensity level, but also by the distribution of energy over the frequency spectrum (spectral balance): increased energy in frequency bands to which the human auditory system is particularly sensitive leads to increased perceived loudness. The spectral balance of speech sounds can be manipulated by changing the symmetry of the glottal pulse, thus changing the spectral tilt of the glottal source: a more asymmetric glottal pulse leads to a glottal spectrum with a less negative tilt and therefore concentrates more energy in mid-frequency harmonics. Sluijter and van Heuven show that stress-related changes in spectral balance plausibly linked to changes in the glottis do occur in Dutch [1]. A related methodology focusing on estimating spectral tilt from the amplitude of spectral prominences has also been successfully applied to English stress [2].

Dutch and English are prosodically similar languages, both possessing lexical word stress that is impressionistically strong, and both are commonly described as strongly stress-timed languages. In this paper, the spectral tilt hypothesis is assessed for three

languages that are prosodically distinct from both Dutch and English; namely, Polish, Macedonian, and Bulgarian. Polish and Macedonian are prototypical syllable-timed languages: they have impressionistically weak stress whose placement is predictable (penultimate for Polish, antepenultimate for Macedonian), and no reduction of unstressed vowels. Bulgarian has lexical stress and is commonly described as stress-timed, but as pointed out in [3], these characteristics are more weakly realized in Bulgarian than in a prototypical stress-timed language like English. Bulgarian can thus be thought of as weakly stress-timed.

2. ASSESSING SPECTRAL TILT

A number of methods have been used for measuring spectral tilt from speech recordings. In [1], spectral tilt was inferred by comparing sound intensity in different frequency bands: a less negative spectral tilt leads to increased intensity in mid-frequency bands. In other work, glottal spectral tilt was inferred by mathematically removing some of the effects of the supralaryngeal filter to provide an approximation of glottal source characteristics [2], [4]. The current study focuses on the idea that perceived loudness is the link between stress and spectral tilt. Spectral tilt is therefore assessed by comparing sound intensity level (dB) with perceived loudness (phons). In order to control for random variation in speaking level, the measure examined is the difference between loudness and intensity: *phons-dB*. Increased values for this measure can be taken to indicate a less negative spectral tilt: if spectral tilt becomes less negative as intensity is held constant, the difference between loudness and intensity will increase as more energy is concentrated in the mid-frequency range, leading to increased perceived loudness.

For Dutch and English, the relationship between spectral tilt and stress was assessed by comparing stressed and unstressed vowels coming from stress minimal pairs, such as Dutch *canon* ‘cannon’ versus *kanon* ‘canon’. In languages with predictable stress, such as Polish and Macedonian, we do not expect to find many such pairs, if any. (Indeed, they are rare even in lexical stress languages [5].) Therefore, this study uses other types of comparisons. In a ‘different word’ comparison, used for Polish and Macedonian, stressed and unstressed variants of the same vowel were taken from different words, specifically from two different verb forms chosen to display a stress shift (e.g. Polish [pómots] ‘help, inf.’

versus [pomágaj] ‘help, imp.’). In a ‘same word’ comparison, stressed and unstressed variants of a given phoneme were taken from adjacent syllables of polysyllabic words, such as [genétika] or [statístika]. Same word comparisons were made for all three languages.

3. DIFFERENT WORD COMPARISONS

Four stressed-unstressed vowel pairs of Polish and Macedonian were compared, as shown in Table 1. Since stress is predictable in these languages, varying the number of suffixes attached to a verbal stem causes stress to shift. As illustrated, postverbal clitics in Macedonian count for stress placement.

Polish:		
ótkr[i]ç-otkr[í]vaj	‘open’	(<i>infinitive – imperative</i>)
[ó]tkriç-[o]tkrívaj	‘open’	
z[á]t[õ]ç-z[a]t[í]naj	‘start’	
p[ó]mots-p[o]mágaj	‘help’	
Macedonian:		
ótkr[i]jam-otkr[í]vaj go	‘I open’ – ‘open it’	
[ó]tkrijam-[o]tkrívaj go		
p[ó]magnam-p[o]mágaj mu	‘I help’ – ‘help him’	
póm[a]gnam-pom[á]gaj mu		

Table 1: Polish and Macedonian verb pairs

These items were embedded in carrier sentence pairs, as in Table 2.

Polish	
[mám zámjar zát[õ]ç ten kurs]	‘I’m going to start <u>this</u>
[njé zat[í]naj go téras]	<u>course.</u>
	‘ <u>Don</u> ’t start it <u>now.</u> ’
Macedonian	
[sákam da pómagnam na bránko]	‘I want to help <u>Branko.</u> ’
[n’è pomágaj mu tókmu séga]	‘ <u>Don</u> ’t help him <u>just</u>
	<u>now.</u> ’

Table 2: Sample carrier sentence pairs

Sentence pairs were read from index cards by native speakers of Polish (n = 4) and Macedonian (n = 5), respectively, with each pair repeated three times. The sentence pairs were formulated so that in natural readings emphasis would not fall on the experimental word. Participants were recorded using a unidirectional head mounted microphone and DAT recorder. Digital recordings were then transferred to computer for analysis using Praat phonetics software [6]. Each of the experimental vowels was excised from its carrier phrase. The intensity level in dB and the perceived loudness in sones were logged for each vowel. Values were converted from the linear sone scale to the logarithmic phon scale for easier comparison with dB values, according to formula (1).

$$phons = 10(\log_{10}sones / \log_{10}2) + 40 \quad (1)$$

A single value representing the difference between perceived loudness and intensity level was then calculated by subtracting the dB value from the phon value for each vowel. Separate repeated measures ANOVAs were conducted for each language. In both languages stressed syllables had significantly more mid frequency energy, as evidenced by greater values for phons–dB, Fig. 1 (Macedonian: F=23.84, p=.0001; Polish: F=24.73, p=.0001).

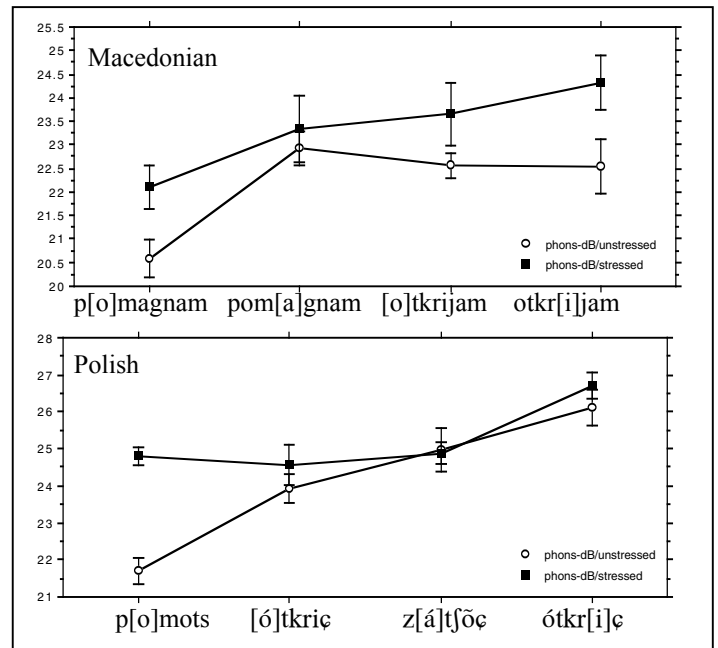


Fig. 1: Effect of stress on phons–dB in Macedonian and Polish, with standard error.

In Macedonian, vowel pair did not significantly interact with stress (F=2.24, p=.27), but in Polish it did (F=8.17, p=.0002). In the latter case, the vowel pair [ó]tkriç-[o]tkrívaj did not show a significant stress effect. This may be due to the word-initial position of the [o]: in Polish, onsetless vowels are often glottalized, and glottalization is independently known to affect spectral tilt, cf. [7]. In Polish, the effect of stress did not interact with speaker (F=1.26, p=.3011), but in Macedonian it did (F=6.24, p=.002). All Macedonian speakers showed a difference between stressed and unstressed phons–dB in the appropriate direction, but there was significant individual variation in the size of this difference.

4. SAME WORD COMPARISONS

Stressed-unstressed vowel pairs taken from adjacent syllables of six polysyllabic words were used for same-word comparisons in Bulgarian, Polish, and Macedonian. In order to facilitate comparisons across the three languages, phonotactically appropriate “international words” that occur in all three languages were chosen, shown in Table 3. (Note that for Polish, these items have

lexically exceptional antepenultimate stress.)

[gramátika]	‘grammar’
[fantástika]	‘fantastic story’
[genétika]	‘genetics’
[kibernétika] (Bulg., Mac.);	‘cybernetics’
[tsibernétika] (Pol.)	
[metafízika]	‘metaphysics’
[statístika]	‘statistics’

Table 3: Same-word comparison items

These items were recorded from native speakers of Bulgarian (n=7), Macedonian (n=5), and Polish (n=4). The Macedonian and Polish items were recorded during the same sessions and from the same participants as were the different-word items discussed earlier. All words were pronounced three times by each participant, using a carrier sentence equivalent to “Don’t write [the word] _____ here!” with contrastive emphasis on the negation. Recording and measurement procedures were the same as described for the different-word comparisons. The last item, [statístika], was problematic: in all three languages, an unstressed high vowel located between voiceless consonants is subject to gradient devoicing. In many tokens of this word, the vowel was entirely voiceless. Any token with fewer than three modal glottal cycles was excluded from analysis; this eliminated most of the [statístika] tokens produced by male speakers, and a small number produced by female speakers.

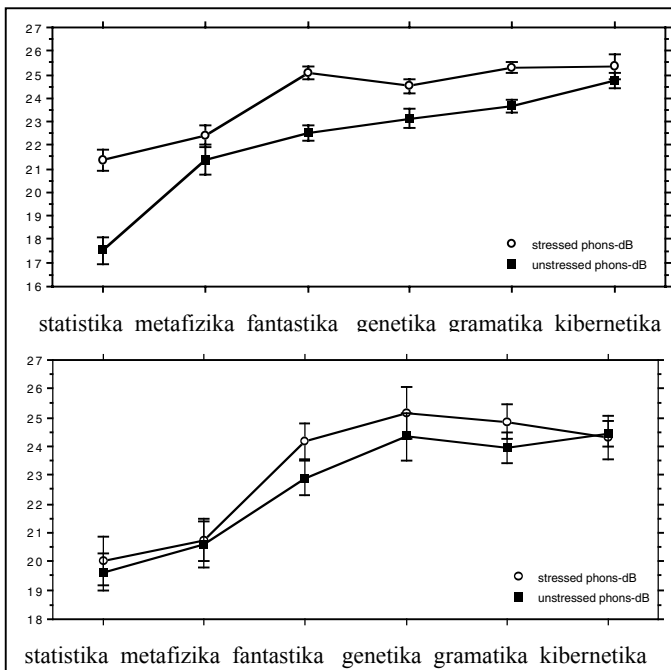


Fig. 2: Stress in Bulgarian and Macedonian same-word comparison items, with standard error

Stress had a significant effect on phons-dB in both Bulgarian ($F=91.91$, $p=.0001$) and Macedonian ($F=8.72$, $p=.0041$), although the effect is stronger and more consistent across items in the former, as shown in Figure

2. Individual variation in how strongly different speakers “punched” the stressed syllable occurred in both languages (Bulg. $F=1.93$, $p=.07$; Mac. $F=5.24$, $p=.0009$). A similar effect was not found for Polish, as illustrated in Figure 3.

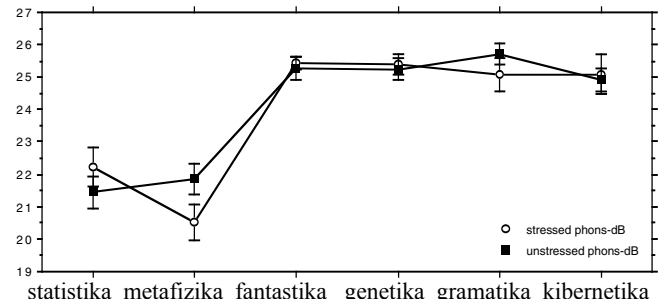


Fig. 3: Null stress effect for Polish same-word comparison items, with standard error

The null result for Polish is surprising both because the very same lexical items had a positive result in the prosodically similar language Macedonian, and because the Polish different-word comparison items had a positive result. Lack of a stress effect in the Polish same-word comparison items may be due to the fact that these words are lexical exceptions to the general Polish pattern of penultimate stress. A second possibility is that initial syllables in Polish bear some degree of secondary stress, as suggested independently in [8]. This hypothesis is supported in the current study by the fact that Polish [metafizika], the only same-word comparison item that does not involve an initial syllable and does not have a vowel voicing problem, did show a significant stress effect ($F=18.49$, $p=.0013$).

5. DISCUSSION AND CONCLUSIONS

The present study finds significant effects of stress in three languages on an acoustic measurement, phons-dB, that is linked to spectral tilt and perceived loudness. Spectral tilt has previously been linked to word stress in strongly stress-timed languages; the current study extends this finding to a prosodically distinct group of languages. The fact that stress has a significant effect on spectral tilt in languages such as Polish, Macedonian, and Bulgarian, where stress is impressionistically weak, supports the idea that spectral tilt and/or glottal pulse asymmetry is correlated with word stress in general, and not with stress timing in specific.

The fact that significant differences were found not only in a lexical stress language (Bulgarian) but also in languages with predictable stress bodes well for the idea that predictable stress can be used in word segmentation, a possibility that was hypothesized as early as Trubetzkoy [9], but which remains unproven. This is important, since it is widely recognized that predictable stress tends to be impressionistically weaker than lexical stress. The current study identifies at least one acoustic characteristic that could be used demarcatively in such languages. This possibility is bolstered by the fact that although spectral

tilt/balance is linked to loudness, it can be varied independently of intensity. As an illustration of this, consider Figure 4, in which intensity level for stressed vs. unstressed vowels for the Bulgarian same-word comparison items is plotted.

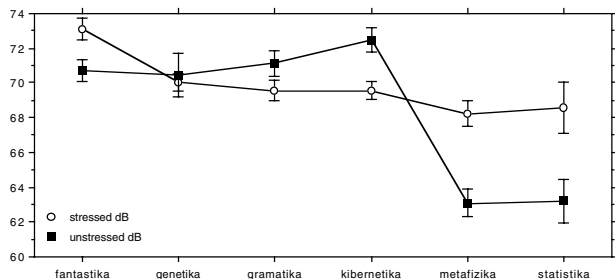


Fig. 4: Intensity level (dB) in Bulgarian same-word comparison items, with standard error

All things being equal, intensity level decreases from the beginning to the end of an utterance. If we consider the items where the stressed vowel precedes its unstressed counterpart (i.e., [metafizika], [statistika]), the stressed vowel has a higher intensity level, as expected. However, no generalization seems to hold for items in which the unstressed vowel comes earlier than the stressed one. In contrast, intensity declination does not affect spectral balance, making it a more reliable cue to stress in same-word comparisons, and therefore a more likely cue for predicting word boundaries in languages with predictable stress.

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