

# Rhythmic stress in Ukrainian: Acoustic evidence of a bidirectional system<sup>1</sup>

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Bidirectional stress systems with internal lapses are rare and their existence has been recently called into question (Newlin-Łukowicz 2012). The present paper reports an acoustic study of secondary stress in Ukrainian based on polysyllabic words with lexical stress located at or near the right edge of the word. The results indicate that Ukrainian has an iteration of secondary stresses from the left edge towards the lexical stress, rather than in the opposite direction. This characteristic makes it metrically related to bidirectional stress systems with internal lapses (e.g. Polish), which invalidates the argument against such systems and proves the empirical adequacy of the metrical theories designed to account for these stress patterns.

KEYWORDS: lexical stress, Metrical Theory, rhythm, secondary stress, Ukrainian

## 1. INTRODUCTION

The main goal of this study is to investigate phonetic underpinnings of lexical and rhythmic stress in Ukrainian. The findings of the present acoustic investigation have implications for current metrical theories because Ukrainian is potentially an example of an intricate bidirectional stress system with an internal lapse adjacent to the main stress. The experimental results are significant from the theoretical perspective as they run afoul of a recent hypothesis that bidirectional stress systems with internal lapses are non-existent (Newlin-Łukowicz 2012).

According to traditional descriptions, Ukrainian has lexical stress and rhythmic stresses radiating from the word edges towards the syllable carrying primary stress, e.g. *pere'pysa,no* 'rewritten', *,velo,sype'dyst* 'cyclist', *'bačy,tyme,te* 'you will see' (Ziłyński 1932, Nakonečnyj 1969).<sup>2</sup> The prosodic system of Ukrainian has been seriously under-researched so far: the few descriptions that are available

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[2] The Ukrainian alphabet is based on the Cyrillic script. In this paper, Ukrainian words are transliterated using the International Scholarly System of Transliteration.

date back to the early-to-mid 20th century and mostly characterise phonetic attributes of stress in impressionistic terms. The only available instrumental study of the Ukrainian prosodic system examines the correlates of primary stress but not secondary stress (Brovčenko 1969). Due to the lack of reliable phonetic sources, the Ukrainian stress system largely remains a *terra incognita* in the phonological literature. Although Ukrainian is listed in the Stress Typ database (available at <http://st2.ullet.net/>), the only information available there is that it has lexical primary stress and secondary stress is ‘none reported’ or ‘verifiably none’. The current study fills this gap by presenting instrumental measurements which confirm the presence of the iterative secondary stress in Ukrainian.

Given that Ukrainian has lexical stress, a word of clarification is in order in what sense its prosodic characteristics might be regarded ‘bidirectional’. By definition, bidirectional systems exhibit primary stress placed at one edge of the word and iteration of secondary stresses from the opposite end (e.g. Kager 2001). Classic examples of such systems are Polish and Garawa, having a rightward and leftward iteration of subsidiary stresses, respectively; see Furby (1974), Rubach & Booij (1985), Halle & Vergnaud (1987), Hammond (1989), McCarthy & Prince (1993), Kraska-Szlenk (2003), McCarthy (2003). Characteristically, in both languages lapses are adjacent to the peak (e.g. *bagatelizowany* (σσ)(σσ)σ(σσ) ‘belittled’ in Polish). The obvious difference between the systems customarily reported as bidirectional and Ukrainian is that in the former both primary and secondary stresses are predictable, and in Ukrainian only secondary stress potentially exhibits an edge-based pattern. Still, there are two theoretically conceivable ways to assign secondary stress in odd-parity words with lexical stress on the penultimate syllable, juxtaposed in (1a) and (1b):<sup>3</sup>

- (1) (a) σσσ'σσ            (b) σ,σσ'σσ    *versyfikacija* ‘versification’  
       σ,σσσσ'σσ        σ,σσ,σσ'σσ    *kapitalizuvaty* ‘to capitalise’

If Ukrainian is a ‘bidirectional’ stress system, acoustic evidence should confirm the former scenario, in (1a), but not the latter, in (1b).

The goal of the present study is to find out whether Ukrainian has secondary stress and, if so, to determine its location with respect to primary stress. To this end, we conducted an acoustic study based on 28 polysyllabic single-root words, collected from 16 monolingual native speakers of Ukrainian. The results reveal a clear subsidiary stress pattern, manifested by syllable duration. In words with primary stress separated by three and more syllables from the left word edge, secondary stress is identified word-initially and on the third syllable, thus confirming the pattern in (1a) above. In addition, a small lengthening effect is found in pretonic position, which appears to be connected with lexical stress rather than rhythm.

[3] Both patterns are attested in the world’s languages. A classic example of the bidirectional pattern in (1a) is Polish (e.g. Rubach & Booij 1985). The pattern in (1b) is exemplified by Warao (Osborn 1966, after Kager 2001: 15).

The paper is organised as follows: [Section 2](#) provides basic generalisations and reviews previous studies of stress in Ukrainian. The design and procedure of the present experiment are described in [Section 3](#). [Section 4](#) presents statistical results, followed by the discussion in [Section 5](#). Conclusions are summarised in [Section 6](#).

## 2. BASIC GENERALISATIONS

Ukrainian has a free lexical stress system. Stress is weight-insensitive: neither syllable structure nor vowel quantity<sup>4</sup> affects stress assignment in Ukrainian. Any syllable within a word can be lexically stressed, as demonstrated by the following examples:

### (2) *Primary stress*

#### (a) Initial stress

*'sonce* 'sun', *'borošno* 'flour', *'naholos* 'word stress', *'zovnišnist'* 'appearance', *'motorošno* 'dizzy', *'jalovyčyna* 'beef', *'lahodytymete* 'you will repair'

#### (b) Medial stress

*ro'bota* 'work', *o'deržuvač* 'recipient', *vy'chodytyme* 'he/she will go out', *obe'režno* 'carefully', *pomir'kovanist'* 'moderation', *obra'chovuvaty* 'calculate', *charakte'rystyka* 'characteristics'

#### (c) Final stress

*se'lo* 'village', *kraso'ta*, 'beauty', *obvynu'vač* 'prosecutor', *universy'tet* 'university', *velosype'dyst* 'cyclist', *municypali'tet* 'municipality'

Standard descriptions of Ukrainian do not agree on how stress is manifested phonetically. Ziłyński (1932: 161) allocates duration, pitch and intensity an equal status, noting that it is not clear which factor is most important in expressing stress. According to Nakonečnyj (1969: 359) and Loboda (2009: 21), Ukrainian stress is dynamic with duration and pitch playing only a subsidiary role. In contrast, Toc'ka (1969: 127; 1981: 136) points to duration as the main exponent of stress in Ukrainian.

The most comprehensive experimental study of Ukrainian stress to date has been conducted by Brovčenko (1969), who compared different acoustic parameters of stressed and unstressed syllables in the data collected from seven native speakers of Ukrainian. The recorded material consisted of 1532 words produced in isolation and in 600 sentences (declarative, interrogative) and in word lists. The overall results showed that duration and intensity were used to differentiate stressed and unstressed syllables, while pitch was not involved in manifesting word stress. In addition, Brovčenko (1969) argues that the most important acoustic parameter of stress in Ukrainian is the total energy, which she calculated by multiplying the average loudness by the duration of the prosodic domain of stressed and unstressed syllables and vowels. The main drawback of this study

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[4] Vowel length is not contrastive in Ukrainian.

is that stressed syllables are compared with unstressed syllables occurring in different prosodic positions. However, Toc'ka (1973) has demonstrated that the duration of unstressed vowels exhibits considerable variation dependent on their position relative to the stressed syllable.

There is no general consensus in the literature as to the presence of secondary stress in Ukrainian. While some descriptive grammars report several degrees of rhythmic stress (Broch 1910, Lehr-Splawiński 1916, Ziłyński 1932, Nakonečnyj 1969), other deny its existence altogether (Brovčenko 1969). According to Nakonečnyj (1969), secondary stress occurs on the initial and/or final syllables if they are separated from the main stress by one or two syllables.

### (3) *Secondary stress*

#### (a) Secondary stress on the initial syllable

- ,σσ'σ     ,holo'va 'head'  
 ,σσ'σσ     ,robit'nyctvo 'working class'  
 ,σσσ'σ     ,peredo'vyk 'leader'  
 ,σσσ'σσ     ,rozpodi'ljaty 'distribute'

#### (b) Secondary stress on the final syllable

- 'σσ,σ     'zolo,to 'gold'  
 σ'σσ,σ     ho'rody,na 'vegetables'  
 'σσσ,σ     'lahody,ty 'repair'  
 σ'σσσ,σ     vy'chovuva,ty 'bring up'

#### (c) Secondary stress on the initial and final syllables

- ,σσ'σσ,σ     ,doglja'dal'ny,cja 'caretaker (NOM, SG, FEM)'  
 ,σσσ'σσ,σ     ,dresyru'val'ny,ka 'tamer (GEN, SG, MASC)'  
 ,σσ'σσσ,σ     ,vporjad'kovuva,nnja 'regulation'

Moreover, an additional degree of stress (referred to as tertiary stress here) appears if word-edge stresses are more than two syllables away from the main stress.

### (4) *Tertiary stress*

- (a) ,σσ,σσ'σ     ,pere,noču'vav 'he slept', ,uni,versy'tet 'university'  
 (b) 'σσ,σσ,σ     'bačy,tyme,te 'you will see', 'jalo,vyčy,na 'beef'

The rhythmic stress pattern for longer words with main stress followed or preceded by five and more syllables is not reported in the literature (e.g. *telefonizu'vaty* 'to set up telephone connection', *amerykani'zovanyj* 'Americanised').

It is not clear how secondary stress is expressed phonetically. Older descriptive grammars (Broch 1910, Ziłyński 1932) entirely ignore this issue. Nakonečnyj (1969) states that syllables carrying secondary stress are produced with greater intensity. However, there are no instrumental measurements to confirm this assertion. Furthermore, it has been observed in the literature that vowels in lexically unstressed positions differ significantly in duration, depending on word length and their distance from main stress (Toc'ka 1973: 172). However, Toc'ka (1973) does not relate this characteristic to any rhythmic pattern.

### 3. PRESENT STUDY

#### 3.1 *Research questions and hypotheses*

The aim of the current research is to conduct an acoustic study of rhythmic stress in Ukrainian. As very little is known about Ukrainian stress, the present research is exploratory and the precursor of a much broader study of the Ukrainian metrical system. To answer the current research questions (formulated in (5) below), we look at stress patterns of words with the main stress removed from the left edge of the word by three, four and five syllables:  $\sigma\sigma\sigma'\sigma(\sigma_n)$ ,  $\sigma\sigma\sigma\sigma'\sigma(\sigma_n)$ ,  $\sigma\sigma\sigma\sigma\sigma'\sigma(\sigma_n)$ .<sup>5</sup>

As mentioned above, standard descriptions of secondary/tertiary prominence have not been confirmed by acoustic evidence. Moreover, Brovčenko (1969: 14–16) explicitly denies its presence in Ukrainian. Therefore, our main objective is to find out whether there is secondary/tertiary stress in the first place. If the standard descriptions of Ukrainian stress are correct, secondary stress is expected to surface on the initial syllable in all the data under investigation, e.g.  $\sigma\sigma\sigma'\sigma(\sigma_n)$ . Another conceivable scenario would be to stress the second syllable in even-parity words:  $\sigma_1\sigma\sigma'\sigma(\sigma_n)$ .<sup>6</sup>

[5] The number of syllables following the main stress ranged from 0 to 2 (indicated by  $(\sigma_n)$  here and below). Note that there is no restriction in Ukrainian on the number of unstressed syllables which can occur to the right of the main stress. Let us note that the distance between the primary stress and the right edge was not a criterion used in selecting the data as the present study focused on words long enough to accommodate both secondary and tertiary stress, as well as internal lapses, to the left of the primary stress.

[6] A *JL* referee points out that derived environments can interact with stress assignment. In English, for example, secondary stress is placed on the first syllable in the word *characteristic* and on the second syllable in the word *abbreviation* because the former is derived from *character* and the latter from *abbreviate*. Similarly, stress preservation is at work in the fourth syllable of the German word *Kontinentalität* 'continentality', derived from *kontinental* 'continental'; compare *Latitudinarismus* 'latitudinarianism', with rhythmic stress on the third syllable (Alber 2005). The interaction of rhythmic stress with morphology in languages such as English or German entails that rhythmic stress is somehow lexicalised. In contrast, stress assignment in languages with grammatical stress following a pattern typical of bidirectional stress systems is clearly postlexical in nature. In Polish, for instance, it is not subject to lexical exceptions and is not affected by morphology, e.g. the word *południe* 'south' has main stress on the penultimate, while its derivative, *południowego* 'southern (GEN, SG, MASC)', is stressed on the initial syllable, not the second one (*\*południowego*), which would be the case if derived

An additional (tertiary) stress intervening between the main stress and the initial stress should appear in words with the main stress removed from the left edge of the word by four syllables:  $\text{,}\sigma\sigma\text{,}\sigma\sigma'\sigma(\sigma_n)$ . Standard grammars do not specify the position of tertiary stress in words with the main stress removed from the left edge of the word by five syllables:  $\sigma\sigma\sigma\sigma'\sigma(\sigma_n)$ . Assuming that secondary stress falls on the initial syllable, either the third or the fourth syllable counting from the left can potentially bear tertiary stress:  $\text{,}\sigma\sigma\text{,}\sigma\sigma\sigma'\sigma(\sigma_n)$  or  $\text{,}\sigma\sigma\sigma\text{,}\sigma\sigma'\sigma(\sigma_n)$ . Interestingly, only the former pattern has been attested cross-linguistically, and languages with a lapse not adjacent to the primary stress are predicted not to exist (Kager 2001, Alber 2005, among others).

In sum, the current research aims to provide answers to the following questions:

- (5) (i) Does Ukrainian have rhythmic stress?
- (ii) Is secondary stress aligned with the left edge of the word?
- (iii) Does Ukrainian have tertiary stress?
- (iv) Which position receives tertiary stress in even-parity words:  $\text{,}\sigma\sigma\text{,}\sigma\sigma\sigma'\sigma(\sigma_n)$  or  $\text{,}\sigma\sigma\sigma\text{,}\sigma\sigma'\sigma(\sigma_n)$ ?

### 3.2 Participants

The data were collected from 16 monolingual native speakers of Ukrainian (four male, 12 female). All of the participants were born and had continuously lived in the Drohobyč region, in western Ukraine. Given the dialectal diversity of modern Ukrainian, the choice of a single region enhances the chance of detecting a uniform pattern. Although most of the participants declared some knowledge of foreign languages, predominantly Russian, Polish, and English, Ukrainian was the language of their everyday use. Therefore, we do not expect any significant interference from other languages. The age of the participants ranged from 18 to 67 years ( $M = 33.4$  years,  $SD = 13.6$ ). The participants had different educational backgrounds – nine had a Masters degree, four had a high-school degree, and three were college students. All of them were naïve about the purpose of the study.

### 3.3 Stimuli

The data set consisted of 28 single-root words with primary stress either on the odd-numbered syllable or on the even-numbered syllable; see Appendix A. The lexical stress in the words chosen for the experiment fell on the antepenultimate, penultimate or final syllable. It was separated from the left edge by minimally

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environments modulated the assignment of rhythmic stress. The main hypothesis of the present study (based on the traditional descriptions of Ukrainian) is that Ukrainian rhythmic stress follows a pattern typical of bidirectional stress systems. If Ukrainian is a bidirectional system, we expect it to have rhythmic stress similar to the one present in Polish, i.e. operating in simple and complex words alike.

three syllables and maximally five syllables. Overall, three prosodic types were distinguished, as shown in Table 1.<sup>7</sup>

Prosodic type		Example	Number of tokens
1 Noniterative	$\sigma\sigma\sigma'\sigma(\sigma_n)$	<i>velosypednyj</i> 'bicycle (NOM, ATTR)'	144 (9 words × 16 speakers)
2 Iterative without a lapse	$\sigma\sigma,\sigma\sigma'\sigma(\sigma_n)$	<i>orhanizuvaty</i> 'organise'	208 (13 words × 16 speakers)
3 Iterative with a lapse	$\sigma\sigma,\sigma\sigma\sigma'\sigma(\sigma_n)$	<i>municipalitet</i> 'municipality'	96 (6 words × 16 speakers)

Table 1  
Division of tokens.

In all the three types, secondary stress is expected to appear on the first syllable. Type 1 and type 3 are predicted to have a lapse on the pretonic syllable, and types 2 and 3, to have an additional secondary stress on the third syllable. Only words with the rightward iteration of the rhythmic stress are included in the present study.<sup>8</sup>

Care was taken to select words in accordance with criteria minimising the risk of biased results. First, words with consonantal clusters in the second or third syllable were discarded. Second, the distribution of high and non-high vowels in the second versus the third syllable did not show bias in favour of the iterative stress hypothesis.<sup>9</sup>

[7] Originally, the study was planned as a paired design with the focus on tertiary stress. The word list contained pairs of morphologically related words that differed in terms of the placement of lexical stress (e.g. *velosy'pednyj* 'bicycle' – *velo,sy'pe'dyst* 'cyclist'). The focus was on the second and third syllables, which were expected to exhibit different proportions in length, depending on whether the third syllable was prosodically weak or strong. The idea of limiting the comparison to the second and third syllables in  $\sigma\sigma\sigma'\sigma(\sigma_n)$  vs.  $\sigma\sigma,\sigma\sigma'\sigma(\sigma_n)$  words was abandoned because a preliminary analysis of the data revealed that the unstressed vowel in the pretonic position received extra length. This ruled out the possibility of finding systematic local differences in relative duration: in both types of words, the third syllable appeared as lengthened as compared to the second syllable, yet apparently for a different reason. Thus, a decision was made to conduct a study of a more exploratory nature, encompassing all syllable positions from initial to tonic.

[8] Words with main stress located at or near the left edge and potentially exhibiting leftward iteration of secondary stresses are less common in Ukrainian, see Łukasiewicz & Molczanow (to appear).

[9] High vowels are known to be inherently shorter than non-high vowels (Peterson & Lehiste (1960)). As a matter of fact, there were more high vowels in the third syllable than in the second syllable in the analysed data set (14 high vowels in the second syllable vs. 17 high vowels in the third syllable). Therefore, the increased duration which is expected to occur in the position of secondary stress (the third syllable) cannot be due to intrinsic vowel differences.

### 3.4 *Experimental procedure*

Recordings were produced in Ukraine, using an H4 Zoom portable digital audio recorder, set at a sampling rate of 44.1 kHz, and an AT897 microphone. Participants read the list of 28 words, consisting of single-root nouns, adjectives and verbs. The words were presented as a list of isolated words printed in Arial typeface, 13 pt letter size. Participants were asked to embed the tokens within a carrier sentence *Vin skazav . . . druhyj raz* ‘He said . . . for the second time’, which was printed at the top of the page. The critical item appeared in a position where it did not carry sentence stress and was not subject to sentence-final lengthening. Primary stress was marked orthographically to avoid hesitations on the speakers’ part.<sup>10</sup> The participants were asked to read the sentences at a natural pace, taking breaks when needed.

### 3.5 *Data analysis*

The data were analysed using Sound Forge and Praat (Boersma & Weenink 1992–2017). Segmentation was done manually by the authors based on the inspection of the waveforms and the spectrograms as well as auditory perception. The syllable boundaries were marked at vowel–consonant junctures. In the tokens containing sonorant–obstruent clusters, the sonorant was syllabified into the coda of the first syllable. There were five such words in the data set: *ver.sy.fi.ka.ci.ja* ‘versification (NOUN)’, *ver.sy.fi.ka.cij.nyj* ‘versification (ADJ)’, *kon.fe.de.ra.ci.ja* ‘confederation’, *kon.fe.de.ra.cij.nyj* ‘confederate’, and *or.ha.ni.zu.va.ty* ‘organise’. Syllable boundaries were aligned with the beginning of the closure phase in stops and the onset of noise in fricatives. Sonorant consonants were identified according to the formant transitions between consonants and preceding vowels. Initial onsetless syllables were extracted on the basis of the formant structure and the dynamics of glottalisation patterns. Out of 448 recorded tokens, 94 tokens were rejected due to mispronunciations and hesitations on the speakers’ part. Rejected tokens were mostly long unfamiliar words of six or seven syllables. Additionally, 170 vowel-initial syllables were excluded from the statistical analyses in order not to underestimate the duration score of the initial syllable. We also discarded a handful of syllables containing clusters or codas. In total, 1410 syllables in six positions were included in the analysis.

The parameters which usually manifest both primary and secondary stress include duration, intensity, and pitch change (Fry 1955, Lehiste & Peterson 1959, Peterson & Lehiste 1960, Morton & Jassem 1965, Lehiste 1970, Beckman 1986, Cutler 2005, Plag, Kunter & Schramm 2011). However, a preliminary inspection of the collected data as well as the previous work on primary stress (Brovčenko 1969) have indicated that the main cue of stress in Ukrainian is duration.

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[10] Let us note that it is customary to indicate primary stress in dictionary entries in Ukrainian.



The results reported in an accompanying pilot study by Łukaszewicz & Mołczanow (2016) point to no correlation between increased intensity or  $f_0$  values and lexical or subsidiary stress in Ukrainian. The contours of the two parameters obtained for the iterative subset, i.e.  $\sigma\sigma\sigma\sigma'(\sigma_n)$  words, are presented in Figures 1 and 2. Clearly, the tonic vowel is not characterised by the highest level of intensity or  $f_0$ . Also, there is no discernible pattern of alternating stresses in the syllables preceding main stress.

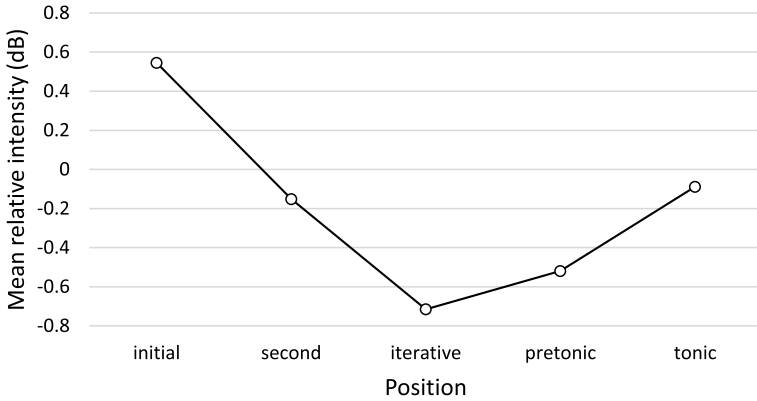


Figure 1

Mean relative intensity in  $\sigma\sigma\sigma\sigma'(\sigma_n)$  words. Relative intensity stands for amplitude standardised in dB (with average amplitude in the word as the reference level).

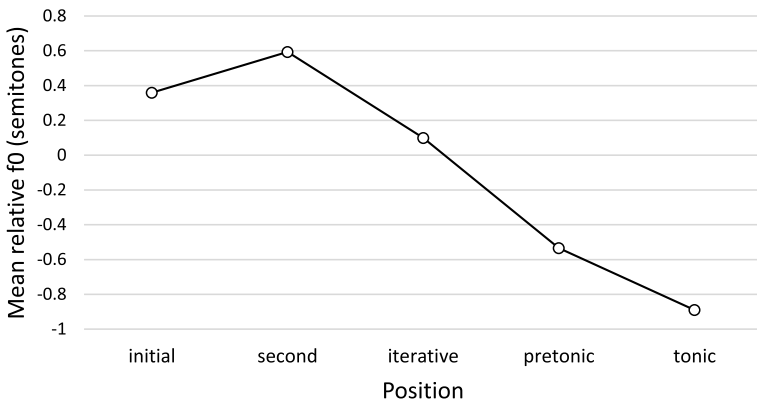


Figure 2

Mean relative  $f_0$  in  $\sigma\sigma\sigma\sigma'(\sigma_n)$  words. Relative  $f_0$  stands for  $f_0$  standardised in semitones (with average  $f_0$  in the word as the reference level).

A recent acoustic study of secondary stress in Polish, which is geographically and historically related to Ukrainian, has revealed that secondary stress is expressed by an increased length of consonants in the onsets of stressed syllables (Łukaszewicz 2015, to appear). As for Ukrainian, there are indications in the literature that vowels have different durations in unstressed syllables depending on their distance from lexical stress (Toc'ka 1973). Since it is possible that both vocalic and consonantal length may be affected in positions of secondary/tertiary stress, a decision was made to measure the duration of the whole syllable. Overall, we expect both primary and secondary/tertiary stress to be manifested by a substantial difference in duration of adjacent syllables.

There is no literature on just-noticeable differences in duration (JNDs) specific to Ukrainian. In the analyses below we tentatively assume 10 ms as the minimal threshold because it is generally agreed that, in the range of durations between 30–300 ms, JNDs are between 10–40 ms, although the limit of perceptibility under optimal conditions may be much smaller (Lehiste (1970: 13); see also the more recent work of Fletcher (2010: 526) and the literature cited therein).<sup>11</sup>

#### 4. STATISTICAL ANALYSES

Six non-overlapping positions were distinguished in the analyses: initial, second, iterative (optional), fourth (optional), pretonic, and tonic. The syllables in the three data subsets were coded as shown in (6). Based on the traditional descriptions, we expected to find longer duration in the initial, iterative, and tonic positions, relative to the neighbouring unstressed positions.

- (6) (a) Noniterative:  $;\sigma\sigma'\sigma(\sigma_n)$   
 initial – second – pretonic – tonic
- (b) Iterative without a lapse:  $;\sigma\sigma,\sigma'\sigma(\sigma_n)$   
 initial – second – iterative – pretonic – tonic
- (c) Iterative with a lapse:  $;\sigma\sigma,\sigma\sigma'\sigma(\sigma_n)$   
 initial – second – iterative – fourth – pretonic – tonic

The statistical analyses were divided into two parts. The first set of analyses had a purely exploratory character and tackled all syllables regardless of their segmental content (Section 4.1). In order to control for the potentially confounding segmental factor, the second set of analyses was designed to compare segmentally identical syllables in different positions (Section 4.2).

[11] For Dutch, Rietveld, Kerkhoff & Gussenhoven (2004) report a 23 ms difference between unstressed syllables and syllables carrying subsidiary stress. For Polish, Łukaszewicz (to appear) reports a 12.5 ms difference (in onset consonant duration measured relative to the preceding vowels) between unstressed and tertiary stress positions.

## 4.1 An overall analysis

The overall analysis was based on 1410 syllable tokens. All of the tokens were of the consonant–vowel type. All other syllable types were discarded.

The effect of stress on syllable duration was tested in terms of linear mixed-effects models, fitted in SPSS (version 23). Syllable duration may be affected considerably not only by prosodic position but also by other factors, such as inter-speaker differences in speech rate or word length. In order to control for such factors, the random effects of Speaker and Item were included. The competing models were compared in terms of likelihood ratio tests (e.g. Pinheiro & Bates 2000, Baayen 2008). The best fit was achieved by the linear mixed-effects model with random intercepts for Speaker and Item, and with Position as the fixed-effect term. The comparison of the nested models, using the standard chi-square reference, shows that the effect of stress is extremely significant ( $\chi^2(5) = 1282.108$ ,  $p < .0001$ ). All positions exhibit significantly smaller duration compared to the baseline, i.e. the tonic position carrying lexical stress (see Table 2). The biggest distance is between the second and the tonic positions ( $\beta_2 = -108.5$ ,  $SE = 2.45$ ,  $t = -44.22$ ,  $p < .0001$ .) The initial position (i.e. the secondary-stress carrying syllable) is the second longest syllable in the word ( $\beta_1 = -78.9$ ,  $SE = 3.24$ ,  $t = -24.33$ ,  $p < .0001$ ). Table 3 depicts the predicted mean durations for the six positions (see also Figure 3). Post-hoc pairwise comparisons (see Appendix B) confirm that the tonic syllable is significantly longer and the second syllable

Parameter	Estimate	Std. error (SE)	df	<i>t</i>	Sig.	95% confidence interval	
						Lower bound	Upper bound
Intercept	237.072580	5.225409	27.800	45.369	.0000	226.365351	247.779808
Initial	-78.935799	3.244834	1393.717	-24.327	.0000	-85.301085	-72.570514
Second	-108.532948	2.454323	1384.424	-44.221	.0000	-113.347541	-103.718355
Iterative	-87.526883	2.775026	1394.269	-31.541	.0000	-92.970560	-82.083206
Fourth	-90.608986	4.240015	1394.291	-21.370	.0000	-98.926483	-82.291489
Pretonic	-83.313738	2.454323	1384.424	-33.946	.0000	-88.128331	-78.499145
Tonic	0 <sup>a</sup>	0	—	—	—	—	—

<sup>a</sup> This parameter is set to zero because it is redundant.

Table 2  
Estimates of fixed effects. Dependent variable: duration (ms).

Position	Mean	Std. error (SE)	df	95% confidence interval	
				Lower bound	Upper bound
Initial	158.137	5.521	34.569	146.924	169.350
Second	128.540	5.110	25.442	118.025	139.054
Iterative	149.546	5.253	28.396	138.791	160.300
Fourth	146.464	6.183	54.055	134.069	158.859
Pretonic	153.759	5.110	25.442	143.244	164.274
Tonic	237.073	5.225	27.800	226.365	247.780

Table 3  
Estimates of means. Dependent variable: duration (ms).

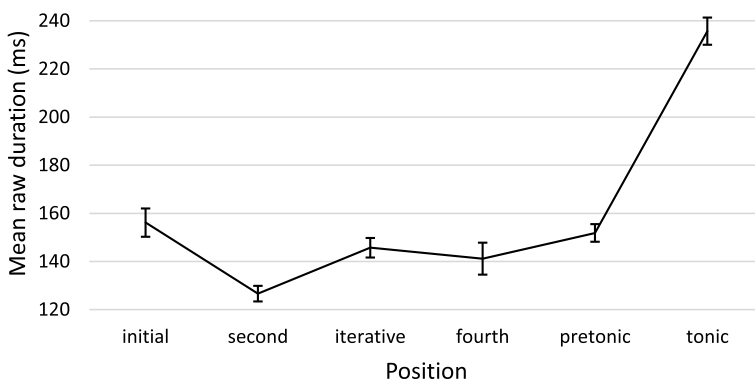


Figure 3

Mean syllable duration depending on position.  
(Error bars represent 95% confidence interval for the mean.)

significantly shorter than all the other positions. On average, the initial syllable is 29.6 ms longer than the second syllable. A significant increase in duration is also reported for the iterative position (the tertiary-stress carrying syllable), which turns out 21 ms longer than the preceding (i.e. second) syllable ( $p < .0001$ ).

As illustrated in Figure 3, changes in syllable durations form a wave-like pattern, in which we can discern three peaks – in the initial, iterative and tonic positions. There is no clear pattern of peaks and valleys corresponding to alternating stresses in the two syllables preceding the tonic syllable (fourth and pretonic): both the downward slope in the fourth syllable and the upward slope in the pretonic position turn out statistically insignificant. As the latter is followed by a much bigger and statistically significant rise in the tonic position, we interpret it as a lengthening effect in the vicinity of lexical stress. Notably, pretonic lengthening recurs regardless of the type of the word, i.e. it is also seen in the noniterative subset. That is why we take it to be unconnected with rhythm and connected with the tonic syllable. In other words, in the close vicinity of the syllable carrying lexical stress, some kind of anticipation of the lexical stress takes place and there is no space for an alternating pattern of smaller peaks and valleys characteristic of rhythm.

#### 4.2 An analysis of segmentally identical syllables

In order to dismiss a possibility that the rise on the iterative syllable could be caused by intrinsic differences in segmental length, another linear mixed-effects model was fitted to compare segmentally identical syllables in different positions. For the purpose of this analysis, we identified three CV syllables (*ka*, *ni*, *li*), each of which recurred in four word-medial positions in the data: second, iterative,

fourth, and pretonic;<sup>12</sup> see Appendix C for the list of words. The analysis was based on 180 tokens (12 words). (Each syllable in each position was represented by 15 tokens.) To make the three segmentally different syllables comparable, raw duration values were standardised ( $z$ -scores were calculated). The random intercept for Speaker was included to control for individual differences in speech rate.

As in the previous analysis, the effect of Position turned out statistically significant ( $\chi^2(3) = 39.853, p < .0001$ ). The pretonic position was longer than all other positions at  $\alpha = .05$  (see Table 4). Crucially, the biggest significant increase in syllable duration (by 0.665 standard deviation; see Appendix D) was found in the iterative position (compare the estimates for the mean standardised duration of the second and iterative syllables in Table 5). In raw duration terms, the iterative syllable was about 16 ms longer than the second syllable ( $p < .0001$ ). The fourth syllable was not statistically different from the iterative position (for post-hoc comparisons see Appendix D). Overall, these findings confirm the pattern obtained in the previous analysis (see also Figure 4).

Parameter	Estimate	Std. error (SE)	df	$t$	Sig.	95% confidence interval	
						Lower bound	Upper bound
Intercept	0.545540	0.167490	41.204	3.257	.0023	0.207339	0.883742
Second	-0.982371	0.150516	158.908	-6.527	.0000	-1.279642	-0.685101
Iterative	-0.317446	0.156008	163.913	-2.035	.0435	-0.625490	-0.009402
Fourth	-0.555032	0.152641	161.698	-3.636	.0004	-0.856458	-0.253606
Pretonic	0 <sup>a</sup>	0	—	—	—	—	—

<sup>a</sup> This parameter is set to zero because it is redundant.

Table 4

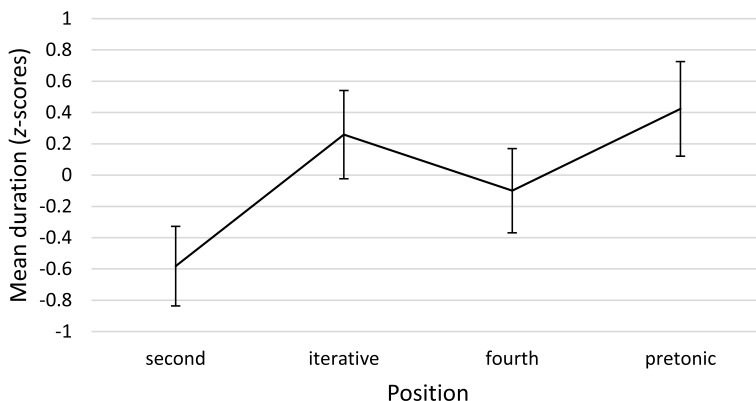
Estimates of fixed effects. Dependent variable: duration ( $z$ -scores).

Position	Mean	Std. error (SE)	df	95% confidence interval	
				Lower bound	Upper bound
Second	-0.437	0.169	41.324	-0.777	-0.096
Iterative	0.228	0.172	43.216	-0.118	0.575
Fourth	-0.009	0.169	41.810	-0.350	0.331
Pretonic	0.546	0.167	41.204	0.207	0.884

Table 5

Estimates of means. Dependent variable: duration ( $z$ -scores).

[12] There were no *ka*, *ni*, *li* syllables in the initial and tonic positions in the data set.



*Figure 4*

Mean standardised syllable duration depending on position.  
(Error bars represent 95% confidence interval for the mean.)

## 5. DISCUSSION

Investigations of stress in various languages have demonstrated that acoustic correlates of stress include increased duration, intensity, the fundamental frequency ( $f_0$ ) changes, as well as differences in vowel quality (e.g. Fry 1955, Lehiste & Peterson 1959, Peterson & Lehiste 1960, Beckman 1986). Previous experimental research suggests that duration is the most robust cue to stress in Ukrainian (Brovčenko 1969). In the light of this finding as well as our pilot study and impressionistic evidence, the focus of the present experiment was on syllable duration measurements. The results of the current research corroborate both intuitive descriptions as well as previous experimental findings, and show that duration is a robust indicator of lexical stress. The comparison of lexically stressed and unstressed syllables has yielded statistically significant differences in length between the two prosodic positions. On average, syllables carrying primary stress are 1.5 times longer than other syllables within a word.

Furthermore, the present study has demonstrated that duration also cues rhythmic stress, which was detected on odd-numbered syllables counting from the left edge of the word. This finding is consistent with traditional descriptions of Ukrainian, which report secondary level of prominence on the basis of impressionistic evidence (Broch 1910, Lehr-Splawiński 1916, Ziłyński 1932, Nakonečnyj 1969). Prior to the present study, there was no experimental research investigating acoustic correlates of secondary stress. Toc'ka (1973) provides a phonetic characterisation of Ukrainian vowels, where she specifies relative duration of vowels in different prosodic positions. However, though she notes (on page 172) that 'there is a tendency in Ukrainian to periodically shorten unstressed

vowels in every second or third syllable',<sup>13</sup> she does not explicitly relate the differences to possible occurrence of secondary stress.

An unexpected finding of the present experiment concerns the increased duration of the syllable immediately preceding the syllable with main stress. The nature of pretonic lengthening is presently little understood. It has been traditionally assumed that the minimum size of the unit of stress realisation is a syllable (Lehiste 1970: 147). However, the Ukrainian data suggest that, at the phonetic level, the domain of stress can be extended to a preceding syllable. Let us note that pretonic lengthening is attested in some East Slavic dialects spoken at the Ukraine–Belarus border (Upper Snov Basin dialect type) and in Russia (Vladimir–Volga Basin dialect type) (Bethin 2006). Bethin (2006) argues that the lengthening of pretonic syllables in these dialects is caused by the presence of a lexical high tone which is associated with the pretonic syllable. However, it is unlikely that the same mechanism underlies the Ukrainian lengthening. First, the immediately pretonic vowels are either equal in duration or longer than the stressed vowel in the East Slavic dialects referred to by Bethin (2006), while pretonic syllables in standard Ukrainian are considerably shorter than the following stressed syllables (having less than two thirds of the tonic syllable's length). Second, the data analysed in the present study were collected in Western Ukraine, which is geographically removed from the area where dialects with pretonic length are spoken.

Similarly to Ukrainian, pretonic syllables are longer than syllables in other unstressed positions in Standard Russian, where relative duration of vowels in the first and second pretonic positions are 68% and 49% of the duration of the stressed vowel (Vysotskij 1973, cited from Bethin 2006: 131). However, Russian is different from Ukrainian in that it does not have rhythmic stress. In contrast, in Ukrainian the duration of the syllable in second pretonic position varies depending on whether or not it appears in the position of tertiary stress. For example, the syllable *ni* occurs in the second pretonic position both in *imu'ni'za'cijnyj* 'immunising' and *uni'fi'kovanyj* 'unified', but it is 90 ms longer in the former due to rhythmic stress (208 ms vs. 118 ms), as illustrated in Figures 5 and 6, with data from a male speaker (M11). (It is interesting to note that the syllable *za* following the *ni* in *imunizacijnyj* is only 132 ms long, although it contains an open vowel.) To the best of our knowledge, no such difference has been reported to exist in Russian. The Ukrainian system is therefore more intricate as it exhibits a complex interplay of pretonic lengthening with rhythmic stress.

The detection of rhythmic stress in Ukrainian is an important result as it demonstrates that Ukrainian has a typologically rare bidirectional stress system in which rhythmic stress is located at the opposite edge of the lexical stress, with stress iteration on the intervening syllables and a lapse adjacent to the peak. The existence of bidirectional iterative stress systems has been recently

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[13] Translation is the authors'.

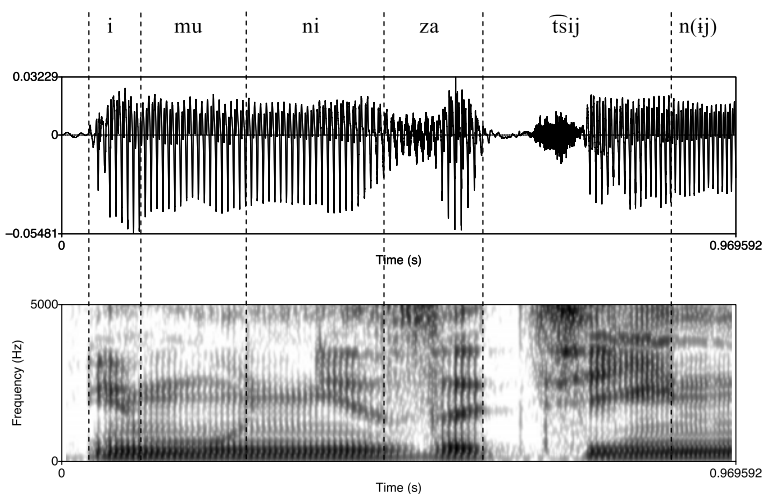


Figure 5  
Waveform and spectrogram for *imu niza'cijnyj* 'immunising'.  
Data from a male speaker (M11).

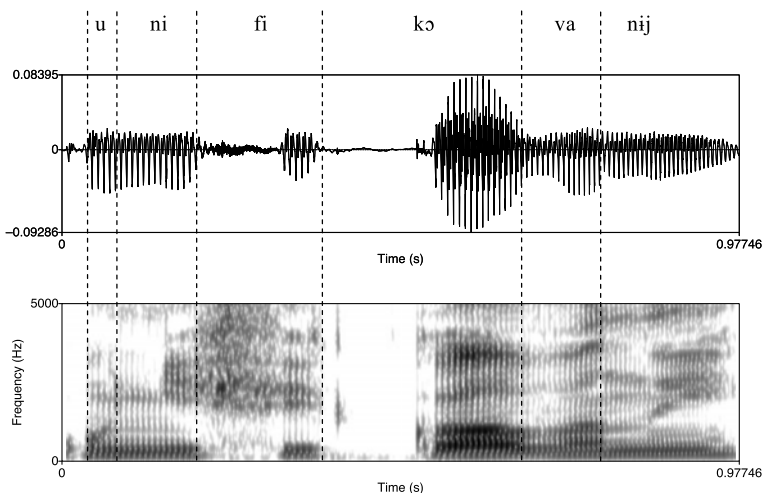


Figure 6  
Waveform and spectrogram for *unifi'kovanyj* 'unified'.  
Data from a male speaker (M11).

called into question by Newlin-Łukowicz (2012), who failed to detect secondary stress in her experimental study of Polish, so far the best documented system with bidirectional iterative stress (Dłuska 1932, Rubach & Booij 1985, Kraska-Szlenk 2003). However, Łukasiewicz (to appear) provides acoustic evidence for



the existence of consonantal rhythm in Polish based on increased duration of onset consonants. The current study demonstrates that a similar rhythmic pattern is found in Ukrainian, where secondary stress appears on initial and every odd-numbered syllable separated from the primary stress by at least one position. The two languages differ in the acoustic manifestation of the rhythmic stress: Polish employs consonant lengthening, while Ukrainian exhibits an increased duration of the whole syllable.

The stress pattern attested in Ukrainian proves the adequacy of theoretical models generating bidirectional systems with internal lapses (see van der Hulst 1996, 2014; Kager 2001, 2005; Gordon 2002; Hyde 2002, 2016; Alber 2005; Bennett 2012, for different approaches). The fragment of Ukrainian metrical system discussed in this paper constitutes an example of a rightward iteration of secondary stresses towards the main stress located near the right word edge, which makes it similar to languages such as Polish (Dłuska 1932), Piro (Matteson 1965) and Lenakel (Lynch 1978). These languages can be analysed equally well in terms of different theoretical models and so cannot be used to choose between the current prosodic theories.

Ukrainian is different from the classic bidirectional systems reported in the literature (as discussed in Section 1) where both primary and secondary stresses are predictable and can be derived by the same mechanism. Unlike other systems, it combines predictable rhythmic stress with unpredictable lexical stress which can move freely back and forth and change the rhythmic structure in its vicinity. As the present study is a first step towards a comprehensive description of the Ukrainian prosodic system, it has only considered words with lexical stress at or near the right word edge. Interestingly, a mirror image pattern potentially occurs in Ukrainian words with primary stress on or near the left edge of the word and secondary stresses to the right of the primary stress. Standard grammars note the presence of secondary stress in such words but disagree as to its exact location. For instance, Nakonečnyj (1969: 360) asserts that the final syllable gets stressed whenever the initial primary stress is separated from the right edge of the word by two or more syllables, with additional prominence on the intermediate syllable, e.g. *'lahody,ty* 'repair', *'bačy,tyme,te* 'you will see'. It is not clear what happens in six-syllable words such as *'vyskorožuvaty* 'to harrow', which are not mentioned in Nakonečnyj (1969). These words can potentially have secondary stress either on the second or the third syllable, in addition to the final subsidiary stress:  $'\sigma\sigma,\sigma\sigma$  or  $'\sigma,\sigma\sigma,\sigma$ . Both patterns are predicted to be unattested in Kager's (2001, 2005) typology. The structure  $'\sigma,\sigma\sigma,\sigma$ , with a lapse between secondary stresses, would also be ruled out by van der Hulst's (1996, 2014) model, which predicts that it cannot coexist within one language with the pattern  $,\sigma,\sigma\sigma'\sigma$ . In this respect, the Ukrainian system is especially interesting as it offers an excellent testing ground for existing metrical theories. Needless to say, this issue cannot be settled without further acoustic research demonstrating whether secondary stresses are present to the right of the primary stress in Ukrainian, and, if so, determining the location of the lapse (see Łukaszewicz & Molczanow to appear).

## 6. CONCLUSION

This paper has reported on an acoustic study of stress in Ukrainian, a language which has not received much attention in the phonological literature. The phonetic measurements have revealed secondary degree of stress, manifested by increased syllable duration. Moreover, a complex pattern of rhythmic stress has been detected on odd-numbered syllables in words with main (lexical) stress on the right-hand word edge with a lapse next to the primary stress: (,σσ)(σσ)σ('σσ). This is an important result for two reasons. First, traditional sources provide contradictory descriptions of secondary stress, not agreeing as to its location or even denying its presence in Ukrainian. Second, this study provides evidence of a typologically rare bidirectional stress, whose existence has been recently called into question (Newlin-Łukowicz 2012).

As the present study has not intended to provide a complete acoustic description of the Ukrainian stress system, we limited its purview to acoustic measurements of syllable duration in words with main stress on the right edge. More research is needed to investigate words with primary stress in the medial position and at the left edge of the word, including the measurements of intensity and pitch levels, as well as vowel quality, as potential cues to stress in Ukrainian.

## APPENDIX A

## List of words

UKRAINIAN SPELLING	TRANSLITERATION	IPA TRANSCRIPTION	GLOSS
американець	<i>amerykanec'</i>	ameri'kanets̃	an American
американізм	<i>amerykanizm</i>	amerika'nizm	Americanism
американізований	<i>amerykanizovanyj</i>	amerikan'i'zovanij	Americanised
ароматизований	<i>aromatyzovanyj</i>	aromati'zovanij	flavoured
ароматизувати	<i>aromatyzuvaty</i>	aromatizu'vati	to flavour
етимологізований	<i>etymolohizovanyj</i>	etimoloh'i'zovanij	etymologised
фетишизований	<i>fetyšyzovanyj</i>	fetiši'zovanij	fetishised
фетишизувати	<i>fetyšyzuvaty</i>	fetišizu'vati	fetishise
імунізація	<i>imunizacija</i>	imun'i'zac'ija	immunisation
імунізаційний	<i>imunizacijnyj</i>	imun'iza'c'ijnij	immunising
капіталістичний	<i>kapitalistyčnyj</i>	kap'itali'i'stičnij	capitalistic
капіталізувати	<i>kapitalizuvaty</i>	kap'itali'izu'vati	capitalise
конфедерація	<i>konfederacija</i>	kɔnfede'rac'ija	confederation
конфедераційний	<i>konfederacijnyj</i>	kɔnfedera'c'ijnij	confederation (ADI)
муніципалітет	<i>munycypalitet</i>	mun'icipali'tet	municipality
організувати	<i>orhanizuvaty</i>	ɔrfian'izu'vati	organise
специфікація	<i>specyfikacija</i>	specifi'kac'ija	specification
специфікувати	<i>specyfikuvaty</i>	specifi'ku'vati	specify
телефонізація	<i>telefonizacija</i>	telefon'i'zac'ija	telephone connection

телефонізувати	<i>telefonizuvaty</i>	telefɔn'izu'vati	to set up telephone connection
телефонувати	<i>telefonuvaty</i>	telefɔnu'vati	to telephone
телефоніст	<i>telefonist</i>	telefɔ'n'ist	telephone operator
уніфікований	<i>unifikovanyj</i>	un'ifi'kɔvanij	unified
уніфікувати	<i>unifikuvaty</i>	un'ifi'ku'vati	unify
велосипедний	<i>velosypednyj</i>	velɔsi'pednij	bicycle (NOM, SG, ATTR)
велосипедист	<i>velosypedyst</i>	velɔsipe'dist	cyclist
версифікація	<i>versyfikacija</i>	versifi'kačija	versification
версифікаційний	<i>versyfikacijnyj</i>	versifika'čijnij	versified

APPENDIX B

Mean differences in duration (ms)

Post-hoc comparisons (based on estimated marginal means).

Condition a	Condition b	Mean difference (a-b)	Std. error (SE)	df	Sig.	95% confidence interval for difference	
						Lower bound	Upper bound
Initial	Second	29.597*	3.027	1393.718	.0000	23.659	35.535
	Iterative	8.591*	3.246	1394.213	.0082	2.223	14.959
	Fourth	11.673*	4.576	1394.291	.0109	2.697	20.650
	Pretonic	4.378	3.027	1393.718	.1483	-1.560	10.316
	Tonic	-78.936*	3.245	1393.717	.0000	-85.301	-72.571
Second	Initial	-29.597*	3.027	1393.718	.0000	-35.535	-23.659
	Iterative	-21.006*	2.518	1387.455	.0000	-25.945	-16.067
	Fourth	-17.924*	4.130	1394.284	.0000	-26.025	-9.823
	Pretonic	-25.219*	2.199	1366.705	.0000	-29.532	-20.906
	Tonic	-108.533*	2.454	1384.424	.0000	-113.348	-103.718
Iterative	Initial	-8.591*	3.246	1394.213	.0082	-14.959	-2.223
	Second	21.006*	2.518	1387.455	.0000	16.067	25.945
	Fourth	3.082	4.241	1393.549	.4675	-5.237	11.401
	Pretonic	-4.213	2.518	1387.455	.0945	-9.152	0.726
	Tonic	-87.527*	2.775	1394.269	.0000	-92.971	-82.083
Fourth	Initial	-11.673*	4.576	1394.291	.0109	-20.650	-2.697
	Second	17.924*	4.130	1394.284	.0000	9.823	26.025
	Iterative	-3.082	4.241	1393.549	.4675	-11.401	5.237
	Pretonic	-7.295	4.130	1394.284	.0775	-15.397	0.806
	Tonic	-90.609*	4.240	1394.291	.0000	-98.926	-82.291
Pretonic	Initial	-4.378	3.027	1393.718	.1483	-10.316	1.560
	Second	25.219*	2.199	1366.705	.0000	20.906	29.532
	Iterative	4.213	2.518	1387.455	.0945	-0.726	9.152
	Fourth	7.295	4.130	1394.284	.0775	-0.806	15.397
	Tonic	-83.314*	2.454	1384.424	.0000	-88.128	-78.499
Tonic	Initial	78.936*	3.245	1393.717	.0000	72.571	85.301
	Second	108.533*	2.454	1384.424	.0000	103.718	113.348
	Iterative	87.527*	2.775	1394.269	.0000	82.083	92.971
	Fourth	90.609*	4.240	1394.291	.0000	82.291	98.926
	Pretonic	83.314*	2.454	1384.424	.0000	78.499	88.128

\* = the mean difference significant at the .05 level

## APPENDIX C

**Items used to compare durations of segmentally identical syllables in different prosodic positions**

Position	<i>ka</i>	<i>ni</i>	<i>li</i>
Second	<i>lokalizувaty</i> 'locate'	<i>unifikovanýj</i> 'unified'	<i>kvalifikovanýj</i> 'qualified'
Iterative	<i>karykaturysta</i> 'caricaturist (GEN, SG)'	<i>imunizacijnyj</i> 'immunising'	<i>kanalizacijnyj</i> 'sewage (ADJ)'
Fourth	<i>amerykanizovanýj</i> 'Americanised'	<i>telefonizувaty</i> 'to set up telephone connection'	<i>kapitalizувaty</i> 'capitalise'
Pretonic	<i>versyfikacijnyj</i> 'versified'	<i>telefonizacija</i> 'telephone connection'	<i>hospitalizacija</i> 'hospitalisation'

## APPENDIX D

**Mean differences in duration (z-scores)**

Post-hoc comparisons (based on estimated marginal means).

Condition a	Condition b	Mean difference (a-b)	Std. error (SE)	df	Sig.	95% confidence interval for difference	
						Lower bound	Upper bound
Second	Iterative	-0.665*	0.156	162.865	.0000	-0.972	-0.358
	Fourth	-0.427*	0.153	161.125	.0058	-0.729	-0.125
	Pretonic	-0.982*	0.151	158.908	.0000	-1.280	-0.685
Iterative	Second	0.665*	0.156	162.865	.0000	0.358	0.972
	Fourth	0.238	0.162	168.529	.1437	-0.082	0.557
	Pretonic	-0.317*	0.156	163.913	.0435	-0.625	-0.009
Fourth	Second	0.427*	0.153	161.125	.0058	0.125	0.729
	Iterative	-0.238	0.162	168.529	.1437	-0.557	0.082
	Pretonic	-0.555*	0.153	161.698	.0004	-0.856	-0.254
Pretonic	Second	0.982*	0.151	158.908	.0000	0.685	1.280
	Iterative	0.317*	0.156	163.913	.0435	0.009	0.625
	Fourth	0.555*	0.153	161.698	.0004	0.254	0.856

\* = the mean difference significant at the .05 level

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