The Rhythm of Heptasyllabic Words: Evidence for Metrical Bidirectionality

Beata Łukaszewicz¹, Ewa Zajbt¹, Urszula Krawczyk¹

¹University of Warsaw, Poland

b.lukaszewicz@uw.edu.pl, e.zajbt@student.uw.edu.pl, urszula.krawczyk@student.uw.edu.pl

Abstract

Polish is considered a classic example of a bidirectional stress system with internal lapses. Such systems are typologically rare and were recently hypothesized to be non-existent [1]. Latest studies [2, 3], based on comparisons of paired five- and six-syllable words, revealed that secondary stress in Polish is iterative and is expressed in terms of onset consonant duration. No acoustic study of Polish words having more than six syllables has been conducted thus far. However, heptasyllabic words, unlike six-syllable words, can be revealing not only about the presence of secondary stress iteration but also about the direction of stress assignment ([(σσ),(σσ)] vs. *[σσ]*). The present paper reports on an acoustic study of heptasyllabic words compared to segmentally matched five- and six-syllable words (eight triplets, e.g. acetylenowego – acetylenu – acetylenowy, collected from eight native speakers of Polish). Four parameters are investigated: onset consonant duration, vowel duration, intensity and fundamental frequency. The results point to the presence of stress on the third syllable of heptasyllabic words, manifested in terms of longer onset consonant duration. This supports traditional descriptions of Polish as a bidirectional stress system.

Index Terms: secondary stress, acoustic correlates of stress, rhythm, prosody, Polish

1. Introduction

In bidirectional stress systems, primary stress is assigned at one edge of the word and secondary stresses iterate from the opposite edge towards the syllable carrying primary stress ([4], [5]). In phonological literature, classic examples of bidirectional systems are Polish and Garawa exhibiting a rightward and leftward iteration of secondary stresses, respectively. Both languages have a lapse (a sequence of two unstressed syllables) adjacent to primary stress in odd-parity words (cf. Polish [(σσ),(σσ)] vs. Garawa [[(σσ),(σσ)]]. Bidirectional systems contrast with unidirectional systems in which secondary stresses radiate from the peak ([(σσ),(σσ)], [(σσ),(σσ)]). Systems with a lapse between secondary stresses (e.g. *[(σσ),(σσ)]*) are predicted to be non-existent in most metrical theories (but cf. [6]).

The stress system of Polish is considered to be the best documented case of metrical bidirectionality [1, pp. 274], however the phonetic evidence confirming the existence of secondary stress in Polish is scarce ([2], [3], [7]). According to traditional descriptions and theoretically oriented studies (e.g. [8], [9], [10], [11], [12], [13]), Polish has main stress falling on the penult and secondary stresses iterating from the left end, as shown in (1) – (4). Stress is assigned based on trochaic feet. Even-parity words are parsed exhaustively into feet; cf. (1), (3).

Odd-parity words have lapses immediately preceding the penult; cf. (2), (4). The presence of iterative secondary stress is illustrated in (3) and (4). The bidirectional nature of the stress system follows from (2) and (4).

![Image](https://example.com/image)

\[ ((σσ)) (ace)(tylen) \] (1)

\[ ((σσ)) (ace)(tylen) \] (2)

\[ ((σσ)) (ace)(tylen) \] (3)

\[ ((σσ)) (ace)(tylen) \] (4)

Bidirectional systems with internal lapses have been recently hypothesized to be non-existent, based on the purported lack of stress iteration in Polish six-syllable words ([1]). Similarly, no iterative secondary stress was reported in [14]. The argument against bidirectional systems was refuted in recent studies (e.g. pomidorowy ‘tomato (Adj., GEN. SG.)’) differs significantly from the third (unstressed) syllable in five-syllable words (e.g. pomidorowy ‘tomato (Adj., GEN. SG.)’) in terms of relative onset consonant duration. The suggestion that secondary stress in Polish is based on consonant duration, and not on vowel parameters as assumed in [1] and [14], first appeared in [7], an early kymographic study of the temporal underpinnings of the Polish stress system. However, the presence of stress iteration in six-syllable words in Polish reported in [2] and [3] is not indicative of the direction of stress assignment, i.e. whether secondary stresses radiate from the left edge towards primary stress (as in bidirectional systems) or from primary stress towards the left edge (as in unidirectional systems). As of yet, there has been no acoustic evidence adduced to directly support the existence of bidirectional systems with internal lapses. The present paper fills this gap, focusing on heptasyllabic words, like (4) above, which are informative both with regard to the presence of secondary stress iteration as well as the direction of secondary stress assignment. If Polish is a bidirectional stress system with internal lapses, seven-syllable words (4) – similarly to six-syllable words (3), but unlike five syllable words (2) – are predicted to have an iteration of secondary stress on the third syllable. Based on previous research (e.g. [2], [3], [7]), secondary prominence in heptasyllabic words is predicted to be expressed in terms of onset consonant duration, not vowel parameters.
2. Method

The protocol of the experiment largely follows the one used in [2] and [3]. In a nutshell, there are four important points which make this protocol different from the methods assumed in earlier acoustic studies ([1], [14]). First, consonant duration is taken into account as a possible secondary stress correlate. Second, the experiment is based on standard Polish spoken in Warsaw. So far, secondary stress has been successfully detected in the speech signal only for native speakers of Warsaw and Cracow Polish, i.e., speakers from central and southern Poland ([2], [3], [7]), but not from other locations ([1]). Third, data comparability is ensured by analyzing segmentally identical but prosodically different sequences. This is particularly important in the case of consonants in which length differences across categories are much bigger than the expected differences in length depending on stress ([3]). Fourth, differences in speech tempo (resulting from individual differences among speakers or from polysyllabic shortening) are controlled for in terms of relative measures (Pairwise Variability Index; e.g., [15], [16]). The point is that the third (stressed) syllable in six- and seven-syllable words does not have to be longer than the third (unstressed) syllable in five-syllable words in raw terms but we do expect the proportions between second and third syllables to be different in six- and seven-syllable words versus five-syllable words, depending on stress ([3]).

2.1. Participants

Eight native speakers of standard Polish (5 men, 3 women; age: M = 22, SD = 3.1) participated in the experiment. All of them were lifelong residents of Warsaw. None of them had speech or hearing problems based on self-report.

2.2. Procedure

The speakers’ task was to read words embedded in a frame (Powtarzam ... dwa razy ‘I am repeating ... twice’), which appeared on a computer screen. Sentences with the items analyzed in the present study were separated by sentences with filler words. The list of items was randomized to avoid order effects. The recordings were done in a sound-treated room, using a Tascam DR-100 MKII recorder, set to a sampling frequency of 44.1 kHz, and an AKG C214 microphone. The speakers followed the task at their own pace, moving to the next slide with a mouse click. Each participant produced eight sets of triplets (like examples in (2) – (4) above), resulting in 192 samples. All second and third syllables, which are the focus of this study, had the canonical CV shape.

2.3. Segmentation

Boundaries were marked for the consonants and vowels in the second and third syllables of a word, using a high-resolution waveform editor (Sound Forge PRO, version 11). It was based on three standard criteria: (i) visual examination of the waveform, i.e., considering the dynamics of changes in the amplitude and shape of successive glottal pulses, (ii) visual inspection of the spectrogram in Praat (6.0.21; [17]), and (iii) auditory perception. The boundaries of vowel segments were aligned with glottal periods, i.e., they were marked at zero crossings so that each excised segment contained a complete number of cycles. Each token was segmented independently by two trained phoneticians and the outcome was compared to ensure uniform segmentation criteria across all tokens as well as to eliminate potential coding errors. 12 word tokens were rejected because of detected mispronunciation of the word or dysfluency of speech. As a result, the total of 180 items were included in the analysis.

2.4. Measurements

Measurements of four parameters – consonant duration, vowel duration, intensity, and F0 – were automated using Praat scripts. Intensity and F0 were measured within vowel segments using the same pitch floor (75 Hz for male speakers and 100 Hz for female speakers). The pitch ceiling in F0 measurements was set at 300 Hz for male speakers and at 500 Hz for female speakers. The output was examined for possible octave jumps.

2.5. Pairwise Variability Index Calculations

All raw measurements were translated into relative measures, expressed in terms of Pairwise Variability Index (henceforth, PVI; see [2], [3], [15], [16]). The following formulas were used to calculate consonantal duration (5), vocalic duration (6), intensity (7), and F0 (8). In (7) and (8), logarithmic scales are used (decibels and semitones, respectively). Following some previous work ([2], [3], [16]), we use PVI as a local relative measure, and not as a global rhythm metric (cf. [15]).

\[
PVI_{DU} = 100 \times \frac{C_k - C_{k+1}}{1/2(C_k + C_{k+1})}
\]

where \( C_k \) is the duration of the consonant in the onset of the \( k \)th syllable, expressed in ms

\[
PVI_{DU} = 100 \times \frac{V_k - V_{k+1}}{1/2(V_k + V_{k+1})}
\]

where \( V_k \) is the duration of the vowel in the \( k \)th syllable, expressed in ms

\[
PVI_{INT} = 20 \times \log \frac{P_k}{P_{k+1}} = dB_k - dB_{k+1}
\]

where \( P_k \) stands for the mean pressure of the \( k \)th vowel in a word, expressed in Pa

\[
PVI_{F0} = 12 \times \log \frac{F_{0_k}}{F_{0_{k+1}}} = ST_k - ST_{k+1}
\]

where \( F_{0_k} \) stands for the mean F0 of the \( k \)th vowel in a word, expressed in Hz

PVIs were calculated based on the second and third syllables. In all three types of words, second syllables were unstressed and thus could serve as a reference point. Third syllables were expected to be stressed in six- and seven-syllable words and unstressed in five-syllable words. The unstressed/stressed value of the stress condition in the analyses below is thus defined on the basis of the prosodic status of the third syllable in a word. Since PVI values depend heavily on intrinsic segmental length, in order to ensure that differences in parameter values do not result from differences in segmental structure, we compared segmentally identical second and third syllables in related five-, six-, and seven-syllable words.

2.6. Hypothesis

We expect lower PVI values in seven-syllable words compared to five-syllable words, but not in relation to six-syllable words. The expected mean differences between stressed and unstressed
conditions are small (about 10 ms in raw duration terms) because secondary stress in Polish is optional ([3], [7], [9]).

2.7. Statistical Analyses

The effect of stress on consonant duration, vowel duration, intensity and F0 was tested in terms of linear mixed effects (lme) models, fitted in SPSS (version 23). Separate analyses were conducted for each of the four parameters. Residuals above 2.5 standard deviations in the initial fit were removed from the analyses ([18], [19]). To account for non-independence resulting from replicated data, three random effects were considered: speaker, item, and speaker by item. Following [3], item was understood as a segmentally identical sequence, not as an item on the word list. Therefore, words in a triplet were coded as a single item. Initially, the random structure was fully specified, including speaker- and item-specific intercepts and slopes for the stress condition. The models were simplified in accordance with the standard stepwise procedure: the nested models were compared in terms of likelihood ratio tests using the chi-square reference ([20], [21]). In all final models, speaker- and item-specific slopes for the fixed effect of stress were discarded as they did not contribute significantly to the models’ goodness of fit. In the analyses involving consonant and vowel duration, the best fit was achieved by the lme models with intercepts for item and speaker-by-item. In the analyses of intensity and F0, intercepts for speaker, item, and speaker-by-item were included. In all analyses, the baseline was the heptasyllabic word (the secondary stress condition), to which the five-syllable word (the unstressed condition) and the six-syllable word (the secondary stress condition) were compared.

3. Results

3.1. Consonant duration

In the lme analysis of the effect of stress on consonant duration, the difference between five-syllable words and seven-syllable words (the baseline) – the unstressed and secondary stress condition, respectively – is statistically significant ($\beta_1 = 13.1$, $SE = 2.2$, $t = 5.84$, $p < .0001$). At the same time, six-syllable words and seven-syllable words, both of which represent the secondary stress condition, are not significantly different ($\beta_1 = 0.4$, $SE = 2.2$, $t = 0.2$, $p = .84$). The lower PVI values in seven-syllable and six-syllable words compared to five-syllable words (see Fig. 1) point to the presence of secondary stress in the former. With the mean consonant duration being 87.1 ms, the PVI difference of 13.1 corresponds to 11.4 ms in raw terms.

![Mean consonantal PVIs depending on stress](image)

**Figure 1: Mean consonantal PVIs depending on stress.** Error bars represent standard errors of the mean.

3.2. Vowel duration

In the lme analysis of the effect of stress on vowel duration, there is no statistically significant difference between five-syllable words and seven-syllable words ($\beta_1 = -7.1$, $SE = 3.9$, $t = 1.81$, $p = .073$). The difference between six-syllable words and seven-syllable words is also insignificant ($\beta_1 = 6.6$, $SE = 3.9$, $t = 1.69$, $p = .093$). We thus conclude that vowel length differences are not correlated with secondary stress.

3.3. Intensity

Similarly to the analysis of vowel duration, no significant difference has been observed for intensity between five- and seven-syllable words ($\beta_1 = -0.1$, $SE = 0.3$, $t = -0.5$, $p = .62$) as well as between six- and seven-syllable words ($\beta_1 = 0.3$, $SE = 0.3$, $t = 1.09$, $p = .277$). As anticipated at the beginning of the study, there is no effect of secondary stress on vocalic intensity.

3.4 F0

The effect of secondary stress on F0 also turns out insignificant. The difference between five- and seven-syllable words amounts to $\beta_1 = -2.2$, $SE = 2.6$, $t = -0.84$, $p = .405$; the difference between six- and seven-syllable words is $\beta = 1.4$, $SE = 2.5$, $t = 0.57$, $p = .572$.

4. Discussion

The aim of this study was to establish the stress pattern of heptasyllabic words in Polish and to find out whether there is evidence for the bidirectional nature of the Polish stress system. The stress pattern of seven-syllable words plays a crucial role in the discussion of Polish as a classic example of metrical bidirectionality. Depending on the presence or absence of secondary stress on the third syllable in heptasyllabic words, Polish either can be categorized as a bidirectional stress system or the hypothesis that it is such a system must be rejected.

The results of the present study reveal that secondary stress is realized in terms of onset consonant duration, with vocalic parameters – duration, intensity, and fundamental frequency – playing no role. As anticipated, a significant difference with respect to onset consonant duration was observed between seven- and five-syllable words, pointing to an iteration of secondary stress on the third syllable in heptasyllabic words. On the other hand, none of the vocalic parameters came out as a statistically significant predictor, further supporting the claim that secondary stress in Polish is realized mainly in terms of prolonged onset consonant duration. This makes Polish an unusual stress system not only because stress assignment is bidirectional but also because the secondary stress correlate is consonantal duration (while typically stress is cued by vocalic rather than consonantal parameters).

The direction of stress assignment can also be evidenced to some extent by the metrical structure of five-syllable words, which is \([\sigma\sigma]\) and not \([\sigma\sigma\sigma\sigma\sigma\sigma\sigma]\). Prominence effects on the initial syllable were reported in all empirical studies of Polish secondary stress thus far ([1], [3], [7], [14]). However, the argument based on heptasyllabic words is more compelling for two reasons. First, in five-syllable words, secondary stress can only be assigned on the initial syllable as these words are not sufficiently long to accommodate both word-initial and word-internal secondary stress. As a result, in five-syllable words initial secondary stress may be interpreted
as a word-boundary effect. Such interpretation was proposed in
[1], where some prominence effects were reported for the initial syllable in four-, five-, and six-syllable words, but no acoustic evidence for stress iteration, i.e. the presence of word-internal secondary stress in six-syllable words was found. The purported lack of stress iteration in six-syllable words was refuted in [2]
and [3], where it was shown that the iterating secondary stress is expressed in terms of longer onset consonant duration, and not vowel parameters. The evidence from heptasyllabic words thus provides a clear-cut argument for the bidirectionality of Polish stress system, since the iteration of secondary stress on the third syllable cannot be attributed to any kind of word-boundary effects. The second reason why the argument based on heptasyllabic words is more compelling is that the mere presence of word-initial prominence in five-syllable words can also be considered as evidence for a simpler ‘hammock’ or ‘dual’ system, where secondary stress appears only at word edges ([22]. [23]). In contrast, the appearance of secondary stress on the third syllable of heptasyllabic words indicates both the presence of secondary stress iteration as well as the rightward direction of the assignment of secondary stresses. The internal lapse in five-syllable words points to secondary stresses being assigned from the left end or simply at the word edge, while the stressed third syllable in six-syllable words is indicative only of the iterating nature of secondary stress in Polish. The acoustic evidence from heptasyllabic words adduced in this paper is thus crucial to support the descriptions of Polish as a bidirectional stress system, rather than a ‘hammock’ system or ‘iterative’ system. It also shows that metrical theories designed to account for bidirectional stress systems with internal lapses are empirically adequate.

5. Conclusions

The comparison of PVIs calculated for onset consonant duration, vowel duration, intensity, and fundamental frequency has yielded significant differences in consonantal length, but not in vowel parameters. This confirms that onset consonant duration plays a crucial role in cueing secondary stress in Polish.

A significant difference between onset consonant duration for five- and seven-syllable words confirms that the third syllable in seven-syllable word is stressed. Thus, the syllabification pattern of heptasyllabic words is \([\sigma\sigma (\sigma\sigma \sigma \sigma\sigma\sigma\sigma)]\), which corroborates the status of Polish as a bidirectional stress system with a peak located near the right edge of the word and secondary stresses iterating from the left edge.

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7. References