Rhythmic structure of utterances in native and non-native Polish

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Abstract

This paper presents results of an ongoing study concerning speech rhythm in native and non-native Polish. The goal of the analyses described in the paper was to characterize rhythmically Polish utterances realized by native and non-native speakers with German and Korean accent. The analyses are limited to the domain of duration, but in the future other prosodic parameters will also be investigated. In the current study, different rhythm metrics (%V, ΔV, ΔC, PVIs and Varcos) were applied to provide quantitative description of temporal patterning in native and non-native Polish. Following the assumption that perceived speech rhythm is the effect of meter and grouping which are closely related to prominence and phrasing, durational marking of various levels of prominence and prosodic edges was also analyzed between the three accents (native Polish and German- and Korean-accented Polish). The analyses aimed also at rhythmic classification of Polish – for that purpose the results of quantitative description with rhythm metrics and phonotactic properties of the speech material used in the current study were compared with the data for other languages presented in the literature.

Index Terms: speech rhythm, rhythm metrics, prominence, phrasing, native and non-native Polish

1. Introduction

Speech rhythm can be defined as a systematic temporal organization of prominent and less prominent speech units. In linguistics and phonetics, the notion of speech rhythm is traditionally related to the notion of *isochrony* [1, 2]. Isochrony underlies *rhythm class hypothesis* according to which every language represents a specific rhythm class, i.e. syllable-timed (Spanish, Italian), stress-timed (English, German) or mora-timed (Japanese), on the basis of its temporal organization of syllables. The lack of experimental evidence for stress-, syllable- and mora-based isochrony caused that in rhythm research the focus moved from duration measurements of syllables and feet to investigation of phonetic and phonological factors which affect the timing of syllables and feet, most importantly degree of vowel reduction in unstressed syllables, and phonotactic complexity of syllables. As a results rhythm has been redefined as the perceptual effect of interaction of a number of components: phonetic and phonological on the one hand, and segmental and prosodic on the other [3].

1.1. Rhythm metrics

The differences in vowel reduction, stress-based lengthening and syllable complexity between stress- and syllable-timed languages became the basis of *rhythm metrics* – formulas that measure durational variability in consonantal (C) and vocalic (V) intervals (or syllables). The most widely used metrics include %V-ΔC [4], PVIs [5] and Varcos [6]. Languages with the stress-timed rhythm are expected to exhibit higher nPVI and lower %V and higher consonantal rPVI and ΔC that result from vowel reduction and quite complex syllable structure respectively. Syllable-timed languages generally do not have spectrally reduced and shortened vowels and most syllables have a simple CV structure. Consequently, these languages are expected to exhibit higher %V and lower values of nPVI and the consonantal metrics. There is a growing body of evidence from experimental studies showing that rhythm metrics are not perfect. First of all, they are sensitive to differences in text materials, speech elicitation methods, measurements and changes in speech rate [7, 8]. This sensitivity explains why rhythm metrics take different values in different studies. Second major problem is that metrics reduce rhythm to *timing*, whereas apart from duration, perceived speech rhythm is also the product of properties such as melodic (F0) change and, to a lesser extent, intensity and vowel quality. As a result, different metric scores do not necessarily reflect perceptually different rhythms [9]. Perceived rhythm is the effect of *meter* and *grouping* and therefore research on rhythm should incorporate among others investigation of prominence (which functions as a meter) and phrasing (which is related to grouping, see [10]). Despite criticism, rhythm metrics still constitute the methodological basis of studies concerning topics as diverse as discrimination between rhythm classes [11], acquisition of timing patterns in L1 [12] and L2 [13, 14, 15, 16, 17, 18], detection of speech impairments [19] or dialect discrimination [20].

1.2. Phrasal properties of speech rhythm

It is well known that higher levels of prosodic structure such as prominence marking and prosodic phrasing strongly influence the organization of timing across languages. Analyses based on various languages (including Polish) showed that stressed and pitch accented syllables are produced with additional lengthening compared with unstressed syllables [21, 22, 23, 24]. Final lengthening at the edges of phrasal prosodic constituents is also very widespread [23, 25, 26]. Therefore, it has been acknowledged by many authors (e.g., [10], [27], [28], [29]) that perception of rhythm classes should be examined in relation to prosodic timing phenomena – the durational marking of prominences and phrase boundaries, because they are correlated with the potential rhythm class distinctions and constitute an important ingredient in the rhythm percept across languages.

1.3. Features of Polish, German and Korean rhythm

The speech material used in the current study comes from speakers whose native language was Polish, German or Korean. Polish exhibits phonological properties that are associated with both types of rhythm class [21, 23, 30, 31, 32, 33, 34]. Increased duration of prominent syllables and some compensatory shortening effects together with phonotactic complexity of syllables indicate stress timing. On the contrary, the lack of vowel reduction and a fixed lexical stress on the penultimate syllables indicate syllable timing. Therefore, having some features distinctive of stress-timed languages and others distinctive of syllable-timed languages, Polish would be

predicted to behave rhythmically as an intermediate or mixed language. Yet the acoustic evidence in this respect is contradictory: According to PVIs [5], Polish is close to syllable-timed languages, but, according to %V – ΔC, it is grouped with stress-timed English and Dutch [4].

German is a typical example of a stress-timed language with a phonemic vowel length contrast and vowel reduction in non-prominent unaccented syllables that is manifested acoustically mainly by differences in duration and quality, and allows for longer sequences of consonants in both onset and coda position [35]. This in turn leads to lower %V and higher ΔC, nPVI and rPVI [5, 7].

A perceptual study reported in [36] brought evidence that Korean, like Japanese, has mora-timed rhythm. However, this is at odds with the results of other studies (e.g. [7], [37], [38]) which suggest that Korean has "mixed" rhythm that is closer to syllable-timing than to stress-timing. Thus, at the acoustic level Korean rhythm should be manifested by higher %V and lower ΔC and PVIs than in stress-timed languages.

In the analysis of non-native speech rhythm we expect to find the influence of speakers' L1 on the realization of the durational variability of vocalic and consonantal intervals in Polish. It is assumed that non-native accent should be manifested by values of the metric scores intermediate between those reported for speaker's L1 (German or Korean) on the one hand and those obtained for Polish on the other. The perceptibly weaker non-native accent of German speakers (see sec. 3.1) should be manifested by smaller differences in the metric scores between German-accented and native Polish than between Korean-accented and native Polish.

1.4. Objectives of the current study

The objective of the analyses presented in this paper is to characterize Polish rhythm in utterances realized by native and non-native speakers with German and Korean accent and to provide rhythmic classification of Polish whose rhythmic status is unclear. For this purpose different rhythm metrics will be applied – they will be analyzed in terms of their stability (with respect to speech rate) and robustness (with respect to discrimination between the three accents). The quantitative description of speech rhythm using selected rhythm metrics will be complemented by results of analyses of the phonotactic structure of the utterances and study of durational marking of prosodic heads and phrase edges.

2. Methodology

2.1. Speakers and text

The speech material includes recordings of a literary fairy tale "The teapot" (by H. Ch. Andersen), read by 15 speakers: 5 Polish native speakers, 5 speakers with L1 German and 5 with L1 Korean. The text consists of 19 phonetically and prosodically rich sentences. Recordings of speakers with L1 German come from the *Euronounce* corpus [39], whereas the part representing Korean-accented and native Polish was recorded for the purpose of this study. Recordings were carried out in a sound-treated booth, directly to a disk and with a sampling frequency of 16 kHz. German and Korean speakers represented an intermediate level of proficiency in Polish, but the Koreans were less proficient in pronunciation and took Polish Phonetics course to improve their skills. The non-native speakers were competent, but with a perceivable non-native accent which was more salient in Korean-accented Polish (sec. 3.1). The subjects were asked to read the text once (sentence after sentence), at their own pace. Sentences containing disfluencies or mispronunciations were re-recorded.

2.2. Annotation and measurements

The whole speech material was segmented into vocalic and consonantal intervals on the basis of automatic transcription and segmentation [40] which was verified and manually corrected following standard segmentation criteria. All vowels were marked as vocalic intervals and all consonants (except for post-vocalic glides) – as consonantal intervals. A vocalic interval could contain a single vowel or 2-3 subsequent vowels, or a vowel followed by a glide. Intervals could span across syllable and word boundaries. As in [7] prepausal intervals were not excluded from measurements and segments separated by a pause were treated as two distinct intervals. Despite the applied recording procedure the utterances by non-native speakers are not entirely free of mispronunciations and all insertions and substitutions were included in the C and V intervals. On the one hand, differences in the phonetic realization will affect temporal structure of utterances, but on the other hand, if they are small and few they should not significantly affect metric scores. This issue was investigated using analysis of distribution of various types of syllables between the accent groups (sec. 3.2).

For each sentence the following rhythm metrics have been calculated:

- **%V** – the proportion of vocalic intervals, **ΔV** and **ΔC** – the standard deviation of the duration of vocalic and consonantal intervals respectively [4]
- **rPVI-V** (raw Pairwise Variability Index) and **nPVI-V** (vocalic normalized Pairwise Variability Index): the mean of the duration differences between successive C intervals and the mean of the duration differences between successive V intervals divided by the sum of the same intervals respectively [5]
- **VarcoV/VarcoC**: standard deviation of vocalic/consonantal interval duration divided by mean vocalic/consonantal duration [6]

Prosodic annotation included marking of four levels of prominences and two levels of phrasing. Each syllable and vowel was labeled as unstressed, stressed but unaccented, accented and nuclear accented, and as non-final, final in an intermediate phrase or final in an intonational phrase (see [29], [41], [42]). Syllable boundaries were determined according to criteria presented in [43]. Annotation and duration measurements were done in *Praat*. The data was exported to a spreadsheet where classification into C and V intervals was carried out and values of the rhythm metrics were calculated. For statistical analyses *Statistica 10* was used.

3. Results

3.1. Perception test

The aim of the test was to determine the strength of foreign accent in speech produced by non-native speakers. Seven subjects (students at the Institute of Linguistics) listened to utterances realized by Polish, German and Korean speakers, and marked the strength of foreign accent on a graphical scale from *very strong* to *no accent at all*. The test was carried out using *Annotation System* [44]. The results showed that

utterances realized by speakers with L1 Korean were characterized by strong foreign accent, the accent of speakers with L1 German was assessed as moderate, and in native Polish no foreign accent was perceived. All differences are statistically significant. It can be expected that the strength of foreign accent will be reflected in metric scores and durational marking of prominences and phrase edges.

3.2. Phonotactic properties

In all accent groups **CV** syllables constituted about **50%** of all syllables. The second most common structure was **CCV** (PL: 16.9%, DE: 17.5%, KOR: 16.5%), the third one was **CVC** (PL: 12.2%, DE: 11.6%, KOR: 12.8%) and then **V** (PL: 7.9%, DE: 7.9%, KOR: 8%) and **CCVC** (PL: 7.9%, DE: 7.3%, KOR: 7.1%). Other syllable types – CCCV, VC, CCVCC, CVCC and CCCVC, were much less common (< 3%). Differences in the frequency and distribution of syllable (and interval) types between the three accent groups are below 1%. It can be assumed that mispronunciations that occurred in non-native speech did not affected the overall phonotactic structure of utterances. Comparison of phonotactic properties of native speakers' utterances with data from five languages analyzed in [45] showed that similarly to stress-timed languages, Polish has greater variation in complex syllable structure than rhythmically unclassified Czech (6 types vs. 3 types). But on the other hand, Polish complex syllables most often have the CCV structure (not CVC as in stress-timed languages) and frequency of CCVC syllables is higher than in English and German. These results show that in terms of phonotactic properties Polish, like Czech, does not fit into the binary classification into syllable- and stress-timed languages.

3.3. Quantitative description with rhythm metrics

3.3.1. The effect of speech rate

ANOVA results showed significant differences in the speech rate between native speakers and the two non-native accents ($F=31.2$, $p<0.01$). Speech rate measured in the number of C and V intervals per second (cf. [46]) was higher in native Polish than in German- and Korean-accented Polish (9.2 vs. 8.2 intervals/sec.). Therefore, in the utterances produced by non-native speakers, higher values of the raw consonantal metrics can be expected. In order to select the most stable rhythm metrics correlations between their values and speech rate were investigated (Table 1).

Table 1. *Correlations between metric scores and speech rate (* indicates p<0.05).*

Metric	PL	KOR	DE
%V	-0,01	-0,17	-0,23*
ΔV	-0,33*	-0,59*	-0,64*
ΔC	-0,30*	-0,51*	-0,60*
rPVI	-0,36*	-0,49*	-0,35*
nPVI	-0,07	-0,01	-0,57*
VarcoV	-0,07	-0,10	-0,18
VarcoC	0,13	-0,07	-0,20

It can be seen that with one exception (Varco C, PL) the values of the metrics increase with decreasing speech rate. In some cases (mostly in German-accented speech, DE) the inverse correlations are statistically significant. Varcos, and to lesser degree %V and nPVI, seem to be the most stable metrics. These results indicate need of using rate-normalized metrics instead of the raw ones.

3.3.2. The effect of accent

In order to determine whether there are significant differences in the temporal patterning between native and non-native Polish and between the two non-native accents, ANOVA was carried out with *accent* as predictor variable and *metric scores* as dependent variables (Table 2).

Table 2. *ANOVA results: The effect of accent on the metric scores.*

Rhythm metrics	ANOVA		Scheffe's test
	F test	p	
%V	43,6	0,00	all
ΔV	40,6	0,00	KOR x PL, KOR x DE
ΔC	3,1	0,04	PL x DE
nPVI	77,0	0,00	KOR x PL, KOR x DE
rPVI	0.9	0.4	---
VarcoV	27,2	0,00	KOR x PL, KOR x DE
VarcoC	5,0	0,01	PL x DE

Statistically significant differences in all metric scores except for rPVI can be observed between the three accent groups. The results of ANOVA and post-hoc comparisons (Scheffe's test) indicate that the effect of accent is stronger on vocalic than on consonantal metrics. Taking into account these results and correlations with speech rate (Table 1), it can be assumed that %V, nPVI and VarcoV will be the most robust metrics in discrimination between the three accents.

In native Polish the %V has higher value and nPVI lower value in the current study than in [5]: %V – 47.1 vs. 42.3 and nPVI – 42.1 vs. 46.6. The vocalic metrics place Polish far from stress-timed Dutch, German and English and closer to syllable-timed French and Catalan [5, 7]. Values of the consonantal metrics in the current study show lower variation in the C interval durations comparing to results in [5]: ΔC – 61.3 vs. 71.4 and rPVI – 68.2 vs. 79.1, but they still indicate high variation in structure and duration of C intervals. In a two dimensional space determined by vocalic and consonantal metrics, the latter place Polish far from most languages. These results indicate that Polish rhythm can not be classified using the binary distinction between syllable- and stress-timing.

In German-accented Polish, %V, nPVI and VarcoV have lower values than in native Polish, but the difference is statistically significant only in case of %V (Table 2). In Korean-accented Polish the scores of all the vocalic metrics are higher than in Polish and German: **%V** – 49.7 KOR, 47.1 PL, 45.1 DE, **ΔV** – 61.9 KOR, 45 PL, 45.6 DE, **nPVI** – 54.5 KOR, 42.1 PL, 40.7 DE, **VarcoV** – 51.3 KOR, 44.3 PL, 41 DE. The vocalic metrics take intermediate values between those reported for native Korean [37] and those obtained for native Polish, which indicates *transfer of temporal patterning from L1 Korean to Polish*. In the non-native accents consonantal metrics have higher scores than in native Polish, but these differences might result from different speech rates as indicated by significant inversed correlations (Table 1). Differences in the temporal patterning between native and non-native Polish are reflected mostly by the vocalic metrics: %V, nPVI and VarcoV. The results of quantitative analysis using rhythm metrics are in line with the results of the perception test, because they indicate greater differences in

temporal patterning between Korean-accented and native Polish than between German-accented and native Polish.

3.4. Phrasal properties of speech rhythm

3.4.1. Prominence level

Multivariate ANOVA results showed significant effect of prominence level on syllable duration (F=354.8, p<0.01) and small, but significant effect of speaker (F=4.5, p<0.01) and speaker and accent (F=8.4, p<0.01). Generally, in all accent groups syllable duration increases with the prominence level from unstressed to nuclear accented. The exception is durational marking of stressed syllables (S) in native Polish: these syllables are significantly shorter than all other syllables, including unstressed syllables (U) in Polish, but excluding U syllables in the two non-native accents (Tukey's HSD test). However, even though S syllables are generally longer than U syllables in Korean- and German-accented Polish, the difference is not statistically significant. Contrary to native Polish, in non-native accents the difference in duration between A (accented) and S syllables is not significant. There is also significant difference in durational marking of the highest level of prominence (NA) between Polish and Korean speakers. Similar patterns of variation due to prominence were found in vowel durations, except for S vowel durations in native Polish which this time were longer (but not significantly) comparing to U vowels.

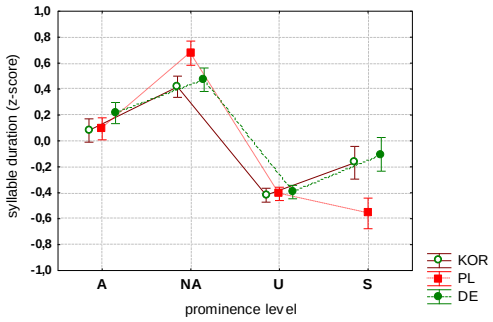

Figure 1: *Mean syllable duration depending on the prominence level (A – accent, NF – nuclear accent, U – no stress & no accent, S – stressed).*

3.4.2. Phrasal position

Similarly to prominence analysis, multivariate ANOVA results showed significant effect of phrasing level on syllable duration (F=533.3, p<0.01) and small, but significant effect of speaker (F=15.2, p<0.01), and speaker and accent (F=19.1, p<0.01). In all accent groups, non-phrase final syllables are significantly shorter than syllables at the edges of intermediate (iip) or intonational phrases (IP). Interestingly, duration of syllables at the edges of intermediate phrases is the longest, but in German-accented and native Polish it is significantly different only from duration of non-phrase final syllables (NF). IPs in native Polish are signaled by significantly increased duration of phrase-final syllables comparing to the non-native accents. Intermediate phrases are marked by significantly longer phrase-final syllables in native and Korean-accented Polish than in German-accented Polish.

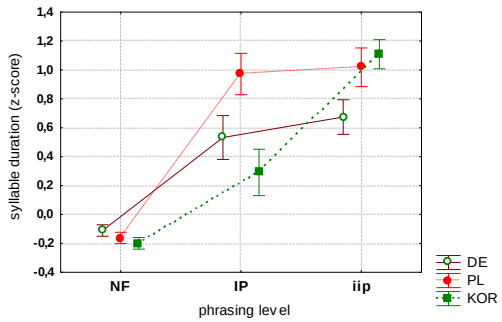

Figure 2: *Mean syllable duration depending on the phrasing level (NF – non-final, IP – intonational phrase, iip – intermediate phrase).*

4. Discussion and conclusions

The results of the analyses indicated significant differences in the rhythmic characteristics between native and non-native Polish. The strength of foreign accent in non-native Polish assessed in a perception study was reflected in more significant differences in the metric scores between native and Korean-accented Polish (strong accent) than between native and German-accented Polish (moderate accent). The results of quantitative analysis using vocalic rhythm metrics showed that Korean speakers transferred some temporal patterns from their L1 to Polish. Generally, Korean-accented Polish is characterized by more vocalic speech (higher %V) and more variation in the duration of V intervals than native Polish and German-accented Polish; the latter accent is characterized by less vocalic speech (lower V%) and less variation in the duration of V intervals than Korean-accented Polish and less variation in C interval duration comparing to native Polish. Generally, %V, nPVI and VarcoV are more stable as regards speech rate differences and more robust than the consonantal metrics. Small, but significant differences in the durational marking of various levels of prominence and phrasing can also be observed between the three accents and they also affect the temporal organization of utterances – this implies the need of including prosodic hierarchy in the analysis of speech rhythm. In the future, the analyses of phrasal properties of Polish rhythm will be complemented by analysis of distribution of prominences and phrasing e.g., position and number of pitch accents and phrase boundaries (see [47]). The phonotactic structure of Polish utterances and the quantitative description using rhythm metrics indicate that in terms of rhythm, Polish does not fit into the binary classification into syllable- and stress-timing. Phonotactically, it is most similar to "rhythmically mixed" Czech, whereas vocalic rhythm metrics provide some evidence of syllable timing and consonantal metrics put Polish aside from both syllable- and stress-timed languages. These results indicate that in order to better characterize Polish rhythm (and speech rhythm in general) it is necessary to go beyond the dimension of timing and to analyze also the contribution of pitch, intensity and tempo to production and perception of rhythmic structure and grouping.

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