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BRAT ADAMA VS *BRATA DAMA*: TEMPORAL PHONETIC PARAMETERS SIGNALLING WORD BOUNDARIES IN POLISH

The paper presents the results of an acoustic analysis of temporal phonetic parameters cueing word boundaries in Polish. Durational variability has been well documented for different languages. Word-final lengthening, word-initial lengthening, and polysyllabic shortening, all predict that segments neighbouring a word boundary will differ in their durations whatever direction such shortening or lengthening should take. In the present study, we obtained two Polish sequences *brat Adama* versus *brata dama* from 24 native speakers of Polish. The obtained results point to a complicated pattern of temporal variability caused by the boundary location in Polish.

Continuous speech encoded in the acoustic signal reaching the listener's ears, unlike written language, is not characterised by white spaces between words to signal where one word ends and another begins (Norris et al. 1997 for a review). A central problem that listeners must solve during speech comprehension is that of locating the boundaries of structural constituents like words even in the absence of reliable silences to signal these boundaries. The speaker is therefore expected to articulate the cues to a boundary that will have acoustic consequences and will be thus deciphered by the listener. That this is indeed the case has been demonstrated in numerous studies investigating boundary driven phonetic detail in speech production and perception. All aspects of the signal – amplitude, duration, and frequency modulation – have been implicated as juncture and boundary cues (Ainsworth 1986, Anderson and Port 1994, Boucher 1988, Christie 1977, Davidsen-Nielsen 1974, Lehiste 1960, Redford and Randall 2005). All these systematic phonetic details are used by speakers to signal not only boundary location, but the whole prosodic structure as well (Cho et al. 2007). The appropriate prosodic cues for boundaries can facilitate both sentence comprehension (Cho 2004, Sanderman and Collier 1997) and word segmentation (Kim 2003 reported in Cho 2004).

Probably the most widely addressed issue in word segmentation literature is temporal phonetic variability. A large body of speech production research reviewed in subsequent paragraphs has reported significant and systematic variation in durations of segments neighbouring word boundaries. Related perception experiments have validated duration variability as a potent perceptual cue to locating word boundaries in continuous speech.

1. Temporal parameters signalling word boundaries

The location of a word boundary has been repeatedly reported to implement durational adjustments on a segmental level. It has been suggested that in contrasting phrases like *poppa pose* vs *pop oppose,* the relative durations of the three syllables reflect the boundary location in that a shorter /pɒp/ and a longer /ə/ are found in *poppa pose* while a longer /pɒp/ and a shorter /ə/ are associated with *pop oppose* (Abercrombie 1965, Beckman and Edwards 1990, Lindblom and Rapp 1973, Lindblom et al. 1976, Turk and Shattuck-Hufnagel 2000). Christie (1977) demonstrated that English listeners use the consonantal duration pattern in an obstruents-sonorant sequence to locate word boundaries in sentences such as *help a snail* and *help us nail.* Similarly, Davidsen-Nielsen (1974) identified stop release duration as a cue to word boundaries in near minimal pair phrases such as *I stop* and *nice top.* Boucher (1988) asked speakers to produce *free Danny* vs *freed Annie* and found vowel duration and closure duration of the stop as cues to the word boundary. Finally, Krakow (1993 reported in Stevens 2005) showed that, in a vowel preceding a nasal consonant in English, nasalization in the vowel extends over a longer time interval when the consonant is a postvocalic component of the syllable (e.g. *seen Alice*) than when it is prevocalic for the next syllable (e.g. *see Nellie*).

Developmental studies indicate that even though full sensitivity to temporal parameters signalling word boundaries may be acquired relatively slowly (Redford 2007), they may be available quite early to infants processing ambient language. Jusczyk et al. (1999 reported in Houston 2005) found that 10.5-month-old English infants are sensitive to temporal information to distinguish between *nitrates* and *night rates* in fluent speech contexts. A bit older, 12-month-old, American infants were observed to prefer to listen to words (e.g. *lore*) that were matched to the word boundaries in two--word sequences (e.g. *toga lore*) that they had been exposed to in a prior familiarisation phrase. No such preference was found when the stimuli did not correspond to the word boundary used in a familiarisation phase but rather straddled the word boundary (e.g. *toe galore*) (Johnson 2003). These results have been taken as evidence that 12-month--olds use acoustic cues to segment continuous speech into words. Similarly, Gout et al. (2004) demonstrated that 13-month-old American infants preferred to turn their head when hearing a familiarised bisyllabic word *paper* in a sentence but that this effect disappeared when the word straddled a word boundary, e.g. *pay permit.* The study by Christophe and colleagues (1994) shows that even very young infants are equipped with mechanism sensitive to boundary cues. They presented three-day-old French infants with bisyllabic stimuli extracted from within words (*mati* from *mathé**mati**cien*) and from across word boundaries (*mati* from *panora**ma ty**pique*). Applying a high-

-amplitude sucking paradigm, they determined that infants discriminated between the two types of stimuli, which was taken to indicate that the infants were able to recognise acoustic correlates of a word boundary. When in the school period, children are reported to process durational cues to word boundary as effectively as adults. DeMarco and Harrell (1995) found that adults and children at the age of eight and nine are able to discriminate such minimal word pairs as *its wings* versus *it swings* with 95% accuracy in a neutral carrier phrase.

Psycholinguistic research points to the fact that acoustic cues signalling word boundaries may not always be fully and reliably accessible to the listener (Lehiste 1972, Nakatani and Dukes 1977). Bond (2005) lists several examples of slips of the ear in English when listeners fail to detect word boundaries, insert spurious word boundaries, or shift the location of a word boundary. For instance, *acute back pain* is perceived as *a cute back pain*, *Americana* as *a Mary Canna*, *an ice bucket* as *a nice bucket*.

2. Word-final lengthening

The fact that segments located at a word-final boundary are lengthened as compared to corresponding segments in nonword-final position is well documented in the phonetic literature (Beckman and Edwards 1990, Nakatani et al. 1981, Oller 1973, Umeda 1975). Nakatani and colleagues demonstrated in a reiterant rendition paradigm longer CV syllable duration in word-final position than in nonword-final position. Similarly, Beckman and Edwards (1990) found word-final lengthening for /ə/ in word-final position as in *poppa pose* rather than word-initial position as in *pop oppose*. Word-final lengthening for the whole syllables was suggested by Turk and White (1999), who observed that, in sequences like *shakedown stairs* versus *shake downstairs*, the first syllable (*shake*) was longer when a word boundary immediately followed it (*shake downstairs*) than when it was the first syllable in a bisyllabic word (*shakedown stairs*).

Word-final positions have not only a lengthening but also a strengthening effect on vowels and consonants. Final vowels are produced with greater articulatory magnitude (Cho 2004, Fougeron and Keating 1997) and they have more extreme articulation, e.g. with greater jaw lowering (Edwards et al. 1991). As noted by Cho (2004), the pre-boundary, word-final phenomena can be thought of as strengthening rather than simply as lengthening.

It is however difficult to separate word-final lengthening from phrase-final lengthening in the studies reviewed above. Turk and Shattuck-Hufnagel (2000) discuss the fact that if the tested word is located at the end of a prosodic constituent like an intonational phrase, the observed lengthening may be associated with phrase-final rather than word-final position. To resolve this issue, they placed tested sequences *tune acquire* and *tuna choir* in a nonphrase-final position and found no support for word-final lengthening in tested sequences. They add, however, that lengthening may occur at a slow speech rate or in certain speech styles.

3. Word-initial lengthening

Word-initial positions are well attested to have a lengthening effect on segments. The duration of a consonant constriction is longer word-finally than word-medially in the same stress environment (Cooper 1991, Fougeron and Keating 1997, Oller 1973). EPG studies (measures of linguopalatal contact) have shown that consonants are generally produced with greater articulatory magnitude initially than medially in Korean (Cho and Jun 2000 reported in Cho 2004, Cho and Keating 2001), French (Fougeron 2001), and English (Keating et al. 1999). Voice Onset Time values have been reported to be longer when /p, t, k/ are in word-initial positions than elsewhere (Choi 2003, Cole et al. 2007). For instance, Cooper (1991) found that the VOT of initial /k/ in /ki'kik/ was longer than the VOT of medial /k/ in /'kikik/, which means that under the same stress conditions, initial stops have longer VOT values than medial stops. Turk and Shattuck-Hufnagel (2000) found evidence for word-initial lengthening in *tuna choir* versus *tune acquire*, where /k/ in *choir* (word-initial) was longer than /k/ in *acquire* (word-medial). Moreover, word-initial lengthening is reported not only to affect an initial consonant but also to spread on a following vowel (Cho 2005, Fougeron 1998 reported in Turk and Shattuck-Hufnagel 2000, but see Byrd 2000)

Word-initial durational lengthening has been demonstrated to be effectively processed by the listeners. For example, recently Shatzman and McQueen (2006) used an eye-tracking paradigm to show that durational differences between word-final /s/ and word-initial /s/ in Dutch ambiguous sequences such as *eens pot* (once jar) and *een spot* (a spotlight) are utilised by listeners to resolve lexical ambiguity. Similarly, Cho and colleagues (2007) used a cross-modal identity priming paradigm and demonstrated that domain-initial (intonational phrase, word boundary) strengthening is used as an acoustic cue in the segmentation of continuous speech by American English listeners.

4. Polysyllabic shortening

The term originally proposed by Lehiste (1972) refers to the shortening of a stem syllable as more syllables are added to its right in the same word. Her measurements revealed that *stick* was longest when produced as a monosyllabic word, shorter when produced as a two-syllable word *sticky*, and even shorter when in a three-syllable word *stickiness*. The effect of shortening was gradual in that the second syllable added caused the greatest shortening and the addition of the third syllable resulted in small but consistent shortening. This phenomenon has been repeatedly reported for English (Harris and Umeda 1984, Klatt 1973, Nakatani et al. 1981, Port 1981). More recently, Turk and Shattuck-Hufnagel (2000) found support for polysyllabic shortening in their analysis of *tune acquire* versus *tuna choir*. For other languages, Lindblom and Rapp (1972 reported in Turk and Shattuck-Hufnagel 2000) found evidence for polysyllabic shortening in Swedish, where both stressed and unstressed segments were shortened as more syllables were added to a word. They also observed that adding syllables to the left did not have as large an effect as adding syllables to the right.

5. The present study

In the present study we set out to determine the effect that a word boundary location has on segment durations in Polish. The research reviewed above has mostly concentrated on languages such as English, Korean, French, or Swedish. We have no acquaintance with similar research on any of the languages belonging to the Slavonic branch. The discussed durational adjustments taking place in the vicinity of word boundaries allow us to make certain predictions about durational differences between segments depending on the location of a word boundary. It is worth emphasising that word-final lengthening and word-initial lengthening are opposing forces, so that predictions based thereon will stand in contrast, awaiting empirical verification.

Word-final lengthening predicts that *brat Adama* versus *brata dama*[1] will differ in that /a/ and /t/ will be longer in *brat* where they constitute a word-final VC sequence than in *brata* where they are followed by another segment /a/. Since the lengthening is reported to be asymmetric (Berkovits 1994, Turk and Hufnagel 2000), with more lengthening on the syllable coda than on the nucleus, the lengthening of /t/ is expected to be greater in magnitude than lengthening of /a/.

Word-initial lengthening predicts that /a/ in *A̲dama*, where it is word-initial will be longer than /a/ in *brata̲*, where it is word-final. Similarly, word-initial /d/ in *dama* is predicted to be longer than word-medial /d/ in *Adama*. The vowel /a/ following /d/ is not expected to show durational variability as vowels following onset consonants are reported to be unaffected by word-initial lengthening (Byrd 2000, Fougeron 1998).

Polysyllabic shortening predicts that /a/ and /t/ in monosyllabic *brat* will be longer than in polysyllabic *brata*.

We expect to observe the greatest magnitude of temporal variation in segments located nearest to the word boundary. Therefore, we decided to segment analysed sequences in the following way: /br/ /a/ /t/ # /a/ /d/ /a/ /ma/ versus /br/ /a/ /t/ /a/ # /d/ /a/ /ma/.

6. Experiment

6.1. Subjects

Thirty-one native speakers of Polish (26 females, 5 males) served as subjects in the experiment. They were all recruited from students at the University of Silesia. All subjects volunteered in the experiment and were not paid for their participation. None of the subjects reported any speech or hearing disorders nor had any indication of such.

Out of the original group of thirty-one speakers, 7 speakers (6 females, 1 male) were eliminated after the acoustic analysis session due to mispronunciations of seg-

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[1] *brat Adama* (Adam's brother) versus *brata dama* (brother's lady).

ment sequences. Consequently, only data obtained from 24 speakers (20 females, 4 males) were qualified for final analysis.

6.2. Procedure

The stimulus set consisted of identical phoneme strings organised into two different word boundary patterns: *brat Adama* versus *brata dama*. The sequences were presented on a computer screen and the orthography specified the word boundary location (blank space). The two stimuli were separated by other sequences collected for a different project. The subjects were encouraged to read each sequence as naturally as possible, without pausing between words in a test sequence.

6.3. Recording

A recording session took place in a quiet room. A Media Tech MT385 USB microphone with a flat response between 100 and 16000 Hz was positioned at a distance of approximately 20 centimetres from a speaker's mouth. The speech input was processed and recorded by an external Sound Blaster X-Fi X-MOD sound card with a 24 bit sampling rate, frequency range 140 – 20000 Hz and sensitivity 112 dB +- 3 dB. The recording was sampled at 16 kHz. All samples were directly recorded to hard disc as WAV files.

6.4. Acoustic measurements

The obtained forty-eight sequences (*brat Adama* versus *brata dama* from 24 subjects) were analysed using a Praat 4.6.18 speech-analysis software package (Boersma 2001, Boersma and Weenink 2007) by means of a visual inspection of spectrographic displays and waveforms. The sequences were segmented into /br/ /a/ /t/ /a/ /d/ /a/ /ma/. Measurements were made using standard acoustic phonetic criteria. The sequence /br/ was determined from the onset of prevoicing (the time interval from voice onset to stop release)[2] of /b/ to the onset of regular periodicity signalling a following vowel. Vowels were measured from the onset of periodicity showing clear formant structure to the end of periodicity signalled by a drop in amplitude. Stop consonant boundaries were indicated by the onset of closure and the offset of the release burst. If there was no release burst, the closure boundary was marked by the onset of regular formant structure signalling the onset of a following vowel. The onset of a sequence /ma/ was indicated by a sudden change in the formant structure signalling the beginning of a nasal segment.

All acoustic measurements were made by the author, so the criteria were always the same. Many sequences were measured repeatedly at different times to ensure measurement reliability.

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[2] Polish is known to prevoice initial stops, which is evidenced by negative VOT values (Keating 1984, Rojczyk 2008)

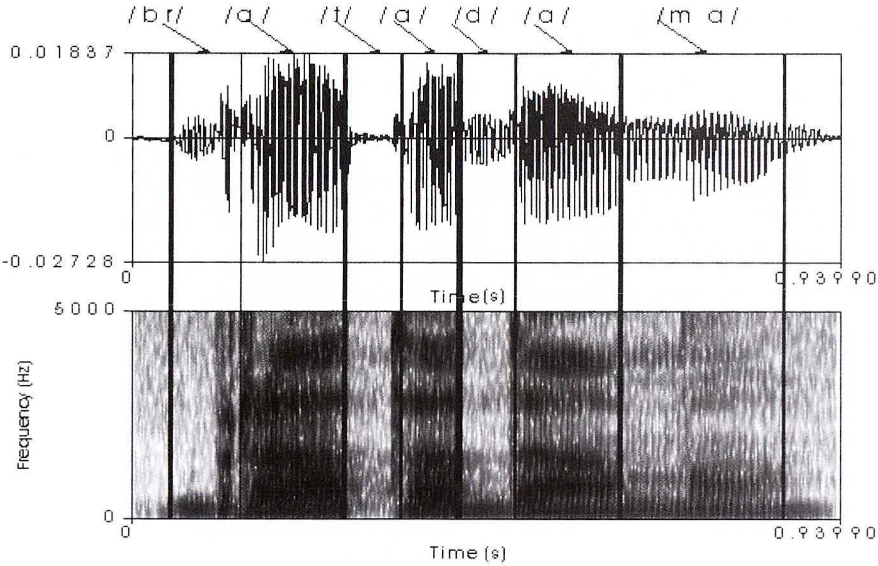

Figure 1. Waveform and spectrogram of a sequence *brat Adama* demonstrating segmentation procedure.

As a unit of comparison, we propose a ratio of segment duration to sequence duration. The duration of each analysed segment is thus represented proportionally, not nominally, for instance /br/ in *brat Adama* is a ratio of /br/ (in ms) / *brat Adama* (in ms). We believe that the proportional analysis is more reliable than nominal analysis in that it is impervious to variation in speech rate. Any differences in speech rate between *brat Adama* and *brata dama* would necessarily produce distorted results. A proportional analysis, on the other hand, retains the exact temporal unity of analysed segments despite variability in the production rate (e.g. Rojczyk in press, Waniek-Klimczak 2005 for the same methodology).

It was assumed *a priori* that reliable segmentation would be difficult in two points. First, some of the instances of *brat Adama* had visible glottal compression after the release of /t/ and the onset of /a/ to enhance the perceptual robustness of a word boundary. In such case, /t/ was measured to the offset of a release burst and /a/ was measured from the onset of clear formant structure. The glottal compression period was excluded from analysis. Second, the reliability of measurements of /d/ in *brata dama* is strongly undermined by the fact that the time interval between the offset of final /a/ in *brata* and the onset /a/ in *dama* may contain not only compression for /d/ but also a silence period between two words. This caveat notwithstanding, we decided to include this measurement, however any conclusions concerning the comparison of /d/ durations in *brat Adama* versus *brata dama* will be drawn cautiously due to their limited reliability.

7. Results and analyses

7.1. /br/ in brat Adama versus brata dama

The repeated-measures ANOVA for dependent variables failed to indicate a statistically significant difference between duration of /br/ in *brat Adama* (Mean: 0.124; Min: 0.067; Max: 0.183, Std. Dev: 0.036) and *brata dama* (Mean: 0.129; Min: 0.053; Max: 0.203; Std. Dev: 0.037) with F(1, 23) = 0.56369, p = 0.460.

7.2. /a/ in brat Adama versus brata dama

The comparison of /a/ in *brat Adama* (Mean: 0.134; Min: 0.105; Max: 0.159; Std. Dev: 0.015) and /a/ in *brata dama* (Mean: 0.123; Min: 0.089; Max: 0.157; Std. Dev: 0.015) reached high statistical significance (repeated-measures ANOVA F(1, 23) = 12.665, p = 0.002**). Proportional values for /a/ in monosyllabic *brat* were much longer than the values obtained for corresponding /a/ in polysyllabic *brata*.

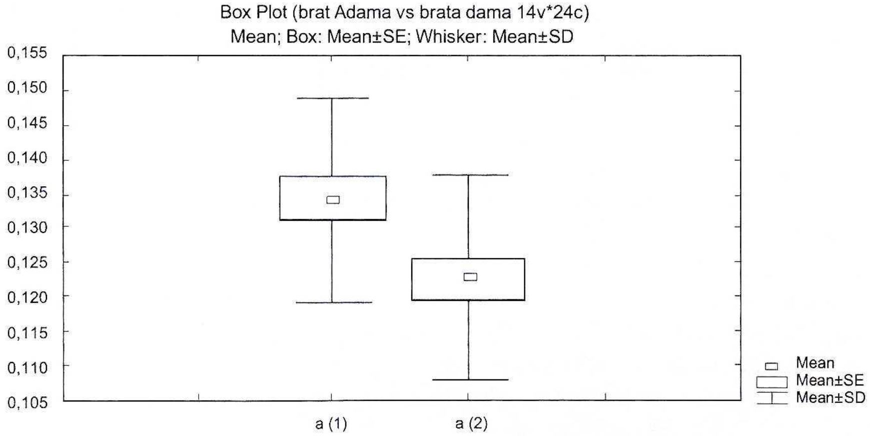

Figure 2. Box Plot. /a/ in *brat Adama* (a1) and /a/ in *brata dama* (a2)

7.3. /t/ in brat Adama versus brata dama

The analysis revealed a significant difference between /t/ in *brat Adama* (Mean: 0.117; Min: 0.068; Max: 0.174; Std. Dev: 0.026) and /t/ in *brata dama* (Mean: 0.131; Min: 0.109; Max: 0.168; Std. Dev: 0.015). The mean values of /t/ in *brata* were greater than the values of /t/ *brat* at a significant level (repeated-measures ANOVA F(1, 23) = 6.798, p = 0.016*).

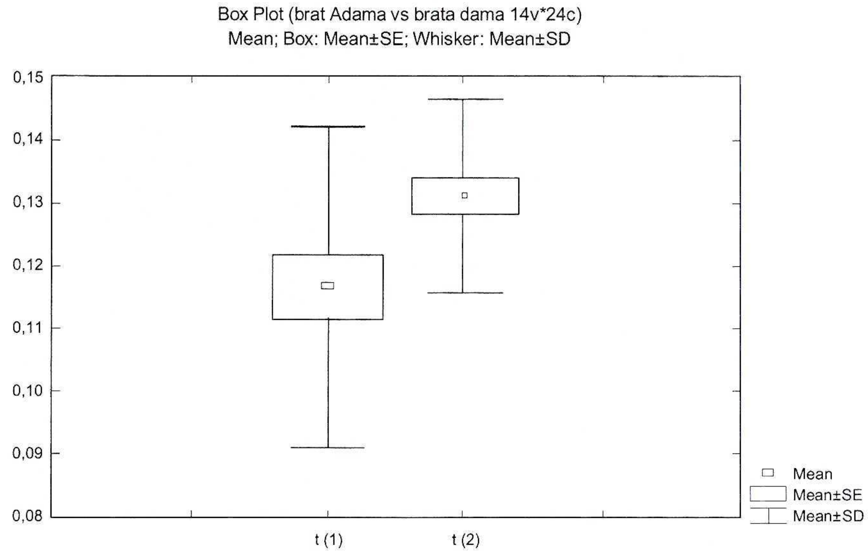

Figure 3. Box Plot. /t/ in *brat Adama* (t 1) and /t/ in *brata dama* (t 2)

7.4. /a/ in brat Adama versus brata dama

The comparison between /a/ in *brat Adama* (Mean: 0.094; Min: 0.038; Max: 0.135; Std. Dev: 0.024) and /a/ in *brata dama* (Mean: 0.106; Min: 0.077; Max: 0.168; Std. Dev: 0.024) revealed that /a/ in the former sequence was shorter than corresponding /a/ in the latter sequence. When tested for significance with repeated-measures ANOVA, the difference appeared, however, to be only close to significant, $F(1, 23) = 3.9259$, $p = 0.06$. Despite the fact the difference between the two sets of measurements was not significant at a $p<0.05$ level, both the minimal and maximal values for word-final /a/ in *brata* were greater than word-initial /a/ in *Adama.*

7.5. /d/ in brat Adama versus brata dama

The analysis of the durational values obtained for /d/ in *brat Adama* (Mean: 0.104; Min: 0.065; Max: 0.152; Std. Dev: 0.019) and /d/ in *brata dama* (Mean: 0.106; Min: 0.084; Max: 0.146; Std. Dev: 0.013) failed to show significance (repeated-measures ANOVA $F(1, 23) = 0.6449$, $p = 0.43$). There was no systematic variation in duration between word-medial /d/ in *Adama* and word-initial /d/ in *dama.*

7.6. /a/ in brat Adama versus brata dama

The measurements obtained for /a/ in *brat Adama* (Mean: 0.152; Min: 0.104; Max: 0.204; Std. Dev: 0.019) and corresponding /a/ in *brata* dama (Mean: 0.145; Min: 0.113; Max: 0.192; Std. Dev: 0.023) did not differ significantly (repeated-measures ANOVA $F(1, 23) = 2.4026$, $p = 0.13$).

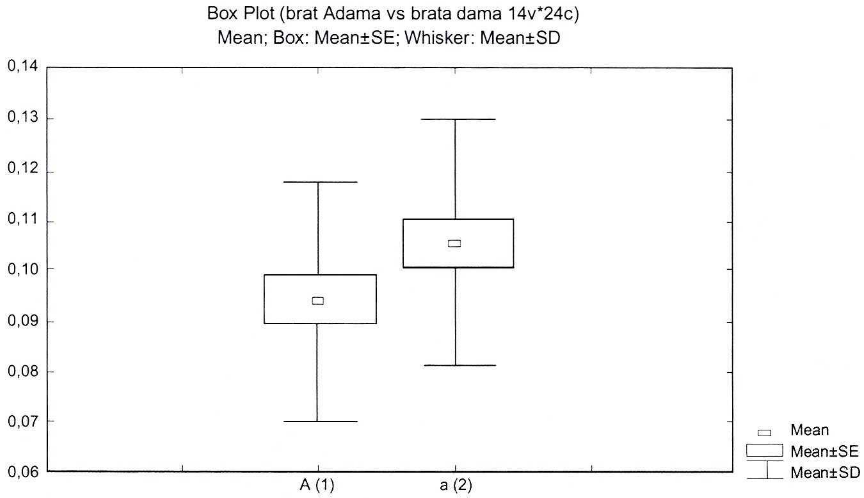

Figure 4. Box Plot. /a/ in *brat* ***A**dama* (A 1) and /a/ in *brat**a** dama* (a 2)

7.7. /ma/ in brat Ada<u>ma</u> versus brata da<u>ma</u>

Repeated-measures ANOVA revealed a close to significant difference between /ma/ in *brat Adama* (Mean: 0.285; Min: 0.220; Max: 0.398; Std. Dev: 0.041) and in *brata dama*. (Mean: 0.266; Min: 0.196; Max: 0.337; Std. Dev: 0.031). The sequence /ma/ in *Adama* was longer than the corresponding sequence /ma/ in *dama*, however the difference was only close to significant, $F(1, 23) = 4.1574$, $p = 0.053$.

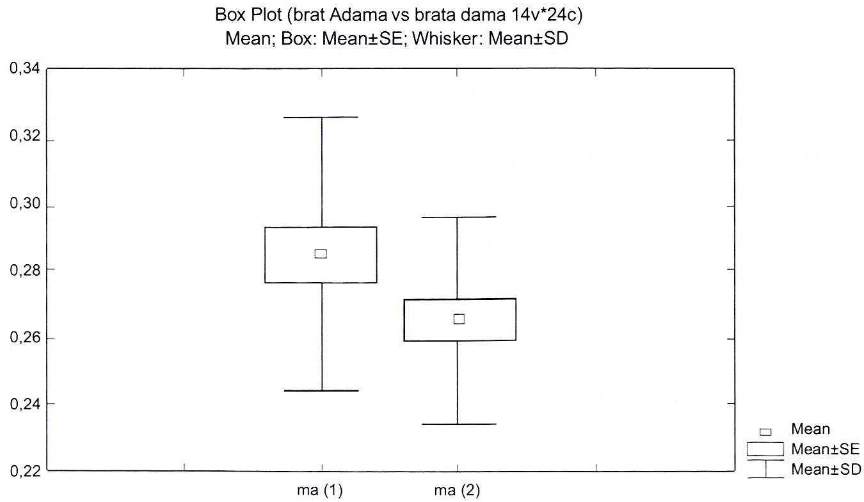

Figure 5. Box Plot. /ma/ in *brat Ada**ma*** (ma 1) and /ma/ in *brata da**ma***

8. General discussion

As suggested by the results of studies reviewed earlier, segments in sequences differentiated by a boundary location are characterised by variability in durational values. Three major factors, such as word-initial lengthening, word-final lengthening, and polysyllabic shortening have been found to influence temporal reorganisation on the level of segments and syllables.

Predictions from other languages that boundary location is signalled by differences in durational values have been confirmed in the present study of Polish sequences *brat Adama* versus *brata dama*. Proportional analysis, understood as a ratio of segment nominal duration to sequence nominal duration, revealed variability in durational measurements as a function of boundary location. The segments mostly affected were the ones in close vicinity to the boundary. The direction of lengthening was concentrated to the left rather than to the right of the boundary.

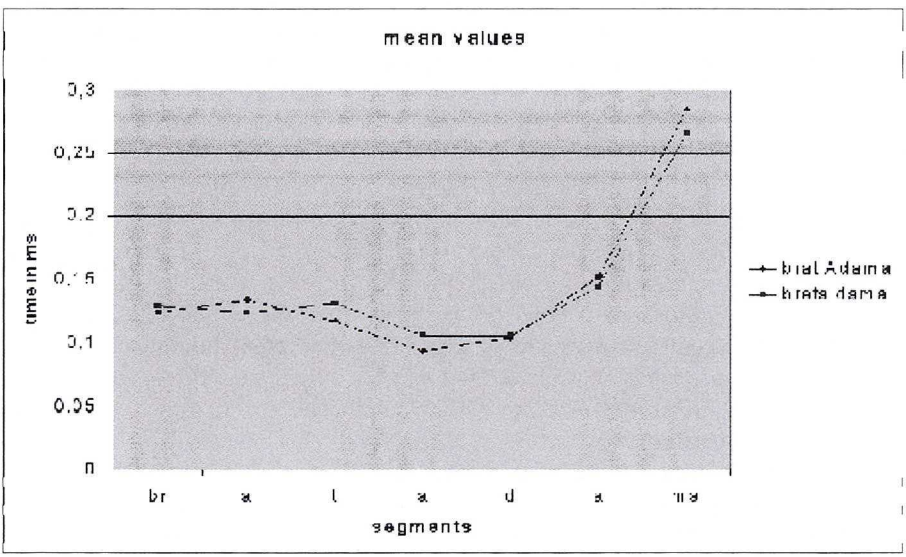

Figure 6. Mean values for *brat Adama* (dots) and *brata dama* (squares)

The observed, statistically significant, greater duration of /a/ in br<u>a</u>t as compared to corresponding /a/ in br<u>a</u>ta is compensated by the duration of /t/, which is shorter in *brat* and longer in *brata*. This, rather complicated, pattern is difficult to reconcile with both the polysyllabic shortening and word-final lengthening. Both of these would predict that /a/ and /t/ in *br<u>at</u>*, which is both word-final and monosyllabic, should be longer than in *br<u>at</u>a*, which is polysyllabic, and where the two segments are separated from the boundary by another /a/ segment. The results obtained in our study point to a pattern of reversed durations caused by the shift in boundary location. Thus, the difference between *brat* and *brata* may be represented as /br/ (same) /a/ (longer) /t/ (shorter) and /br/ (same) /a/ (shorter) /t/ (longer) /a/.

It is interesting to note shorter constriction and release burst for /t/ in word-final rather than in nonword-final positions. Two types of explanations may account for the observed pattern. For perception-based account, it may be argued that shortened duration of /t/ serves as a perceptual cue to the word boundary location. Along this line of reasoning, the inversed pattern with /a/ being longer and /t/ being shorter in word-final *brat* should provide perceptual boost for a word boundary location. Longer values for /a/ perceptually decrease values for /t/, thus making it perceptually more robust and, accordingly, more effective in signalling the word boundary. The production-based account would accommodate shorter values for /t/ by claiming that /t/ in *brat* is shorter because of the ensuing glottal constriction before word-initial /a/ in *Adama*. Indeed, our acoustic analysis revealed that some, but not all, analysed samples were characterised by a glottal compression at a word boundary between word-final /t/ and word-initial /a/ in *brat Adama*. More research is in order, especially focused on the perceptual aspect of word-final /t/ shortening pattern observed in this study, to resolve this issue. If perception studies demonstrated that increasing durations of /a/ and decreasing durations of /t/ in *br<u>at</u>a dama* causes a shift in boundary location towards *brat Adama*, it will provide experimental evidence for the perceptual salience of the observed inverse pattern.

The comparison of values obtained for word-initial /a/ in *<u>A</u>dama* and word-final /a/ in *brat<u>a</u>*, although only close to significant, revealed longer values for /a/ in *brat<u>a</u>*. This pattern is predicted by word-final lengthening according to which segments preceding a word boundary will be longer than corresponding segments following a word boundary. Word-final lengthening observed for /a/ in *brata* stands in opposition to shorter values for word-final /t/ in *brat*. It is unclear from the sequences used for this study whether the contradictory patterns are a result of different durational strategies for vowels and consonants or whether they may have been caused by other factors. Future studies should seek to determine if the data obtained here are a reflection of a more global regularity.

The unexpected, close to significant, durational difference between /ma/ in *Adama* and corresponding /ma/ in *dama* is difficult to interpret in terms of durational strategies for boundary location. It is very unlikely that the word boundary had any effect on the observed difference. Since the effect was not statistically significant at $p<0.05$, it may have as well resulted from random variation in the data.

9. Conclusions

Temporal variation in segmental duration is an acoustic strategy employed by speakers to encode cues to word segmentation. Listeners read those cues to parse the incoming signal into meaningful words. Durational variability seems to be a negotiated strategy shared by speakers and listeners, whereby the words can retain their integrity even in running speech which lacks pauses to signal word boundaries. Understanding this mechanism is essential for both linguistic and technological reasons.

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