REARTICULATED GEMINATES ARE NOT SEQUENCES OF TWO IDENTICAL SOUNDS: EVIDENCE FROM POLISH AFFRICATE GEMINATES

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ABSTRACT

The study investigates rearticulated affricate geminates in Polish. Polish has voiceless affricates with three different places of articulation, all of which undergo gemination. Twenty-three native speakers of Polish produced words with intervocalic affricate geminates in two sentence positions. Rearticulation occurred in 76.5% of the productions. Durational measurements revealed that the first affricate had a significantly longer closure phase and a shorter frication release than the rearticulated affricate. The frication release in the second consonant tended to have higher maximum and mean intensity, however the difference was not significant. These results are interpreted to reflect bidirectional alignment of the two articulations to two different syllables.

Keywords: geminates, affricates, duration, Polish

1. INTRODUCTION

Most of the research on geminates in the world's languages has concentrated on single-articulated geminates [most recently see 1, 3, 7, 10], because single-articulation appears to be a dominant realization type in geminate production. As a result, geminates are frequently referred to as long sounds [8] that are created from the uninterrupted succession of two identical short consonants [5]. Less attention has been paid to rearticulated geminates. If, as in the case of single-articulated geminates, rearticulated geminates (also referred to as double-articulated) are sequences of two identical short consonants, we should observe identical durational parameters of the occlusion and frication component in affricate geminates. However, this scenario becomes complicated if prosodic factors are taken into account. According to Lehiste et al. [9] intervocalic rearticulated geminates belong to separate syllables in that the first articulation closes a syllable and the second articulation starts the next syllable. If this is the case, we should observe differences in durational properties between the two articulations, because prosodic boundaries have been shown to affect segment durations [4, 15; for Polish see 11, 12]. Moreover, previous studies have shown that syllable-initial segments exhibit higher articulatory strength than syllable-final segments [6]. Accordingly, if the two affricates are separated by a word boundary, we should see higher intensity of the release into frication in the second rather than the first articulation.

Polish consonantal inventory includes three categories of affricates: alveolar /ts/, retroflex /tʂ/ and palatal /tɕ/. All these three affricates may create phonological word-internal geminates that will form lexical minimal pairs with phonological singletons in words such as *świeccy* /ɕfjɛt͡st͡si̯/ 'laymen' vs. *świecy* /ɕfjɛt͡si̯/ 'candle' (Gen.), *uczczą* /ut͡ʂt͡ʂõ/ 'they will celebrate' vs. *uczą* /ut͡ʂõ/ 'they teach', *jedźcie* /jɛt͡ɕt͡ɕɛ/ 'travel' (Imp.) vs. *jecie* /jet͡ɕɛ/ 'you eat'. Previous research has shown that Polish affricate geminates may have two patterns of realization: they may be single-articulated by lengthening the occlusion phase with one final fricative component or they may be rearticulated with two short occlusions. The actual choice of articulation type appears to be largely speaker-dependent. Thurgood [13] tested the production of two geminates /ts/ and /dz/ in a repetition task. The results showed that 63% of the speakers were consistent in producing either single-articulated /t:s/ or rearticulated /tsts/. 37% of the speakers produced both /t:s/ and /tsts/. Geminates with voiced /dz/ were rearticulated 59% of the time.

In a follow-up study, Thurgood and Demenko [14] employed a reading task with geminates including all three voiceless affricates /ts/, /tʂ/ and /tɕ/. Rearticulation occurred in 69% of the productions. Rearticulated geminates were significantly longer than single-articulated geminates in the case of /tʂ/ and /tɕ/ but not for /ts/. There was also observable between-speaker variation in the choice of articulation type. Some speakers tended to rearticulate most of the time, while others tended to single-articulate, however all speakers used both types of articulation. In their analysis, the authors largely concentrated on single-articulated geminates even though they were less frequent than rearticulated geminates. The ratio of singletons to single-articulated geminates was 1:1.7. Two types of single-articulated geminates were separated: those produced with increased durations of closure (/t:s/, /t:ʂ/, /t:ɕ/) and those produced with increased durations of a

fricative component (/ts:/, /tʂ:/, /tɕ:/). Out of the collected 32 single-articulated geminates, 56% were produced with increased closure and 44% were produced with increased friction.

2. THE CURRENT STUDY

In this study we investigate rearticulated affricate geminates to find if the two articulations are different in terms of:

1. duration of the occlusion phase
2. duration of the release into frication
3. intensity of the release into frication

We predict to find differences in some or all of these parameters, because, as discussed earlier, the two articulations are assumed to be governed by different positions in a syllable. In sum, a rearticulated geminate is not expected to be a mere sequence of the same sounds.

2.1. Participants

Twenty-three native speakers of Polish participated in the study. All of them were born and residing in Poland. There were 17 females and 6 males, ranging in age from 20 to 27 years (M = 21,6). None of the speakers reported any speech or hearing disorders nor had any indication of such.

2.2. Materials

The stimuli were the abovementioned three minimal pairs exhibiting the singleton-geminate contrast in Polish voiceless affricates, i.e.:

świeccy /ɕfjɛt͡st͡sɨ/ vs. *świecy* /ɕfjɛt͡sɨ/

uczczą /ut͡ʂt͡ʂɔ̃/ vs. *uczą* /ut͡ʂɔ̃/

jedźcie /jɛt͡ɕt͡ɕɛ/ vs. *jecie* /jɛt͡ɕɛ/

All these items represent the most frequent trochaic word structure with the tested consonants in an intervocalic, post-stress position. They were placed in carrier sentences in two accented positions: initial (theme) and final (rheme). Each element of a contrastive pair appeared in a rhythmically identical context, including the equal number of syllables and identical lexical stress distribution, in order to ensure comparable prominence conditions. The corresponding Polish voiced affricates were not included in the study because they rarely form within-word geminates and there exist no minimal pairs where the singleton-geminate contrast could be analysed. In this study, we focus on the realization of geminates alone, without investigating the two accented positions separately.

2.3. Procedure and recording

The participants were asked to read the test sentences using their natural speech tempo. They were instructed to repeat a sentence in the case of any disfluencies. The recordings took place in a sound-proof booth at the Acoustic-Phonetic Laboratory, University of Silesia. The signal was captured at 44100 Hz using a headset dynamic microphone Sennheiser HMD 26 fed by a USBPre2 (Sound Devices) amplifier. The microphone was positioned approximately 5 cm from the speaker's mouth.

2.4. Measurement criteria

The rearticulated geminates were annotated using textgrids in Praat [2] from waveform and spectrogram using standard segmentation criteria. The closure phase of the first affricate was marked by the end of a preceding vowel indicated by cessation of formant structure and drop in intensity. The following release was delimited from an abrupt rise in energy of a fricative portion to the drop in energy for the closure of the second affricate. The closure of the second affricate was delimited from an offset of preceding frication to an onset of the following frication indicated by rises and falls of high-frequency energy. The offset of the release of the second affricate was marked by a rise in intensity and the onset of the formant structure of a following vowel. It must be noted that many rearticulated productions were characterised by incomplete closures with a certain degree of frication, especially in the second affricate. They were visible in both waveform and spectrogram as weak fricative components between the first and second release. However, even in these cases closures could be determined by observing drops and rises in frication intensity. Figure 1 shows segmentation of the production with complete closures and Figure 2 shows segmentation of the productions with incomplete closures.

Figure 1: Segmentation of a rearticulated geminate with complete closures in the word *jedźcie* /jɛt͡ɕt͡ɕɛ/.

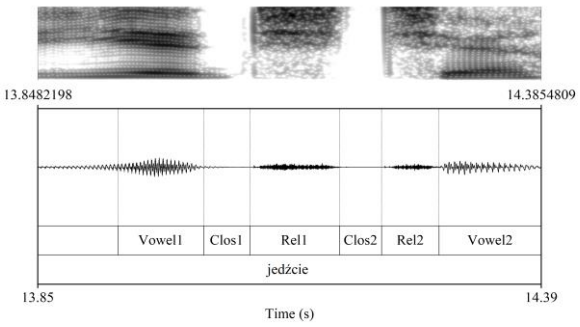
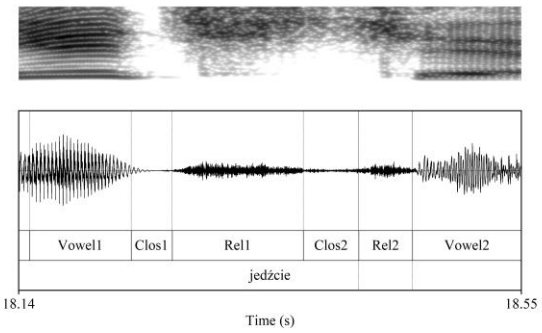


Figure 2: Segmentation of a rearticulated geminate with incomplete closures in the word *jedźcie* /jɛtɛtɛɛ/.



Mean and maximum intensity values were measured for the first and second release in the range between 20 and 100 dB using mean energy as the averaging method. For the first release, intensity was measured from the whole frication portion. In the second release, in order to make the two releases comparable, it was decided to measure intensity to the beginning of a robust rise in energy near the frication offset that clearly resulted from the following vowel.

3. ANALYSIS AND RESULTS

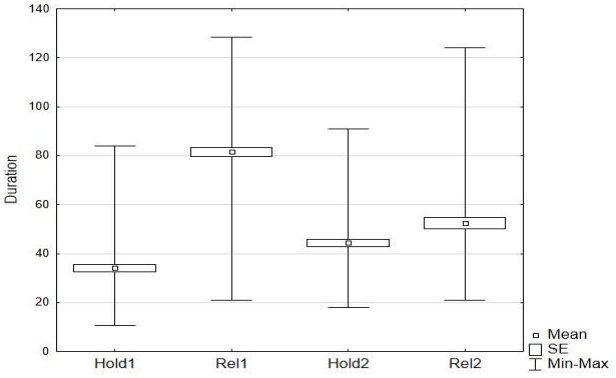
Out of the total 138 recorded geminates (23 speakers x 3 consonants x 2 repetitions) 2 productions were discarded because of incorrect articulation. Rearticulation was observed in 104 cases (76%) and the remaining 32 productions (24%) were single-articulated. The single-articulated productions had a mean of 108 ms (*SE* = 7.36) for closure duration and 82 ms (*SE* = 5.25) for release duration. There was observable between-speaker variation in articulation type. The speaker-individual range of rearticulation was from 17% (1/6) to 100% (6/6).

Altogether, a total of 104 rearticulated tokens were subject to further analyses. The tested parameters were analysed using Mixed Model ANOVA with speaker and word as random effects and consonant portion (Hold1, Rel1, Hold2, Rel2 for duration; Rel1, Rel2 for intensity) as a fixed effect. This model estimates the variance of random factors by constructing sums of squares and cross products matrix for independent variables by using Satterthwaite's method of denominator synthesis. The dependent variables were duration and intensity.

3.1. Duration

Durational measurements showed that the two articulations differed in temporal organisation of the closure and release into frication. Figure 3 presents mean durations of the closure and release of the first affricate (Hold1 and Rel1) and its rearticulation (Hold2 and Rel2).

Figure3: Mean durations with *SE* and ranges of the closure and release of the first (Hold1 and Rel1) and second (Hold2 and Rel2) articulation.



The closure duration of the first articulation (*M* = 34; *SE* = 1.35) was significantly shorter than the closure duration of the rearticulation (*M* = 44; *SE* = 1.51) [F(1, 2.43) = 13.73, p = .048]. The opposite pattern was observed for the release into frication. The first articulation had a significantly longer release (*M* = 82; *SE* = 1.85) than the rearticulation (*M* = 52; *SE* = 2.24) [F(1, 7,75) = 238.65, p < .001]. These results clearly point to the asymmetry between the first and second articulation. Moreover, the interaction between articulation (first vs. second) and the consonant component (hold vs. release) was highly significant [F(1, 39.48) = 158.49, p<.001], which shows a uniform pattern in which the first articulations are characterised by shorter occlusions and longer releases and rearticulations are characterised by longer occlusions and shorter releases.

3.2. Intensity

Intensity measurements did not reveal any significant differences between the first and the second release into frication. Table 1 shows the means and standard deviations of maximum and mean intensity in the first (Rel1) and rearticulated affricate (Rel2).

Table 1: Means and standard deviations of maximum and mean intensity of the first (Rel1) and second (Rel2) release.

	Max Intensity		Mean Intensity	
	M	*SD*	*M*	*SD*
Rel1	45.4	7.6	43.2	7.6
Rel2	47.0	7.2	45.3	7.3

Maximum intensity was not statistically different between the first (M = 45.4; SE = 0.8) and the second release (M = 47.0; SE = 0.7) [F(1, 2.94) = 2.63, p=.21]. Similarly, no significant difference was found for mean intensity between the first (M = 43.2; SE = 0.8) and the second release (M = 45.3; SE = 0.7) [F(1, 2.63) = 4.72, p = .13].

4. DISCUSSION

The current results show that rearticulated affricate geminates in Polish differ significantly in their durational make-up. The first articulation was characterised by a shorter occlusion and longer frication release. The second articulation had a longer occlusion and shorter release. The differences in release durations were not accompanied by significant changes in intensity, which may indicate that the two articulations differ solely in temporal organization.

As discussed in the Introduction, the fact that the two articulations differ in duration of their occlusion and release components may stem from their non-identical position in a syllable in that the first articulation may be (but does not have to be, as argued later) aligned to a coda position of the first syllable and the rearticulation to an onset position of the second syllable. However, an assumption that rearticulated geminates are necessarily divided by syllable boundary is not straightforward, at least in the case of Polish. Polish allows affricate geminates in syllable onsets, e.g. in the words *czczy* /t̪st̪ʂɨ/ 'idle' or *dżdżysty* /dʐdʐɨstɨ/ 'rainy'. Accordingly, in *uczczą* /utɕtɕõ/, we may have two potential syllabification patterns: /utɕ.tɕõ/ and /u.tɕtɕõ/. At present, we are not aware of any studies that would attempt to connect the individual strategies of syllabification with phonetic properties of geminate production, so we suggest that future studies should take up this issue more thoroughly.

Another interpretation of the current results, which is independent of syllable alignment, is that geminate rearticulation is a weakened repetition of the first articulation. This claim is supported by a significantly longer frication release and a more complete closure in the first articulation. In other words, the first articulation is intended by a speaker to provide important place-of-articulation cues to listeners and rearticulation is only a geminate marker. This strategy is contrary to single-articulation of geminates, where place cues are delayed onto the final release. As shown in the Measurement criteria, rearticulations were frequently characterised by inclomplete closures with leaking frication, indicating that speakers invested less articulatory force in the second consonant. However, more studies on rearticulated geminates from other languages are needed in order to establish if this pattern is specific to Polish, or if it is shaped by other factors such as speaking style or individual speaker variability.

6. CONCLUSIONS

The current results on rearticulated affricate geminates showed that:

1. The first articulation is characterised by shorter closure and longer release into frication
2. There are no significant differences in intensity of frication between the first articulation and rearticulation
3. Rearticulations tend to have incomplete closures with leaking frication.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] Al-Tamimi, J., Khattab, G. 2018. Acoustic correlates of the voicing contrast in Lebanese Arabic singleton and geminate stops. *J. Phonetics* 71, 306-325.

[2] Boersma, P. 2001. Praat, a system for doing phonetics by computer. *Glot Int.* 10, 341-345.

[3] Bouarourou, F., Vaxelaire, B., Laprie, Y., Ridouane, R., Sock, R. 2018. The timing of geminate consonants in Tarifit Berber. *Proc. Comp. Science* 128, 25-31.

[4] Byrd, D., Saltzman, E. 2003. The elastic phrase: Modeling the dynamics of boundary-adjacent lengthening. *J. Phonetics* 31(2), 149-180.

[5] Clark, J., Yallop, C. 1990. An introduction to phonetics and phonology. Oxford: Blackwell.

[6] Krakow, R. A. 1999. Physiological organization of syllables: a review. *J. Phonetics* 27, 23-54.

[7] Kubozono, H. (ed.). 2017. The phonetics and phonology of geminate consonants. Oxford: Oxford University Press.

[8] Ladefoged, P., Maddieson, I. 1996. The sounds of the world's languages. Oxford: Blackwell.

[9] Lehiste, I., Morton, K., Tatham, M. 1973. An instrumental study of consonant gemination. *J. Phonetics* 1973, 131-148.

[10] Mitterer, H. 2018. Not all geminates are created equal: Evidence from Maltese glottal consonants. *J. Phonetics* 66, 28-44.

[11] Porzuczek, A., Rojczyk, A. 2011. Word boundaries in native Polish speech. In: Androsova, S. (ed.), *Proceedings of the 1st International Conference 'Phonetics without Borders', June 13-15 2011*, 91-95.

[12] Rojczyk, A. 2009. *Brat Adama* vs. *brata dama*: Temporal phonetic parameters signalling word boundaries in Polish. *Linguistica Silesiana* 30, 59-73.
[13] Thurgood, E. 2001. The phonetic realizations of phonologically geminate affricates in Polish: The Long and the Short of it. *Speech and Language Technology* 5, 9-19.
[14] Thurgood, E., Demenko, G. 2003. Phonetic realizations of Polish geminate affricates. In: Solé, M. J., Recasens, D., Romero, J. (eds), *Proceedings of the 15th International Congress of Phonetic Sciences*, 1895-1898.
[15] Turk, A., Shattuck-Hufnagel, S. 2000. Word boundary-related duration patterns in English. *J. Phonetics* 28, 397-440.