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The perception of rearticulated and single-articulated geminates in Polish

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1. INTRODUCTION

Geminates are a group of consonants that are articulated for a longer period of time than their corresponding singleton consonants. In all known geminating languages other than Polish, longer constrictions of geminates are undisrupted, and they are therefore referred to as long counterparts of singletons (Davis 2011). Constriction lengthening appears to be the default and dominant type of geminate articulation; no other articulation type is mentioned in the two cumulative publications on geminates in the world's languages (Kawahara 2015, Kubozono 2017), or in numerous journal publications on durational and spectral properties of geminates (references in Hamzah et al. 2016, Rojczyk and Porzuczek 2019a). Polish is an exception here, because it has both true (lexical) and fake (concatenated by morphological process) geminates that may be either single-articulated by lengthening the constriction phase, or rearticulated. Rearticulation is manifested by the production of each consonant separately with central disruption of the whole geminate. The result is the perceptible release of the first consonant, especially observable in the case of stops and affricates. Figures 1 and 2 show the single-articulated (left) and rearticulated (right) productions of the word *getto* 'ghetto' and *lekko* 'lightly' in Polish.

Although rearticulation of Polish geminates appears to be a unique feature of geminate production, it has drawn relatively little attention to date. Thurgood (2001) recorded the production of geminate affricates by 27 speakers of Polish and found that 61% of the collected tokens were rearticulated. Thurgood and Demenko (2003) reported a similar ratio (68%) of rearticulated geminate affricates produced by nine speakers. They also observed a large between-speaker variation in the articulation type in that some speakers rearticulated most of the time, while others tended to single-articulate. Rojczyk and Porzuczek (2014) analysed the production of nasal geminates by 26 speakers and found that only 3.8% of them were rearticulated,

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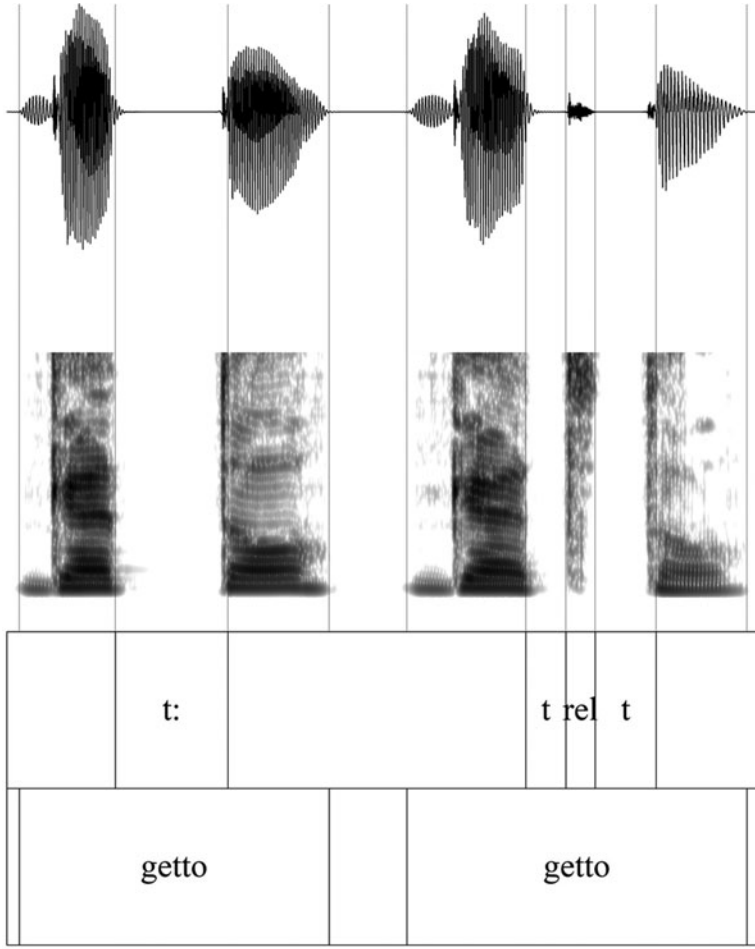

Figure 1: Two pronunciations of *getto* 'ghetto'

suggesting that the articulation type may not only be specific to an individual speaker but may also depend on the consonant group (affricates versus nasals). More recently, Rojczyk and Porzuczek (2019b) found a rearticulation ratio of 76.5% in affricate geminates produced by 23 speakers. Durational measurements revealed that the first affricate had a significantly longer closure phase and a shorter frication release than the following affricate. This durational disproportion was interpreted to reflect bidirectional alignment of the two articulations to two different syllables. Finally, Rojczyk and Porzuczek (2019a) had 54 speakers produce geminates belonging to different consonant groups such as affricates, stops, nasals and fricatives. The largest rate of rearticulation was reported for affricates (35%), followed by stops (29%), nasals (18%), and fricatives (2%). As in the study by Thurgood and Demenko (2003), they noted an observable speaker-dependent variation in the

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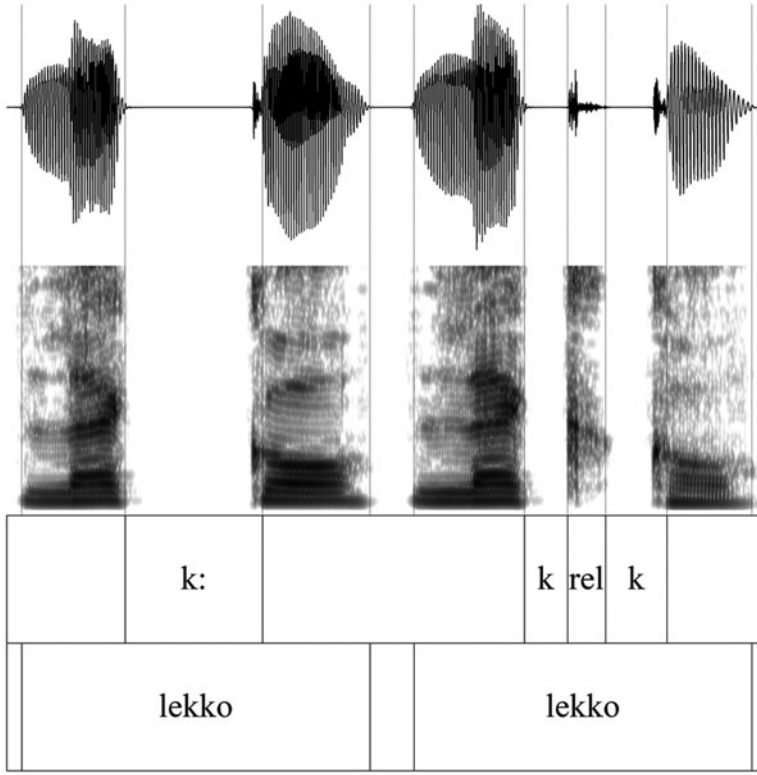

Figure 2: Two pronunciations of *lekko* 'lightly'

choice of articulation type with some speakers producing only single-articulated geminates and other speakers producing rearticulated geminates up to 83% of the time.

The following conclusions can be drawn from the review of prior studies on rearticulated geminates. Firstly, geminate rearticulation appears to be a unique feature of Polish since it is not reported for any of other geminating languages. Secondly, the rearticulation rate is speaker-dependent, with some speakers tending to single-articulate and others having rearticulation as a dominant articulation type. Thirdly, the frequency of rearticulation relies on a consonant group, in that affricates and stops are characterised by more rearticulation compared to nasals of fricatives. An issue that has not been addressed in previous studies is how rearticulation contributes to the perception of geminates. Rojczyk and Porzuczek (2019a) suggested that rearticulation in Polish may be a perceptual feature that enhances the singleton/geminate contrast. This interpretation results from the fact that Polish geminates, unlike geminates in other languages, lack durational cues in the preceding and following vowels (no vowel shortening or lengthening – see references for other languages in Rojczyk and Porzuczek 2019a). Consequently, the only perceptual cue for

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the singleton/geminate contrast is consonant duration; rearticulation may serve as an additional robust cue in signalling the geminate category. If this is indeed true, rearticulated geminates should be perceived more accurately and more quickly than single-articulated geminates. In this study we address this issue by using an identification task with rearticulated and single-articulated geminates.

2. The current study

The goal of this study is to investigate if Polish rearticulated geminates are perceived more accurately and more quickly than single-articulated geminates. The rationale relies on the suggestion by Rojczyk and Porzuczek (2019a) that rearticulation may facilitate the perception of the singleton/geminate contrast. The study addresses the following research questions:

1. Are rearticulated geminates perceived more accurately than single-articulated geminates in the singleton/geminate identification task?
2. Are rearticulated geminates perceived faster than single-articulated geminates?

2.1. Materials

The materials were created from 20 target nonwords with rearticulated geminates produced by five native speakers of Polish (three females and two males) with a mean age of 20.03 years. The segmental frame for each production was /pɛCCak/. Nonwords rather than real words were chosen to bypass top-down lexical effects in perception. All geminate targets had corresponding singleton targets recorded by the same speakers. The recording took place in a sound-proof booth in the Speech Processing Laboratory of the University of Silesia in Katowice. The signal was captured at 44100 Hz through a dynamic Shure SM7B microphone fed by a Steinberg UR44 (Yamaha) audio interface into a PC unit and stored as wav. files. The stimuli included 15 voiceless stops (five bilabial /p/, five dental /t/, and five velar /k/) and five alveolar affricates /ts/. Table 1 lists the recorded target geminate/singleton pairs.

The single-articulated targets were created by silencing the occlusion portion of a rearticulated geminate in Praat (Boersma 2001). This method permitted full control over other stimulus parameters such as occlusion duration or word duration. As a result, the only difference between rearticulated and single-articulated targets was

Consonant group	Consonant	Number of speakers	Geminate	Singleton
affricate	/ts/	5	pe͡ccak	pe͡cak
stop	/p/	5	pe͡ppak	pe͡pak
stop	/t/	5	pe͡ttak	pe͡tak
stop	/k/	5	pe͡kkak	pe͡kak

Table 1: The list of recorded geminate/singleton pairs.

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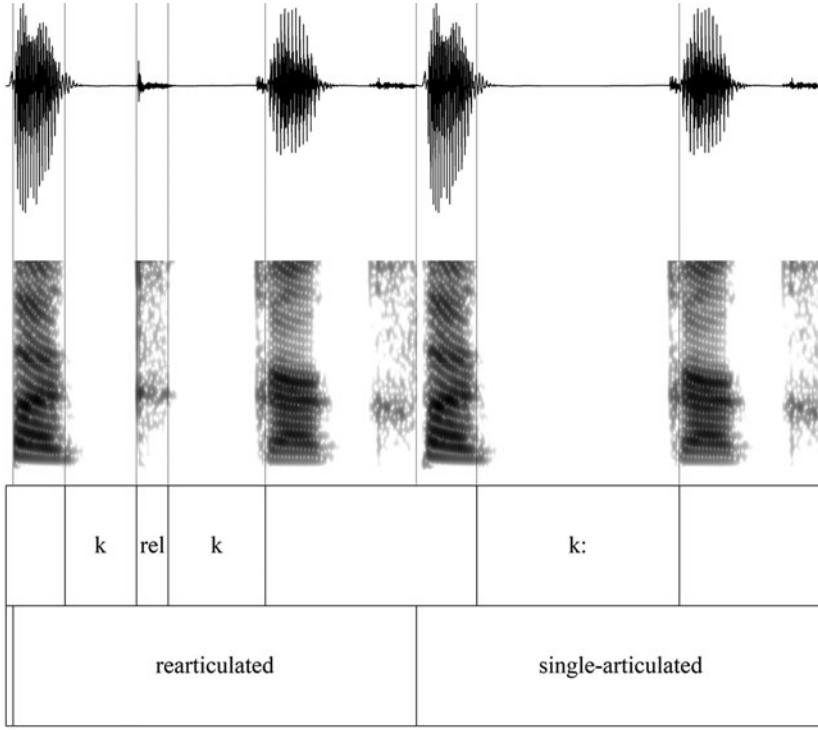

Figure 3: Two pronunciations of *pekkak*

the presence or absence of the release burst of the first consonant. Figure 3 shows the nonword *pekkak* with the rearticulated (left) and edited single-articulated (right) geminate /kk/.

The same speakers recorded an additional 30 tokens containing geminates other than stops or affricates, such as nasals, approximants, or liquids, that were used for familiarization and distraction.

2.2. Participants

A total of 37 participants (20 females and 10 males), aged 19 to 26 ($M = 20.5$), took part in the perception experiment. They were all native speakers of Polish, recruited from the University of Silesia in Katowice. Each participant received remuneration of 30 PLN (approximately 7 EUR). None of the participants reported any speech, hearing or manual disorders. All participants had normal or corrected-to-normal vision.

2.3. Procedure

The participants were tested individually in the Speech Processing Laboratory of the University of Silesia in Katowice. The design was a two-alternative forced-choice

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identification task. The experiment was run using E-Prime 3.0, and accuracy scores and reaction times (RTs) were collected using the Serial Response Box (Psychology Software Tools). The audio stimuli were delivered through Philips SBC HP840 headphones at a comfortable listening level of 70 dB. The listeners were seated in front of a 17-inch monitor and were instructed to put their left and right index fingers on the flashed buttons of the response box. They were informed that they would see a pair of two words aligned left and right on the screen and next they would hear one of the words spoken through the headphones. Their task was to press the left or right button to indicate which word they had just heard. The participants were instructed that not only accuracy scores but also RTs were measured, so they should press the correct button as soon as they had made a decision. The singleton word always appeared aligned to the left and the geminate word to the right of the screen (e.g., *petak – pettak*; *pekak – pekkak*). Each cycle of stimulus presentation had the following structure: (1) get-ready screen with the phrase *Get ready!* flashed for 1500 ms; (2) display of the target words for 3000 ms; (3) audio stimulus presentation. The time limit for making the decision was 4000 ms. In order to increase the participants' commitment, correct/incorrect feedback was provided. Figure 4 shows the experimental design of decision making.

The core aspect of the experimental design was that the geminate word in each pair had two variants, one containing a rearticulated geminate and the other containing a single-articulated geminate. For example, for the *petak – pettak* pair, the listeners heard three audio stimuli: (1) *petak* with singleton /t/; (2) *pettak* with rearticulated geminate /tt/; (3) *pettak* with single-articulated geminate /tt/. Accuracy scores were calculated by comparing the rate of correct identification of geminate words between the rearticulated and single-articulated tokens. RTs were calculated by comparing the speed of correct identification of the rearticulated and single-articulated tokens. In order to balance the number of singleton and geminate correct responses, the singleton word was presented twice for each token. The order of stimulus presentation was randomized for each participant. Altogether, each listener was exposed to 80 target trials and 24 distractor trials.

The experiment commenced with collecting personal data (age, gender). After being briefly instructed about the nature of the task, the participants proceeded to the familiarization stage which contained six trials with word pairs including fricative and nasal consonants (e.g., *pefak – peffak*; *penak – pennak*). The whole session for each participant lasted approximately 25 minutes.

3. Analysis and results

Identification accuracy was calculated as the proportion of correct responses to the total responses. RTs of correct identifications were trimmed below 400 ms and above 2500 ms (14 out of 740 trials rejected). The Shapiro-Wilk *W* test of normality of distribution revealed that, despite trimming, the RTs were not normally distributed for either single-articulated [$W(740) = .915$, $p < .001$] or rearticulated [$W(740) = 0.916$, $p < .001$] geminates. As a result, the nonparametric Wilcoxon matched pairs test was used to compare two dependent samples.

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Figure 4: Experimental design of decision making

The analysis of accuracy scores revealed that there was no significant difference in perception of single-articulated (96.9%) and rearticulated (97.7%) geminates [$\chi^2 = .63$, $p = .43$]. Both types of geminates approached the ceiling level of perception, indicating that rearticulation does not facilitate perception accuracy. The analysis of RTs in milliseconds, using the Wilcoxon matched pair test for within-group comparisons, revealed that rearticulated geminates were identified faster ($M = 657$; $SE = 4.69$) than single-articulated geminates ($M = 686$; $SE = 5.64$) [$Z = 4.21$, $p < .001$]. The mean RTs for singletons were 654 ms ($SE = 4.5$).

When the analysis was broken into separate consonantal groups, it showed that rearticulated geminates were identified faster than single-articulated geminates for /ts/ ($M = 628$; $SE = 9.14$) vs. ($M = 700$; $SE = 11.23$) [$Z = 5.69$, $p < .001$], and /t/ ($M = 649$; $SE = 9.14$) vs. (M 680; $SE = 11.23$) [$Z = 2.07$, $p = .037$]. The difference was not significant for either /p/ [$Z = .91$, $p = .36$] or /k/ [$Z = 1.35$, $p = .16$]. Figure 5 shows mean RTs with confidence intervals for each individual consonantal group.

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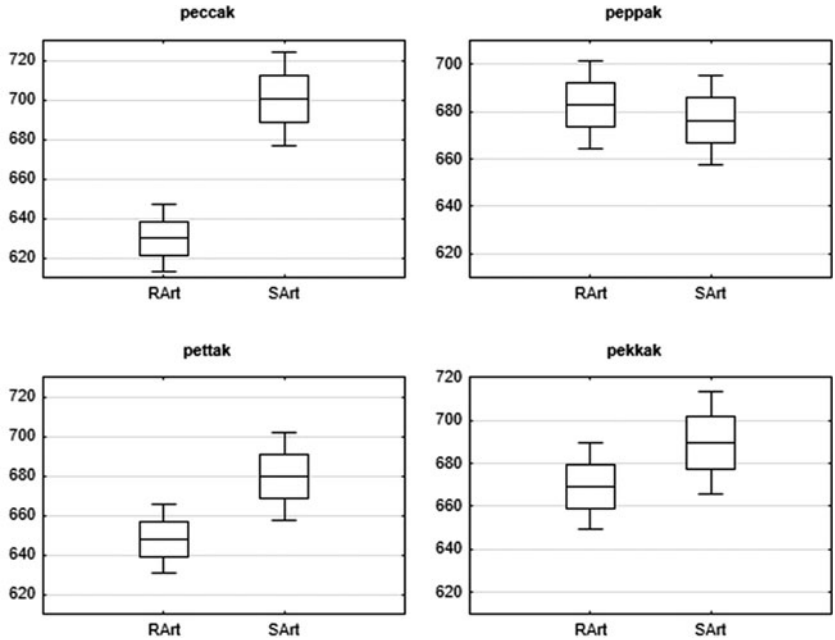

Figure 5: Mean RTs with confidence intervals for each individual consonantal group

4. Discussion

The results suggest that rearticulation of geminates has a mixed effect on their perception. On the one hand, rearticulation does not lead to increased accuracy, mainly because single-articulated geminates themselves have a very high accuracy rate (97.7% for rearticulated and 96.9% for single-articulated geminates). On the other hand, as revealed by the analysis of reaction times, rearticulated geminates are perceived faster than single-articulated geminates. This result is difficult to interpret, considering the complex interplay between accuracy and identification speed. A similar problem was observed in speech segmentation from allophonic cues (Rojczyk 2019). Moreover, the perceptual benefit obtained from rearticulation was observed for /ts/ nd /t/, but not for /p/ and /k/. At this stage, relying on the current results, it may be concluded that rearticulation in geminates has a potential to facilitate perception; however, future studies should use more challenging perception tasks in order to achieve lower accuracy scores, which in turn may reveal significant differences between the perception of single-articulated and rearticulated geminates.

As noted by one of the reviewers, if rearticulated geminates consist of two successive stops, it may be assumed that listeners might make an early decision that what they hear is a singleton consonant rather than a geminate. We admit that this a plausible interpretation of the RT distinctions; however, we predict that the release burst of the first consonant will cue a singleton only if it proceeds straight into a following

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vowel. In the case of rearticulated geminates, we observe a release burst into a following closure, which may cue gemination earlier than the total duration of the geminate would. Future experiments may validate either of these two hypotheses.

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