Allophonic Variation in the Polish Vowel /ɨ/: Results of a 3D Ultrasound Study and their Phonological Implications*

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Abstract: This article presents new data on allophonic variation of the Polish vowel commonly transcribed as /ɨ/ and frequently analyzed as phonologically back (e.g., Rubach 1984; Gussmann 2007). The new data were collected using 3D ultrasound images from ten native speakers of Polish. While vowels in the context of labial and dental stops do not differ significantly, being articulated with a high front position of the tongue in both environments, the /ɨ/ assimilates to preceding velar stop consonants and is produced with relatively more raising of the tongue body and with a constriction extending further back. This is to be expected if /ɨ/ is taken to be a front vowel that assimilates to a [+back] consonant. This finding has potential consequences for the analysis of palatalization in Polish.

1. Introduction

Apart from the extensive system of assimilatory palatalizations resulting in sequences of palatalized consonants followed by front vowels, Polish also exhibits a constraint that cannot be easily labeled as an assimilation. In particular, the vowel /ɨ/ does not normally follow a velar stop (although it can follow a velar fricative) in native vocabulary (**kɨ*, **gɨ*). The constraint is somewhat mysterious, given the current standard assumption that Polish /ɨ/ functions in phonology as a back (unrounded centralized) vowel (Rubach 1981, 1984; Gussmann 1980, 1992, 2007; Szpyra 1995; Rydzewski 2017; Czaplicki 2013, 2019; and many others), which should make it perfectly compatible with a back consonant. This idiosyncrasy has theoretical implications that we shall explore below. This study reports on the results of an articulatory investigation of /ɨ/ in various consonantal environments using 3D ultrasound methodology. We will argue that the results of the study indicate that /ɨ/ in modern Polish in the

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context of labial and dental stops is a front vowel, while in the context of velar sounds the constriction in /ɨ/ extends further into the back vowel region. The existence of the allophonic variant supports the analysis of /ɨ/ as a front vowel that is modified in the context of a velar stop to assimilate to its backness. On the other hand, this allophony is difficult to explain under the assumption that /ɨ/ is a back vowel in the neutral context of labial or coronal stops.

While making an argument based on phonetic evidence, we assume is that features are abstract categories with a set of phonetic correlates, which may be acoustic, articulatory, or both (cf. e.g., Hayes 2009: 75). The interpretation of phonological features as abstract entities with phonetic correlates follows the core research in phonological feature theory, starting with Jakobson and Halle 1956, Chomsky and Halle 1968, and Halle 1983, among others. The abstract categories necessarily have to be anchored in phonetics. They remain stable as long as they have a relation to verifiable phonetic facts. Hayes and Steriade (2004: 14) call it the stabilization problem—"the problem of maintaining the (relatively) stable phonology in the face of extensive variation in the phonetic factors that govern the phonological constraints"—and review different formal solutions to it.

In general, it is nowadays not particularly controversial to assume that the functioning of phonological categories reflects or is constrained to a large degree by phonetics (Natural Phonology, e.g., Stampe 1973; Grounded Phonology, e.g., Archangeli and Pulleyblank 1994; Feature Geometry, e.g., Halle 1995; Dispersion Theory, e.g., Flemming 1995; Functional Phonology, e.g., Boersma 1998). A bone of contention is how and to what extent phonetic information is present in phonology (see Hayes and Steriade 2004 and references therein). The approaches range from encoding phonetic information directly in Optimality Theoretic constraints (e.g., Pater 1999; Kager 1999; Flemming 2001) to postulating separate modules of grammar that encode phonetic detail (e.g., P-map in Steriade 2008) to accounting for the phonetic patterns in phonology by reference to diachronic language change and mechanisms connected to language perception and learning (e.g., Blevins and Garrett 2004). The articulatory data we present can be interpreted in the most straightforward way in a model incorporating phonetic information directly into phonological constraints. However, the arguments remain valid even if we move phonetic detail outside of phonology per se, given some formal approach to the stabilization problem.

In the rest of this section, we will set the discussion of **Kɨ* (i.e., *kɨ* and *gɨ*) sequences in a broader context of controversies surrounding Polish /ɨ/ (section 1.1.) and discuss the choice of the methodology used to investigate the articulation of /ɨ/ (section 1.2). Section 2 describes in detail the methodology we employed. Section 3 presents the results of the ultrasound study. Section 4 moves on to discuss the results and their consequences for the interpretation of the phonological system of Polish and beyond, and section 5 summarizes the findings.

1.1. Setting the Stage

A broadly accepted assumption is that Polish has six oral vowel phonemes, written orthographically as *i*, *y*, *e*, *a*, *o*, and *u*, and most often transcribed as /i, ɨ, e, a, o, u/. Among them, the vowel /ɨ/ in particular has been the focus of many phonological debates. First, some early analyses assume the pair of vowels [i]-[ɨ] to be allophones of one phoneme, parallel to some analyses of Russian (Avanesov 1956; Avanesov and Sidorov 1945). Indeed, the pair /i/-/ɨ/ patterns like the pairs of allophones of all other Polish vowels, which we will elaborate on below. However, a number of arguments speak for the phonemic status of /ɨ/, irrespective of the assumptions about its featural make-up. The arguments for the phonemic status of /ɨ/ include phonological ones (e.g., Rubach 1984) as well as native speakers' intuition. For a review of arguments, see, for example, Rydzewski 2017. While we believe that the evidence supports the analysis of /ɨ/ as a separate phoneme, this assumption has no consequences for the analysis presented in this paper.

As mentioned earlier, all oral vowels in Polish—except for /i/ and /ɨ/—participate in an allophonic alternation conditioned by a neighboring consonant. They are reportedly fronted and raised when the preceding and/or following consonant has a prepalatal (alveopalatal) or palatal place of articulation (/t͡ɕ, d͡ʑ, ɕ, ʑ, ɲ, j/), as in (1), cf. Sawicka 1995; Wiśniewski 1997. Recent articulatory-acoustic evaluations point to tongue root advancement in the context of a prepalatal consonant as the consistent effect of the process across all vowels and speakers, with inconsistent collateral raising and fronting (Lulich and Cavar 2019).

(1) (Pre)palatal-context vowel allophony

/u/: neutral context [u] (e.g., *tupać* 'to stump')
vs. prepalatal context [ʉ] (*Maciuś* 'person name')

/e/: neutral context [ɛ] (e.g., *test* 'test')
vs. prepalatal context [e] (*sieć* 'net')

/o/: neutral context [ɔ] (e.g., *sos* 'sauce')
vs. prepalatal context [ɵ] (*cioć* 'aunt, gen pl')

/a/: neutral context [a] (e.g., *tak* 'yes')
vs. prepalatal context [a̟] (*ciaśniej* 'tighter')

In contrast, the vowels /i/ and /ɨ/ do not have two allophones each. Instead, the two vowels observe the same phonotactic distribution as allophones of all the other vowels and show the same involvement of tongue root phonetically (Ćavar 2007), where /i/ patterns with prepalatal-context vocalic allophones and /ɨ/ patterns with 'neutral' consonant-context vowel allophones. Therefore, Ćavar 2007 and Lulich and Cavar 2019 concluded that /i/ and /ɨ/ are both high front vowels, supporting descriptions in, e.g., Wierzchowska 1980. In particular, like the prepalatal-context allophones of other vowels in Polish, /i/ shows a conspicuous advancement of the tongue root.[1] This analysis stands in sharp contrast with the common assumption that /ɨ/ is a back vowel. If we take /ɨ/ to be a back vowel, then we have no way to express the affinity between /i/ and /ɨ/ as being parallel to the allophonic relationships of the other vowels.

The assumption that /ɨ/ is a back vowel is in itself a necessary consequence of the standard analysis of palatalization as triggered by front vowels. Some authors observe the fact that /ɨ/ is not a back vowel phonetically, however, they analyze /ɨ/ as a back vowel based on phonological arguments (e.g., Gussman 2007). Since surface /ɨ/ does not trigger a phonetic palatalization of consonants the way /i/ does, it has been argued to be a back vowel, contrary to phonetic descriptions that align /ɨ/ with front rather than with back vowels. If, however, palatalization is triggered by /i/ that is [+ATR] and not triggered by /ɨ/ that is [–ATR], cf. Ćavar 2007, we do not need to propose an abstract analysis of /ɨ/ as a back vowel, attributing palatalization to the advancement of the tongue root instead. Thus we believe that /ɨ/ is a front vowel and that no abstract analysis is necessary to account for palatalization producing surface-palatal(ized) consonants.

Phonetically-grounded and phonologically consistent, the assumption that /ɨ/ is a front vowel allows us also to account for an otherwise mysterious constraint on **Kɨ* sequences, which is the focus of this paper. In particular, Ćavar 2007 postulated that the sequence **Kɨ* is a violation of Place Agreement, requiring that a velar consonant agree with the following vowel in terms of place (coronal or dorsal). The same constraint excludes **ki* sequences (as opposed to preferred /ci/, where the consonant is fronted to assimilate to the vowel)[2].

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[1] In a similar vein, Avanesov 1956 and Panov 1967: 41–43 argued that /i/ and /ɨ/ in Russian are a pair comparable to pairs of allophones of all other Russian vowels, in that members of each pair differ in exactly the same way.

[2] One of the reviewers points out that the same violation of Place Agreement arises in sequences of velar stops followed by mid front vowels, which are (synchronically) not problematic in Polish. Cavar (forthcoming) argues that Place Agreement is a family of constraints sensitive to the height of the vowel. Place Agreement referring to high vowels is higher-ranked than the general Place Agreement. Cavar argues that this universal ranking is phonetically motivated. Historically, Place Agreement also affected sequences with mid front vowels in Polish, rendering phonetic [ce/ɟe] morpheme-internally in words that nowadays have [kɛ/gɛ] (e.g., *kelner* 'waiter,' *geografia* 'geogra-

A problem of the analysis in terms of Place Agreement immediately presents itself. The constraint **Kɨ* holds exceptionlessly across a morpheme boundary, but there is one morpheme-internal exception with an unclear etymology—the exclamation *a kysz!* ('go away')—and a small number of evidently new borrowings (after World War II) and/or words in learned vocabulary, such as *kynolog* and *androgyne*, which allow the sequence. To account for these apparent exceptions to **Kɨ*, Ćavar (2007) postulated that /ɨ/ after a velar stop is retracted to match the velar consonant in backness.

The ultrasound study we report on in this paper sets out to phonetically test claims about the articulation of /ɨ/ in various consonantal contexts and to decide between the competing analyses of /ɨ/ as a front or as a back vowel. The paper explores the articulatory properties of Polish /ɨ/ as a function of the place of articulation of adjacent consonants (including labial /p/, coronal /t/, and velar /k/) and discusses the phonological implications of the findings. In particular, we will argue that (non-palatalized) velar stops and a default realization of /ɨ/ do not agree in backness, which underlies the constraint on **Kɨ* sequences. If the sequence is produced, as happens in new borrowings, /ɨ/ needs to be modified. A retracted allophone of /ɨ/ is produced, thus assimilating to the place of articulation of the back consonant. A retraction of /ɨ/, however, should not be expected if the vowel is back. Consequently, the results support the analysis of /ɨ/ as a front vowel.

1.2. The Choice of Methodology

Articulatory data can be collected using a number of different methods, each with its own advantages and disadvantages. For Polish, older studies used palatography (Benni 1915), X-rays (Koneczna and Zawadowski 1951; Wierzchowska 1965/1971, 1980), and labiography (Dłuska 1950). A number of newer studies used electropalatography (e.g., Pompino-Marschall and Żygis 2003) and/or electromagnetic articulatography (Lorenc and Święciński 2014/2015). The latter methods enjoy excellent time resolution and thus can be used to investigate dynamic aspects of speech. On the other hand, they suffer from poor spatial coverage of the articulator surfaces. The limited number of tongue sensors (for example, three or four sensors on the tongue midline, and two sensors on the sides of the tongue blade in the study of Lorenc and Święcicki 2014/2015) give only a limited number of spatially distributed data points at any given instant in time, and the tongue surface between the sensors is not observed. Given a limited number of sensors, little information can be gathered about asymmetric articulations, and no information can be obtained

phy.') This pronunciation could still be found into the late 20th century. Synchronically, the constraint is still active in sequences spanning a morpheme boundary.

about the tongue position behind the sensors, which limits its suitability for research targeting the tongue body and tongue root.

In contrast, research using ultrasound is well suited to show the back and root of the tongue, and the results are direct images, though their interpretation, occasionally, requires some knowledge of anatomy. Ultrasound has been used in speech research only since the 1990's, with only one earlier 2D ultrasound study of Polish by Wein et al. 1991. More generally, 2D ultrasound has by now been employed in numerous studies of a substantial number of languages and is quickly becoming a very popular method for studying articulation. The 3D-imaging we use in our study is a relative newcomer in speech research. While 2D data with equivalent spatial resolution would have better time resolution, 3D data (with time as the fourth dimension) gives more spatial information and is easier to interpret. First, it helps to verify the location of the midsagittal plane. Second, in cases when the image is of relatively poor quality, one can very often disambiguate the location of the surface of the tongue in the mid-sagittal plane by comparing images directly left and right of the mid-sagittal plane. Using 3D instead of 2D helps to avoid misinterpretation and provides additional information in cases when the articulation is not entirely symmetric along the coronal plane (left-to-right of the speaker). In our case, the use of 3D as opposed to 2D allowed us to disambiguate between retraction of the whole tongue body and a groove along the mid-sagittal plane in the same area.

2. Method

In our study, lingual articulation was imaged using a Philips EPIQ 7G ultrasound system with an xMatrix x6-1 digital 3D/4D transducer, as described by Lulich, Berkson, and de Jong 2018 and Lulich and Pearson 2019. Data were collected from 10 native speakers, five females and five males, from central and southern Poland. Participants were all speakers of standard Polish and ranged from 35 to 55 years old at the time of the recording. Seven of the speakers had lived in the United States for an extended period of time. These seven participants use Polish most of the time, paying particular attention to the quality of their language for professional or other reasons. Their Polish speech had no detectable foreign accent. Some earlier studies such as Sancier and Fowler 1997 indicate that extensive contact with a second language may impact fine phonetic details in speech. But as reported in Lulich and Cavar 2019, which made use of a complementary data set from the same 10 speakers, there were no detectable differences in vowel quality among the speakers, and this was supported by statistical analyses that showed no main effect of speaker for any of the first three formant frequencies or articulatory measures of tongue root position.

Participants were instructed to read word lists presented visually in Polish orthography, which is phonetically unambiguous. We focused on stressed vowels in disyllabic nonce words like *pypyp*, *tytyt*, *kykyk*. Nonce words like *titit*, *tetet*, *tatat*, *totot*, and *tutut* were also recorded. Additional real and nonce words were recorded as part of a larger study, but are not presented here (but see Lulich and Cavar 2019). For five speakers, the word list was read three times, resulting in three independent tokens of each of the stimuli (3 x 3 x 5 tokens with /ɨ/ + 3 x 5 x 5 tokens with other vowels = 120 tokens total). Five other speakers produced only two repetitions of each nonce word, yielding 2 x 3 x 5 tokens with /ɨ/ + 2 x 5 x 5 tokens with other vowels, or 80 tokens total. Together, a combined total of 200 tokens were analyzed.

The ultrasound transducer was secured under the chin with an Articulate Instruments ultrasound stabilization headset, see Scobbie, Wrench, and van der Linden 2008. Ultrasound files were analyzed using a custom MATLAB toolbox (The MathWorks 2018), called 'WASL', developed in the Speech Production Laboratory at Indiana University and available for download at https://spliu.sitehost.iu.edu/software/software.html. We targeted the midpoint of the vowel but due to relatively low time resolution (9.3—15.0 frames per second), with 2–4 frames for any vowel, often it was not possible to analyze the articulation exactly in the middle of the vowel, and the frame closest to the midpoint was selected. Because the vowels we investigate are monophthongs, that is, they are not expected to significantly change their quality throughout the duration of the steady-state portion and because they are articulated slowly (compared to stop consonants), the frame rates were judged to be sufficient for the present study. The appropriate frame was identified with the help of the synchronized audio spectrogram, and the midsagittal plane was verified from coronal slices of the three-dimensional ultrasound image. The shape of the tongue in the midsagittal plane was manually traced using the built-in WASL function and the tracing was copied over to a MATLAB figure for annotation. To compare the shape of the tongue across articulations, the tracings from a number of frames were copied into a single figure with the same spatial scale.

Audio recordings were made synchronously using a SHURE KSM32 microphone placed approximately one meter in front of the speaker and slightly to one side. Audio files were subsequently analyzed in Praat (Boersma and Weenink 2018) and formant frequencies were extracted using the Burg algorithm with default parameters for window length (0.025s), number of formants (4), and maximum formant frequency (3000Hz). The audio and ultrasound recordings were synchronized using the method described by Lulich, Berkson, and de Jong (2018), which has an uncertainty of about 30 ms.

For technical details about 3D/4D ultrasound in comparison with 2D ultrasound, and for details on audio synchronization, we refer the reader to Lulich, Berkson, and de Jong 2018 and Lulich and Pearson 2019. 3D/4D ultrasound has been used in phonetics/phonology research involving other languages, e.g., Brazilian Portuguese (Charles and Lulich 2019), Korean (Hwang, Charles, and Lulich 2019), and American English (Berkson, de Jong, and Lulich 2017). Estimates and discussion of the magnitude of articulatory analysis errors (e.g., during manual segmentation of tongue surfaces) for this 3D/4D ultrasound system are given in Csapo and Lulich 2015 and Lulich, Charles, and Lulich 2017, with a maximum uncertainty of less than 0.25 cm.

3. Study Results

Before discussing the variation in articulation of /ɨ/, let us consider the place of the vowel within the larger system of Polish oral vowels. In Figure 1 on the following page, the acoustic vowel space is plotted for the /t/ context for Speaker 5. Speaker 5 imaged particularly well, and is fairly representative of the entire group of participants. Figure 1 on the following page presents a vowel inventory with three front vowels (/i, ɨ, e/) and three back vowels (/u, o, a/)[3]. The lingual articulations of all vowel phonemes in the /t/ context for Speaker 5 are represented in Figure 2 on the following page. The /ɨ/ and /i/ have more advanced tongue root and tongue body than the vowels /a/, /o/ and /u/. The vowel /e/, realized as phonetic [ɛ], has more advanced tongue root and tongue body than /o/ and /u/ but is only marginally more advanced than /a/. These data confirm that the vowel /ɨ/ is phonetically a front vowel, in terms of both acoustics and articulation.

The articulation of [ɨ] is not uniform across contexts, although the variation is systematic. Systematic differences are visible in the ultrasound images. Figure 3 (on pages 10–11) shows the tracings of the tongue surface in the mid-sagittal plane for the 10 native speakers. Speakers 1–5 produced three repetitions of the CɨCɨC nonce words, where C was /p, t, k/, and the stressed vowel[4] was traced in each repetition. Speakers 6–10 recorded two repetitions each. In order to supplement the data from Speakers 6–10, we also traced the unstressed vowel in the repetition that produced the clearest ultrasound image. We made the decision to add measurements from the unstressed vowel because the stressed and unstressed realizations of /ɨ/ were not perceptually different. Subsequent articulatory analysis supported this decision. Thus each vowel context is represented by three measurements for all 10 speakers. In Figure 3, the tongue surface during the articulation of /ɨ/ (1) between labial

[3] Formant frequencies for all Speakers of the three high vowels (/i/, /ɨ/, /u/) are summarized in the Appendix. Formant frequencies for /i/ and /u/ are included as context for understanding the frequency ranges occupied by the formants of /ɨ/ within the larger vowel space of Polish.

[4] The default stress pattern in Polish falls on the penultimate. Speaker 3 consistently stressed the second syllable, which we traced. Other speakers stressed the penultimate syllable.

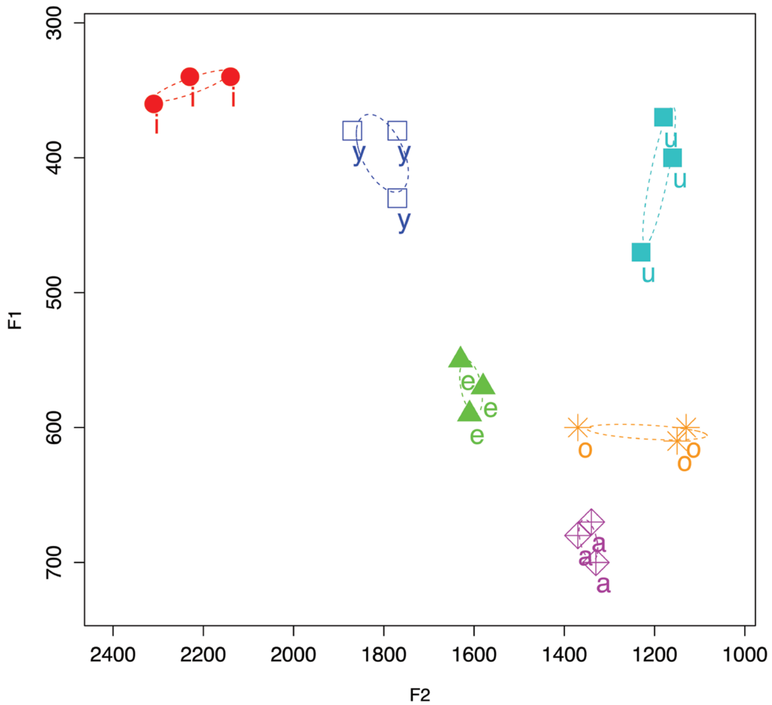


Figure 1. Vowel formant space for Polish (Speaker 5, male) in Hz. (Orthographic symbols used: "y" = [ɨ], "e" = [ɛ], "o" = [ɔ])

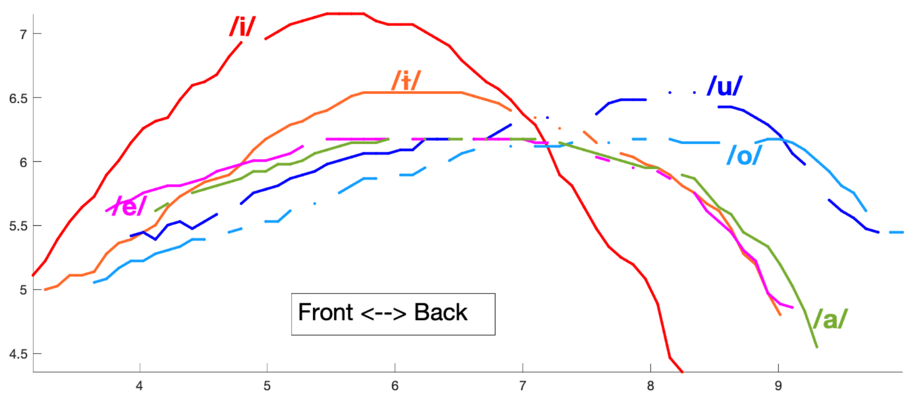


Figure 2. The lingual articulation of vowel phonemes for Speaker 5 in /t/ context.

stops is depicted in blue, (2) between coronal stops is depicted in red, and (3) between velar stops is depicted in black. The tip of the tongue points left in every case.

The results are very consistent, with all participants displaying a clear and systematic allophony. The vowel /ɨ/ is articulated in a velar context differently than in other contexts, namely, with a greater degree of tongue body raising and a longer constriction. All ten speakers have substantially more raising in /ɨ/ in the context of the velar stop. The constriction generally extends more posteriorly in the velar context. For all speakers except Speakers 4 and 6, the whole tongue (including the tongue root) is retracted in the velar context. For Speakers 4 and 6, increased raising results in a longer constriction extending both further to the front and further back in velar context.

The raising of the mass of the tongue has the consequence of substantially extending the length of the constriction, usually further back into the region

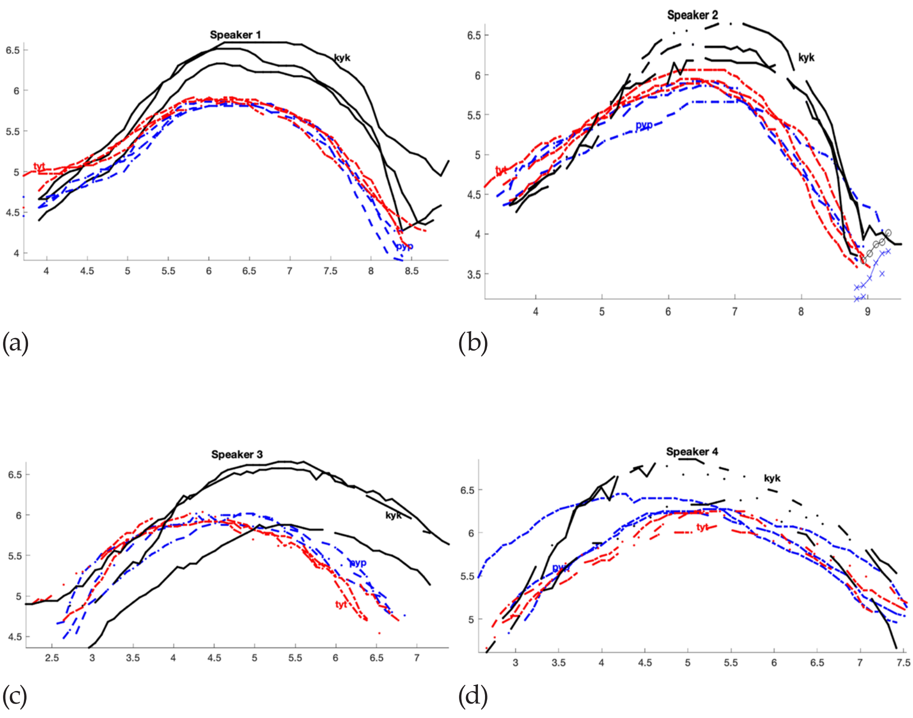


Figure 3. Mid-sagittal tongue contours for vowel /ɨ/ in the context of /p/ (blue), in the context of /t/ (red) and in the context of /k/ (black). (a) Speaker 1 (female); (b) Speaker 2 (male); (c) Speaker 3 (female); (d) Speaker 4 (female)

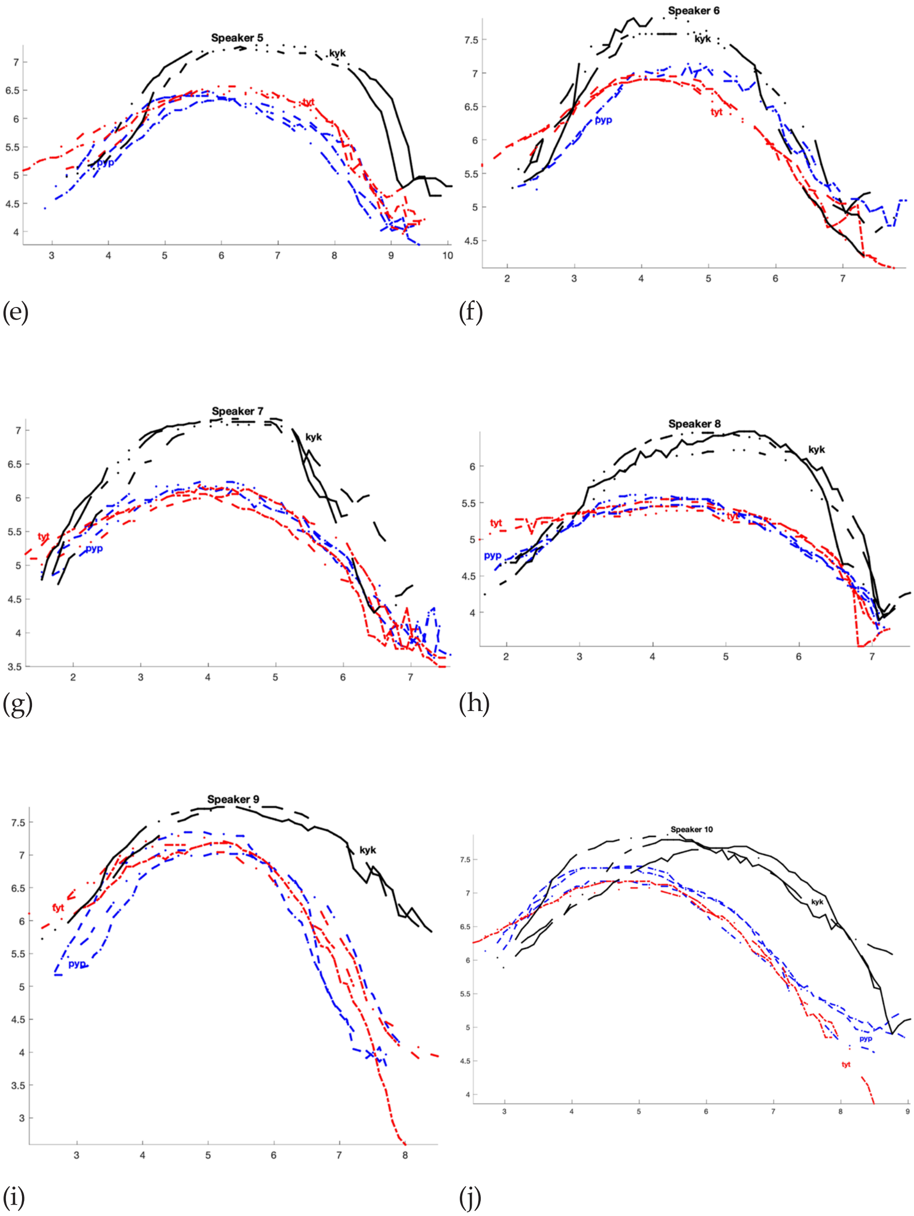


Figure 3 (cont'd). (e) Speaker 5 (male); (f) Speaker 6 (female); (g) Speaker 7 (female); (h) Speaker 8 (male); (i) Speaker 9 (male); (j) Speaker 10 (male)

of back vowels in eight of the 10 speakers. For eight of the 10 speakers, /ɨ/ in velar context is also articulated with a clearly visible retraction of the tongue root compared to other contexts.

Preliminary analysis of other vowels produced by Speakers 7 and 9 revealed that the vowels [ɛ] and [a] are also raised in the context of the velar stops, but only /ɨ/ is retracted (see Figure 4 on the following page for examples from Speaker 9).

4. Discussion

In the context of a velar stop, we observe the extension of the constriction for /ɨ/ into the back vowel region without losing the constriction produced by the blade of the tongue. By being raised and retracted from its neutral position, /ɨ/ in the context of /k/ assumes a position closer to that needed for the articulation of a velar stop. In other words, the vowel assimilates to the velar consonant. The opposite analysis, namely that of a putatively back vowel /ɨ/ assimilating to labial and coronal consonants, is unlikely. The position of the tongue body of /ɨ/ in the context of labial and dental stops is identical, even though labial and dental stops do not share a place of articulation, and thus we conclude that /ɨ/ in the context of labial and dental stops shows its default value.

However, the standard assumption has thus far been that /ɨ/ is phonologically a back vowel (Rubach 1981, 1984; Gussmann 1980, 1992, 2007; Szpyra 1995; Rydzewski 2014; Czaplicki 2013, 2019; etc.). Under this assumption, the retraction of /ɨ/ in the context of velars is puzzling. There is no phonological justification for retracting a vowel that is already back. If we assume, on the other hand, that /ɨ/ is a front vowel, then it appears that the neutral version of /ɨ/, a front vowel, is not compatible with a velar stop in terms of the position on the front-back axis. The retraction can then be interpreted as a case of assimilation. We argue then that /ɨ/ is phonologically a coronal vowel in terms of Clements and Hume's (1995) feature geometry and that in the velar consonant context it is realized also as dorsal without losing its coronal articulation, becoming a doubly-articulated segment, namely both coronal and dorsal, as shown in (2) on page 14.

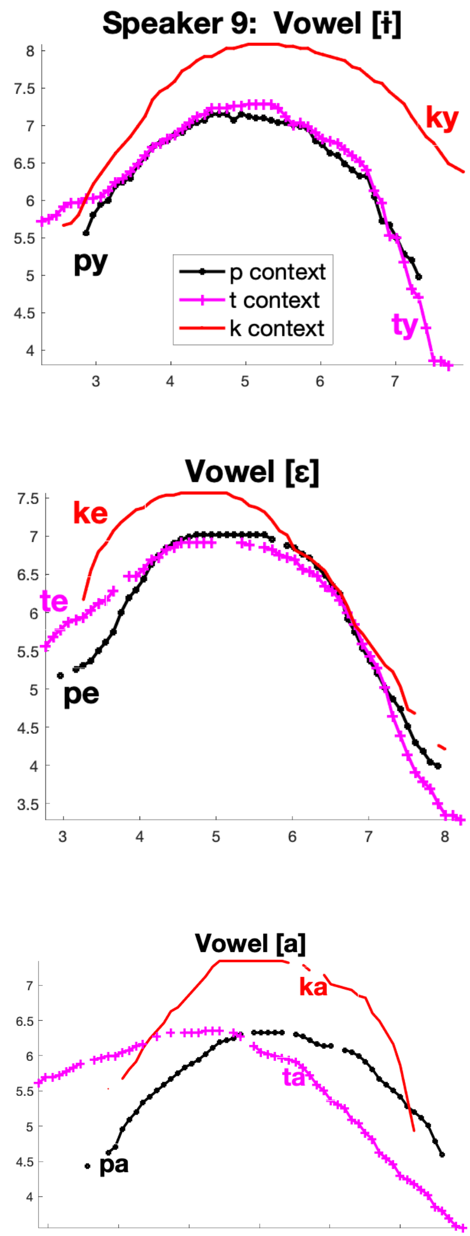
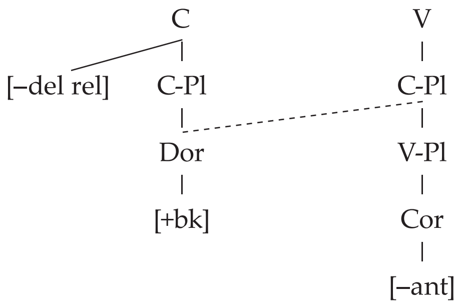


Figure 4. Mid-sagittal tongue contours for vowels /ɨ, ɛ, a/ in the context of /p/ (black squares), in the context of /t/ (pink crosses) and in the context of /k/ (red solid). Displayed data are from Speaker 9.

(2) /ɨ/-retraction



The retraction of front vowels in the context of velar stops is motivated as an assimilation through spreading of the dorsal node without delinking the coronal node. This interpretation is phonologically sound only if /ɨ/ is a front vowel. Back vowels are already dorsal and/or [+back] and they agree in specification with the velar consonant.

It is possible that the retraction is merely a result of phonetic coarticulation and thus provides no argument in support of the claim that /ɨ/ is not a back vowel (compare with the dialectal centralization of English /u/ in the context of coronal consonants, which is not a phonological process). While the analysis of English is outside of the scope of this article, we have reason to believe that the retraction of /ɨ/ repairs a phonological constraint in Polish, specifically the constraint that sequences of velar stops followed by [ɨ] cannot span a morpheme boundary and historically were excluded stem-internally (though they are now allowed in a couple of borrowings, cf. Cavar, forthcoming).

The conclusion that /ɨ/ is a front vowel begs the question about the difference between /ɨ/ and /i/. Ćavar 2007 argues that the distinction is expressed in terms of the [ATR] feature, with /i/ being [+ATR] and /ɨ/ being [–ATR]. Both phonetic and phonological arguments may be drawn in support of this position (Lulich and Cavar 2019).

If the distinction between /i/ and /ɨ/ lies in the position of the tongue root, then the interpretation of palatalization processes must be revisited. Traditionally, Polish /ɨ/ was argued not to be a front vowel—against the phonetic reality—because of the understanding that it is front vowels that trigger palatalization, and that palatalization is fronting (and perhaps also raising) of the tongue body. Polish /ɨ/ does not trigger palatalization, and so analyzing it as a front vowel like /i/ is problematic on this understanding. On the basis of prior phonological work and recent phonetic investigations (e.g., Ćavar 2007; Lulich and Cavar 2019), we propose that palatalization does not begin as a spreading of coronal but instead is initially a spreading of [+ATR]. At least since the 1970's (Lindau 1978), it has been known that [+ATR] is accompanied by passive raising and fronting of the tongue body in vowels. We extend this observation to consonants and propose that at least some palatalization processes are represented by spreading of [+ATR] accompanied by collateral raising and fronting of the tongue body. The process, once it is phonologized, and later morphologized, may stop relying on [+ATR] entirely.

One prediction of this approach is that the vowel [ɛ], which we posit is either [–ATR] or [Ø ATR] (see Lulich and Cavar 2019), should not be able to trigger palatalization even though it is a front vowel. This holds in Polish, but Bateman (2007: 63) says explicitly that vowel such as [ɛ] can trigger palatalization in some languages. She formulates implicational universals stating that if a lower vowel (such as [ɛ]) triggers palatalization in a given language, so does a relatively higher one, e.g., [e, i] (Bateman 2007, 2011). It may be that such cases represent historically [+ATR] processes that were retained morphophonologically, even as the [+ATR] vowel trigger underwent a change to [–ATR]. That is, the phonological contrast might be phonetically reinterpreted. The association between the tongue root position and the tongue body gesture might be lost, with the phonetic contrast shifting towards assibilation and a tongue blade gesture. Morphological and lexicalized palatalizations do not need the triggering vowel to be [+ATR] (Cavar and Lulich 2018).

If /ɨ/ is a front vowel like /i/, arguments referring to the combinability of these vowels with posterior consonants in Polish need to be reinterpreted. Hard posteriors—transcribed differently by different sources as [ʂ, ʐ, t͡ʂ, d͡ʐ] (e.g., Hamann 2003), [ʃ, ʒ, t͡ʃ, d͡ʒ] (e.g., Dogil 1990), [ṣ, ẓ tṣ, dẓ] (Ladefoged and Disner 2012: 169; Mihajlović and Cavar 2018), or [š, ž, tš, dž] in the Slavic linguistic tradition—combine with /ɨ/ but only to a limited extent with /i/, cf. the discussion in Hamann 2003. The distributional constraints are often presented as an incompatibility in terms of frontness. However, if /ɨ/ is a front vowel, we cannot capture the incompatibility of Polish hard posteriors with [i] in terms of frontness. On both phonetic and phonological grounds, we have proposed that this incompatibility is in terms of [ATR] (Ćavar 2007; Lulich and Cavar 2019).

The question remains whether velar fricatives trigger allophonic variation in /ɨ/ like the velar stops. This study has not examined the effects of velar fricatives on /ɨ/ articulation or acoustics. The phonotactic constraints prohibiting **Kɨ* sequences—as described in Section 1—pertain only to velar stops; *xɨ*-sequences are allowed in Polish, both morpheme-internally and across a morpheme boundary. It is therefore doubtful that the articulatory allophony of /ɨ/ observed in the present study should also be triggered by velar fricatives. Exceptional behavior in the context of stops but not fricatives is not surprising. From the articulatory point of view, stop consonants generate a tighter constriction and might thus induce a stronger need for coarticulation than fricatives. An analysis within the framework of Optimality Theory could capture the issue of violations that exclude **Kɨ* but not *xɨ*, with the dispreferred (i.e., non-assimilated) form being excluded only during a very tight constriction. However, to unambiguously answer such questions, further instrumental research is necessary.

5. Conclusions

This paper describes allophonic variation in the articulation of the Polish vowel /ɨ/ depending on the place of articulation of the preceding stop consonant. For the labial and dental stop context, we propose that the back of the tongue is in neutral position, while in the velar stop context the tongue is raised and the constriction extends further into the back vowel region. Although this study has broad implications for understanding palatalization, its most striking and direct consequence for the interpretation of the phonological system of Polish is that the neutral /ɨ/ (outside of the velar stop context) is articulatorily incompatible with a dorsal articulation, and it thus provides new support for the claim that Polish /ɨ/ is a front vowel. The retraction of /ɨ/ in the context of velar stops is assimilatory and serves as an argument in support of the analysis of /ɨ/ as a front vowel.

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Appendix

Sample formant values (in Hz), in the contexts of /ɕ/ for /i/ and in the context of /t/ for all other vowels, Speakers 1–10):

	S01 F	S02 M	S03 F	S04 F	S05 M	S06 F	S07 F	S08 M	S09 M	S10 M
[i]										
F3	3222	2936	3020	3288	2635	3480	3184	2444	3152	2529
F2	2602	2020	2252	1750	2039	2612	2566	2150	2020	1925
F1	470	290	403	287	304	480	354	455	384	380
[ɨ]										
F3	3131	2383	2717	2916	2302	2865	2779	2515	2578	2379
F2	2232	1942	1822	1889	1716	1784	1908	1846	1807	1758
F1	553	358	410	475	377	461	434	511	375	394
[u]										
F3	3051	2473			2409	2920	2897	2042	2315	2359
F2	1105	1155			1070	1221	1016	1046	823	1035
F1	353	316			379	483	444	491	388	408
[ɛ]										
F3	3326	2217	2798	2936	2319	2965	2774	2503	2384	2217
F2	2126	169	1709	1988	1513	1723	1805	1735	1714	1507
F1	758	562	529	715	564	560	725	511	448	486
[ɔ]										
F3	3277	2993	2815	2796	2173	3101	2750	2501	2778	2506
F2	1061	1170	1168	1343	1200	1358	1212	1184	839	1003
F1	676	575	574	676	577	661	760	596	478	559
[a]										
F3	2700	2181	2752	2888	2285	3040	2697	2552	2556	2302
F2	1406	1354	1479	1597	1361	1587	1435	1427	1233	1266
F1	934	630	722	912	679	934	906	821	633	605