



# Three-dimensional ultrasound images of Polish high front vowels

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## Introduction

- Polish has one unambiguous high front vowel and another one that in the phonological literature is variously referred to as high central or back unrounded and transcribed as [i] (Rocławski 1976, Rubach 1984, Gussmann 2007, Rydzewski 2016).

Polish vowel phonemes		
i	ɨ	u
o		e
	a	

- While there exists a sizeable body of articulatory research on Polish, including X-rays from as early as the 50's and 60's (Koneczna & Zawadowski 1951, Wierzchowska 1967), the ultrasound data reveal more detail about the position of the tongue center and tongue root.
- The data support the view that the vowel transcribed as [i] is a front vowel.

## Method

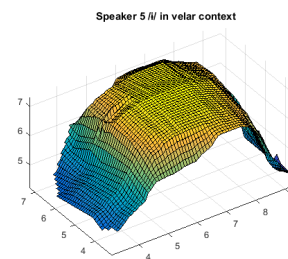
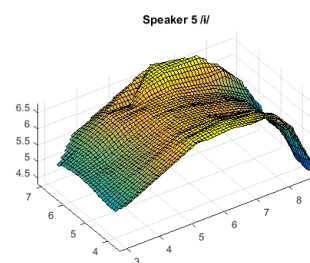
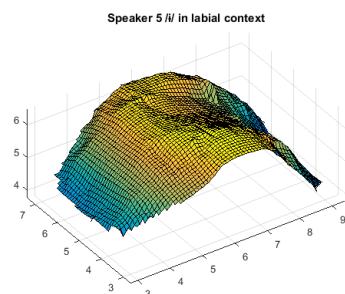
- 5 Polish native speakers (3 women, 2 men) participated in the recordings, some of them in multiple sessions. Participants read word lists consisting of 2-syllable nonce words of the shape C<sub>1</sub>V<sub>1</sub>C<sub>2</sub>V<sub>2</sub>C<sub>3</sub>. The consonantal contexts: /p, t, k, tɕ/ The vowels: /i, ɨ, u, e, o, a/
- Palate impressions were made using dental alginate & digitized with a NextEngine3D laser scanner; data were saved in binary STL format.
- Ultrasound images were recorded with a Philips EpiQ7G system using an xMatrix6-1 digital3D transducer secured under the chin using an Articulate Instruments ultrasound stabilization headset.
- Fully uncompressed DICOM ultrasound files were transferred to a Windows 7 computer.
- Ultrasound/palate files were analyzed w/ a custom MATLAB toolbox, called "WASL".
- Palates were manually registered with the tongue data.
- Audio was recorded with a SHURE KSM32 microphone placed approximately 1 meter in

## References

- Gussmann, Edmund. 2007. Phonology of Polish. Oxford: Oxford University Press.
- Koneczna, Halina, & Zawadowski, Witold. 1951. Przekroje rentgenograficzne głosek polskich. Warszawa: Państwowe Wydawnictwo Naukowe.
- Rocławski, B. 1976. Zarys fonologii, fonetyki, fonotaktyki i fonostatystyki współczesnego języka polskiego. Gdansk: Wydawnictwo Uniwersytetu Gdańskiego.
- Rubach, J. 1984. Cyclic and Lexical Phonology. The Structure of Polish. Dordrecht: Foris Publications.
- Wierzchowska, Bożena. 1967. Opis fonetyczny języka polskiego. Warszawa: Państwowe Wydawnictwo Naukowe.

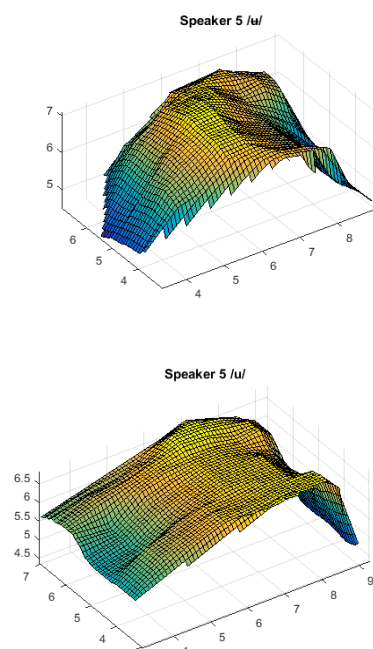
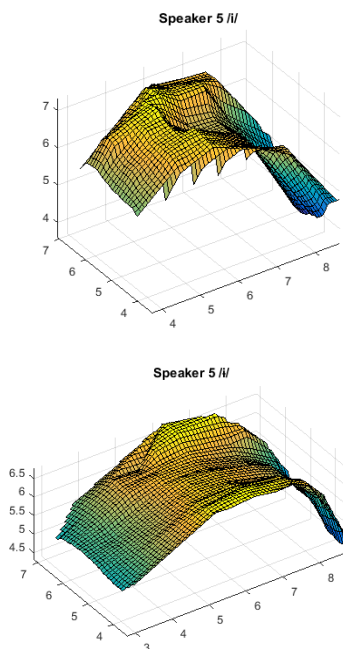
## Results

### /ɨ/ across different consonantal contexts

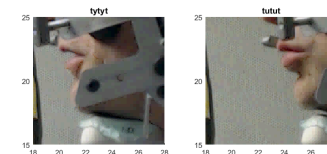
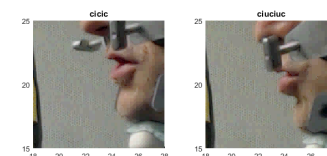


- /ɨ/ across contexts is articulated as a front vowel
- In the context of velar stops, the constriction is longer and extends to include the back part of the tongue.

### Tongue root: Coronal consonant context



### Lip position



- /u/ is articulated with rounding of the lips.
- Based on the data evaluated so far, no conclusive generalization could be established with regards to the role of lip position in the articulation of /ɨ/ and /i/.

## Acknowledgements

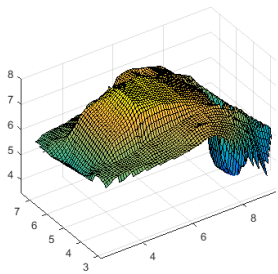
We would like to thank Sherman Charles and Olivia Fowley for their help in the data collection process.

- /ɨ/ and /i/ differ slightly in the extent of tongue raising.
- /ɨ/ and /i/ differ in the position of the tongue root.
- The tongue root position in /ɨ/ is parallel to the tongue root position for an allophone of /u/ in the context of prepalatal consonants, and the tongue root position in /i/ is parallel to the configuration in /u/ in the neutral position.
- With the exception of the velar context, /ɨ/ and /i/ do **not differ** in the position of the tongue on the front-back axis.

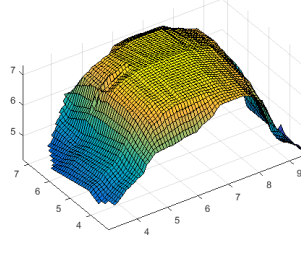
## Results

### /i/ and /i/ in the velar consonant context

Speaker 5 /i/ in velar context



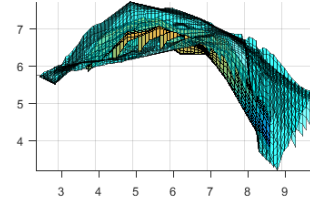
Speaker 5 /i/ in velar context



- /i/ is a front vowel articulated with an advancement of the tongue root.
- Velar consonant followed by /i/ is fronted to pre-velar/palatal.
- /i/ is a front vowel but the constriction additionally extends into the back of the tongue.

### /i/ in (pre)velar and prepalatal consonant contexts

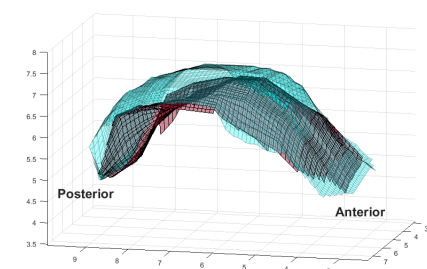
Speaker 5 /i/



No substantial differences in the two contexts for /i/

### /i/ in velar context - /u/ in prepalatal context

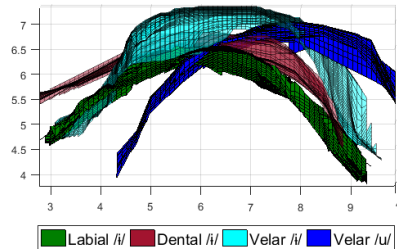
/u/ in prepalatal context and /i/ in velar context



- Back /u/ is substantially advanced in the prepalatal context.
- Fronted /u/ and /i/ in velar context have both a relatively longer constriction.
- They differ in the position of the tongue root (no advancement for /i/)

### /i/ across contexts compared to a neutral back /u/

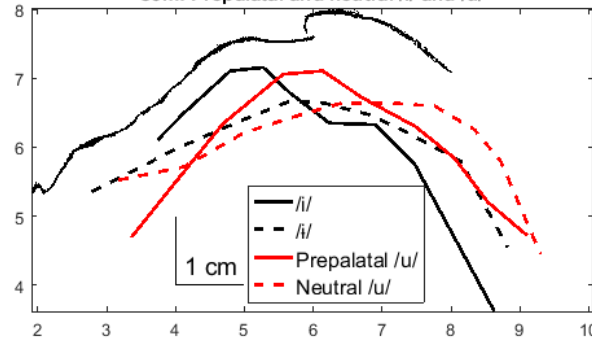
Speaker 5: /i/ in labial, dental, and velar contexts and /u/ in velar context



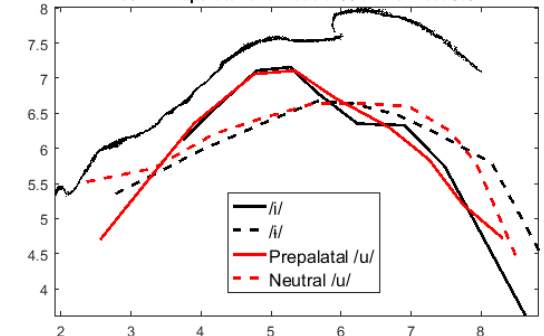
/i/ in the labial and dental contexts are front vowels and do not differ substantially.  
/i/ in the velar context, unlike back /u/ involves both front and back part of the tongue.

### Tongue body position on the front-back axis: coronal consonant context

s5m: Prepalatal and neutral /i/ and /u/



s5m: Prepalatal and neutral /i/ and shifted /u/



## Discussion

\*~~ki~~  
\*~~ki~~ (native vocabulary) versus  
\*~~ci~~

✓ ci  
✓ ~~ki~~ (new borrowings)

- Cavar (2004) postulates that /i/ and /i/ in Polish are both front and differ in the position of the tongue root. The current study confirms this assumption.
- 2004 analysis assuming OT constraints: Velar consonant + front vowel sequence has to agree in the position of the tongue body AND in the position of the tongue root.
- Assuming that /i/ is front (=Coronal), sequence \*~~ki~~ with a Dorsal consonant is excluded.
- For /ki/ in the borrowings, Cavar (2004) stipulates that /i/ is in these sequences both Coronal and Dorsal. The current study confirm this hypothesis.
- The results of the current study strongly support the analysis in Cavar (2004)

Native vocabulary	/i/ Coronal +ATR	/i/ Coronal -ATR
[k] Dorsal -ATR	* <del>ki</del>	* <del>ki</del>
[c] Dorsal-Coronal +ATR	✓ ci	* <del>ci</del>
New borrowings	/i/ Coronal +ATR	/i/ Coronal-Dorsal -ATR
[k] Dorsal -ATR	* <del>ki</del>	✓ <del>ki</del>
[c] Dorsal-Coronal +ATR	✓ ci	* <del>ci</del>

## Conclusions/Future Directions

- The two front vowels differ in the position of the tongue root and slightly in the degree of the raising of the tongue body.
  - The two front vowels do not differ substantially with regards to the tongue body advancement on the front-back axis in the labial and coronal stop context. In these contexts [i] is a front vowel.
  - The constriction in [i] in the context of the (fronted) velar stop is longer to include the back part of the tongue.
- Further issues:
- Is there variation in the articulation of [i] in the context of velar stops versus velar fricatives?
  - More data needs to be collected in order to come to the generalization regarding the lip position.
  - The temporal aspect of the vowels has not been investigated due to too low temporal resolution of the ultrasound recordings.