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Differences in Acoustic Features Between the Standard and the New Variant of Polish /ɛ/

SUMMARY

The paper presents preliminary results of research on differences in selected acoustic features between two variants of the Polish alveolo-palatal voiceless sibilant: the standard realization of /ɛ/, and its fronted palatalized version [sʲ]. Four spectral parameters, namely standard deviation, skewness, kurtosis and center of gravity (COG) are analyzed to identify significant and distinctive spectral features of the tested fricative segments. The study also examines variation in the use of the two variants among the speakers and their occurrence depending on the preceding vocalic contexts. Statistical tests reveal significant differences between the two variants of the Polish phoneme in COG for the middle portion of the segment following three non-high vowels: /ɛ, a, ɔ/.

Key words: Polish phonetics, alveolo-palatal fricatives, fronted palatalized sibilant, female speakers, speech analysis, acoustic features, spectrogram, standard deviation, skewness, kurtosis, center of gravity,

INTRODUCTION – CROSS-LINGUISTIC PROFILE OF /ɛ/

Consonant inventories featuring contrasts among two or more sibilant fricatives are attested in 191 languages (Maddieson & Precoda, 1989). Of these, the majority – 180 languages – maintain a contrast between anterior and non-anterior places of articulation. In 39 languages, contrasts depend on different tongue shapes employed in articulation. In systems with more than three sibilants, inventories typically exploit both anterior – posterior contrasts and tongue-shape differences (Maddieson & Precoda 1989).

The most widespread sibilant is the hard, non-palatalized fricative /s/, documented in 276 languages (Maddieson 1984). Its principal variants – the dental-alveolar /s/ (131 languages), the alveolar /s/ (112 languages), and the dental fricative /ʃ/ (33 languages) – are far more common than their palatalized counterparts. Soft palatalized dentals and alveolars (/ʃʲ/, /sʲ/) occur in only seven languages. Palato-alveolar fricatives /ʃ/ are relatively frequent, attested in 146 languages. Surprisingly, Maddieson's (1984) UPSID database does not list alveolo-palatal /ɕ/ as an independent category, despite its use in languages such as Polish, Mandarin, and others. Ladefoged and Maddieson (1996, p. 154) classify /ɕ/ as a palatalized post-alveolar, though the IPA allows its placement in the alveolo-palatal category. Within their framework, "post-alveolar" encompasses three distinct types: retroflex /ʂ/ (flat tongue), palato-alveolar /ʃ/ (domed tongue), and alveolo-palatal /ɕ/ (palatalized tongue). The principal distinguishing feature across these types is the tongue body shape adopted in articulation.

Phonologically, all sibilants in this set are [+coronal]. Only /s/ is [+anterior]; both /ʃ/ and /ɕ/ are [–anterior, +distributed]. Thus, /ɕ/ can be specified as [+coronal, –anterior, +distributed] (Halle & Clements 1983). Because /ʃ/ and /ɕ/ share identical specifications (Hall 1997), they tend to be mutually exclusive within a language's phoneme inventory. Contrasts involving both are unstable and systematically disfavored. This observation is supported by languages such as Modern Polish and Mandarin Chinese, which feature alveolo-palatal /ɕ/ alongside retroflex /ʂ/ but lack palato-alveolar /ʃ/ (Żygiś & Padgett 2010).

Articulation

In the Polish sibilant system, the term *postalveolar* actually refers to three distinct modes of articulation: alveolo-palatal, retroflex, and palato-alveolar (cf. Padgett & Żygiś 2007, p. 157). However, this label does not precisely describe the articulation of these consonants. Within Polish, the subgroup of alveolo-palatals includes four independent phonemes: two fricatives, the voiceless /ɕ/ and the voiced /ʒ/, as well as two affricates, the voiceless /tɕ/ and the voiced /dʒ/. The present study focuses on the first of these, /ɕ/.

According to Maddieson (1984), [ɕ] does not correspond to a single, clearly definable place of articulation. Instead, he argues that the IPA symbol [ɕ] should represent the entire alveolo-palatal region. Languages, dialects, and individual speakers produce variants that fall within this range but are consistently represented by one symbol. Ladefoged and Maddieson (1996, p. 138) describe [ɕ] as a palatalized post-alveolar sibilant. More specifically, they identify the /ɕ/ of Mandarin Chinese, Standard Polish, and Ubykh as laminal palatalized post-alveolars (i.e., alveolo-palatals) (Ladefoged & Maddieson 1996, p. 164). They further note that the Polish /ɕ/ is articulated with a gesture similar to that found in Standard Chinese.

In Polish, alveolo-palatal fricatives and their affricate counterparts are produced with considerable tongue-blade or tongue-body raising and fronting (Padgett & Żygis 2007, p. 160). This gesture resembles the tongue configuration for the high front vowel /i/ (Rocławski 1976, p. 151) and is typical of sounds commonly referred to as *soft* consonants (Dłuska 1986). These phonemes in Chinese, Polish, and Ubykh differ from laminal flat post-alveolars transcribed as [ʃ], also called *laminal retroflexes*. This term distinguishes them from the subapical palatal retroflex consonants of Toda, represented as /ʃ/ (Dłuska 1986). Nonetheless, the same symbol is sometimes applied to Chinese and Polish laminal palatalized post-alveolars (cf. Żygis 2003; Hu 2008; Chiu 2010).

Dłuska (1986, p. 87) observes that Polish sibilants share a uniform interdental spacing. However, she notes differences in the shape and size of the tongue groove, which directs airflow toward the anterior constriction. For [ʃ] and its voiced counterpart, the aperture is broader, longer, and less regular than for dental [s], and it is broadest and least regular for [ç]. Proctor et al.'s (2012, p. 115) MRI study of Chinese sibilants suggests a different hierarchy: [s] produces the largest total aperture area, with progressively smaller areas for [ʃ] and [ç]. In [ç], the palatal channel narrows most tightly at the front due to pronounced doming or bunching of the tongue dorsum (Toda et al. 2010, p. 359; Fanfang et al. 2007). Wierzchowska (1971, pp. 192–193) further highlights the strong muscular tension of the tongue during the palatal gesture, visible in the sharply broken contour of X-ray images. Toda et al. (2010, p. 359) also report variation in the horizontal alignment of the upper and lower incisors across sibilant types, with the greatest antero-posterior distance occurring for [ç].

Acoustically, [ç] is shaped by the combined resonances of the anterior cavity and the palatal channel, whose relative contributions may vary (Toda et al. 2010, p. 359). Its articulatory properties also create a strong palatalizing effect on the following vowel, often raising vowels that are not underlyingly high or front (Bukmaier & Harrington 2016, p. 324). The elevated tongue dorsum at vowel onset tends to persist through much of the vowel, while the second formant (F2) decreases during the first half, signaling a fronted quality. Thus, the distinctive articulatory and aerodynamic settings of [ç] are directly reflected in its spectral characteristics, which are discussed in the next section.

Acoustic features

Sibilants are a distinctive class of fricatives, defined by Ladefoged and Maddieson (1986, p. 57) as fricatives whose turbulence is generated precisely at the site of constriction, which functions as the obstacle to the passing airstream. According to Shadle (1990, p. 206), this obstacle source is characterized by a flat spectral shape that declines as frequency increases. In contrast, non-sibilants are generated at a “wall source,” where friction arises along a rigid wall parallel to the

airstream flow. This configuration gives rise to spectra with a broad peak (Shadle 1990, p. 206).

One of the most fundamental properties of sibilant spectra is that the frequency of the most prominent peak increases as the anterior cavity shortens (Hughes & Halle 1956). Consequently, the alveolo-palatal [ʃ], which has a more fronted constriction, typically shows greater spectral energy at higher frequencies than the retroflex [ʂ], whose constriction is located further back (cf. Bukmaier & Harrington 2016, p. 324). As a general rule, fricatives articulated further back in the vocal tract exhibit greater noise concentration at lower frequencies (Gordon et al. 2002, p. 29). The posterior cavity, as argued by Toda et al. (2010, p. 343), contributes minimally to acoustic output. Instead, the formant structure of a sibilant fricative primarily reflects front cavity resonances. In addition, the voice source located centrally in the vocal tract, near the teeth, produces antiresonances (Toda et al. 2010).

Center of gravity (COG) values, derived from fricative spectra, also increase with more anterior places of articulation. Gordon et al. (2002) show that the dental/alveolar sibilant [ʃ] consistently exhibits the highest COG values across all fricative inventories studied. As they note Gordon et al. (2002, p. 32), COG values decrease as the constriction site shifts posteriorly.

In terms of spectral maxima, McGuire (2007, p. 396) reports that the fully alveolo-palatal [ʃ] reaches its most intense noise of 25 dB/Hz at around 3.75 kHz. A spectrogram of Polish [ʃ] presented by Wierzchowska (1971, p. 194) shows a broad concentration of spectral energy exceeding 20 dB from approximately 2 kHz to beyond 17 kHz, with a prominent peak at 3.5 kHz reaching 35 dB, identified as the second formant of the fricative. Lisker's (2001, p. 228) spectral model of Polish [ʃ], averaged over the duration of the segment, reveals two peaks: one between 2.5–3 kHz and another between 5–6 kHz. Bukmaier and Harrington (2016, p. 319) similarly describe ensemble-averaged spectra for Polish [ʃ] with double peaks: a dominant one near 4 kHz (35 dB) and a secondary one above 7.5 kHz (33 dB). For comparison, Hu (2008, p. 108) reports that a female speaker of Standard Chinese produces [ʃ] with an intense peak just below 20 dB at around 1.8 kHz and a weaker peak at 6.5 kHz.

COG values reflect the distribution of spectral energy across the entire frequency range, and thus highlight tendencies that differentiate sibilant phonemes. In Polish, Żygiś (2003) finds that COG values for [ʃ] range from 3.5–5.5 kHz and generally do not overlap with values for retroflex /ʂ/ within individual speakers. The frequency distance between [ʃ] and dental [ʃ] is consistently the greatest, ranging from 1–1.5 kHz per speaker. Żygiś (2003, p. 397) confirms a similar tendency, though only for female speakers. This suggests that within the COG domain, /ʃ/ and /ʂ/ are the most acoustically distinct sibilant phonemes in Polish.

Żygis and Padgett (2010) also report a robust separation between [ɕ] and [s], with mean differences approaching 3.5 kHz.

Further analysis by Żygis (2010, p. 125) reveals significant differences in COG values among Polish /s/, /ɕ/, and /ʂ/. However, Żygis (2010, p. 127) also shows that when comparing Polish and Bulgarian sibilant systems, the distinction between alveolo-palatal /ɕ/, palato-alveolar /ʃ/, and palatalized palato-alveolar /ʂ/ becomes blurred in terms of mean COG values. Such patterns have clear implications for the perceptual categorization of sibilants and the organization of phonemic inventories, since the selection of sibilant phonemes depends critically on their acoustic distinctiveness.

Perception

Based on measurements and systematic comparisons of COG values for Polish sibilant phonemes, Żygis (2010, p. 129) proposes the introduction of a distinctive perceptual notion of sibilant tonality, which reflects the acoustic noise characterizing individual sibilants. Polish [ɕ] is marked by middle tonality, corresponding to a COG value of 4 kHz (Żygis, 2010, p. 129). The other two contrasting sibilants, [s] and [ʂ], are characterized by high (6 kHz) and low (3 kHz) tonality, respectively. Within this scale, the alveolo-palatal [ɕ] clearly stands out as a relatively “high-pitched” fricative, producing a robust hissing or hushing noise.

Given that the frequency interval between [s] and [ɕ] reaches as much as 2 kHz, it seems plausible that there is potential space for an additional contrast between these two fricatives. Indeed, Padgett and Żygis (2007, p. 164) note that the sibilant systems of related Slavic languages such as Bulgarian and Russian contain another sibilant phoneme – the palatalized dental fricative /sʲ/. In terms of COG measurements, this phoneme occupies a position between the non-palatal dental /s/ and the long alveolo-palatal /ɕ:/ in Russian, and between /s/ and the palato-alveolar /ʃ/ in Bulgarian. It is worth noting, however, that the difference in mean COG values between the alveolo-palatal [ɕ] and the palato-alveolar [ʃ] is not significant.

Nevertheless, fricative noise does not appear to be the only, or even the primary, cue in the perceptual identification of sibilant phonemes, as shown by Chiu (2010). Listeners successfully identified syllable-final alveolo-palatal [ɕ] on the basis of vowel-to-fricative formant transitions, which proved to be a stronger cue than fricative noise in Polish. Interestingly, in the same study, native speakers of Taiwanese Mandarin relied more heavily on fricative noise than on formant transitions when classifying sibilants. The importance of vowel context as a perceptual cue in Polish is further supported by Nowak (2003), who argues that vowel environment often overrides the acoustic properties of sibilant noise in perceptual discrimination.

From the perspective of systemic stability, Żygiś (2003, p. 209) shows that the Polish three-way contrast – dental vs. alveolo-palatal vs. retroflex – emerges as robust, particularly from a perceptual standpoint. Historically, alveolo-palatal /ɕ/ proved perceptually more stable than palatalized dental /sʲ/, while the palato-alveolar /ʃ/ was retracted, evolving into retroflex /ʂ/. This development suggests that a system containing both /ɕ/ and /ʃ/ would have been unstable (*ibid.*). Perceptual categorization tests by Żygiś (2003, p. 395) confirms the clarity of the Polish tripartite system, showing near-perfect identification rates (98.5–99.9%). Even the marginal variant – the palatalized palato-alveolar [ʃʲ] – was reliably distinguished from [ɕ] by Polish listeners, with a correct classification rate of over 96%.

As the following section will demonstrate, certain developments in contemporary Polish pronunciation suggest that the sibilant system may undergo further optimization. Such changes would remain consistent with patterns observed in other Slavic languages as well as with diachronic developments within Polish itself.

REPORTED NEW VARIANT OF POLISH /ɕ/

Findings by Czaplicki et al. (2016) describe a striking innovation observed in Polish, limited to young female speakers at the time of the study. The authors classify this development as the beginning of a more lasting process affecting the status of the alveolo-palatal consonants /ɕ/, /z/, /tɕ/, and /d͡z/, which are increasingly realized as palatalized dento-alveolars [sʲ], [zʲ], [tɕʲ], and [d͡zʲ] in line with the new trend (Czaplicki et al. 2016, p. 2). The fact that this novel pronunciation style is characteristic of women accords with the findings of Fuchs and Toda (2010, p. 293), who show that German female speakers produce more anterior articulations of the sibilant /s/ than men, and further argue that such anterior tendencies are universal among women. The Polish change thus suggests that an anterior mode of articulation may extend to other sibilants as well.

Earlier, Osowicka-Kondratowicz and Serowik (2009, pp. 169–170) observed female speakers depalatalizing palatalized sibilants or replacing them with hard equivalents as a fashionable mannerism. These were produced with a half-smile and tense lips, flattening the tongue and yielding only partial palatalization.

Ciecierska-Zajdel (2019, pp. 132–134) found depalatalization in 44% of tokens from female speakers, particularly when multiple palatalized segments co-occurred. The affricate /tɕ/ was most affected, especially near /a/ or /e/. She classified this as a disordered tendency, undermining speech aesthetics.

A study of 770 university students of both sexes by Ciecierska-Zajdel (2021) reveals that 87% occasionally or regularly produced non-standard realizations of palato-alveolars, with 21% of tokens outside accepted norms. Distortions vary in

form, including [sʲ], [zʲ], [tsʲ], [dzʲ], [ʃʲ], [ʒʲ], [tʃʲ], [dʒʲ], and nearly depalatalized [s], [z], [ts], [dz]. Social background mattered: rural and younger students showed more distortions than urban peers. Non-standard forms occurred more in spontaneous than read speech, implying partial situational control.

Most recently, Ciecierska-Zajdel (2024, pp. 51–58) links depalatalization to anatomical, functional, and perceptual conditions rather than cultural or gender factors. In spontaneous speech, correlations between anatomy and depalatalization ranged from $r = 0.6$ (males) to $r = 0.8$ (females). Roughly 20% of speakers – mainly women with a “smiling” lip gesture – show higher depalatalization rates. Faster speech reduce the effect. These findings support a biologically grounded explanation.

Czaplicki et al. (2016, p. 22) also notes that acoustically, [sʲ] lies farther from retroflex [ɕ] than [ɛ], potentially optimizing contrasts. This could lead to the conclusion that the innovation contributes to an optimization of the Polish sibilant system. In addition, Czaplicki et al. (2016, p. 27) discuss possible sociolinguistic motivations for the “over-palatalization” of sibilants, linking it to the desire to project youthfulness, achieve a higher tonal quality associated with smaller female vocal tracts and larynges, and conform to social pressures within female peer groups.

In terms of acoustic features, Czaplicki et al. (2016) provide detailed evidence concerning spectral moments. The spectral peak frequency of [sʲ] is significantly higher than that of standard [ɛ] (approximately 5.5 kHz vs. 4 kHz, respectively). Similarly, the average center of gravity (COG) of [sʲ] (5367 Hz) is around 1 kHz higher than that of [ɛ] and differs significantly from it. The overall tonality of [sʲ] is clearly more “s-like” and comparable to the COG ranges reported for two female speakers of Ocotepéc Mixe, a Mixe-Zoquean language, in the study by Hamann and Avelino (2007, p. 951). In that case, individual token values ranged between 4.5 and nearly 8 kHz, entirely overlapping with [s] and identified by the authors as the highest among sibilants.

Likewise, average COG values for Russian palatalized /sʲ/, as reported by Kochetov (2017, p. 15), approximated 7 kHz, with female speakers showing higher values than men. A cross-linguistic study of fricatives by Gordon et al. (2002) found that mean COG values for [s] across six unrelated languages ranged from 4530 Hz to 5460 Hz. The lower values of this range correspond to “middle” tonality (cf. Żygiś 2006), typical of palato-alveolar or alveolo-palatal articulations, while the higher values (above 5 kHz) fall between “middle” and “high” tonality. The mean COG value for the new Polish [sʲ] thus classifies its tonality as near-“high,” characteristic of an s-like fricative. This conclusion is supported by Kochetov (2017, p. 22), who found that the COG of [sʲ] remained similar to that of [s] throughout the fricative’s duration, including at offset.

Further evidence from Żygis (2003) shows considerable overlap in COG values for /s/ and /sʲ/ among Bulgarian and Russian speakers. For most speakers, however, frequency ranges for [sʲ] began about 0.5–1.0 kHz lower than those for [s]. In Bulgarian specifically, mean values for both phonemes were identical (7 kHz) (Żygis 2010, p. 129), suggesting that an additional feature must distinguish them. Żygis (2010 p. 129) proposes the perceptually grounded feature of *vocalic transition*: {non-rising F2} for [s] versus {rising F2} for [sʲ]. This distinction refers to the trajectory of the second formant from the consonant into the following vowel. Thus, the principal acoustic cue for palatalization of [sʲ] lies in the shape of the second formant transition in the neighboring vowel segment. As for other acoustic characteristics of the palatalized [sʲ], the spectral pattern of the new Polish variant (Czaplicki et al., 2016, pp. 13–15) was found to be left-skewed compared to the spectrum of /e/, which is skewed to the right. The spectral slope in the 0.5–5 kHz range was significantly lower for [sʲ] than for [e], while in the higher range of 5–11 kHz the new variant exhibited a markedly sharper spectral decline.

The articulatory description of the palatalized variant [sʲ] provided by Wierchowska (1971, p. 187) concerns a relatively small number of Polish words of foreign origin containing the sequence “(-)si-.” According to the author, the articulatory channel is formed between the front part of the tongue and the roof of the mouth in the region between the gums and the praepalatum. Large portions of the sides of the tongue make contact with the palate, and both [sʲ] and its voiced counterpart [zʲ] are classified as dentalized. The involvement of the laminal portion of the tongue, which constricts against the apex of the alveolar ridge, and the tongue dorsum, which creates an aperture in the palato-alveolar region, is further supported by Proctor et al.’s (2012, p. 115, Fig. 4) study of Mandarin Chinese [sʲ]. In the context of a preceding or following high-front vowel /i/, the constriction extends across the entire palato-alveolar region. The authors argue that in Beijing Standard Chinese the pinyin grapheme *x* should be interpreted as a palatalized variant of the dental /s/, namely [sʲ], rather than as a separate palatal phoneme /e/ (Proctor et al. 2012, p. 115).

In the historical development of Slavic sibilant systems, the shift from palatalized /sʲ/ to alveolo-palatal /e/ resulted from the overlap of /sʲ/ with dental/alveolar /s/ (Żygis 2003, p. 209). Standard Polish alveolo-palatal /e/ emerged around the 13th century from Old Slavic /sʲ/ (Padgett & Żygis 2007). This development represents a broader process affecting palatalized sibilants in certain Russian and Irish dialects, as well as in Japanese and Chinese (cf. Proctor et al. 2012). In modern Slavic dialects, realizations of the underlying palatalized variant vary. In Kashubian, for instance, alveolar /s/ replaces Standard Polish alveolo-palatal /e/, whereas in Mazurian, the equivalent of Standard Polish *siano* /eãno/ (‘hay’)

is produced with palatalized palato-alveolar /ʃ/ (Żygis 2003). Alveolo-palatals occur in Lower Sorbian and Western Ukrainian, where they are realized as “near” alveolo-palatals, and in Eastern Herzegovinian dialects (among Orthodox speakers), in the Zeta-Lovćen dialect of Serbian and Croatian, in Slavonian dialects, and in western Belorussia. In the latter case, palatalization is so strong that Polish listeners across the border perceive the sounds as alveolo-palatals (Żygis 2003). Canonical palatalized [sʲ] remains part of the phoneme inventories of Standard Russian, eastern Ukrainian dialects, Transcarpathian, Bulgarian, and Standard Belorussian (Żygis, 2003).

As the present study suggests, owing to the acoustic and perceptual similarity between strongly palatalized and purely alveolo-palatal articulations, historical trends may in some cases be reversed – whether to optimize contrasts within the articulatory space or to enhance perceptual clarity.

MATERIAL AND METHODS

The research described in this study is of a preliminary nature and includes an experiment conducted in 2018 on a group of twelve young Polish speakers. The subjects were asked to read a list of short phrases containing the Polish voiceless alveolo-palatal fricative phoneme /ɕ/. The consonant was placed in the context of six non-nasalized Polish vowels, which preceded the segment, and the following low-central vowel /a/ located in word-final position (see Appendix 1 for the complete list of phrases). Acoustic parameters of the standard and newly attested realization of the consonant /ɕ/ (Czaplicki et al., 2016) were calculated and compared. Details of the experiment are presented in the following subsections.

Subjects

The subjects were all females selected from the population of students of the English Philology at University of Applied Sciences in Tarnów, Poland. They were all native speakers of Polish, between 19–20 years of age, originating exclusively from the region of Lesser Poland, mostly from the town of Tarnów and its vicinity. The participants were ignorant of the purpose of the experiment and were chosen impressionistically on the basis of their Polish accent which could easily be judged or classified by the native listener as typical of the younger generation of Poles.

Method and equipment

The informants were placed in a phonetic laboratory in partially noise-dumping conditions where their faces were surrounded from the front and both sides by plastic barriers without a top covering over their heads. Each subject was asked

to read a list of phrases in a casual manner and neutral speed repeating each item twice with the view to obtaining a possibly unmarked natural version of the phrase at the second, usually more relaxed attempt. The tested consonantal segment was placed in word-medial position in vocabulary items placed in the final, tonic position in a phrase to ensure falling intonation, desired loudness and prominence facilitating clarity of the examined context.

The speakers used dynamic microphone of MB Quart K-800 model with headphones constituting the regular equipment of Mentor language laboratory. The frequency response of the microphone is $40 \div 15000$ Hz. Acoustic mono signal was captured, transmitted and digitalized at the sampling frequency of 22 kHz and 16 bits/sample resolution to be saved as WAV format files for later acoustic examination using Open Source PRAAT software (Boersma, Weenink 2021). In order to conduct acoustic analysis words containing the fricative segment (see column 2 in Appendix 1) were extracted and saved as separate WAV files. These files were subsequently subject to manual segmentation (see Figure 1 below). Spectrogram viewing was set at view range from $0 \div 11$ kHz with window length of 0.002 s and dynamic range of 35 dB.

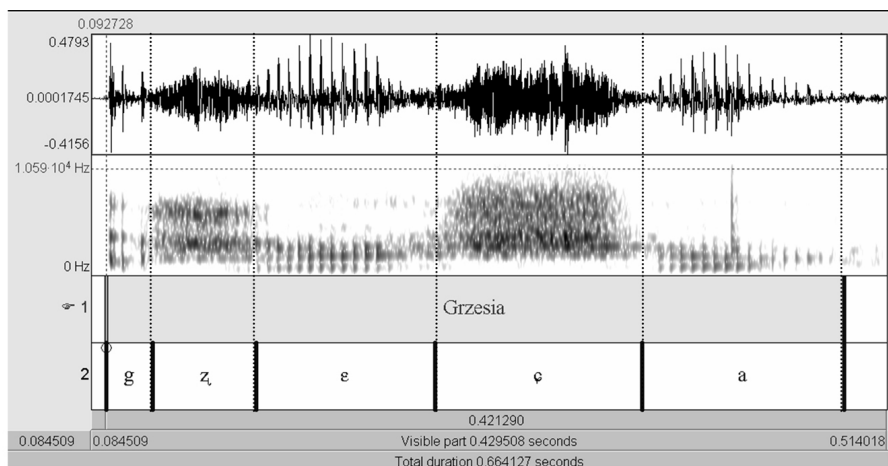


Figure 1. Exemplary oscillogram and spectrogram of the word *Grzesia* (Gregory-DIM-GEN-SG) in its repeated version by speaker AA with segmentation and phonetic labeling

Segmented acoustic material further served to calculate mean values of six acoustic parameters characterizing the examined fricative segment [ɛ]. The parameters include standard deviation, skewness, kurtosis, spectral center of gravity. Formal definitions of the parameters are presented in Table 1 below.

Table 1. Types of acoustic parameters calculated on the basis of the spectra of the fricative segment. See (Forrest et al. 1988, p.115; Czaplicki et al. 2016) for the interpretation of spectral moments

Acoustic parameter	Definition	Variables' description	Significance
COG - Spectral center of gravity ³³	$COG = \frac{\sum_{i=1}^N i \cdot A_i}{\sum_{i=1}^N A_i}$	Pairwise weighting of spectral amplitude with frequency	shows mean central frequencies of the whole spectrum
STD - standard deviation	$S = \sqrt{\frac{1}{N-1} \sum_{i=1}^N A_i - \mu ^2}$	A_i - i-th element of the spectral vector A . μ - mean of the spectral vector A ; N - spectral vector length (number of the observation)	points the amount of frequencies within the spectrum which deviate from COG
skewness	$s = \frac{\mu - m}{S}$	μ - mean of the spectral vector A ; m - median of the spectral vector A ; S - standard deviation of the spectral vector A ;	indicates whether the spectrum is skewed towards higher or lower frequency ranges
kurtosis	$k = \frac{\frac{1}{N} \sum_{i=1}^N (A_i - \mu)^4}{\left(\frac{1}{N} \sum_{i=1}^N (A_i - \mu)^2\right)^2}$	A_i - i-th element of the spectral vector A . μ - mean of the spectral vector A ; N - spectral vector length (number of the observation)	can be interpreted as a measure of spectral peakedness

The assessment of the parameters started with calculation of the spectrogram encompassing the segment defined as the fricative consonant representing the alveolo-palatal phoneme /ɕ/ or its new fronted palatalized variant [sʲ]. Next, for each spectral vector constituting a column of the spectrogram particular parameters from the table were calculated. Finally, mean values of the individual parameter listed in Table 1 were obtained.

RESULTS AND DISCUSSION

The following section presents the results of measurements and calculations based on the gathered set of tokens, including the incidence of the non-canonical fronted variant of the alveolo-palatal phoneme in the examined corpus, as well as four spectral parameters – standard deviation, skewness, kurtosis, Center of Gravity (COG). Statistical methods were applied to check the level of significance of differences between both variants of the examined phoneme.

Frequency of the occurrence of the new variant

In the group of twelve examined female speakers (see Appendix 2 for detailed results) most of the attested realizations are those of the standard alveolo-palatal sibilant phoneme /ɕ/ (see Fig. 2 below). A non-parametric Kruskal–Wallis test (Kruskal & Wallis 1952) shows a highly significant difference in frequency of the occurrence of the new variant of the phoneme /ɕ/ between speakers ($p \approx 0$). Within the examined group, the pronunciation of the seven speakers was evidently highly homogeneous, not marked by the use of the novel fronted palatalized [sʲ].

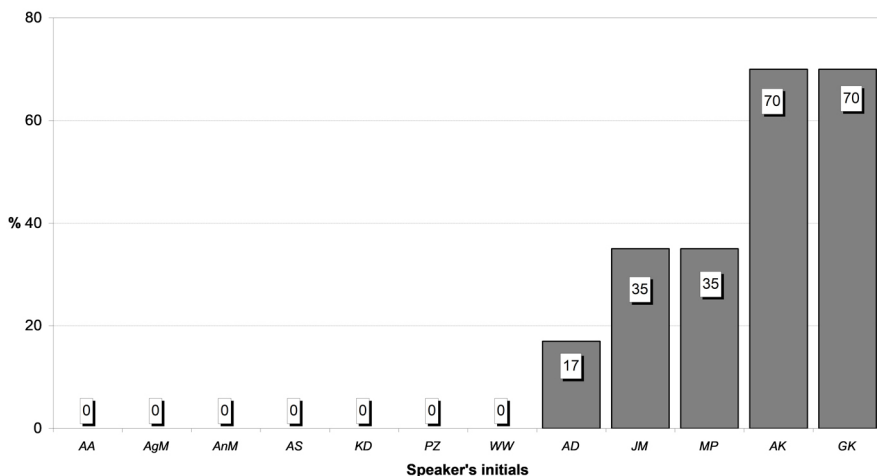


Figure 2. Mean occurrence of the fronted palatalized variant [sʲ] in individual speakers

The new pronunciation of the phoneme /ɕ/ was identified in 5 speakers, in four of whom the ratios range from over 30–70% of the examined vocabulary items. Two speakers out of twelve (AK and GK) displayed a radical habit of realizing almost three-quarters of all the cases of the tested segment as the fronted

palatalized fricative, systematically differing from those speakers who used the standard variant /*ç*/ invariably. Three other speakers (AD, JM, MP) might be considered as representing a transitional phase in the development of a new pronunciation habit, marked by occasional instances of the fronted variant [*sʲ*]. If we split all the informants into two groups and discard those who never showed tokens with the fronted palatalized [*sʲ*], the mean occurrence of the variant reaches over 40% in those whose accent is characterized by that feature (see Fig. 3 below), albeit incidentally.

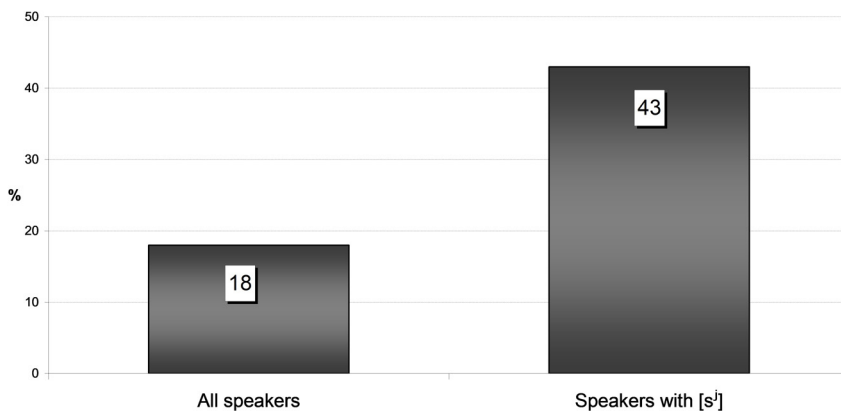


Figure 3. Mean occurrence of the fronted palatalized variant [*sʲ*] in those speakers who tended to pronounce it (right), and all tested speakers (left)

In order to check the statistical significance of the difference in the frequency of occurrence of the two variants of the phoneme /*ç*/ between the group of speakers pronouncing the consonant in a standard fashion and those speakers who articulated the new, fronted variant of the phoneme, Chi² tests were conducted. The tests confirmed the existence of statistically significant difference in the frequency of the occurrence of the novel variant [*sʲ*] between the two groups of speakers at the level of significance $\alpha < 0.05$ with p-values < 0.00001 for the Chi² Pearson's test (Pearson, 1900) and the Chi² NW test (Mantel et al. 1985). Table 2 below presents the contingency table for both tests.

Table 2. Contingency table for differences in the frequency of the occurrence of the novel variant of the consonant /ɛ/ between speakers pronouncing the standard variant and speakers who pronounced the new variant

speakers group	Dual summary table: observed frequencies (differences between speakers) Number of cells > 10		
	Correctness 0	Correctness 1	Verse together
standard	84	0	84
%	100.00%	0.00%	
novel	34	26	60
%	56.67%	43.33%	
Sum	118	26	144

Subsequently, the significance of pairwise differences between speakers was tested using the post-hoc Dunn's test without tied ranks correction of the statistics (Siegel and Castellan 1988, pp. 213–215):

$$z_{u,v} = |\bar{R}_u - \bar{R}_v| / \sqrt{N \cdot (N + 1) / 12 \cdot \left(\frac{1}{n_u} + \frac{1}{n_v} \right)} \quad (1)$$

The *p*-values were multiplied according to the Bonferroni adjustment (Miller 1966). Results of the test are presented in Table 3 below.

Table 3. *p*-values of the Dunn's test for pairwise multiple comparisons of differences in the frequency of occurrence of the new variant of the consonant /ɛ/ between speakers

Variable: correctness	<i>p</i> -value for multiple comparisons (pairwise); correctness (differences between speakers) Independent variable (grouping): speaker Kruskal-Wallis test: $H(11, N=144) = 60.22034$ $p = .0000$											
	AA R:59.5	AD R:71.5	AgM R:59.5	AK R:107.5	AnM R:59.5	AS R:59.5	GK R:107.5	JM R:83.5	KD R:59.5	MP R:83.5	PZ R:59.5	WW R:59.5
AA		1	1	0.32	1	1	0.32	1	1	1	1	1
AD	1		1	1	1	1	1	1	1	1	1	1
AgM	1	1		0.32	1	1	0.32	1	1	1	1	1
AK	0.32	1	0.32		0.32	0.32	1	1	0.32	1	0.32	0.32
AnM	1	1	1	0.32		1	0.32	1	1	1	1	1

table 3 cont.

AS	1	1	1	0.32	1		0.32	1	1	1	1	1
GK	0.32	1	0.32	1	0.32	0.32		1	0.32	1	0.32	0.32
JM	1	1	1	1	1	1	1		1	1	1	1
KD	1	1	1	0.32	1	1	0.32	1		1	1	1
MP	1	1	1	1	1	1	1	1	1		1	1
PZ	1	1	1	0.32	1	1	0.32	1	1	1		1
WW	1	1	1	0.32	1	1	0.32	1	1	1	1	

Dunn's test revealed lack of statistical significance in the differences between speakers at the adopted level of significance $\alpha=0.05$. However, these differences achieve statistical significant at the level $\alpha=0.35$, which is noteworthy, since the number of samples naturally decreases if we treat individual speakers separately.

If we consider the context of the vowel after which the tested segment was located, it seems evident that if the preceding context is a high-front vowel /i/, it facilitates radical palatalization and acts as a factor invariably triggering the canonical standard realization of the alveolo-palatal fricative phoneme among the tested speakers. After non-high front vowels / ε , α , υ , u/, however, the novel fronted realization of the phoneme ([sⁱ]) is found in between 20–30% of the instances of the phoneme in the whole tested group of speakers (top part of Fig. 4 below). Excluding those speakers whose pronunciation was devoid of the new variant and considering the speakers who follow the novel fashion of articulating the sibilant, the mean occurrence of [sⁱ] rises to 40–70% after a non high-front vowel, or to 60–70% after a non-high vowels (/ ε , α , υ /) (bottom part of Fig. 4 below).

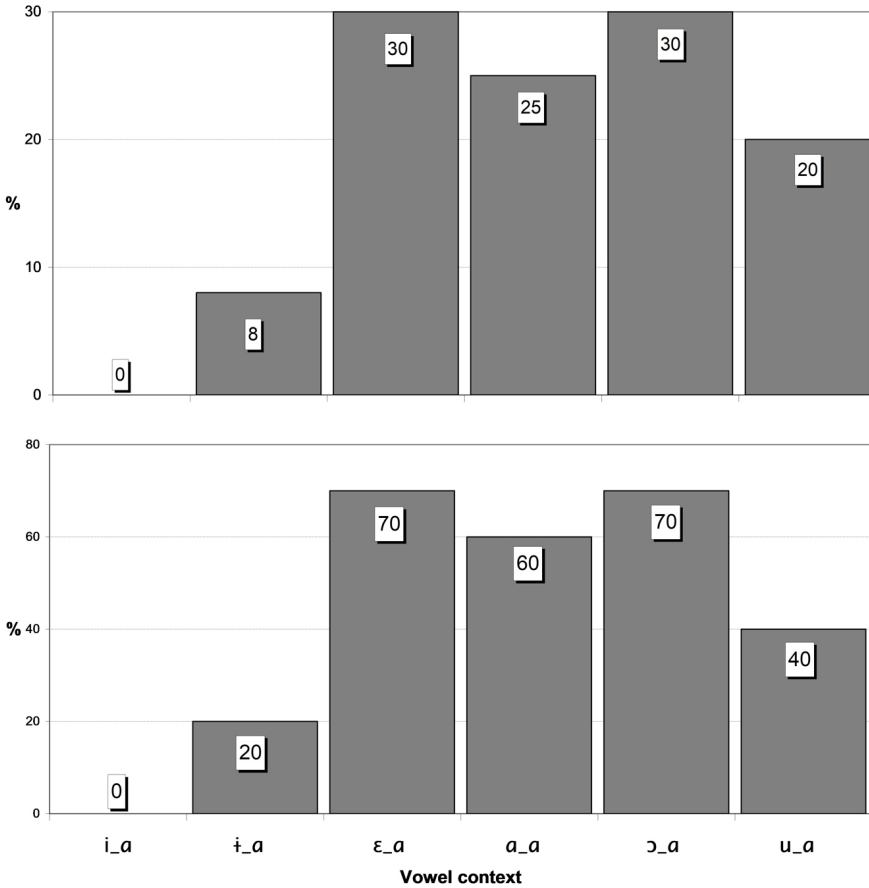


Figure 4. Mean occurrence of the fronted palatalized variant [sʲ] in particular vowel contexts in all speakers (top), and only those speakers who pronounced [sʲ] (bottom)

A non-parametric Kruskal–Wallis test shows a significant difference in frequency of the occurrence of the new variant of the phoneme /s/ between contexts ($p = 0.0054$). The test was limited only to speakers pronouncing [sʲ]. In order to assess more precisely the significance of the differences between contexts pairwise, a post-hoc Dunn’s test without tied ranks correction was used. The p -values were multiplied according to the Bonferroni adjustment. Results of the test are presented in Table 4 below.

Table 4. p-values of the Dunn's test for pairwise multiple comparisons of the differences in frequency of occurrence of the new variant of /ɛ/ between contexts

Dependent: correctness	p-values for multiple pairwise comparison; correctness (differences between speakers) dependent variable (grouping): context Kruskal-Wallis test: H (5, N= 60) =16.55204. $p = .0054$					
	ɑ_ɑ R:35.5	ɛ_ɑ R:38.5	i_ɑ R:17.5	ɔ_ɑ R:38.5	u_ɑ R:29.5	i_ɑ R:23.5
ɑ_ɑ		1	0.32	1	1	1
ɛ_ɑ	1		0.11	1	1	0.83
i_ɑ	0.32	0.11		0.11	1	1
ɔ_ɑ	1	1	0.11		1	0.83
u_ɑ	1	1	1	1		1
i_ɑ	1	0.83	1	0.83	1	

The results of the Dunn's test reveal no statistical significance of the differences between contexts at the adopted level of significance $\alpha=0.05$. Yet, if we raise the level of significance to $\alpha=0.11$ differences in the use of the two variants of the phoneme /ɛ/ depending on the vowel context become significant. One can infer from the results presented in Table 4 above that the most significant differences appear between the context with the high-front vowel /i/ at first place and contexts with three non-high vowels at first place, namely /ɑ/ ($p=0.32$), /ɛ/ ($p=0.11$), /ɔ/ ($p=0.11$). The differences between the contexts including the mid-high centralized vowel /i/ and mid-low front /ɛ/ and mid-low back /ɔ/ may be classified as non-significant ($p=0.83$). Recapitulating, it seems evident that there is a systematic difference between the frequency of occurrence of the standard and the new variant of the consonant /ɛ/ in the contexts after the high-front vowels and the contexts after the non-high vowels. With the view to testing the statistical significance of this difference Chi² tests were carried out. The tests apparently prove the statistical significance of the difference in the frequency of use of the fronted variant [s'] in those vocalic contexts at the level $\alpha<0.05$ with p -value = 0.00026 for the Chi² Pearson's test and with p -value = 0.00019 for the Chi² NW test. Table 5 below presents the contingency table for these two tests.

Table 5. Contingency table for differences in the frequency of the occurrence of the novel variant of the consonant /ɛ/ between contexts with the preceding high-front vowels and the preceding non-high vowels

first context vowel	A Summary two-way table: observed frequencies (differences between speakers) Number of marked cells > 10		
	correctness 0	correctness 1	Verse together
front	10	20	30
% total	16.67	33.33	50.00
back	24	6	30
% total	40.00%	10.00	50.00
Total	34	26	60
% Total	56.67	43.33	100.00

As for the spectral differences between the standard realization of the alveolo-palatal sibilant phoneme /ɛ/ and its new fronted palatalized version ([sʲ]), apart from perceptual features serving for aural identification of either variant, one can observe differences in the shape of the spectra, even at their preliminary visual inspection. It seems especially the case with immediately successive readings of the same vocabulary item by the same speaker with apparently two different variants of the fricative segment (see Fig. 5).

It appears that the chief observable spectral characteristics, even if one considers as limited evidence as the four tokens presented in the figure above, is the beginning of the concentration of fricative noise at higher frequencies for the fronted palatalized fricative type ([sʲ]) (top and bottom right of Fig. 5). This might presumably testify to the acoustic impression of higher tonality and clearly perceivable ‘sharpness’ of the fricative noise. This trait proved crucial in the aural identification of the variant in the set of the examined tokens in the present study.

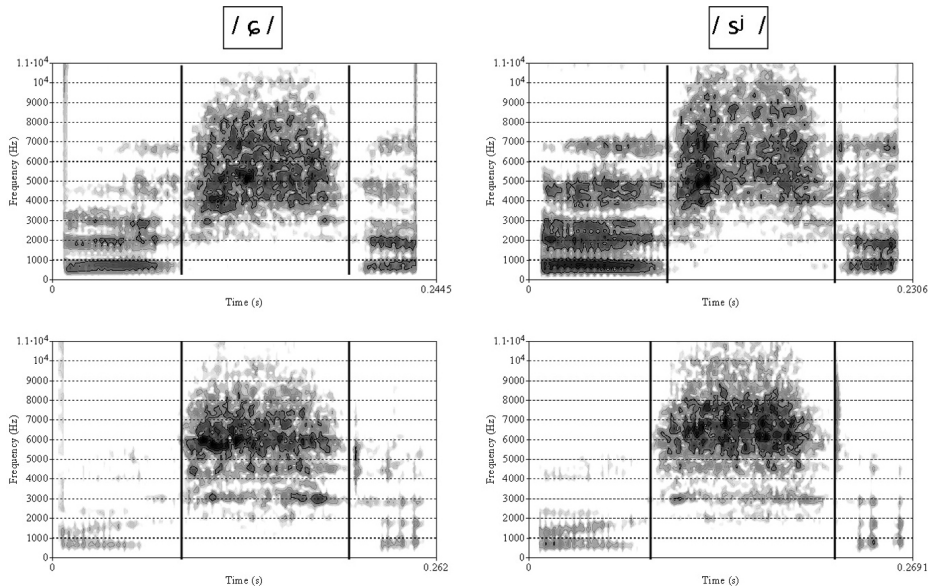


Figure 5. Comparison of the spectrograms for the standard /ɛ/ (top and bottom left) and the non-standard ([sʲ])realization of the consonant (top and bottom right) for two speakers: top part – JM pronouncing the word *Grzesia* ('Gregory'-DIM-GEN-SG), bottom part – MP pronouncing the word *losia* ('elk'-GEN-SG). Sibilant segments are shown with portions of the preceding and following vowel

This albeit subjective, perceptual impression seems to be successfully borne out by the results of the analysis of the spectral moments presented in the following section.

Selected spectral parameters and their statistical significance

As it was signaled before (see Table 1 earlier), differences in four spectral parameters (standard deviation, skewness, kurtosis, COG) were taken into consideration for the identification of significant spectral features differentiating between the standard variant of the phoneme /ɛ/, whose tokens are hence also labeled as 'correct' and the new variant [sʲ], the tokens of which are from now on also referred to as 'incorrect'. The differences, assessed on the basis of the whole length of the spectra of the examined tokens, are shown graphically by the box plots in the Fig. 6 below.

The application of statistical tests upon of the experimental data was considerably limited due to a relatively small amount of the examined tokens. Nevertheless, certain statistical tests could be performed, some of them with partially violated assumptions. Statistically significant difference between values of the four parameters (standard deviation, skewness, kurtosis, COG) for the standard

and the fronted palatalised version of the consonant /ɕ/ was tested. Those tests were carried out for each version of the alveolo-palatal sibilant phoneme /ɕ/ in three different independent samples as listed below:

- 1) globally, for all collected tokens,
- 2) for particular vowel context groups,
- 3) for tokens produced by speakers using both variants of the consonant.

The assumption about the independence of samples containing either variant was not fully observed as some of the examined speakers were able to pronounce both the standard and the non-standard variant. Therefore, samples included two different variants of the consonant /ɕ/ produced by the same speakers. The adopted level of significance for all of the following tests was $\alpha=0.05$.

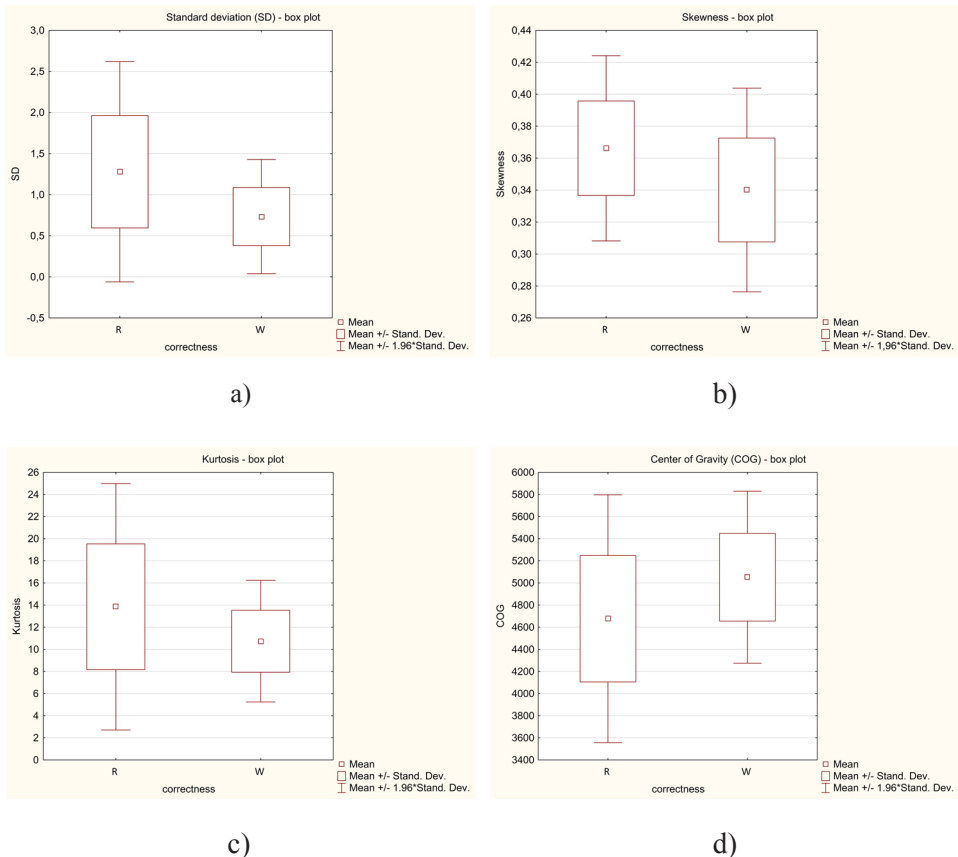


Figure 6. Box plots for the four spectral parameters: a) standard deviation (SD), b) skewness, c) kurtosis, d) center of gravity (COG) calculated from the total length of the consonants. Note: Capital R below each plot refers to the standard variant of the phoneme, whereas capital W signals the new variant

First, all calculations were performed considering the total length of each tested segment (see part *a* of Tables 6, 7, 8). Subsequently, analogical tests were applied to 50ms long central fragments of each examined fricative segment, discarding the edges of the segment to remove possible coarticulative influence of the adjacent segments. The analysis started with the Shapiro–Wilk test (Shapiro, Wilk, 1965) in order to determine whether the distribution of the examined parameter was normal or not. If the latter was the case the Mann–Whitney U test (Mann, Whitney 1947) was applied for the assessment of the differences between mean values of parameters in groups of the standard and palatalized version of the consonant /ç/. For normal distribution of a parameter in the compared groups, *t*-tests were used; Welch’s *t*-test (Welch 1947) for samples marked by considerable disproportion in the number of tokens (more than a double), and for small disproportion in the number of tokens but for heterogeneous variances within groups. Student’s *t*-test (Student, 1908) was applied if disproportions within samples turned out to be small and variances between compared groups were homogeneous.

Global tests presented in Table 6 below indicate highly significant (at $p \leq 0.01$) differences between the four spectral parameters in the tested variants of the fricative segment.

Table 6. Results of statistical tests for the tested parameters for all tokens

a) the whole segment

Tested parameter	Number of tokens		Mean		Shapiro–Wilk test (Distribution)		Brown-Forsythe test (variances)	Test probability (p)		Difference
	[ç]	[çʲ]	[ç]	[çʲ]	[ç]	[çʲ]		Mann-Whitney U test	Welch’s t-test	
Standard deviation	118	23	1.3	0.7	not normal	normal		0.000007		significant
Skewness	118	23	0.4	0.3	normal	normal	n/a, disproportion in N		0.001	significant
Kurtosis	118	23	14	11	not normal	not normal		0.01		significant
COG [Hz]	118	23	4676	5052	not normal	not normal		0.002		significant

b) central portion of the segment

Tested parameter	Number of tokens		Mean		Shapiro–Wilk test (Distribution)		Brown–For-sythe test (variances)	Test probability (p)		Difference
	[ɛ]	[sʲ]	[ɛ]	[sʲ]	[ɛ]	[sʲ]		Mann–Whitney U test	Welch’s t-test	
Standard deviation	118	23	1.4	0.8	not normal	normal		0.00008		significant
Skewness	118	23	0.35	0.34	normal	normal	n/a, disproportion in N		0.005	significant
Kurtosis	118	23	14	11	not normal	normal		0.2		non significant
COG [Hz]	118	23	4917	5497	not normal	normal		0.000001		significant

Note. In b). central portion of the segment refers to 50ms with removed edges of the segment. Grey fields show cases where a test could not be applied. Numbers in bold type highlight cases where statistical significance was found. The adopted level of significance was $\alpha=0.05$.

The sole exception, at $p=0.2$, is the difference in kurtosis between the two variants calculated for central portion of the segment. It should be also noted that p -values resulting from the tests conducted for parameters calculated from the central portion of the consonant are systematically higher (the statistical significance of the differences is proportionally lower) than in case of parameters reflecting spectral features of the whole length of the segment. A significantly lower p -value (ca. 2000 times) occurred only for the centre of gravity, which makes this parameter more discriminating. This can be easily noticed comparing the box plots for COG showing the parameter calculated from the total length of the consonant segment (Fig. 7, part *a* below) and the parameter assessed on the basis of the central part of the segment (Fig. 7, part *b*).

A glance at the average values of the spectral parameters shows evident analogical proportions between the fronted and standard variant of the fricative /ɛ/. Visible differences between the two variants include standard deviation values being consistently lower for the fronted variant [sʲ], which indicates its considerably less spread spectra than the spectral energies of the standard [ɛ]. Welch’s t -test proves significant difference between skewness values (at $p=0.001$) with a lower figure for the fronted new variant, which agrees with findings by Czaplicki et al. (2016). Kurtosis values suggest minimally more peaked distribution of spectral energy in the case of [ɛ].

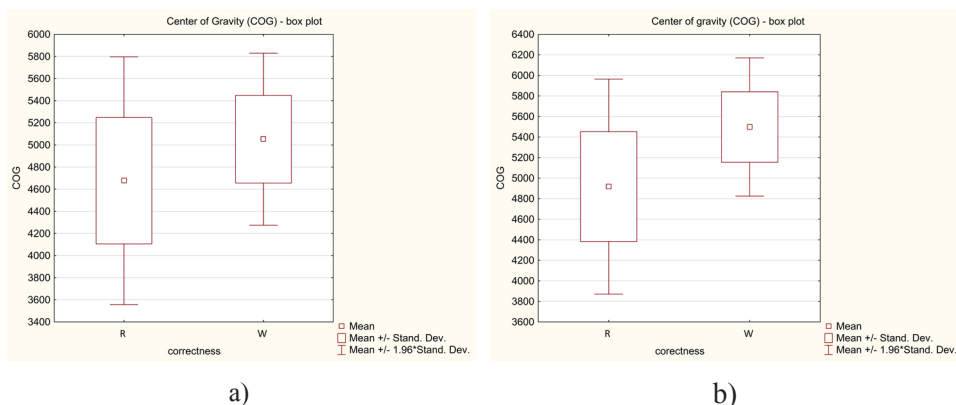


Figure 7. Comparison of box plots for COG calculated for: a) the whole consonant segment; b) a 50ms long central part of the segment. Note: Capital R below each plot refers to the standard variant of the phoneme, whereas capital W signifies the novel variant

As regards the Center of Gravity, its means differ significantly for both variants with around 0.5kHz of average dominance of COG for [s^j] (Czaplicki et al. 2016), though the difference appears more distinctly pronounced by measurements based on central portions of the segment (see part *b* of Table 7).

As for the differences between spectral parameters for both examined variants of /ε / depending on the context of the preceding vowel segment (see Table 8 below) considering the whole duration of the fricative signal, statistical tests reveal significant differences in standard deviation and skewness for the non-high vowel+ /ε / (at $p < 0.05$). The two segments differed significantly only in kurtosis values after the vowel /ɔ/ (at $p < 0.01$). Strikingly, statistical results for the central portion of the fricative reveal that all three vowel contexts differ significantly for COG values ($p \leq 0.02$). Mean COG values show 0.5 kHz differences between both variants. A comparison of tendencies possibly evident in results of statistical tests in part *a* and *b* of Table 8 points at irregularities in differences between tested parameters. Lack of significant differences between the two sibilant variant located within particular vocalic contexts compared to highly significant variation across all tokens may be owing to the limited number of samples for vocalic contexts.

An analogically low number of tokens per speaker that can be noticed in Table 8 seems to be reflected in the virtual absence of statistically significant results for the differences in spectral characteristics of both variants depending on those speakers who tended to produce samples using both sibilants. The distribution of significant values can be defined as highly regular and the level of significance approximates the adopted critical level of $\alpha=0.05$. As for particular parameters, one

can observe a regular trend for higher average COG values for the fronted variant, but only in the case of measurement based on the central portion of the segment (Table 8, part *b*). In the results based on the whole duration of the fricative (Table 8, part *a*) one speaker (GK) produced COG values in a reverse proportion, with values higher for the standard variant, but differing by less than 200Hz.

Table 7. Results of statistical tests for the tested parameters in particular vowel contexts

a) the whole segment

Context	Tested parameter	Number of tokens (N)		Mean		Shapiro–Wilk test (Distribution)		Brown-Forsythe test (variances)	Test probability (p)		Difference
		[ɛ]	[sʲ]	[ɛ]	[sʲ]	[ɛ]	[sʲ]		Mann–Whitney U test	Welch’s t-test	
a_a	Standard deviation	18	6	1.2	0.6	not normal	normal		0.02		significant
	Skewness	18	6	0.37	0.33	normal	normal	n/a, disproportion in N		0.02	significant
	Kurtosis	18	6	12.4	12	normal	not normal		0.8		non significant
	COG [Hz]	18	6	4930	5032	normal	normal	n/a, disproportion in N		0.6	non significant
ε_a	Standard deviation	17	7	1.3	0.7	not normal	normal		0.004		significant
	Skewness	17	7	0.37	0.34	not normal	not normal		0.004		significant
	Kurtosis	17	7	13	10.2	normal	normal	n/a, disproportion in N		0.06	non significant
	COG [Hz]	17	7	4833	5112	normal	not normal		0.1		non significant
ɔ_a	Standard deviation	17	7	1.1	0.8	normal	normal	n/a, disproportion in N		0.2	non significant
	Skewness	17	7	0.36	0.33	normal	normal	n/a, disproportion in N		0.07	non significant
	Kurtosis	17	7	15.7	10	normal	normal	n/a, disproportion in N		0.002	significant
	COG [Hz]	17	7	4572	4977	normal	normal	n/a, disproportion in N		0.1	non significant

b) central portion of the segment

Context	Tested parameter	Number of tokens (N)		Mean		Shapiro-Wilk test (Distribution)		Brown-Forsythe test (variances)	Test probability (p)		Difference
		[ε]	[sʲ]	[ε]	[sʲ]	[ε]	[sʲ]		Mann-Whitney U test	Welch's t-test	
α_α	Standard deviation	18	6	1.36	0.8	not normal	normal		0.09		non significant
	Skewness	18	6	0.37	0.34	normal	normal	n/a, disproportion in N		0.1	non significant
	Kurtosis	18	6	13	12	normal	normal	n/a, disproportion in N		0.5	non significant
	COG [Hz]	18	6	5146	5678	normal	normal	n/a, disproportion in N		0.02	significant
ε_α	Standard deviation	17	7	1.5	0.8	not normal	normal		0.004		significant
	Skewness	17	7	0.38	0.35	normal	normal	n/a, disproportion in N		0.05	non significant
	Kurtosis	17	7	13	11	normal	normal	n/a, disproportion in N		0.2	non significant
	COG [Hz]	17	7	5049	5506	normal	normal	n/a, disproportion in N		0.016	significant
α_ε	Standard deviation	17	7	1.3	0.9	normal	normal	n/a, disproportion in N		0.1	non significant
	Skewness	17	7	0.36	0.32	normal	normal	n/a, disproportion in N		0.08	non significant
	Kurtosis	17	7	18	9.8	not normal	normal		0.02		significant
	COG [Hz]	17	7	4902	5408	normal	normal	n/a, disproportion in N		0.02	significant

Note. In b). central portion of the segment refers to 50ms with removed edges of the segment. Grey fields show cases where a test could not be applied. Numbers in bold type highlight cases where statistical significance was found. The adopted level of significance was $\alpha=0.05$.

Mean standard deviations retained their proportional differences, remaining higher for the standard variant regardless of the measurement basis. Mean skewness values for both variants per speakers who used them drastically approached each other, whereas the average figures for kurtosis display varying tendencies without visibly regular trends. Obvious disparities in results of statistical tests signaling levels of significance for individual parameters in particular examined contexts might be due to limited number of tokens used for calculations in contextual subgroups. Future related studies should rely upon considerably extended sets of tokens or concentrate on a narrower range of contextualized subsets of tokens.

Table 8. Results of statistical tests for the tested parameters in speakers who used both variants of the phoneme

a) the whole segment

Speaker	Tested parameter	Number of tokens (N)		Mean		Shapiro-Wilk test (Distribution)		Brown-Forsythe test (variances)	Test probability (p)			Difference
		[e]	[sʲ]	[e]	[sʲ]	[e]	[sʲ]		Mann-Whitney U test	Welch's t-test	Student t-test	
AK	Standard deviation	4	8	0.67	0.62	normal	normal	homogeneous			0.8	non significant
	Skewness	4	8	0.34	0.34	normal	normal	heterogeneous		0.7		non significant
	Kurtosis	4	8	14.3	11.5	normal	normal	homogeneous			0.08	non significant
	COG [Hz]	4	8	4124	4926	normal	normal		0.1			non significant
GK	Standard deviation	4	6	1.3	0.8	not normal	normal		0.07			non significant
	Skewness	4	6	0.35	0.34	normal	normal	homogeneous			0.3	non significant
	Kurtosis	4	6	14.3	11	normal	normal	homogeneous			0.2	non significant
	COG [Hz]	4	6	5082	4917	normal	normal	homogeneous			0.4	non significant

table 8a cont.

JM	Standard deviation	8	4	0.9	0.5	normal	normal	homogeneous			0.01	significant
	Skewness	8	4	0.37	0.34	normal	normal	homogeneous			0.04	significant
	Kurtosis	8	4	7.4	7.7	normal	normal	homogeneous			0.8	non significant
	COG [Hz]	8	4	5356	5416	normal	normal	homogeneous			0.6	non significant
MP	Standard deviation	8	3	1.13	1.07	normal	normal	n/a, disproportion in N		0.9		non significant
	Skewness	8	3	0.34	0.33	normal	normal	n/a, disproportion in N		0.7		non significant
	Kurtosis	8	3	12.2	12	normal	normal	n/a, disproportion in N		0.9		non significant
	COG [Hz]	8	3	4893	5211	normal	normal	n/a, disproportion in N		0.4		non significant

b). central portion of the segment

Speaker	Tested parameter	Number of tokens (N)		Mean		Shapiro-Wilk test (Distribution)		Brown-Forsythe test (variances)	Test probability (p)			Difference
		[e]	[s']	[e]	[s']	[e]	[s']		Mann-Whitney U test	Welch's t-test	Student t-test	
AK	Standard deviation	4	8	0.84	0.72	not normal	normal		0.6			non significant
	Skewness	4	8	0.34	0.34	normal	normal	homogeneous			0.9	non significant
	Kurtosis	4	8	15	12	normal	normal	heterogeneous		0.4		non significant
	COG [Hz]	4	8	4587	5410	normal	normal	homogeneous			0.03	significant
GK	Standard deviation	4	6	1.3	1.0	normal	normal	homogeneous			0.1	non significant
	Skewness	4	6	0.35	0.3	normal	normal	homogeneous			0.03	significant
	Kurtosis	4	6	12	12.5	normal	normal	homogeneous			0.8	non significant
	COG [Hz]	4	6	5426	5520	normal	normal	homogeneous			0.6	non significant

table 8b cont.

JM	Standard deviation	8	4	0.9	0.5	normal	normal	homogeneous			0.03	significant
	Skewness	8	4	0.37	0.34	normal	normal	homogeneous			0.1	non significant
	Kurtosis	8	4	7.6	7.2	normal	normal	homogeneous			0.8	non significant
	COG [Hz]	8	4	5486	5512	normal	not normal				1.0	non significant
MP	Standard deviation	8	3	1.2	1.1	normal	normal	homogeneous			0.8	non significant
	Skewness	8	3	0.35	0.34	normal	normal	homogeneous			0.7	non significant
	Kurtosis	8	3	10.5	13	normal	normal	homogeneous			0.2	non significant
	COG [Hz]	8	3	5103	5398	not normal	normal				0.5	non significant

Note. In b). central portion of the segment refers to 50ms with removed edges of the segment
 Grey fields show cases where a test could not be applied. Numbers in bold type highlight cases where statistical significance was found. The adopted level of significance was $\alpha=0.05$.

CONCLUSION

The present study demonstrates that young female Polish speakers increasingly produce a fronted palatalized variant [sʲ] in place of the canonical alveolo-palatal fricative [ɕ]. While this phonetic innovation appears to be a regular socio-phonetic trend rather than a clinical disorder, it has direct implications for speech therapy practice in Polish.

First, the systematic acoustic differences observed between [ɕ] and [sʲ], particularly in center of gravity values and spectral spread, show that these two variants are perceptually distinct. Replacing [ɕ] with [sʲ] might be classified as pronunciation error or articulatory defect by speech therapists. Most probably, as acoustic evidence seems to suggest, it is a case of a new variant attested within certain age and gender groups.

Second, vowel context plays a crucial role: the fronted [sʲ] appeared significantly more often after non-high vowels, whereas the standard [ɕ] dominated after the high front vowel /i/. This finding suggests that clinicians assessing sibilant production in Polish must carefully consider the influence of phonetic context when evaluating accuracy. A child who produces [sʲ] in non-high vowel environments may still demonstrate phonetic competence consistent with current speech patterns among peers.

Third, the data highlight the importance of distinguishing between dialectal or generational variation and speech sound disorder. Without awareness of such ongoing changes, clinicians risk overdiagnosing atypical palatalization or misidentifying socially conditioned pronunciation as pathological.

Fourth, future research should consider enlarging the group of respondents, among others, by the inclusion of not only young women but also young men, incorporating consultation and evaluation during subject selection by qualified speech therapists.

Finally, these findings may inform therapy goals. For children struggling with sibilant production, therapists may need to decide whether to target the traditional [ɕ] or accept [sʲ] as a socially acceptable alternative, depending on the communicative environment of the child. Continued monitoring of this trend will be crucial to determine whether [sʲ] stabilizes as a standard variant in Polish, which would directly affect norms for speech assessment and intervention.

REFERENCES

- Boersma P., Weenink D., 2021, Praat: doing phonetics by computer, [computer program], University of Amsterdam, Phonetic Sciences, version 6.1.51 retrieved 23 July 2021 from www.fon.hum.uva.nl/praat/.
- Bukmaier V., Harrington J., 2016, *The articulatory and acoustic characteristics of Polish sibilants and their consequences for diachronic change*, "Journal of the International Phonetic Association", 46, 311–329. <https://doi.org/10.1017/S0025100316000062>
- Chiu C., 2010, Attentional weighting of Polish and Taiwanese Mandarin sibilant perception, Proceedings of the 2010 Canadian Linguistics Association Annual Conference.
- Ciecierska-Zajdel B., 2019, *Wewnętrzny językowy uwarunkowania zniekształceń wymowy polskich sybilantów palatalnych*, „Logopedia”, 48, 1, s. 121–136.
- Ciecierska-Zajdel B., 2021, *Zróżnicowanie realizacji sybilantów dziąsłowo-palatalnych w wymowie studentów Uniwersytetu Warszawskiego* (niepublikowana rozprawa doktorska), Uniwersytet Warszawski.
- Ciecierska-Zajdel B., 2024, *Biologiczne uwarunkowania modyfikacji wymowy polskich sybilantów dziąsłowo-palatalnych przez młodych dorosłych*, „Poradnik Językowy”, 2, s. 44–59.
- Czaplicki B., Żygis M., Pape D., Luis J., 2016, *Acoustic evidence of new sibilants in the pronunciation of young Polish women*, „Poznań Studies in Contemporary Linguistics”, 52, pp. 1–42. <https://doi.org/10.1515/psicl-2016-0004>
- Dłuska M., 1986, *Fonetyka polska. Artykulacje głosek polskich*, Kraków.
- Fangfang L., Edwards J., Beckman M.E., 2007, *Spectral measures for sibilant fricatives of English, Japanese, and Mandarin Chinese*, Proceedings of the 16th International Congress of Phonetic Sciences (ICPhS XVI), vol. 4, pp. 917–920.
- Forrest K., Weismer G., Milenkovic P., Dougall R.N., 1988, *Statistical analysis of word initial voiceless obstruents: Preliminary data*, "Journal of the Acoustical Society of America", 84 (1), pp. 115–123.
- Fuchs S., Toda M., 2010, *Do differences in male versus female /s/ reflect biological or sociophonetic factors?*, In: *Turbulent sounds: An interdisciplinary guide*, (Eds.) S. Fuchs, M. Toda, M. Żygis, Berlin, pp. 281–302. <https://doi.org/10.1515/9783110226584>

- Gordon M., Barthmaier P., Sands K., 2002, *A cross-linguistic acoustic study of voiceless fricatives*, "Journal of the International Phonetic Association", 32, pp. 141–174. <https://doi.org/10.1017/S0025100302001020>
- Hall T.A., 1997, *The historical development of retroflex consonants in Indo-Aryan*, "Lingua", 102, pp. 203–221. [https://doi.org/10.1016/S0024-3841\(96\)00050-2](https://doi.org/10.1016/S0024-3841(96)00050-2)
- Halle M., Clements G.M., 1983, *Problem Book in Phonology: A Workbook for Introductory Courses in Linguistics and in Modern Phonology*, Cambridge.
- Hamann S., Avelino H., 2007, *An Acoustic Study of Plain and Palatalized Sibilants in Ocotepc-Mixe*, Proceedings of the 16th International Congress of Phonetic Sciences (ICPhS XVI), pp. 949–952.
- Hu, F., 2008, The three sibilants in Standard Chinese. Proceedings of the 8th International Seminar on Speech Production (ISSP 2008), 105–108.
- Hughes G., Halle M., 1956, *Spectral properties of fricative consonants*, "Journal of the Acoustical Society of America", 28(2), pp. 303–310.
- Kochetov A., 2017, *Acoustics of Russian voiceless sibilant fricatives*, "Journal of International Phonetic Association", 47(3), pp. 321–348. <https://doi.org/10.1017/S0025100317000019>
- Kruskal W.H., Wallis W.A., 1952, *Use of Ranks in One-Criterion Variance Analysis*, "Journal of the American Statistical Association", 47(260), pp. 583–621. <https://doi.org/10.2307/2280779>
- Ladefoged P., Maddieson I., 1996, *The Sounds of the World's Languages*, Oxford.
- Lisker L., 2001, *Hearing the Polish sibilants [s ʃ ś]: Phonetic and auditory judgements*, In: *Travaux du Cercle Linguistique de Copenhague XXXI. To honour Eli Fischer-Jørgensen*, (Eds.), N. Grønnum, J. Rischel, Copenhagen, pp. 226–238.
- Maddieson I., 1984, *Patterns of Sounds. Cambridge studies in speech science and communication* (1st ed.), Cambridge.
- Maddieson I., Precoda K., 1989, *Updating UPSID*, "UCLA Working Papers in Phonetics", 74, pp. 104–111.
- Mann H.B., Whitney D.R., 1947, *On a Test of Whether one of Two Random Variables is Stochastically Larger than the Other*, "Annals of Mathematical Statistics", 18(1), pp. 50–60. <https://doi.org/10.1214/aoms/1177730491>
- Mantel N., Smith K.C., Robertson J.L., Savin N.E., 1985, *Maximum Likelihood vs. Minimum Chi-Square*, "Biometrics", 41(3), pp. 777–783. <https://doi.org/10.2307/2531298>
- McGuire G., 2007, *English listeners' perception of Polish alveopalatal and retroflex voiceless sibilants: A pilot study*, UC Berkeley Phonology Lab Annual Report.
- Miller R.G., 1966, *Simultaneous Statistical Inference*, New York.
- Newman R.S., Clouse S.A., Burnham J.L., 2001, *The perceptual consequences of within-talker variability in fricative production*, "Journal of the Acoustical Society of America" 109(3), pp. 1181–1196.
- Nowak P.M., 2003, *The role of vocalic context in the perception of Polish sibilants*, In: Proceedings of the 15th International Congress of the Phonetic Sciences, 3, pp. 2309–2312.
- Osowicka-Kondratowicz M., Serowik A., 2009, *Defektywne realizacje spółgłosek palatalnych dentalizowanych przy prawidłowych i nieprawidłowych warunkach zgryzowych. Wskazówki do terapii logopedycznej*, „Prace Językoznawcze”, 11, s. 155–177.
- Padgett J., Żygis M., 2007, *The Evolution of Sibilants in Polish and Russian*, Special volume on "Slavic Phonology. *Journal of Slavic Linguistics*", (Eds.) M. Cavar, T.A. Hall, 15(2), pp. 291–324.
- Pearson K., 1900, *On the criterion that a given system of deviations from the probable in the case of a correlated system of variables is such that it can be reasonably supposed to have arisen from random sampling*, "Philosophical Magazine", series 5, 50 (302) pp. 157–175. [doi:10.1080/14786440009463897](https://doi.org/10.1080/14786440009463897)

- Proctor M., Lu, H.L., Zhu Y., Goldstein L., Narayanan S., 2012, *Articulation of Mandarin sibilants: A multi-plane realtime MRI study*, Proceedings of the 14th Australasian International Conference on Speech Science and Technology, Sydney, Australia.
- Rocławski B., 1976, *Zarys fonologii, fonetyki, fonotaktyki i fonostatystyki współczesnego języka polskiego*, Gdańsk.
- Siegel S., Castellan N.J., 1988, *Nonparametric statistics for the behavioral sciences*, (2nd ed.), New York.
- Shadle C.H., 1990, *Articulatory-Acoustic Relationships in Fricative Consonants*, In: *Speech Production and Speech Modelling*, (Eds.) W.J. Hardcastle, A. Marchal, NATO ASI Series (Series D: Behavioural and Social Sciences): vol 55., Springer, Dordrecht, pp. 187–209 https://doi.org/10.1007/978-94-009-2037-8_8
- Shapiro S.S., Wilk M.B., 1965, *An analysis of variance test for normality (complete samples)*, “*Biometrika*”, 52 (3–4), pp. 591–611. doi:10.1093/biomet/52.3-4.591
- Student, 1908, *The Probable Error of a Mean*, “*Biometrika*”, 6(1), pp. 1–25, <https://doi.org/10.1093/biomet/6.1.1>
- Tabain M., 2001, *Variability in fricative production and spectra: Implications for the Hyper- and Hypo- and Quantal Theories of speech production*, “*Language and Speech*” 44(1), pp. 57–94.
- Toda M., Maeda S., Honda K., 2010, *Formant-cavity affiliation in sibilant fricatives*, In: *Turbulent sounds-an interdisciplinary guide*, (Eds.) S. Fuchs, M. Toda, M. Żygis, Berlin, New York, pp. 343–374, <https://doi.org/10.1515/9783110226584.343>
- Welch B.L., 1947, *The generalization of „student’s” problem when several different population variances are involved*, “*Biometrika*”, 34, pp. 28–35.
- Wierzchowska B., 1971, *Wymowa polska*, Warszawa.
- Żygis M., 2003, *Phonetic and Phonological Aspects of Slavic Sibilant Fricatives*, In: T.A. Hall, S. Hamann (Eds.). *ZAS Papers in Linguistics: Leibniz-ZentrumAllgemeineSprachwissenschaft*, Berlin, vol. 32., pp. 175–213, <https://doi.org/10.21248/zaspil.32.2003.191>
- Żygis M., 2010, *On changes in Slavic sibilant systems and their perceptual motivation*, In: D. Recasens, F.S. Miret, K.J. Wireback (Eds.), *Experimental Phonetics and Sound Change*, München, pp. 115–138.
- Żygis M., Padgett J., 2010, *A perceptual study of Polish sibilants, and its implications for historical sound change*, “*Journal of Phonetics*”, 38(2), pp. 207–226. <https://doi.org/10.1016/j.wocn.2009.10.003>

APPENDIX

1) Reading list (first column) and the tested segment in vocalic context

Elicited phrase	Vocabulary item including the tested context	Surrounding vowel context
Nie lubi misia Uszatka.	misia	/iea/
Widać Krzysia dom	Krzysia	/iea/
Tu stoi samochód Grzesia.	Grzesia	/εea/
Sprzątają ogród Stasia.	Stasia	/aea/
Popatrz, rogi łosia.	łosia	/ɔea/
To na pewno ślady strusia.	strusia	/uea/

2) Results of aural and spectral identification of the examined segment in particular vocalic context for every speaker and each attempt. Zeros under speaker's initials represent standard realization of the fricative (/ɛ /), ones stand for the fronted palatalized variant (/sʲ /)

Attempt	V context	Speaker's initials											
		AA	AgM	AnM	AS	KD	PZ	WW	AD	JM	MP	AK	GK
1	i_a	0	0	0	0	0	0	0	0	0	0	0	0
2	i_a	0	0	0	0	0	0	0	0	0	0	0	0
1	ɨ_a	0	0	0	0	0	0	0	0	0	0	1	0
2	ɨ_a	0	0	0	0	0	0	0	0	0	0	1	0
1	ε_a	0	0	0	0	0	0	0	0	0	1	1	1
2	ε_a	0	0	0	0	0	0	0	0	1	1	1	1
1	a_a	0	0	0	0	0	0	0	1	0	0	1	1
2	a_a	0	0	0	0	0	0	0	1	0	0	1	1
1	ɔ_a	0	0	0	0	0	0	0	0	1	0	1	1
2	ɔ_a	0	0	0	0	0	0	0	0	1	1	1	1
1	u_a	0	0	0	0	0	0	0	0	0	0	0	1
2	u_a	0	0	0	0	0	0	0	0	1	1	0	1