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Articulatory Characteristics of Polish Retroflex Sibilants. Analysis Using Electromagnetic Articulography*

SUMMARY

While the retroflexion of Polish sibilants is not a newly discovered feature, it is nevertheless not yet very popular in the Polish-language literature. The purpose of this article is to provide detailed articulatory evidence for the retroflex character of Polish consonants [ʂ ʐ t͡ʂ d͡ʐ]. A new aspect of this approach is the use of instrumental techniques based on electromagnetic articulography, which has been used in a historically largest group of carefully selected speakers. The articulatory features of Polish retroflex sibilants were distinguished. Those features also represent the classification criteria of this group of consonants. The analysis of articulatory data made it possible to describe the articulatory characteristics of Polish retroflex sibilants present in the majority of the realisations, such as apicality, (post)alveolarity, the presence of the sublingual cavity and tongue retraction.
Key words: electromagnetic articulography, retroflexes, sibilants, articulation

1. INTRODUCTION

Traditionally, Polish (post)alveolar sibilants are recorded using the following symbols /ʃ ʒ tʃ dʒ/ and classified as alveolar laminal consonants (Jassem 2003, p. 104, cf. also Figure 2 in this article). However, the results of the latest research prove the retroflexion of Polish consonants [ʂ ʐ t͡ʂ d͡ʐ]. This is supported by acous-

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tic (cf., e.g., Pape, Żygis 2016, Żygis et al. 2012, Żygis, Hamann 2003, Żygis 2004, Keating 1991), articulatory (cf., e.g., Lorenc et al. 2018, Mik et al. 2018a, Bukmaier, Harrington 2016, Hamann 2003), perceptual (cf., e.g., Łobacz 1995, Jassem, Łobacz 1995) as well as phonological arguments (cf., e.g., Hamann 2003, Żygis 2004, Hall 1997, Dogil 1990, Rubach 1984).

As far as acoustic arguments are concerned, the presence of the sublingual cavity in retroflex articulation has been proven to reduce resonance frequencies (Keating 1991). The volume of the anterior part of the oral cavity, limited by the lips on one side and the articulation gap on the other side, is associated with the acoustic parameter COG (*centre of gravity*) – the centre of gravity of the spectrum. The higher the gap is located (e.g. in a postalveolar position), the lower the value of the COG of the spectrum. In the case of Polish (post)alveolar sibilants, COG takes a low value: from 2.5 to 3.5 kHz, which confirms their retroflex character (Żygis, Hamann 2003, Żygis 2004). Also, parameters such as the duration of the friction phase, F1 and F2 of the following vowel, as well as the inclination and steepness of the spectrum provide reliable indications of retroflexion of the group of consonants discussed here (Żygis et al. 2012, Jassem 1995).

From the perceptual perspective, the strong noise produced during the articulation of sibilant consonants allows us to identify the changes related to the place of articulation (cf., e.g., Łobacz 1995, Jassem, Łobacz 1995). Since the perceptual description in research is usually combined with the acoustic characteristics of sibilants, it can also be found in most of the sources mentioned in the preceding paragraph.

In the light of phonological arguments, Polish postalveolar sibilants do not combine with a high front vowel [i], which speaks in favour of their retroflexivity (Hall 1997, Rubach 1984, Hamann 2003, Żygis 2004). The Polish palatalised consonant /ʂ/ transforms into [ʃʲ] rather than into the retroflex [ʂʲ] in the context of [i] or [j] following it (Żygis 2004), for instance [ʃʲ]iwa, ko[ʃʲ] jabłek. Moreover, Polish alveolo-palatal consonants /ɕ/ /ʑ/ do not appear before vowel /ɨ/, while Polish retroflex sibilants combine with it (Dogil 1990): e.g. [ɕi]ny, [ʂɨ]ny.

The aim of this article is to provide detailed articulatory evidence that Polish consonants [ʂ ʐ t͡ʂ d͡ʐ] are retroflexes. A new aspect of this approach is the involvement of instrumental research with the use of electromagnetic articulography. The research takes into account the articulatory features that have not been analysed to date, such as the position of the back of the tongue or the mandible. Moreover, articulation analyses based on phonetic-instrumental research and the description of Polish retroflex sibilants developed on their basis are the result of research of the largest group of carefully selected speakers used to date.

The following part of this article has the following structure: it synthetically presents (1) sibilantness and (2) retroflexion, followed by (3) the methodology of the author's own research and (4) the results obtained. They were developed while searching for common features characteristic of retroflex articulations (cf. Hamann 2003, 2004) in relation to the place of articulation, the presence of the sublingual cavity, the degree of mandibular abduction and tongue retraction. The article ends (5) with the presentation of conclusions from the research carried out.

2. SIBILANTNESS

Sibilantness is a phonetic-acoustic characteristic of consonants, and its use in classifications is limited to only two groups of speech sounds: fricatives and affricates (Maddieson, Precoda 1992). "In the linguistic tradition, the phonetic feature of sibilantness is viewed as a universal phenomenon. It is assumed that there is at least one fricative element in the phonological system of each language and if there is only one such element then it is *+sibilant* [...]." (Łobacz 1998, p. 135).[1] Among the languages stored in the *UCLA Phonological Inventory Database* (UPSID), 83% have at least one sibilant consonant (Maddieson, Precoda 1992) and usually (89% of all cases) it is a variant of [s]. From an acoustic and auditory point of view, sibilant consonants are distinguished by a strong-amplitude noise in the high frequencies (non-sibilants are also rustling consonants, but with low-energy noise, concentrated also in the lower frequencies). The mechanism behind this very intense noise results from the fact that a strong air flow is directed at an obstacle, such as the front incisors (cf., e.g., Shaddle 1991). This mechanism is additionally supported by the high position of the mandible and, consequently, of the lower incisors[2] (cf. Lee et al. 1994, Mooshammer et al. 2007). The strong noise of sibilant consonants is always generated when the air flows along the middle line of the vocal tract and during expiration: these are mostly pulmonic egressive consonants (Łobacz 1998, p. 137). From the perspective of auditory phonetics, the feature involving strong noise is most independent in perceptual terms and it is the most important factor that helps to distinguish sibilants that differ, e.g., in terms of the place of articulation, such as the English /s/ vs. /ʃ/, or Polish sibilant consonants (cf. Łobacz 1995, Jassem, Łobacz 1995). Contemporary articulation research has shown that the tip of the tongue and its vertical orientation are the most effective physiological parameters helping to draw a clear line between the three places of articulation of Polish sibilants (cf. Bukmaier, Harrington 2016).

[1] The quoted publication by P. Łobacz, entitled *Sybilantność* [Sibilantness], is entirely devoted to the phonetic and phonological characteristics of sibilant consonants, also from the perspective of therapy and speech development. Readers interested in a more comprehensive description of the phenomenon of sibilantness are hereby referred to that publication.

[2] The high position of the mandible results in a significant convergence of the upper and lower incisors, which is commonly referred to as "dentalisation" in the Polish literature on speech therapy.

According to the UPSID database (Maddieson, Precoda 1992), apart from characteristics such as voiced/voiceless and anterior/non-anterior, one of the most frequently used ways of contrasting fricative sibilants is the shape of the tongue mass (including features such as palatal, dental/alveolar, or palatal/retroflex/palatal-alveolar).

The Polish language has a complex system of sibilants that differ both in the manner and place of articulation, cf. (1).

(1) The Polish system of sibilants

	(post)dental	retroflex	alveolo-palatal
fricatives	s z	ʂ ʐ	ɕ ʑ
affricates	ʦ ʤ	t͡ʂ d͡ʐ	ʨ ʥ

The retroflexion of Polish sibilants is not a newly discovered feature, although it is still insufficiently popular in Polish-language literature. It was discussed, among others, by B. Wierzchowska[3] (cf. 1980), M. Rochoń and Pompino-Marschall (1999), S. Hamann (cf. 2003), M. Żygis (cf. 2004), A. Trochymiuk and R. Święciński (2009), A. Lorenc and R. Święciński (2014).

3. RETROFLEXION

In the light of many traditional approaches, the definition of the term ‘retroflex’, including its etymology (Latin *retro* – ‘backwards’, *flexio* – ‘bending’), is connected with the description of the shape of the tongue, either bent upwards or bent into an arch with the tip pointing backwards. This leads to apical articulation (using the tip of the tongue – the apex) or even subapical[4] articulation (using the underside of the tongue blade, below the apex). This is how the retroflex plosive consonants in Hindi, Tamil and Telugu are created (cf. Figure 1).

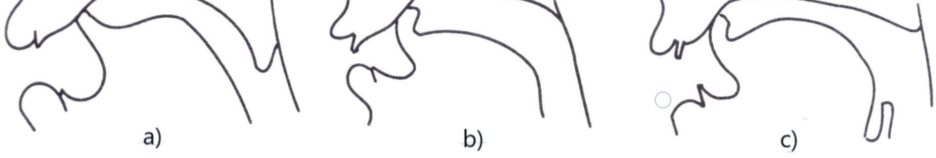


Figure 1: Articulation sections made on the basis of X-ray examination of retroflex plosive consonants: a) apical in Hindi, and subapical in b) Tamil and c) Telugu.

Source: Author’s own analysis based on Ladefoged, Maddieson 1996, p. 27.

[3] Using the term ‘cerebral consonants’.

[4] In some approaches also referred to as ‘sublaminal’ (quoted after: Hamann 2003, p. 13).

The tongue mass is either raised or bent in a characteristic way and the apex touches the postalveolar area (cf. apical articulation, Figure 1a), or the underside of the tongue blade forms a stop in the palatal area (cf. subapical articulation Figures 1b and 1c).

It should be noted here that articulation using the upper surface of the tongue blade is referred to as 'laminal' (see Figure 2 below). All the aforementioned types of articulation, i.e. apical, laminal and subapical (sublaminal), belong to coronal articulations, realised with the coronal, i.e. the most mobile, front part of the tongue stretching from 1 to 2 cm (Keating 1991), from 1 to 1.5 cm (Catford 1977), from 1.5 to 2 cm (Dart 1988) behind the tip of the tongue.

In the international IPA classification, the term 'retroflex' refers to the place of articulation of consonants, situating them between postalveolar and palatal consonants (cf. IPA 1999, http1). However, the term retroflexion (cerebrality, cacuminality) is associated with the shape of the tongue rather than a specific place of articulation, since it can be situated between the alveolar and pre-palatal areas. Retroflex sounds may have different places of articulation, e.g. postalveolar, as in Malayalam, palatal-alveolar in Herero (South Africa) or palatal in Tamil (cf. Laver 1994, Ladefoged, Maddieson 1996). A similar diversity can be observed with respect to the manner of articulation: in languages of the world, retroflexes can be found among stops, fricatives, nasals, approximants[5] and vowels. The analysis of consonants with a different manner of articulation shows that the 'bending' of the front part of the tongue, characteristic of retroflexes, does not always occur. This is the case, for instance, with Serbian fricatives (Keating 1991) and Polish retroflex sibilants (Lorenc et al. 2018, Mik et al. 2018a). In the light of the latest descriptions, retroflexes, as a diverse group of speech sounds, are classified according to several articulation criteria (cf. Hamann 2003). These are:

(1) place of articulation – the function of passive articulator is performed by the upper areas of the oral cavity, from the alveolar to the palatal area;

(2) apicality, where the active articulator is either the tip of the language (apical articulations) or its underside (subapical articulations), cf. Figure 2;

(3) the presence of a sublingual cavity, a relatively large area under the tongue, created during articulation, cf. Figure 2, Figures 3a and 3b.

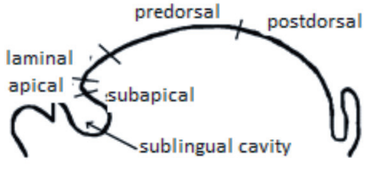


Figure 2: Schematic diagram of parts of the tongue and sublingual cavity.
Source: Based on Catford 1977.

[5] Most recent studies using electromagnetic articulography provided articulatory evidence for the retroflex character of the Polish lateral approximant (cf. Lorenc 2016a).

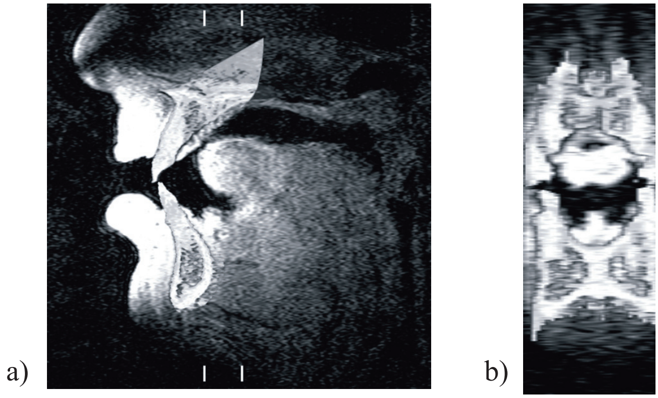


Figure 3: MRI-based (a) peroneal and (b) coronal cross-sections (taken from the place marked with lines in Figure 3a) of the prolonged articulation of the Polish consonant [ʂ] realised by speaker P2 in the imaginary context of the vowel [a].
Source: Toda, Maeda, Honda 2010, pp. 358–359.

(4) Tongue retraction (cf. Figure 4).

Figure 4: Retraction (middle movement), velarization (highest movement) and pharyngealization (most backward movement) compared to the neutral position of the tongue (filled in white).
Source: Hamann 2003, p. 35.

4. AUTHOR'S OWN RESEARCH

1.1. SPEAKERS

The study included a group of 20 adult users of the Polish language (10 women and 10 men) aged from 22 to 46. In the opinion of the team of experts, all the speakers who qualified for the study used the careful style of the standard variety of contemporary Polish language in official situations and had tertiary education.

Bilingual or fluent speakers of at least one foreign language (i.e. students of foreign language departments) were excluded from the study based on the assumption that this fact may influence the pronunciation in their mother tongue. Other excluded subjects were those who, in connection with their education or current training (e.g. performing arts or journalism), practised their pronunciation, consciously changed it or were able to manipulate it. On the other hand, people with high language awareness and linguistic culture connected with their current or completed study programme (Polish studies, speech therapy) were qualified for research.

Regional differentiation was not sought when designing the experiment, as it was found that despite the high number of subjects (20) for a phonetics experiment, this number was still insufficient to draw any generalisations based on geographical variables.

The screening procedure, conducted by a team of experts (two phoneticians and three speech therapists) was based on phonetic, orthophonic, cultural-linguistic and biological (anatomical, functional and perceptual) criteria, described in detail in other publications [cf. Lorenc 2016a, Lorenc 2016b]. In this way, the existence of the following was excluded among the study subjects: anatomical defects in the articulation apparatus (e.g. concerning occlusion, dentition, structure of lips, tongue or palate), motor disorders of speech organs (lips, tongue, mandible, soft palate), disorders of para-functions (such as swallowing or chewing) as well as abnormalities related to physical hearing and hearing of speech.

1.2. LINGUISTIC MATERIAL

The list for evaluating the realisation of retroflex sibilants consisted of 26 words (ten for voiceless consonants [ʂ] and [t͡ʂ] and three for each of their voiced equivalents [ʐ] and [d͡ʐ]). The pronunciation of Polish retroflex sibilants was evaluated in the intra-word position in accented syllables. Thus, those had to be three-syllable words. The studied consonants were always located in the bilateral vicinity of the central, low vowel [a] (cf. Table 1).

Table 1: List of words used for assessing the pronunciation of the basic consonant variants of [ʂ], [ʐ], [t͡ʂ], [d͡ʐ].

Words			
kaszanka	bażanty	kaczany	Adżaria
kaszalot	strażacy	maczanie	Adżanta
straszaki	Marzanna	taczanka	Madżarda
zaszaleć		zaczadzieć	
zraszacze		sflaczały	
blaszany		zbaczanie	
ptaszarnia		Kaczawa	
kaszaki		wkraczanie	
kraszanka		staczanie	
zraszanie		krzaczasty	

Source: Author's own resources.

The speakers were tasked with remembering the lexical units presented for 2 seconds on a screen located at eye level at a distance of 1.5 m (the pilot study checked whether the font size used was sufficient to read the words freely). Then the subject pronounced the memorised word upon the agreed light-based signal (green screen), as naturally as possible.

On the basis of the standardisation conducted (cf. Lorenc 2016a, pp. 129–131), a total of 441 words used for the assessment of Polish retroflex sibilants were classified for further assessment: 170 for [ʂ], 161 for [t͡ʂ], 41 for [ʐ] and 69 for [d͡ʐ].

1.3. TESTING TOOL: ELECTROMAGNETIC ARTICULOGRAPH

The recordings were made with the simultaneous use of Carstens articulograph (AG500 model), a video system consisting of three high-speed Point Grey cameras (Gazelle GZL-CL-22C5M-C) and a dedicated self-designed and built audio recorder with a 16-channel microphone array (Lorenc et al. 2015; Król et al. 2015; Mik et al. 2018b). For the purposes of this article, the data collected using the AG500 electromagnetic articulograph have been used. Thanks to the technology applied, this device enables recording, storing, presenting and assessing the movements of articulators (tongue, lips, mandible, soft palate) in a three-dimensional space in real time, i.e. while the subject is speaking. The general principle of operation (cf. http2) of this articulograph is based on the induction of alternating voltage in sensors mounted on the articulatory organs of the research subjects, through a magnetic field of different frequencies produced by six transmitter coils. During that process, sensor coordinates in three-dimensional space (*XYZ* coordinates), as well as two angle measures (φ, θ) can be computed in real time. Thanks to the software included with the device, the collected data can be easily managed, viewed and edited.

The AG500 articulograph allows up to 12 sensors to be used during a test. In the presented experiment, three sensors were used as a reference for the others and later served to normalise the data related to the correction of head movements. They were placed respectively on the left and right mastoid parts of the temporal bone and on the nasal bridge. One sensor, attached to a wooden medical spatula, was used to record the speaker's individual anatomical conditions (in order to outline the upper incisors, gums and palate while the subject was breathing through the nose and mouth). It was also used to locate the temporomandibular joints. All other sensors were used to control the moving speech organs. Five sensors were placed on the tongue, with four along the central line (tip of the tongue – TT, tongue front – TF, tongue dorsum – TD and back of the tongue – TB) and one on the tongue left side – TLS). Two sensors recorded the work of the upper lip (UL) and lower lip (LL), and were placed in the central part just above the red part of the lip. One sensor (J), glued inside the oral cavity at the border between the lower incisors and gums, was used to control the operation of the mandible (cf. Figure 5).

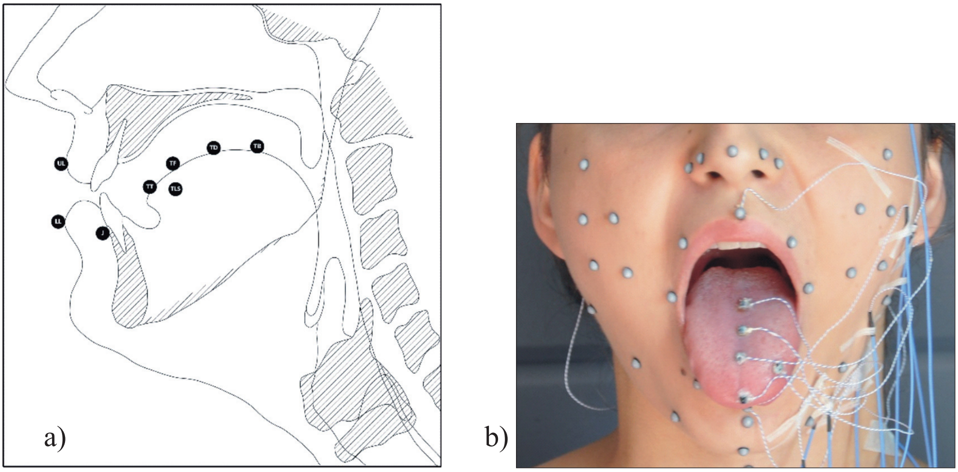


Figure 5: Distribution of the articulograph sensors: a) on movable speech organs, b) on a subject's tongue.
Source: Author's own resources

1.4. SEGMENTATION AND ANALYSIS OF ARTICULATION GESTURES OF POLISH RETROFLEX SIBILANTS

With this experiment in mind, a decision was made to develop dedicated software in the Matlab environment. The *phoneEMAtool*[6] application (Mik, Lorenc 2015a) enables dynamic visualisation of the trajectory of movement for all sensors (except the reference sensors) in the X (front – back) and Z (top – bottom) axes, as well as analysis and extraction of information related to the position of different sensors in all axes over time, taking into account angular deflections φ and θ. In addition, the software enables the user to compute the speed of sensor movements over time and to determine its minima and maxima. In addition, it is possible to determine the 20% level of increasing and decreasing speeds.

To perform the segmentation and analysis of articulatory gestures created by mobile speech organs, the model used in world phonetic research with the use of EMA systems was adopted (cf. Best et al., 2014). To perform the analysis, it was required to identify the articulator whose movement played the main role in creating the target articulations. When assessing the realisation of Polish retroflex sibi-

[6] The authors of most articulation gesture analyses based on articulation data use the FindGest feature available in the *MVIEW* application.

lants, it was assumed that the role of the critical (key) articulator was performed by the tip of the tongue (Browman, Goldstein 1992). Figure 6 presents a fragment of the realisation of the word *kaszalot* together with the articulatory segmentation of the consonant [ʂ] according to the adopted criteria (for more information, please refer to A. Lorenc 2016a, pp. 144–146).

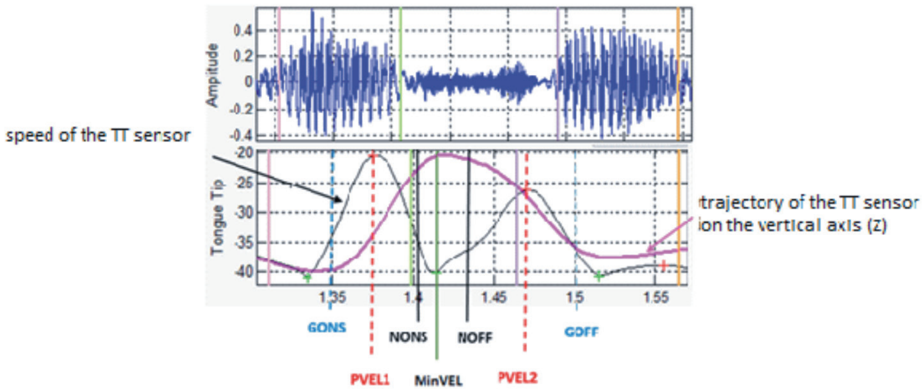


Figure 6. Oscillogram as well as the trajectory and speed of the tongue tip (TT) sensor movement in the Z axis (top–bottom) during the realisation of the [aʂa] segment in the word *kaszalot* (speaker PT_m, file 305)

Source: Author's own sources based on *phonEMAtool* (Mik, Lorenc 2015).

The results of research on Polish retroflex sibilants presented in this article were processed at the moment when the tip of the tongue (primary articulator) assumed the extreme inclination in the Z axis (top–bottom) while reaching the lowest value of its velocity (*MinVEL – minimum velocity)* within the nuclear phase of the articulation gesture (between NONS, *nucleus onset* and NOFF, *nucleus offset*, i.e. the beginning and end of the articulation nucleus).

5.6. RESULTS OF OWN RESEARCH [UWAGA, PROBLEM Z NUMERACJĄ]

The analysis covered the articulatory features of Polish retroflex sibilants, most commonly identified as the classification criteria for this group of consonants (Hamann 2003). The evaluation of the relationship between the tip of tongue sensor (TT) and passive articulators helped to determine the place of articulation of the sounds in question. Moreover, the difference in the position of the sensors of the tongue tip (TT) and lower jaw (J) in the Z axis was calculated (cf. vertical arrow in Figure 7), thus concluding about the height of the sublingual cavity. The degree of mandibular abduction was determined taking into account the difference between the position of the mandibular sensor (J) in the Z-axis of retroflex sibilants and the consonant [t]. The last element of the analysis concerned the degree of tongue retraction during articulation. It was determined by calculating the difference in the position of the sensor placed on the back of the tongue (TB) in the X axis during the realisation of retroflex sibilants and consonant [t] (cf. horizontal arrow in Figure 7).

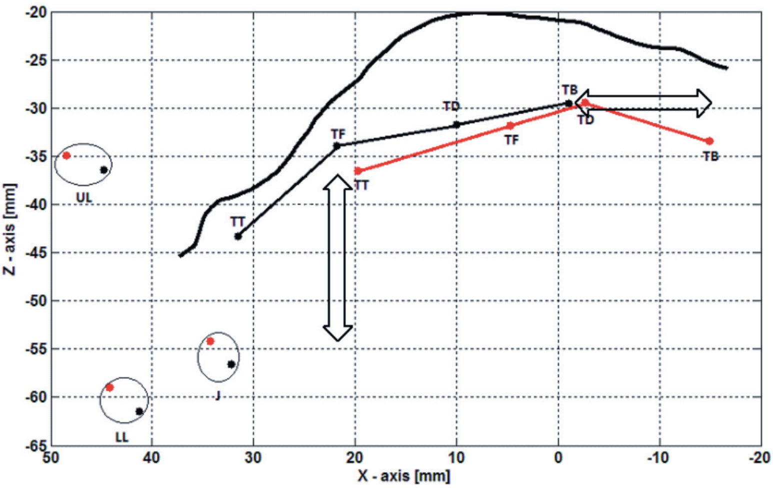


Figure 7. The outline of passive articulators and the difference in the position of the sensors of the tongue tip (TT) and jaw (J) in the Z axis (top – bottom, vertical arrow) in the realisation of consonant [ʂ] (red colour) in the word *zaszaleć* (speaker ZK_f, file 066) and the difference in the position of the sensor of the back of the tongue (TB) in the X axis (front – back, horizontal arrow) in the realisations of consonants [ʂ] and [t] (black colour) in the word *latarka* (speaker ZK_f, file 345).

Source: Author's own analysis based on *EMAviewer* (Mik, Lorenc 2015b).

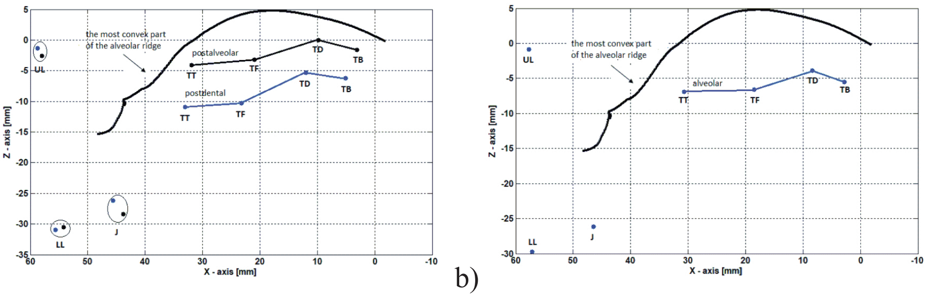
5.6.1. THE PLACE OF ARTICULATION

On the basis of the measurement presented in Figure 7, the position of the tip of the tongue in the Z axis was calculated during the articulation of retroflex sibilants by all the subjects. Next, the horizontal position of the critical articulator, i.e. the tip of the tongue, was determined in relation to the most convex part of the alveolar ridge. It was determined on the basis of the assessment of individual palatal contours of each speaker. The outlines of passive articulators (the posterior wall of upper incisors, hard palate and partially soft palate) were made in the middle line during each articulograph measurement using one of the sensors. The position of the sensor glued to the tip of the tongue (TT) in relation to the most convex part of the alveolar ridge (marked with an arrow in Figure 8) was interpreted as follows:

a) postdental articulation: in the nuclear phase of the articulation gesture, once its minimum velocity (MinVEL) is reached, the TT sensor below the reference point (cf. Figure 8a),

b) alveolar articulation: in the nuclear phase of the articulation gesture, once its minimum velocity (MinVEL) is reached, the TT sensor is directly vis-à-vis the reference point (cf. Figure 8b),

c) postalveolar articulation: in the nuclear phase of the articulation gesture, once its minimum velocity (MinVEL) is reached, the TT sensor is above the reference point (cf. Figure 8a).



a) b)

Figure 8. The outline of passive articulators and the position of articulograph sensors in the realizations of: a) postalveolar closure (black colour) and the postdental gap (blue colour) of consonant [t͡ʂ] in the word kaczany (speaker JS_f, file 408) and b) alveolar consonant [ʂ] in the word Marzanna (speaker JS_f, file 84) when the tip of the tongue sensor (TT) reaches the minimum velocity (MinVEL) in the Z axis in the nuclear phase of the articulation gestures.

Source: Author's own analysis based on *EMAviewer* (Mik, Lorenc 2015b)

Tables 2 and 3 below summarise the results of the analysis of the place of articulation for retroflex sibilant fricatives and affricates.

Table 2: Place of articulation for retroflex sibilant fricatives.

Place of articulation	[ʂ]	[ʐ]
postdental	1.8 % (3/170)	4.9 % (2/41)
alveolar	73.5% (125/170)	87.8 % (36/41)
postalveolar	24.7 % (42/170)	7.3 % (3/41)

Source: Author's own analysis.

Table 3: Place of articulation for retroflex sibilant affricates.

Place of articulation	[t͡ʂ]	[d͡ʐ]
postdental (closure and gap)	1.9% (3/161)	0% (0/69)
alveolar (closure and gap)	52.2% (84/161)	33.3% (23/69)
postalveolar (closure and gap)	4.3% (7/161)	1.5% (1/69)
postalveolar (closure) alveolar (gap)	41.6% (67/161)	65.2% (45/69)

Source: Author's own analysis.

A total of 441 realised retroflex sibilants were analysed, where the position of the tip of the tongue in relation to the outline of passive articulators was assessed. Out of 170 realisations of the voiceless fricative [ʂ], the majority (125, which represents 73.5%) were interpreted as alveolar articulations because upon reaching its minimum velocity (MinVEL) in the nuclear phase of the articulation gesture the sensor of the tip of the tongue (TT) was placed directly opposite the reference point, i.e. the most convex part of the alveolar ridge. An example of such realisation is illustrated in Figure 8b. Less than 25% of the examples were interpreted as postalveolar articulations. As regards the voiced fricative [ʐ], the predominant number of analysed examples (36 out of 41) were also interpreted as alveolar articulations (87.8%) with 7.3% being interpreted as postalveolar ones.

In the case of sibilant affricates, the analysis of the place of articulation was performed separately in the segments of closure and gap. As a result, it was possible to determine the number of realisations where the articulation occurred in a single place, i.e. postdental, alveolar or postalveolar, or in two places, i.e. postalveolar first, followed by alveolar. As regards the voiceless affricate [t͡ʂ], slightly more than a half of the assessed articulations, i.e. 52.2% (84 out of 161) were realised in the alveolar region, both in the closure and in the gap segment. Further on, there were articulations beginning with a closure in the postalveolar area, morphing further into a gap formed directly opposite the alveolar ridge. A total of 67 such realisations were noted among the 161 assessed ones, which represents 41.6%. In the case of the voiced affricate [d͡ʐ], the prevailing articulations were those starting with postalveolar closure, morphing into a gap formed in the alveolar area. These realisations accounted for 65.2% of occurrences of this consonant (45 out of 69). One third (33.3%) of the articulations of consonant [d͡ʐ] were assessed as fully alveolar.

Occasional postdental articulations were recorded for all retroflex sibilants (all from the same woman: JS_f, cf. Figure 8a). The postalveolar realisations of affricates, recorded both in the closure and the gap segment, constituted a small percentage of the total.

5.6.2. HEIGHT OF THE SUBLINGUAL CAVITY

The subsequent part of the study was carried out to determine the distance between the degree of elevation of the tip of the tongue and the position of the mandible in order to determine the height of the sublingual cavity during the articulation of retroflex sibilants. For this purpose, a measurement was performed at the moment when the sensor of the tip of the tongue (TT) slowed down maximally (reaching the minimum velocity in the nexus phase of the articulation gesture) and was raised highest in the Z axis (top – bottom), while also determining the position of the lower jaw sensor (J) exactly at the same moment. In order to determine the distance between the tip of tongue sensor (TT) and the lower jaw sensor (J), their average position at the MinVEL point was calculated first for all the realisations performed by each speaker. Next, the average position of the jaw sensor was subtracted from the average position of the tip of the tongue sensor at the same time point. The difference calculated in this way was used as the basis for determining the height of the sublingual cavity during the realisation of retroflex sibilants.

Table 5. Average height of sublingual cavity [mm] (difference between the tip of the tongue sensor (TT) and the jaw sensor (J) in the Z axis) during the articulation of retroflex sibilants and the plosive [t].

Consonant	TT (Z) – J (Z)
[t]	13.39 mm
[ʂ]	15.69 mm
[ʐ]	15.33 mm
[t͡ʂ]	18.49 mm
[d͡ʐ]	18.76 mm

Source: Author's own analysis.

The average height of the sublingual cavity created during the articulation of retroflex sibilant fricatives [ʂ] and [ʐ] is approx. 2 mm greater than in the case of the plosive consonant [t]. The pronunciation of retroflex sibilant affricates is characterised by an even larger sublingual cavity (further 3 mm). It should be emphasised here that its height was calculated in the closure segment, which, according to the analysis of the place of articulation, is often realised in the postalveolar area.

The position of the lower jaw (J) in the Z axis (top – bottom) was also assessed during the realisation of retroflex sibilants and consonant [t]. The average value of the position of the secondary articulator (mandible) was calculated in the nexus phase of the articulation gesture when the sensor of the tip of the tongue (TT) reached the highest position and, at the same time, the lowest velocity (MinVEL). The analysis helped to determine the degree of mandibular abduction and the differences in the realisation of retroflex sibilants and consonant [t] in this respect (cf. Table 6).

Table 6: Difference in the degree of mandibular abduction [mm] during the articulation of retroflex sibilants and consonant [t].

J (Z) retroflex – J (Z) [t]		
Consonant	J (Z) retroflex > J (Z) [t]	J (Z) retroflex < J (Z) [t]
[ʂ]	0.42 mm (8 speakers)	1.78 mm (12 speakers)
[ʐ]	1.01 mm (4 speakers)	1.25 mm (14 speakers)
[t͡ʂ]	1.11 mm (10 speakers)	1.29 mm (10 speakers)
[d͡ʐ]	1.11 mm (8 speakers)	1.47 mm (11 speakers)

Source: Author's own analysis.

The analysis of the data shows that most subjects realise retroflex sibilants with, on average, a lower degree of mandibular abduction (right column in the table) than in the case of consonant [t]. The difference ranges between 1.29 mm for consonant [t͡ʂ] and 1.78 mm for consonant [ʂ].[7] When articulating retroflex sibilants, some subjects show a slightly greater mandibular abduction than with [t], and the differences are smaller than those mentioned above and fall within 0.42 mm for [ʂ] and 1.11 mm for [t͡ʂ] and [d͡ʐ].

5.6.3. THE DEGREE OF RETRACTION OF THE BACK OF THE TONGUE

The subsequent part of the study assessed the degree of tongue retraction. For this purpose, for all realisations of retroflex sibilants, the value of the position of the TB sensor in the X axis (front – back) was calculated at the minimum velocity (MinVEL) of the primary articulator, i.e. the tip of the tongue (TT sensor). For

[7] For the sake of comparison, the realisation of the Polish lateral consonant [l] is associated with a lower position of the mandible than in the articulation of [t]. The average difference is significant and amounts to 5.75 mm for all the studied speakers (for more on this subject, see monograph by A. Lorenc 2016a, pp. 225–232).

retroflex sibilant fricatives, the measurement was made in the gap segment, while the closure segment was considered for affricates. In order to carry the relevant comparisons, analogous measurements were carried out in relation to the voiceless plosive consonant [t]. On this basis, the degree of tongue retraction during the realisation of the tested consonants as well as the differences in this respect were assessed. The table below shows the average difference in the position of the back of the tongue during the articulation of retroflex sibilants compared to consonant [t] (cf. Table 7).

Table 7. Difference in retraction of the back of the tongue [mm] between retroflex sibilants and consonant [t].

Consonant	TB (X) retroflex > TB (X) [t]
[ʂ]	7.92 mm
[ʐ]	7.47 mm
[t͡ʂ]	6.06 mm
[d͡ʐ]	5.74 mm

Source: Author's own analysis.

The articulation of retroflex sibilants is characterised by the retraction of the back of the tongue that accompanies the primary articulation occurring in the front part of the oral cavity (in the postalveolar, alveolar or, occasionally, dental area, cf. Table). In the case of sibilant fricatives, it is, on average, over 7 millimetres larger versus the plosive consonant [t]. It is interesting to compare the sibilant affricates with the same consonant since the same articulation segment, i.e. closure, was taken into account in all cases. Here, too, it turned out that in the case of retroflex sibilant affricates, the closure created in the front part of the vocal tract is accompanied by a simultaneous retraction of the back of the tongue, which is on average by 5.74 mm greater for [d͡ʐ] and by 6.06 mm greater for [t͡ʂ] when compared with the plosive consonant [t].

6. CONCLUSIONS

The analysis of articulographic data allows us to list the following articulation features of Polish retroflex sibilants that are present in most realisations:

- apicality,
- (post)alveolarity,
- presence of the sublingual cavity,
- tongue retraction.

All the aforementioned features are classified as the common features, characteristic of retroflex articulations (Hamann 2003, 2004). The articulation of Polish retroflex sibilants is also characterised by a high position of the mandible, which leads to a significant approximation of the lower and upper incisors and thus creates an obstacle onto which the stream of air is directed that produces a strong noise effect (cf. also: Toda, Maeda, Honda 2010).

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