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Voicing Contrast Disorders. Acoustic and Auditory Analysis

SUMMARY

The article deals with the issue of voicing implementation in the speech of normally hearingand hearing impaired individuals from the perspective of speech-language pathology, phonetics and phonology. The research is based on data acquired in an experiment employing acoustic phonetic methodology in the form of voice onset time (VOT) measurements in plosives as well as auditory analysis and transcription of the recorded material performed by specialists.

The paper presents a novel typology of voicing disorders and a comparative analysis of objective acoustic measurements and subjective auditory impressions. The final part of the article is devoted to a discussion on a selection of voicing disorder-related claims available in relevant literature and a new interpretation of the matter.

Key words: voicing disorders, children with and without hearing impairment, Voice Onset Time (VOT), phonetic transcription.

1. INTRODUCTION

The effect of voicing should be viewed as resulting from an array of complex aerodynamic and myoelastic mechanisms that are controlled by the central nervous system and managed by the motor cortex, together with an interaction of the sensory and auditory feedback mechanism. The action of the larynx needs to be coordinated with specific movements of supralaryngeal speech organs. From the physiological perspective, voiced elements of speech are characterised by concomitant closings and openings of the glottis repeated at short time intervals. These vibrations are a consequence of two opposing forces: rising subglottal pressure induces the separation of the vocal folds, whereas the contraction of larynge-

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al muscles prevents the contained air from escaping. As a result of the differences in pressures, the induction of vocal fold vibrations facilitates gradual escape of the compressed subglottal air. The laryngeal tone is created by the alternating phases of rarefying and compressing the air that travels between the vocal folds.[1]

Aerodynamic variables are closely related to the sets of articulatory movements within the larynx and resonating cavities. Experimental studies of laryngeal activity (Sawashima, Hirose 1983; Hirose 1997) distinguished four basic types of movements, two of which are particularly relevant in the process of speech sound production:

1) adduction/abduction of the vocal folds – regulating the degree of opening between the folds depending on sound characteristics and phonation type (voiced, voiceless, whispered and their combinations),[2]
2) stiffening/slackening of the vocal folds – regulating the length, surface area and tension of the folds, depending on the changes of the fundamental frequency (F_0).[3]

Additional types of movements are:
3) raising/lowering – due to these the larynx moves up and down,
4) adduction of the upper part of the larynx – crucial in the production of the glottal stop.

The effect of voicing does not result solely from laryngeal activity. Differences between voiced and voiceless sounds are also created in the supralaryngeal area, which is best exemplified by the phonetic dichotomies of tense/fortis (voiceless) and lax/lenis (voiced) sounds that relate to the force of articulation. Thus, in the case of voiceless consonants, one can observe a more intensive and extensive articulatory contact than in the case on voiced consonants (see T. Benni 1931), a stronger closure between the velum and the back wall of the pharynx as well as a greater elevation of the epiglottis, the hyoid bone and the larynx (cf. H. Koneczna, W. Zawadowski 1951). Voicelessness is also related to longer articulatory duration (cf. Trochymiuk 2008).

[1] The laryngeal tone is a complex quasi-periodic sound created by regular vocal fold vibrations.

[2] The division of phonation types into voicing, voicelessness, whisper and their combinations (*falsetto, creak, modal voice, breath, nil phonation*) is assumed here after Laver (1994, s. 199).

[3] The fundamental frequency (also called 'F_0' or 'the fundamental') is the lowest component frequency of the source sound generated in the larynx (the so-called laryngeal tone) that reflects the frequency of vocal fold vibrations (number of cycles per second). Changes in the fundamental frequency are related to changes of intonation contours in speech (see Jassem 1973). The fundamental frequency in a natural conversation ranges from 50 to 250 Hz in male voices and from 120 to 480Hz in female voices (Laver 1994).

2. ± VOICE CONTRAST IN THE STUDIES OF CHILDREN'S SPEECH

The voicing contrast is also subject to linguistic description in the area of speech pathology, and its disorders are termed *voiceless speech* (Kania 1982, Sołtys-Chmielowicz 2008) or *voiceless pronunciation* (Kaczmarek 1988). Children with this impediment produce voiced fricatives, affricates and plosives as their voiceless counterparts. The phonetic system typical for voicing disorders comprises, on one hand, sounds that are non-contrastive regarding the feature of voicing (vowels, approximants, nasals, laterals and rhotics)[4] and articulated with active laryngeal participation, whereas, on the other hand, obstruents (i.e. plosives, affricates and fricatives) are realized voicelessly. In this way the feature of voicing appears to be related to yet another important phonetic distinction – the manner of articulation. The first, and the most extensive, account of this phenomenon is presened by J. T. Kania (1975, 1982). The author classifies voiceless speech as one of the types of dyslalia[5] due to the fact that this disorder affects the most frequent phonological distinction in Polish. Kania assumes, after Sieber, that the Polish sound system consists of 42 phonemes. Such an approach predicts that the voicing contrast in Polish appears in 13 pairs of distinctive plosives, affricates and fricatives.

J.T. Kania distinguishes two types of voiceless speech: complete voicelessness, in which the disorder affects the voicing of all obstruents; and partial voicelessness whereby only some pairs become affected. Most frequently attested changes involve substituting voiced consonants with their voiceless counterparts; however, Kania also points to the distortion of sounds resulting in the production of partially voiced consonants with a voiced initial part and a voiceless offset (or the opposite). Such partially voiced consonants were observed by Kania as transitory realizations appearing in the course of speech therapy. The author did not encounter cases with the voiced-voiceless distinction realized through the fortis-lenis contrast. It should be borne in mind, however, that Kania's observations were made exclusively on the basis of auditory judgements. Regarding the causes

[4] The classification of vowels and consonants, their names and international phonetic symbols are adopted here after IPA (1999) and its version for Polish (Jassem 2003). A comprehensive description of articulatory gestures and their basic as well as extended IPA symbols may be found in an article by A. Trochymiuk and R. Święciński (2004).

[5] The term *dyslalia* is usually understood as relating to all speech impediments, within which particular subcategories are distinguished, e.g. voiceless speech. J.T. Kania (1982) classifies disorders relating to the size of the inventory of sounds as paradigmatic and distinguishes their three subtypes: substitution, distortion and elision. I. Styczek (1979) claims that dyslalia is a descendant form of alalia – a speech disorder resulting from delayed speech acquisition. In the logopaedic classification of speech disorders (Grabias 2001), dyslalia is also regarded as a descendant form of alalia, alghough Grabias views the lack and disorder of competence as phonological only.

of voiceless speech, Kania enumerates: physical hearing impairment (deafness), phonemic hearing disorders, problems with the coordination of vocal fold activity and the articulating organs as well as disorders with kinaesthetics. Both M. Demel (1959) and J.T. Kania (1982) notice that the disorder under discussion affects boys and girls with the same gravity. Moreover, J.T. Kania, and later A. Sołtys-Chmielowicz (1989), notice that voiceless speech is almost always accompanied by difficulties in reading and writing, including spelling mistakes, hypercorrectness, substituting voiced and voiceless sounds, voicing neutralizations and dissimilations.

Statistical studies carried out by M. Demel in 1959 showed that voiceless speech occurs in 1% of the population above the 6th year of age (it was attested in 26 children out of the sample of 2488 first and second grade primary school pupils). The study was based on auditory analysis of speech.

The issue of the realization of voicing in children has also been discussed by Łobacz (1996) in a monograph on the development of phonological competence in pre-school children. Due to the high frequency of occurrence of this phenomenon in 3-year-olds, Łobacz views it as a developmental matter and, on the basis of spectrographic analysis, distinguishes four realization types of voiced plosives in syllable onsets:

1) normative realization – the segment is voiced for at least 50ms,
2) voiceless realization – the spectrographic image shows only plosion and aspiration,
3) partially voiced realization – the final portion of the closure (at least 30ms) is voiced,
4) partially voiceless realization – the initial part of the closure is voiced after which there is a voiceless interval of at least 30ms before the burst and aspiration (Łobacz 1996, s. 181).

Table 1 presents the frequency of occurrence of the four realization types in various age groups, confirming the claim of the developmental nature of the phenomenon.

Tabela 1. The percentage of four realization types of voicing in word-initial plosives by preschool children (Łobacz 1996, p. 181).

Realization type	4-year-olds	5-year-olds	6-year-olds	7-year-olds
1) normative	46,3	64,8	73,8	80,6
2) voiceless	43,3	30,7	9,8	13,9
3) partially voiced	6,0	2,3	16,4	2,8
4) partially voiceless	4,5	2,3	–	2,8

In her work on the characteristics of pre-school children's pronunciation, A. Sołtys-Chmielowicz (1998) diagnosed voiceless speech in approximately 2% of the population – in 20 out of 1063 assessed children (see Table 2).

Tabela 2. The percentage of voiceless realizations of voiced consonants in pre-school children (Sołtys-Chmielowicz 1998, p. 136).

Realization type	3-4-year-olds	4-5-year-olds	5-6-year-olds	above 6-year-olds
2) voiceless	1,8	3,8	1,9	0,4

There are evident discrepancies between the numerical data for voiceless speech obtained by the two authors. The differencies may only be explained by the fact that they employed different research tools and methodology. A. Sołtys-Chmielowicz interprets voiceless speech, similarly to J.T. Kania, in terms of a binary opposition whereby voiced obstruents are substituted by their voiceless counterparts, which she describes as complete consonantal devoicing. Auditory impressions were the basis for the analysis. P. Łobacz, on the other hand, used acoustic and auditory methods of analysis, which strengthened the objectivity of her study and allowed for a greater specificity in her description.

3. CHARACTERISTICS OF THE PARTICIPANTS AND RESEARCH TOOLS

The study involved 20 children aged between 8 and 12 with a diagnosed bilateral hearing impairment of the severe (2 children) and profound (18 children) degree. The participants had been educated and raised with the use of the cued speech method. It was imperative that the participants should have been using cued speech for at least three years as it is assumed that this period of time is sufficient for the acquisition of a language's phonology (cf. Krakowiak 1995). All of the children were equipped with two independent hearing aids. Children with additional ailments, speech motor control disorders or physically anomalous speech organs were not included in the study.

For comparative purposes, a control group of children was selected (5 girls and 5 boys) aged between 8 and 12 years (two children per age group). Logopaedic examination revealed in neither of them any abnormalities in speech, physical and phonemic hearing, anatomy or functioning of the vocal tract.

The language material for acoustic analysis was based on two specially-made word lists (Trochymiuk 2008) and an articulatory test by M. Golanowska (1999).

Thus prepared lexical sets comprised 198 isolated lexical items to be produced by each of the participants.

The realizations were recorded digitally, transferred to a computer hard drive in the form of .wav files and analysed with the use of dedicated software.

4. METHODOLOGY

Voice onset time (VOT)

Acoustic studies of speech are based on the visualization of sounds and their specific properties. Contemporarily, such research involves most frequently waveform, spectrogram and spectrum analysis.

Trochymiuk (2008) carried out a study of voicing with the use of waveform analysis, which is one of the most precise methods of establishing a sound's length or its components. It allows for a precise placement of boundaries between two elements of a sound wave (segmentation) and for determining the type of the examined wave since the shape of the waveform provides information on the periodicity and complexity of the sound. Presence or lack of waveform periodicity (or, to be more specific, quasi-periodicity that is characteristic of voiced speech) facilitates distinguishing voiced and voiceless segments; various shapes of the waveform enable one, for instance, to establish boundaries between consecutive voiced segments. In the present study, the analysis of the waveform was the main method. Additionally, in order to identify a given segment with greater accuracy, spectrographic and pitch contour analaysis were employed.

The analysis of voicing in plosives was carried out in the form of temporal measurements of the durational distance between the onset of voicing in relation to the moment of consonantal release, i.e. voice onset time (VOT).[6]

Regarding various definitions (cf. Lisker, Abramson 1964; Lisker, Abramson, 1970; Cooper 1974; Klatt 1975; Kent, Read 1992; Pickett 1999; Ladefoged, 2001; Roach 2002), it is assumed that VOT is the temporal distance in which voicing (vocal fold vibrations) appears relative to the release of the oral closure, i.e. the plosive burst. The degree of voicing in a plosive may be thus described as the duration of periodicity that may precede or follow the consonantal release.

If quasi-periodic vibrations, characteristic of the action of the vocal folds, precede the burst, VOT has negative numerical values (*voicing lead*); if the periodicity appears after the release, VOT's values are positive (*voicing lag*). When the onset of vocal fold vibrations coincides with the release, the VOT equals zero.

[6] For more information on VOT see Trochymiuk (2007, 2008).

Transcription

The transcription is defined as a record of an utterance with the use of special symbols in order to identify specific features of pronunciation. Hence, it may be asserted that transcribing is a process of transforming an acoustic-auditory signal into a graphic form (Ball et al. 1996). Basically, two transcription types are distinguished: phonemic and phonetic (Ball, Rahilly 1999; Ball et al. 1996). The former is used when the transcriber classifies sounds as realization of particular phonemes, making reference to major phonological categories so as to establish the sound inventory of the speaker. Only basic transcription symbols are used since diacritics are excluded from this type of notation. Phonetic transcription, on the other hand, allows for recording sounds graphically with the use of any available symbols. Narrow phonetic transcription is the most detailed type of transcription which includes all details of articulatory quality and quantity of sounds, while broad phonetic transcription limits the amount of phonetic information to the minimum or focuses on a particular aspect of description (Roach 2002).

In the present study, phonemic transcription was created with the use of the symbols of IPA. It was performed by two trained phoneticians with the final level of concordance of 83.3%[7]. In the description of spectrograms, however, phonetic transcription was employed with the use of the IPA and ExtIPA symbols.

5. ACOUSTIC ANALYSIS RESULTS

In the present study, the examination of the voicing contrast concerned measurements of VOT in word-initial plosives. The reference point for the measurement was the time of the release of the consonants, which was arbitrarily given the time value of 0ms (cf. Fig. 1).

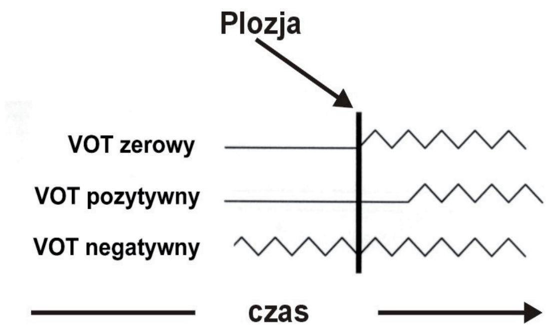

Fig. 1. VOT measurement diagram.

[7] In studies on the transcription of disordered speech (cf. Ball et al. 1996) it is emphasized that high unanimity of phonetic transcripts is very rare even in the case of highly qualified transcribers. L. Shriberg and G. Lof (1991), in an article on the transcription of disordered speech in children, show that the level of concordance between particular transcribers ranged from 28% to 58%.

In total, 210 measurements were obtained for [p], [t], [k] in the experimental group, and 140 in the control group.

Mean VOT for [p], [t] and [k] in hearing-impaired children was positive, with the lowest nominal value for [t], highest for [k] and intermediate for [p]. The attested high level of variability and differences between the lowest and highest VOT values for [p] and [t] indicate that there is significant lack of stability in their articulation as well as considerable difference in relation to the control group. The consonant [k] was pronounced with greatest accuracy as the VOT values were always positive in the experimental group. The presence of negative VOT values in the case of anterior plosives [p] and [t], as well as their absence in the measurements of [k], confirms the observation of voiceless speech therapy that it is easier to voice consonants that are further away from the larynx.

The results obtained from the control group reflect the universal tendencies related to VOT found in various languages:

– VOT value rises relative to the degree of backness of the supralaryngeal place of consonantal articulation and assumes the lowest value (22ms) for labials, intermediate one for post-dentals (29ms) and the greatest one for velars (54ms);

– the greater the degree of inter-articulator contact, the greater the VOT value;

– the faster the articulatory movement, the shorter the VOT value.

Figure 2 below illustrates mean VOT values for voiceless plosives as realized by children in both examined groups. For comparison, data from adult speakers of Polish are also included (after Keating et al. 1981).

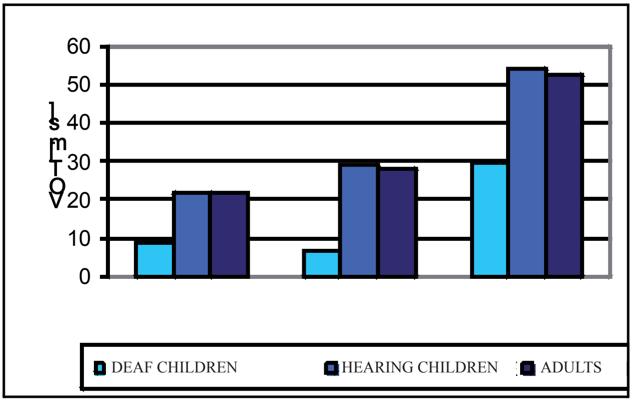

Fig 2. Mean VOT values [ms] in intended voiceless plosives [p], [t], [k] realized by the examined children in the experimental group (deaf children) and the control group (hearing children), in comparison with the results for adults (after Keating et al. 1981, p. 1262).

The mean VOT values for [p], [t] and [k] realized by hearing children and adults display a high degree of similarity. It allows for an assumption that the normative process of the acquisition of articulatorily voiceless consonants is complete by the age of 8, which cannot be asserted with reference to children with hearing impairment aged 8-12.

The VOT measurement values for intended voiceless plosives were also assessed in relation to the number of positive and negative results in both groups of children (cf. Table 3).

Tabela 3. The number and percentage of positive and negative VOT values (in ms) of intended voiceless consonants [p], [t] and [k] pronounced by hearing-impaired children from the experimental group [E] and normally hearing children from the control group [C].

CONSONANT	*VOT*							
	NUMBER OF POSITIVE VALUES		NUMBER OF NEGATIVE VALUES		PERCENTAGE OF POSITIVE VALUES		PERCENTAGE OF NEGATIVE VALUES	
	E	C	E	C	E	C	E	C
p	77	50	11	0	87,5	100,0	12,5	0,0
t	64	40	6	0	91,4	100,0	8,6	0,0
k	49	50	0	0	100,0	100,0	0,0	0,0

In the experimental group of hearing-impaired children, negative VOT values were attested in the measurements of anterior plosives [p] and [t]. Of all realizations of [p], 12.5% displayed negative VOT and in the case of post-dental [t] the percentage was 8.6%. Only positive VOT results were attested in the pronunciation of tokens containing the velar plosive [k]. The normally hearing children constituting the control group pronounced all their intended voiceless plosives with positive VOT values.

In what follows, there is an analysis of the results of the data obtained for intended voiced plosives [b], [d] and [g].

In total, 224 recorded audio tokens were subjected to analysis in the group of hearing-impaired children and 146 in the control group. Mean VOT for [b] and [g] in the experimental group displays short positive values of high variability, which indicates that there is considerable dispersion of the data around the mean and that particular realizations are highly idiosyncratic. The normally hearing children in the control group articulated the intended voiced plosives with a long negative VOT; longest for [d], intermediate for [b] and shortest for [g]. It may be argued that the negative VOT values become greater together with the increase of the distance between the place of articulation and the larynx. Minimum and maximum values range from positive to negative ones in both groups of children.

Figure 3 illustrates the means of VOT measurements obtained for intended voiced plosives in both examined groups. For comparison, similar data for adults are also shown (Keating et al. 1981).

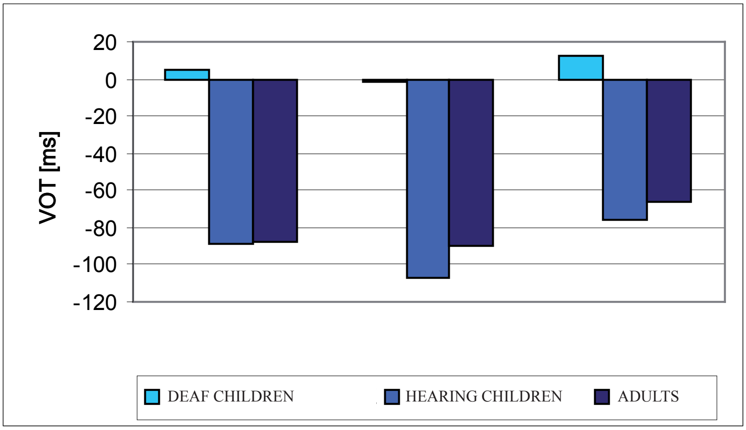

Fig. 3. Mean VOT values [ms] in intended voiced plosives [b], [d] and [g] realized by the examined children in the experimental group (deaf children) and the control group (hearing children), in comparison with the results for adults (after Keating et al. 1981, p. 1262).

The results of normally hearing children approximate closely those of adults, particularly in the case of the consonant [b]. One could argue that the results show stability in the realization of the feature of voicing. Mean VOT values for [b], [d] and [g] in the group of hearing-impaired children, however, depart significantly from the normative realizations of hearing children and adults, which shows that the feature under investigation is still in the process of articulatory development.

The VOT measurement values for the consonants [b], [d] and [g] were also analyzed in relation to the number of positive and negative results in both groups of children (cf. Table 4).

Positive VOT results appear in the articulation of intended voiced plosives [b], [d] and [g] in both groups of children. Nevertheless it should be noted that this type of pronunciation is dominant in the case of hearing-impaired children, whereas it appears only occasionally in the speech of normally hearing children. This kind of articulation occurred most frequently in the pronunciation of the velar plosive [g]; 86% of its realizations in the experimental group had positive VOT and 8.3% in the control group. Such pronunciations of [d] in the experimental group totalled 79.9% of all the tokens containing the consonant and 2% in the control group. As for the bilabial plosive [b], positive VOT realizations occurred in 77.3% of the recorded tokens in the experimental group and 4.2% in the control

Table 4. The number and percentage of positive and negative VOT values (in ms) of intended voiced consonants [b], [d] and [g] as pronounced by hearing-impaired children from the experimental group [E] and normally hearing children from the control group [C].

CONSONANT	VOT							
	NUMBER OF POSITIVE VALUES		NUMBER OF NEGATIVE VALUES		PERCENTAGE OF POSITIVE VALUES		PERCENTAGE OF NEGATIVE VALUES	
	E	C	E	C	E	C	E	C
b	68	2	20	46	77,3	4,2	22,7	95,8
d	63	1	16	49	79,7	2,0	20,3	98,0
g	49	4	8	44	86,0	8,3	14,0	91,7

group. Thus it may be generalized that the more distant the place of articulation of intended voiced plosives from the larynx, the less frequently there occurs positive VOT.

Thus observed great variability in the realization of plosive voicing as pronounced by the two groups of children may be classified in the following manner:

1. Full voicing – vocal fold vibrations considerably precede the consonantal release and the voiced segment is at least 50ms long and characterized by an extensive negative VOT; auditorily, the consonant is perceived as voiced.
2. Partial voicing – vocal fold vibrations slightly precede the consonantal release and the voiced segment is not longer than 50ms and is characterized by a short negative VOT; auditorily, the consonant is perceived as either voiced or voiceless.
3. Partial voicelessness with short affrication[8] – vocal fold vibrations appear in the initial phase of the closure, after which there is a segment of silence before the consonantal release that is followed by a short period of affrication; auditorily, the consonant is perceived as either voiced or voiceless.
4. Partial voicelessness with long affrication – vocal folds vibrate in the initial phase of the closure, after which there is a segment of silence before the consonantal release that is followed by a long period of affrication; auditorily, the consonant is perceived as voiceless.
5. Voicelessness – the entire duration of the closure is voiceless and quasi-periodic vibrations appear shortly after the release resulting in positive VOT; auditorily, the consonant is perceived as voiceless.

[8] Affrication is a period of fricative noise that may occur after the burst of both voiced and voiceless plosives. Aspiration, in turn, is a segment that appears immediately after voiceless plosives and bears the acoustic characteristics of a voiceless vowel (Jassem 1973).

6. Voicelessness with short affrication - the entire duration of the closure is voiceless and quasi-periodic vibrations appear after the release and a short period of affrication, resulting in positive VOT; auditorily, the consonant is perceived as voiceless.

7. Voicelessness with long affrication - the entire duration of the closure is voiceless and quasi-periodic vibrations appear after the release and a long period of affrication, resulting in positive VOT; auditorily, the consonant is perceived as voiceless.

6. RESULTS OF AUDITORY ANALYSIS

The lists presented below aim at showing the scale and characteristics of consonantal voicing and devoicing as judged by expert transcribers. First, we provide the symbol of the intended consonant that was subjected to one of these processes, followed by the percentage of their occurrence in relation to all realizations of the sound. Then the substitutes are listed in the descending order of appearance.

Consonantal devoicing

– **[ʣ] 73%**: **[t]** 35%, [s] 14%, [ʦ] 7%, [p] 5%, [x] 3%, [k], [ʨ], [ʃ], [ɕ] 2% each, [ʧ] 1%;
– **[v] 70,6%**: [f] 57,5%, **[t]** 6,6%, [p] 5,6%, [k] 0,9%;
– **[d] 66,6%**: **[t]** 66,6%;
– **[b] 56,5%**: [p] 52,7%, **[t]** 1,6%, [c] 1,1%, [f] 1,1%;
– **[vʲ] 55,6%**: [f], [fʲ] 16,7% each, [p], **[t]** 11,1% each;
– **[g] 55%**: [k] 40%, [x] 7,8%, **[t]** 5,7%, [p], [pʲ] 0,7% each;
– **[ɟ] 52,3%**: [k] 22,2%, [x] 12,7%, **[t]**, [c] 6,3% each, [ɕ] 3,2%, [p] 1,6%;
– **[ʒ] 50,8%**: [ʃ] 21,9%, **[t]** 10,5%, [p], [ʧ] 3,5% each, [k], [s] 2,6% each, [ʦ], [ɕ], [x] 1,7% each, [ʨ] 0,9%;
– **[ʥ] 48,5%**: **[t]** 23,2%, [ʨ] 7,2%, [ʦ] 5,8%, [ʧ] 5,1%, [s], [ɕ] 2,9% each, [k], [c] 1,4% each;
– **[bʲ] 47,8%**: [pʲ] 22,5%, [p] 18,3%, [f] 4,2%, [k] 2,8%;
– **[z] 46,7%**: **[t]** 16%, [s] 11,8%, [ʦ] 4,2%, [ʧ], [x] 2,8% each, [p], [k], [c], [ʨ], [ʃ], [ɕ] 1,4% each, [f] 0,7%;
– **[ʤ] 44,3%**: **[t]** 22,2%, [ɕ] 11,1%, [ʨ], [s] 5,5% each;
– **[ʑ] 28,8%**: [ʨ] 9,6%, [ɕ] 5,8%, [x] 4,8%, **[t]** 2,9%, [pʲ], [ʧ], [ʃ] 1,9% each;
– **[mʲ] 27%**: [p] 16,2%, [pʲ] 10,8%;
– **[ɲ] 17,2%**: **[t]** 13,8%, [ɕ] 3,4%;
– **[n] 15,4%**: **[t]** 13,1%, [ɕ] 1,5%, [ʦ] 0,8%;
– **[j] 6,9%**: **[t]** 6,9%;
– **[l] 6,1%**: [k] 3,7%, **[t]**, [x] 1,2% each;
– **[m] 2,8%**: [p] 2,8%;

– **[r] 2%**: **[t]** 1%, [p], [k] 0,5% each;
– **[w] 0%**.

Consonantal voicing

– **[ɕ] 48,3%**: [j] 10%, [ʑ] 8,6%, [ʥ] 7,1%, [d], [n] 5,7% each, [b], [z], [ɲ], [l] 2,8% each;
– **[fʲ] 39,1**[b] 11,1%, [v], [vʲ], [z], [mʲ], [n] 5,6 each;
– **[ʧ] 39,2** [n] **5,**6% [d], [g], [ɟ], [ʤ], [ʥ], [v], [z], [ʒ], [ʑ], [l], [r], [w] 2,8 each;
– **[ʃ] 32,4%**: [l] 9,8%, [d], [ʒ], [ʑ] 3,9% each, [n] 2,9%, [g], [ʤ], [ʥ], [w] 2% each;
– **[c] 30,9%**: [l] 10,3%, [ʑ], [n] 6,9% each, [ɟ], [ʤ] 3,4% each;
– [**ʨ] 26,1%**: [l] 8,9%, [ʥ], [j] 4,5% each, [ɟ], [z], [ʑ], [n], [ɲ] 1,5% each, [v] 0,7%;
– **[ʦ] 25,4%**: [l] 7,1%, [j] 6,1%, [d], [z] 4,1% each, [m], [w] 2% each;
– **[pʲ] 23,7%**: [b] 8,3%, [ɲ] 5,6%, [n] 4,2%, [bʲ], [d] 2,8% each;
– **[p] 20,6%**: [b] 19,9%, [v] 0,7%;
– **[s] 18,2%**: [l] 8,6%, [n] 5,4%, [m], [r] 2,1% each;
– **[t] 15,1%**: [d] 10,6%, [n] 2,8%, [ʥ] 1,4%, [b] 0,3%;
– **[f] 11,8%:** [d] 4,9%, [b] 2,9%, [v], [m] 2% each;
– **[k] 8,9%**: [j] 4,4%, [l] 3%, [b] 1,5%;
– **[x] 6,2%:** [ɲ] 6,2%.

There occurred more instances of consonantal devoicing than voicing, which is in line with the general developmental norm. In the majority of monographs on the acquisition of speech in children it is emphasized that voiceless segments are acquired before voiced ones in opposing pairs of obstruents. Undoubtedly, both processes in the speech of hearing-impaired children appear with greater intensity and different proportions. It should be noted that in the lists above there appears the consonant [t] (presented in bold font) as a substitute for nearly all devoiced consonants. This fact can be explained in a number of ways. First of all, [t] is a primary consonant that is mastered very early in the process of normative speech acquisition. Developmentally, it functions for a long time as a substitute of consonants that are more demanding articulatorily, including velars, affricates and fricatives (cf. Smoczyński 1955; Styczek 1979; Sołtys-Chmielowicz 1998; Łobacz 1996, 2005). In extreme cases of speech delay in children, it is claimed that primary sounds [t] and [a] constitute 50% of segments used in utterances (cf. Kania 1982, p. 145). The abovementioned findings explain the high occurrence of [t] as a substitute in the speech of hearing-impaired children. Additionally, the articulation of [t] is subject to visual and sensorimotor control, which is highly relevant in the study of the experimental group. Thus, the more difficult and insufficiently acquired articulations tend to be realized as [t]. This type of substitution, however, has not been observed in the case of labials (with the exception of [f]) and velars, which shows the speakers' profound awareness of the setting of the active articulator.

Considerably fewer instances of devoicing appear in the case of sonorants. The process is most frequent in the articulation of consonants that are characterized by a low score of correct realizations, i.e. affricates and some fricatives.

Table 5 contains numerical results of auditory judgments of intended plosives in relation to their voicing, juxtaposed against the results of acoustic VOT analysis.

Tabela 5. Auditory and acoustic results for intended plosives pronounced by hearing-impaired children.

		PERCEIVED CONSONANT		VOT	
		VOICED	VOICELESS	NEGATIVE	POSITIVE
INTENDED CONSONANT	p	[b] 21,8%	[p] 78,2%	12,5%	87,5%
	t	[d] 11,8%	[t] 88,2%	8,6%	91,4%
	k	[g] 12,6%	[k] 87,4%	0%	100%
	b	[b] 43,6%	[p] 56,4%	29,4%	70,6%
	d	[d] 26,5%	[t] 73,5%	21,6%	78,4%
	g	[g] 28,2%	[k] 71,8%	26,1%	73,9%

The divergent methods of analysis, i.e. the subjective auditory judgements of experts and the objective acoustic analysis, produced a high level of convergence in the assessment of consonants [g] and [t] (the differences range from 2.1% to 3.2%). In the examination of the remaining consonants, the differences between auditory and acoustic analysis results were much more considerable and varied from 4.9% to 14.2%.

Needless to say, the objective acoustic assessment illustrates the real scale of voicing disorders. It also shows the degree of inadequacy of traditional diagnostic auditory methods in creating unambiguous statements related to the normativeness of pronunciation.

7. DISCUSSION

The results of the carried out phonetic research oblige one to engage in a discussion about the previous findings related to the issue of voicing disorders as presented in Polish speech therapy literature. Regarding the realization of the voicing contrast by the examined groups of children, the study undermines the claims that the so-called voiceless speech in the case of plosives is a homogenous phenomenon based on a binary opposition in which voiced consonants are substituted by their voiceless counterparts (cf. Kania 1982, Sołtys-Chmielowicz 2008). The herein proposed classification of the manners of realization of voicing in disordered speech shows their diversity and highly idiosyncratic character. Mean VOT values of intended voiced and voiceless plosives pronounced by hearing-impaired children are positive, which indicates disorders in the realization of contrast within the examined domain. The lack of voicing of [k], which was always articulated with positive VOT by hearing-impaired children, lower frequency of consonantal voicing in the context of the following high back vowel [u] (the study also involved an analysis of the influence of the following vocalic element on the length of VOT, cf. Trochymiuk 2008), and the greater incidence of occurrence of consonantal devoicing in the case of anterior sounds allows one to stipulate the following order of voiced plosives for articulatory training: [b b^j d ɟ g][9].

The more distant the place of articulation from the larynx, the easier it is to apply voicing to a consonant. The optimal vocalic context for practising the articulation of voiced consonants constitute front vowels and the vowel [a] as the examined children achieved negative VOT values in the vicinity of these sounds (least often next to the vowel [u]). Therefore the condition of greater displacement from the larynx during the induction of voiced consonants should also hold for the neighbouring vocalic context.

Needles to say, voicing disorders in hearing-impaired children are caused by the lack of full auditory control and problems with phonation. The frequent occurrence of the phenomenon may also be explained in terms of the tendency to favour sensimotor feedback by people with hearing deficiencies – voiceless consonants are articulatorily strongest and thus produce more intensive kinaesthetic sensations than their voiced equivalents. The dominance of devoicing processes in the speech of hard-of-hearing children can also be explained by the tendency to minimize articulatory effort. The presence of reinforced affrication and long delays in the onset of phonation after consonantal release point to deficiencies in airflow control.

Designing therapeutic syllabi for children with hearing impairments, one should place particular emphasis on the practice of breathing, phonation and kinaesthesia. Listening exercises are also crucial for hard-of-hearing children. In the case of voicing disorders, they should involve perception, differentiation and identification of low frequency sounds up to 1000Hz. They should be initiated

[9] J.T. Kania (1982) suggests an order for voiced consonant practice along the following lines: open consonants (fricatives) before more constricted ones (plosives) and more distant from the larynx (labio-dentals) before those closer to it (velars). It is worth noticing that the author presents an inadequate order of sounds to be induced, since this account predicts that palatal [c] and [ɟ] should be trained before velar [k] and [g] (cf. Kania 1982, p. 296).

by practise on the basis of non-linguistic material (sounds produced by musical instruments, e.g. drums, by machines, e.g. vacuum cleaner, or by nature, e.g. mooing of a cow) and with the passage of time they should be supplemented by language-oriented materials (discrimination and identification of changing intonation, various types of voices, sentences, words, syllables with a high load of low-frequency sounds, i.e. the vowels [u] [ɔ] [a], nasal sonorants [m] [n] [ɲ], the lateral [l], approximants [w] and [j] as well as the rhotic [r]). The last, and at the same time most difficult and demanding, group of exercises concerns distinguishing voiced and voiceless obstruents, beginning (in accordance with the proposed order of the induction of voiced sounds) with the most open and proceeding to the more constricted sounds (fricatives, affricates, plosives). A similar listening training programme should be construed for children whose voicing disorders are caused by phonemic hearing deficiencies related to the feature in question.

The last postulate concerns the transcription. International Phonetic Association provides a wide array of symbols for transcribing various details related to the realization of voicing in disordered speech. Apart from the basic IPA phonetic alphabet (IPA 1999), transcribers may resort to extended international phonetic alphabet (ExtIPA 2002) devoted specifically to the transcription of disordered speech (cf. Table 6). In this way one can easily present various forms of voicing realization in a graphic form, including those that are presented in this article.

Tabela 6. ExtIPA diacritics intended for transcribing voicing in disordered speech (after http 1).

Diacritic	Phonetic process	Example of usage
ˬ	pre-voicing	ˬz
ˬ	post-voicing	zˬ
₍̥₎	partial devoicing	₍z̥₎
₍̥	initial partial devoicing	₍z̥
̥₎	final partial devoicing	z̥₎
₍̬₎	partial voicing	₍s̬₎
₍̬	initial partial voicing	₍s̬
̬₎	final partial voicing	s̥₎
⁼	unaspirated	p⁼
ʰ	pre-aspiration	ʰp

The summary presented below compares the main differences in the interpretation of voicing in disordered speech as presented in available literature and the author's own research.

Voicing disorders	
State of research	**Own research**
voicing disorders viewed as substitutions of voiced consonants by their voiceless counterparts (Kania 1982, Sołtys-Chmielowicz 2008)	voicing disorders viewed as a complex multistage phenomenon
the assessment of ±voice based primarily on auditory impressions (Kania 1982, Sołtys-Chmielowicz 2008), rarely on acoustic analysis (Łobacz 1996)	the assessment of ±voice based on auditory and acoustic criteria
disregarding acoustic and perceptual sound properties in designing therapeutic programmes for voicing disorders	designing therapeutic programmes for voicing disorders in relation to articulatory, acoustic and auditory criteria; inducing voiced articulations in children with hearing dysfunctions should be preceded by intensive listening practice involving reception, differentiation and identification of low-frequency sounds below 1000Hz, based on non-linguistic (environmental sounds) and language-related material (intonation, voice types, low-frequency sounds, the voicing contrast in obstruents)
the order of sounds for inducing voiced articulations as proposed by J.T. Kania (1982) and repeated by subsequent scholars: [v] [vʲ] [z] [ʐ] [ʑ] [d͡z] [d͡ʐ] [d͡ʑ] [b] [bʲ] [d] [g] [ɟ]	in line with the observation that voicing is most easily induced in sounds whose place of articulation is most distant from the larynx, the palatal [ɟ] should be taught before the velar [g]
lack of research on the optimal phonetic context for inducing voiced sound articulations	the principle of the distance from the larynx should be observed not only in the case of the target sound, but also its immediate context, with preference for front vowels and [a]
transcribing with the use of symbols for specific voiceless consonants or with a diacritic denoting complete devoicing, e.g. [b̥]	transcribing with the use of extIPA symbols, which allows to represent various types of realizations on the ±voice continuum

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