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Phonetic Audiometry and its Application in the Diagnosis of People with Speech Disorders

SUMMARY

Phonetic audiometry is a form of verbal audiometry used to precisely determine the perception of words. Measurement of the correct perception of individual sounds in a word avoids an error that in classical verbal audiometry can disqualify a word in which only one voice was incorrectly recognized. In addition, verbal audiometry does not give a precise measurement in people with speech problems. The developed lists of words, primarily phonetically and semantically balanced, allow easy recording of research results by people without phonetic preparation. The paper will present the results of the use of phonetic audiometry in the assessment of speech perception in people with hearing aids and with speech disorders.

Key words: phonetic audiometry, speech audiometry, speech disorders

The assessment of speech perception is an important issue in logopedic diagnosis and therapy. Speech perception significantly differs from the perception of other sounds. It is based, like the perception of other sounds, on physiological processes occurring in the peripheral and central auditory system. The essence of the phenomenon occurs, however, in the mental sphere. It can be said that it is not our ear that hears but the mind. At the mental level, speech processing depends on complex abilities.

In acoustic terms, these processes are differently presented. Speech perception consists of several stages that depend on the type of hierarchically processed information – acoustic, neuroelectric, phonetic, lexical, semantic, or pragmatic.

The lowest level is the process of speech perception and the signal reaching the hearing organ. At the acoustic-physiological level, acoustic sound features and phonetic information are processed and discriminated. At the next level of auditory integration, information is coded in the course of neurophysiological processing, and distinctive, segmental and suprasegmental features are discriminated (psychophysiological processing). The highest psycholinguistic level corresponds to the formation of linguistic units: syllables and words. The last stage is the interpretation of the obtained information that leads to understanding the utterance [Surmanowicz-Demenko 2011].

U. Jorasz [1998, 150] presents a speech model in which the speech signal is analyzed at individual stages like: "filtering in the perfect auditory system – detection of acoustic properties – detection of phonetic features – lexical segmentation and structuring". The first stage covers the conversion of the acoustic signal into an electric stimulus in the Corti organ of the inner ear. The next part is the decoding of formants or the detection of spectral structure. The subsequent stage makes one realize that speech perception does not occur in a hierarchical way but through many connections with other levels. Of importance is the information on the structure of a language, grammatical rules, context, as well as the listener's intelligence, memory, attention, and experience.

There is no explicit adoption of a universal speech model. Different views accentuate selected aspects. Different models are presented inter alia in the studies by D. Kądzielawa [1983], U. Jorasz [1999], E. Ozimek [2002], G. Surmanowicz-Demenko [2011], and G. Demenko [2015].

The assessment of speech perception is a significant issue from the audiological standpoint. This ability is diagnosed using first of all speech audiometry, which is an integral part of audiological testing. It is used to assess auditory communication under natural and laboratory conditions, or in noise, to diagnose the hearing organ damage of conductive type, cochlear and non-cochlear, central and psychogenic damage, to fit hearing aids (selection and adjustment of a hearing aid, help to patients with cochlear implants), in hearing rehabilitation, and to dynamically assess procedures meant to enhance hearing. (Pruszewicz and Wiskirska-Woźnica, 2011)

Speech audiometry, part of the group of so-called psychoacoustic tests, can be carried out exclusively with the active participation of the subject. The patient's task is to repeat the verbal unit heard: a sound, syllable, word or a sentence. The test is listened to at different levels of signal intensity, with the researcher recording the percentage of correctly received elements. In this way, the so-called articulation curve is obtained. Its course depends on the kind of test, testing device, or testing technique, and on the type of pathology of the hearing organ.

The first tests for measuring speech perception began in the early twentieth century when the telephone signals and quality of telephone connections were tested. On the basis of these tests, Fletcher in 1929 noticed the potential values of the tests for measuring speech perception in persons with hearing loss.

The first phonetically balanced lists used in Poland were the tests developed by Zakrzewski and associates in 1953. In the 1960s Taniewski, Kugler and Wysocki developed their own classification of the frequency of occurrence of phones (sounds) in Polish, and on its basis, they drew up lists of words with one- and two-syllable words, which are now utilized in many centers. In 1963 Iwankiewicz and Sieciński devised phonetically balanced tests comprising sentence lists for adults and children, and numerical lists. At the same time, Szmeja, Pruszewicz and Dukiewicz drafted phonetically and structurally balanced lists for school age children. New articulation lists, fully balanced in phonetic and structural terms, were published in 1971 by Zakrzewski, Pruszewicz and Kubzdela. In 1994 Pruszewicz, Demenko, Richter and Wika introduced the still relevant articulation lists (NLA-93) that are fully balanced in phonematic, structural, grammatical and acoustic terms, which were disregarded in the previous tests. The test consist of 10 lists, each containing 24 exclusively one-syllable nouns (Obrębowski, 2005).

2.3 PHONETIC AUDIOMETRY

Phonetic audiometry is one of the varieties of speech audiometry. This tool, like classical speech audiometry, serves to detect thresholds of speech detection, reception and discrimination. The most important aspect that distinguishes the test in question from others is the assessment of individual words taking the phonetic criteria into account. The purpose of the test is to assess the words repeated by the patient in respect of correctly recognized constituent elements of a word – phones (sounds).

The possibility and need for this form of conducting speech audiometry and interpreting its results was highlighted by A. Pruszewicz and B. Wiskarska-Woźnica [2011]. They pointed out that in the case of changing only one sound in the word, the whole word is disqualified. That is why they suggested it was necessary to study the "distinctiveness" (qualitative changes) and discriminability of sounds (quantitative changes). According to these authors, such approach permits better interpretation of testing results than in conventional speech audiometry.

Phonetic audiometry was developed by the author of this study as part of research work conducted in the Institute of Physiology and Pathology of Hearing (IFPS) in Warsaw, and its computer version at Maria Curie-Skłodowska University in Lublin.

The Phonetic Audiometric Test contains eighteen articulation lists consisting of ten one-syllable meaningful words, each word consisting of three sounds. The words used in the test were selected in accordance with the requirements that have to be observed when constructing tools for testing using speech audiometry. The verbal material was prepared in the form of CD recordings. Tests are conducted using an audiometer additionally equipped with a calibrated CD player. The verbal material is played via air-conduction headphones, separately for the right and left ear (testing starts with the ear in which lower sound detection thresholds were observed in tonal audiometry). The verbal material is played at a volume correlated with hearing thresholds for tonal audiometry, determined on the basis of the frequencies of 1000 Hz, 2000 Hz, and 4000 Hz. Before the commencement of the test, the patient is informed how to respond to the signal heard: his/her task is to repeat the words heard. The patient's scores are recorded on the test form and using a percentage scale on the speech audiogram chart: the thresholds of speech detection, speech reception and speech discrimination are marked, and in the computer version they are respectively marked in the test panel.

The articulation lists of Phonetic Audiometry are balanced in phonematic terms so that the number of phonemes in the test will reflect their frequency of occurrence in Polish - the collected data are presented in the Table below.

Table 1. Phonetic balance of Phonetic Audiometric Test [own study].

THE PHONETIC BALANCE OF PHONETIC AUDIOMETRIC TEST																				
Pho-neme	Articulation List																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	TO-TAL	%
a	3	3	3	2	2	2	1	3	1	4	3	2	3	4	3	2	3	2	46	8.5
o	2	1	3	2	4	2	3	2	4	3	2	1	2	1	3	2	3	4	44	8.2
k	2	2	2	1	2	2	2	1	1	2	2	2	2	2	2	1	3	2	33	6.1
e	1	3	1	1	2	3	3	1	1	1	2	2	1	2	1	3	2	1	31	5.7
t	2	1	2	3	1	1	2	3	2	2	1	1	1	3	1	1	1	2	30	5.5
s	2	2	2	3	1	3	1	1	1	2	2	1	2	1	2	1	1	1	29	5.4
l	2	1	1	2	2	1	2	2	1	1	2	2	1	1	1	2	1	1	26	4.8
u	1	1	2	1	2	1	1	1	2	1	2	1	2	1	1	1	1	2	24	4.4
m	1	1	1	2	1	1	2	1	1	1	2	1	1	1	1	1	1	1	21	3.8
r		2	1	1			1	2	2	2		1	2	2	2	1	1	1	21	3.8
i	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	18	3.3
d	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	18	3.3
j	1	1	2	1	1	1	1	1		1	1	1	1	1	1	1	1	1	18	3.3
b	1		1	1	1	1		2	2	2		1	2		2			1	17	3.1
sz	1	1	2		2	1		1	1		2	1	1		1	1	1	1	17	3.1
n	2	1	1	1			1	1	1	1		1		1	1	1	1	1	15	2.7
y	1			1		1	1	2	1			3	1	1	1	1			14	2.6

Table 1. Continued. Phonetic balance of Phonetic Audiometric Test [own study].

w	1	1	1	2	1	2					1	1			2			1	13	2.4
p	2	3		1		1	1		1	1		1		1			1		13	2.4
ł	1	1			1		1	1	1			1	1	1	1	1		1	12	2.2
cz		1			1	1	2			1	1	1	1			1	1		11	2
c			1			1	1		1	1					1	1	1	1	9	1.6
g			1					1	1	1	1	1		1			1	1	9	1.6
ż		1	1					1					1	1		1	1	1	8	1.4
ch					2	1			1	1	1	1						1	8	1.4
z					1			1	1		1		1	1		1			7	1.2
ć											1	1	1	1	1	1		1	7	1.2
ś						1	1						1	1		1	1		6	1.1
f	1				1				1								1		4	0.7
ń				1		1										1			3	0.5
ą	1			1															2	0.3
ę		1		1															2	0.3
p’											1						1		2	0.3
m’							1												1	0.2
w’																1			1	0.2
f’ dz dż dź b’ k’ g’																			0	0
TO-TAL (30)	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30		

The foregoing Table contains a quantitative list of sounds (phonemes) present in the test in question. The sounds are ranked by the frequency of occurrence: from the largest number to the smallest. Moreover, the Table contains the distribution of individual phonemes in a given articulation list (1-18).

The Phonetic Audiometric Test is recorded using the signs of Polish – this is a phonetic-orthographic notation. The transcript was prepared in accordance with the articulation rules of Polish; however, the Slavic or international IPA notations were not used. The test takes into account all phonetic phenomena by transcribing them orthographically. This device was consciously used, having in mind different test users who may legitimately not know them. Owing to this fact, the test can be successfully conducted by audiologists or doctors, who can correctly read and interpret the obtained results without knowing the phonetic phenomena that occur in Polish.

When analyzing the patient's answers according to the principles of phonetic audiometry, the number of individual sounds in an articulation list is added up. The total is multiplied by 3.3% (30 phonemes in a list is 100%), thereby determining percentage values that can be transferred to the speech audiogram. In the computer versions, calculations are made automatically, which enables obtaining not only a quantitative but also qualitative assessment.

Verbal audiometry is a quantitative test defined by strict criteria and requirements that pertain to the verbal material used in the test, to the conditions in which the test is conducted, as well as to the assessment of results. The Polish standards pertaining to the testing conditions and interpretation of results are defined by the Polish Committee for Standardization – PN-EN ISO 88253-3[1]. This study shows that testing using verbal audiometry can be performed when the following conditions are fulfilled [Świdziński, Wiskirska-Woźnica, Pruszewicz 2011, 57]:

a) define requirements that should be satisfied by the recorded verbal material ,
b) define the level of the recording (speech signal) and the masking level (if necessary),
c) define the level of the acoustic pressure of background noise in the testing room, both in headphone testing and via speaker testing,
d) prepare and instruct the patient,
e) determine the way the patient will answer,
f) set the threshold of speech detection (speech detection threshold and speech recognition threshold) with and without an interference sound (if necessary),
g) determine the level of masking in the better hearing ear when testing the worse hearing ear,
h) determine and chart the form of the verbal audiogram,
i) calibrate the audiometric equipment, headphones and speakers with strictly defined time frame.

The verbal material, i.e. systematized lists, should be prepared as recordings. A recording should have a test signal needed to calibrate the audiometer and the set for free field testing. Furthermore, the frequency characteristics of

[1] PN-EN ISO 88253-3 – the standard developed by the Polish Committee for Standardization, which defines the method of testing with the speech audiometry method in the direct acoustic wave field (headphones) and in the free wave field (speakers). Source of 3 December 2005, "Akustyka. Metodyka pomiarów audiometrycznych [Acoustics. Methodology of Audiometric Measurements]. Part 3: Audiometria słowna [Verbal Audiometry]" [Świdziński, Wiskirska-Woźnica, Pruszewicz 2011].

the verbal material should be identified with the spectrum of all recorded words (using the *Long-Term Analysis* [LTA] method). Testing is conducted using the audiometer with a calibrated tape-recorder/CD player, a gauge for measuring the level of speech signal, and speakers. The equipment should make it possible to listen to the auditory material every 5 dB, separately for the right ear and the left ear. Signal level fluctuations must not exceed 1.5 dB, the space between signal and noise should be 45 dB SPL, and the interval between words should range between 4–5 seconds. Testing should be carried out in a room in which the noise level is lower than 40 dB, the time being shorter than 0.5 second [Świdziński, Wiskirska-Woźnica, Pruszewicz 2011, 58]. The tester should find out whether it is necessary to use the procedure for effective masking and inform the patient how to respond to the sound heard. The testing starts from the better hearing ear (after establishing the mean value of hearing loss for frequencies of 500, 1000, 2000 Hz) [Świdziński, Wiskirska-Woźnica, Pruszewicz 2011]. The results of testing are presented on the speech audiogram in the form of a chart (Figure 1.), constructed on the basis of the percentage value of signal intelligibility (X-axis) sent at different volumes (Y-axis). The standard curve should be marked in the chart, representing the score for the auditory standard and the curve for the right and left ear obtained in a particular test.

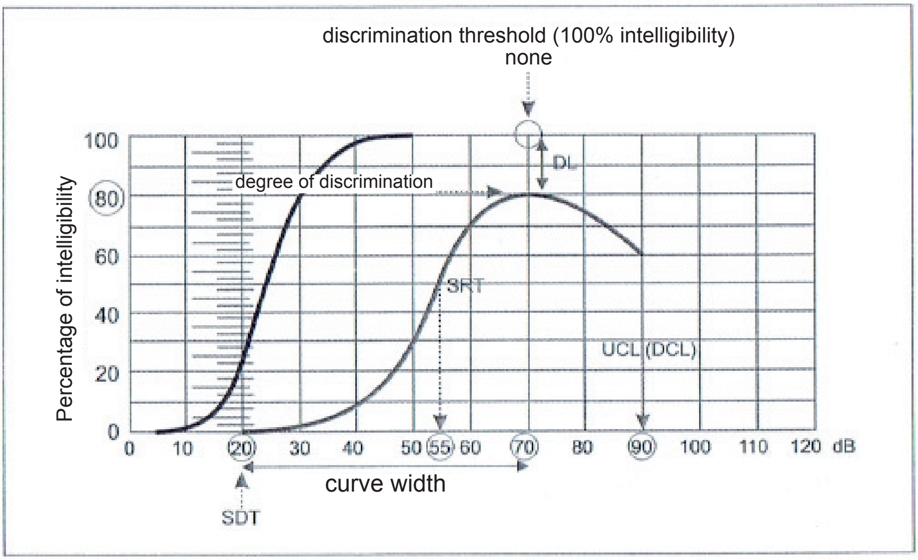

Fig. 1. Speech intelligibility curve as exemplified by a 35-year-old patient with cochlear hearing impairment [Świdziński, Wiskirska-Woźnica, Pruszewicz 2011, 60].

The standard curve presented in Fig. 1 is defined by the following characteristics [Świdziński, Wiskirska-Woźnica, Pruszewicz 2011, 59-60]:

a) Speech Detection Threshold – SDT, or the lowest volume at which the patient detects 50 percent of signal (sounds are heard but the meaning is not yet understood),
b) Speech Reception Threshold – SRT, or the volume at which the patient correctly repeats 50 percent of the produced words,
c) Discrimination threshold, or the volume at which the patient repeats 10 percent of the produced words,
d) articulation, discrimination score, or the maximum percentage of correctly repeated test elements,
e) Discrimination Loss, DL, or the difference between the discrimination threshold and the achieved discrimination score,
f) The curve width, or range given in dB between the beginning and end of the curve (0% and 100% of discrimination),
g) Uncomfortable Level – UCL; Discomfortable Level – DCL, or the hearing threshold that evokes discomfortable sensations,
h) Dynamic range (UCL – SRT), or the difference between uncomfortable level and the speech reception threshold,
i) Curve spread, or the width between the worst and best curve in standard tests.

The testing procedure in phonetic audiometry has to satisfy the criteria used in classical speech audiometry. The prepared word lists satisfy the phonetic-lexical-semantic criteria and were recorded in accordance with the adopted procedures in the Institute of Physiology and Pathology of Hearing (IFPS) in Warsaw.

The prepared test was used in pilot studies to assess the advantages of hearing aids. The studies conducted by A. Ptaszkowską [2016] showed the usefulness of this form of speech audiometry for more precisely defining the advantages of hearing aids. The examples below show the differences between the classical evaluation using speech audiometry and the evaluation using phonetic audiometry. The material obtained from individual patients was analyzed and recorded on the speech audiogram, both as phonetic audiometry (marked in green in the audiograms) and as classical verbal audiometry (marked in red) – the results were presented separately for the right ear and the left ear.

Below will be presented two examples of tests comparing the assessment of speech perception using the classical method of verbal audiometry and the method of phonetic audiometry developed by A. Ptaszkowską (2016)

Patient 1. is a woman aged 83. The tone audiogram below (Chart 24.) presents in the right ear a sensorineural hearing loss with the mean hearing loss at 58 dB, and in the left ear – a sensorineural hearing loss with the mean hearing loss at 44 dB. In the right ear, a severe moderate hearing loss is diagnosed, and in the left ear – mild-moderate.

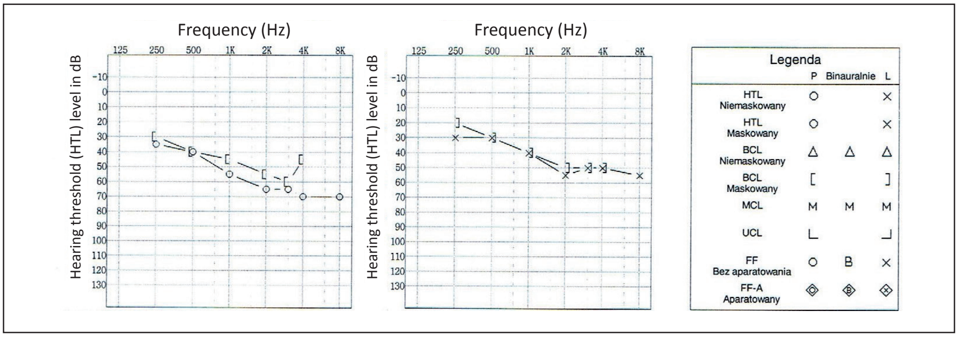

Fig. 2. Tone audiogram (right and left ear), woman aged 83
Źródło: Aleksandra Ptaszkowska 2016.

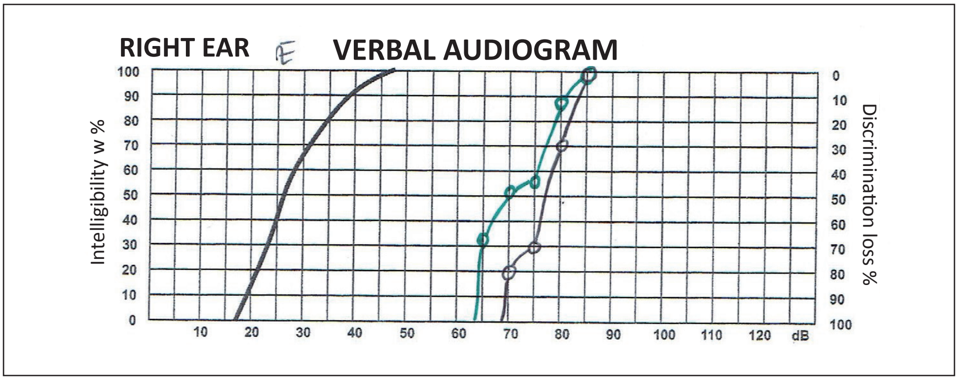

Fig. 3. Verbal audiometry curve – in black, phonetic audiometry curve – in green; right ear, woman aged 83
Źródło: Aleksandra Ptaszkowska 2016.

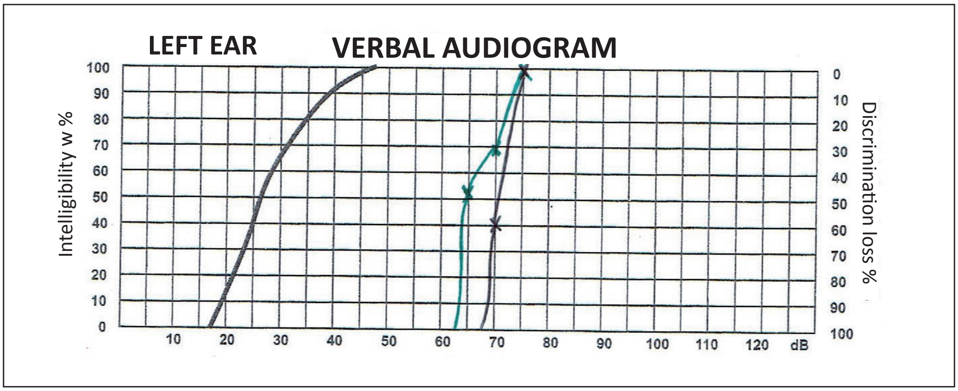

Fig. 4. Verbal audiometry curve – in black, phonetic audiometry curve – in green; left ear, woman aged 83
Źródło: Aleksandra Ptaszkowska 2016.

The foregoing audiograms (fig. 3 and 4) demonstrate that in the right ear the speech detection threshold for verbal audiometry was 70 dB, and for phonetic audiometry this threshold was achieved at 65 dB with as many as 33% of recognized phonemes. A similar case is observable for the left ear, in which also the SDT thresholds are 70 dB for verbal audiometry and 65 dB for phonetic audiometry. The difference being that in the left ear, with the volume of 65 dB, the patient recognizes 52.8% of phonemes, at the same time reaching the speech reception threshold (SRT). In the right ear, the SRT was exceeded after sounds were produced at the 80 dB volume; in the case of phonetic audiometry, 89.1% of correct answers are obtained for this volume. In the right ear, the discrimination thresholds for both audiometric curves were 85 dB, and in the left ear - 75 dB.

Patient 2 is a woman aged 83. The tone audiogram presented below (Chart 5.) shows that the patient has a binaural mild-moderate sensorineural hearing loss. In the right ear, a mean hearing loss is 51 dB, and in the left ear - 53 dB.

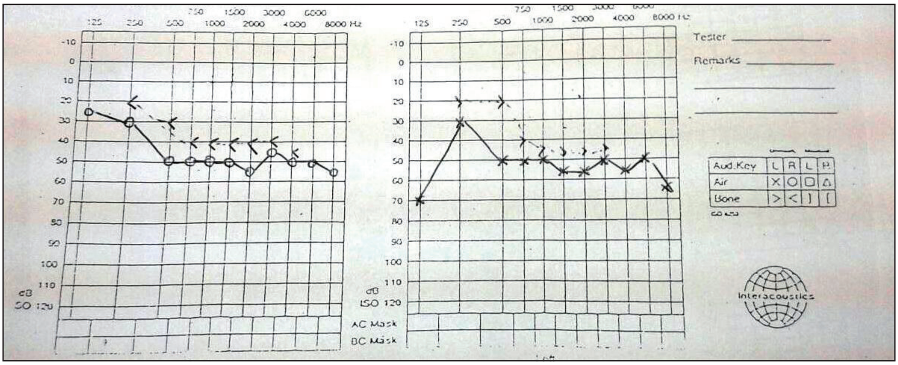

Fig. 5. Tone audiogram (right and left ear), woman aged 83.
Źródło: Aleksandra Ptaszkowska 2016

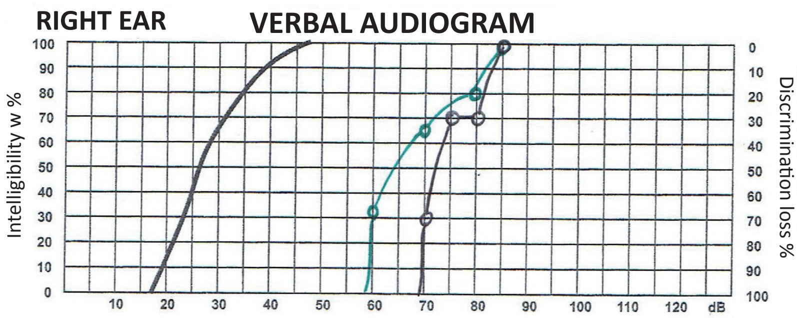

Fig. 6. Verbal audiometry curve – in black, phonetic audiometry curve – in green; right ear, woman aged 83
Źródło: Aleksandra Ptaszkowska 2016

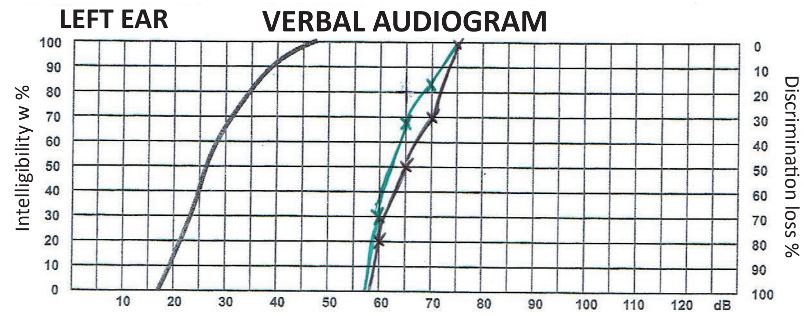

Fig. 7. Verbal audiometry curve – in black, phonetic audiometry curve – in green; left ear, woman aged 83

Źródło: Aleksandra Ptaszkowska 2016.

The audiogram (Fig. 6.) presented above shows that in the right ear the difference between the speech detection threshold for verbal audiometry and the speech detection threshold for phonetic audiometry was as much as 10 dB. For verbal audiometry, the SDT threshold was reached at 70 dB (30% of words were repeated), and for phonetic audiometry this threshold was attained at 60 dB (33% of phonemes were repeated). The volume at which the speech detection threshold was reached in verbal audiometry was already the determinant of the speech reception threshold for phonetic audiometry (70 dB – 66% of repeated phonemes). The discrimination thresholds for both modes of analysis were 85 dB.

In the left ear (Fig. 7.) the SDT threshold was identical for verbal and phonetic audiometry – 60 dB. In verbal audiometry, 20% of repeated words were reached, and for phonetic audiometry - 30% of repeated phonemes was attained. After the volume was increased by 5 dB, the patient was able to receive 50% of words and 69.3% of phonemes – speech reception thresholds. A volume of 75 dB turned out to be the value at which the patient repeated 100% of the presented signal.

Table 2 below contains speech reception thresholds for phonetic audiometry and verbal audiometry obtained from the tested patients (broken down into the scores from the right and the left ear). The obtained data were subsequently presented as bar charts (Chart 8 and Chart 9.).

Table 2. Speech reception thresholds - phonetic audiometry and verbal audiometry (right ear and left ear).

SPEECH RECEPTION THRESHOLDS					
Right ear			Left ear		
Patient	Phonetic audiometry [dB]	Verbal audiometry [dB]	Patient	Phonetic audiometry [dB]	Verbal audiometry [dB]
1	76	82	1	63	72
2	92	104	2	96	103
3	65	72	3	65	70
4	66	71	4	65	68
5	70	75	5	71	74
6	74	80	6	75	80
7	64	73	7	60	65
8	70	77	8	65	70
9	65	72	9	63	65
10	76	85	10	60	70
11	0	0	11	100	110
12	73	81	12	75	81
13	73	75	13	85	87
14	65	76	14	65	75
15	55	55	15	40	45
16	52	55	16	49	53
17	56	65	17	55	59
18	99	101	18	80	91
19	95	98	19	96	98
20	75	82	20	73	80
21	80	85	21	65	73

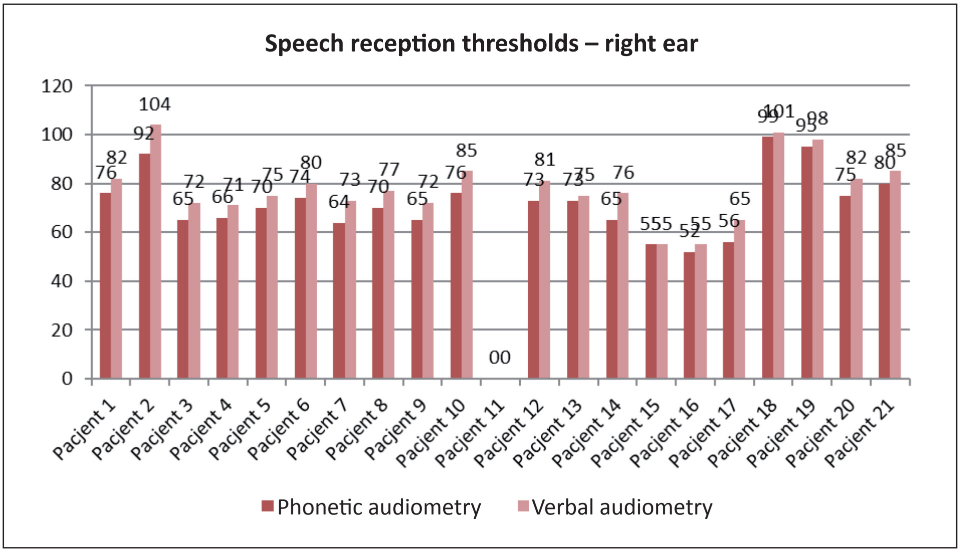

Fig. 8. Speech reception thresholds – phonetic audiometry and verbal audiometry
Źródło: Aleksandra Ptaszkowska 2016.

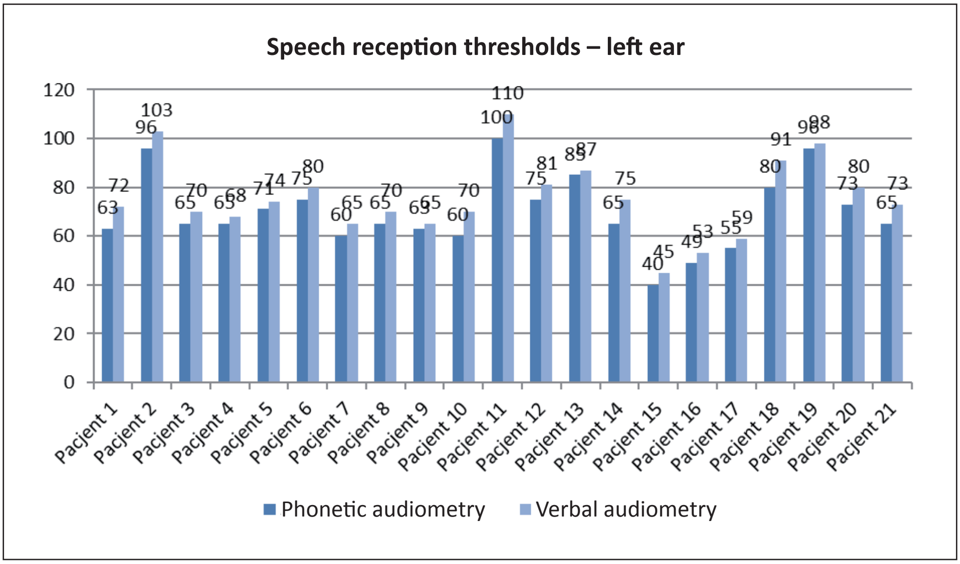

Fig. 9. Speech reception thresholds – phonetic audiometry and verbal audiometry
Źródło: Aleksandra Ptaszkowska 2016.

The foregoing data on speech reception thresholds (Table 2; Fig. 8 and 9) prove that SRT thresholds in phonetic audiometry are attained at lower volumes than in the case of verbal audiometry. The patients receive 50% of the sent signal faster in the case of phonemes than words. In the right ear, only in the case of one patient the speech reception signal was obtained at the same volume for both modes of analysis. In two patients there was a slight difference of 2 dB, and in the next two patients the difference was 3 dB for phonetic audiometry. In the collected data there is also an observable shift to the left of the phonetic articulation curve relative to the verbal articulation curve by 5 dB (3 cases), 6 dB (2 cases), 7 dB (4 cases), 8 dB (1 cases), 9 dB (3 case). Furthermore, differences in attaining SRT thresholds amounting to as much as 11 dB and 12 dB are also observed. A similar situation is observable in the left ears, in which slight differences in reaching SRT thresholds are reported in two patients at 2 dB, another two at 3 dB, and the next two at 4 dB. In many cases (7 patients) there is a reported tendency to shift the phonetic articulation curve relative the verbal articulation curve by 5 dB. Between the SRT thresholds for both modes of analysis there are also observable differences at 6 dB, 7 dB, 8 dB, 9 dB. In two cases the difference between reception thresholds for phonetic audiometry and verbal audiometry is as much as 10 dB, and in one patient this difference amounts even to 11 dB.

Table 3 below provides information on the speech discrimination thresholds reached by all the subjects tested (with the breakdown into the scores from the right and left ear) in phonetic audiometry and verbal audiometry. The data obtained were subsequently presented as bar charts (Fig. 10 and 11.).

Table 3. Speech discrimination thresholds - phonetic audiometry and verbal audiometry (right and left ear).

SPEECH DISCRIMINATION THRESHOLDS						
Right ear				Left ear		
Patient	Phonetic audiometry [dB]	Verbal audiometry [dB]		Patient	Phonetic audiometry [dB]	Verbal audiometry [dB]
1	85	85		1	75	75
2	120	120		2	110	110
3	80	80		3	80	80
4	75	75		4	75	75
5	85	85		5	85	85

Table 3. Speech discrimination thresholds - phonetic audiometry and verbal audiometry (right and left ear).

6	85	85	6	85	85
7	80	80	7	75	75
8	85	85	8	75	75
9	85	85	9	75	75
10	90	90	10	75	75
11	0	0	11	120	120
12	90	90	12	85	85
13	90	90	13	95	95
14	80	80	14	80	80
15	60	60	15	60	60
16	65	65	16	60	60
17	75	75	17	65	65
18	110	110	18	95	95
19	115	115	19	110	110
20	85	85	20	90	90
21	90	90	21	80	80

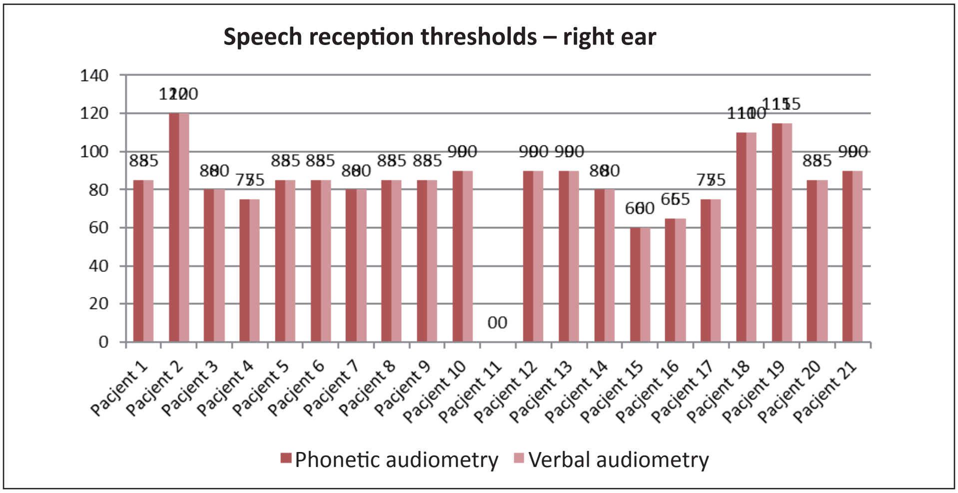

Fig. 10. Speech discrimination thresholds – phonetic audiometry and verbal audiometry
Źródło: Aleksandra Ptaszkowska 2016.

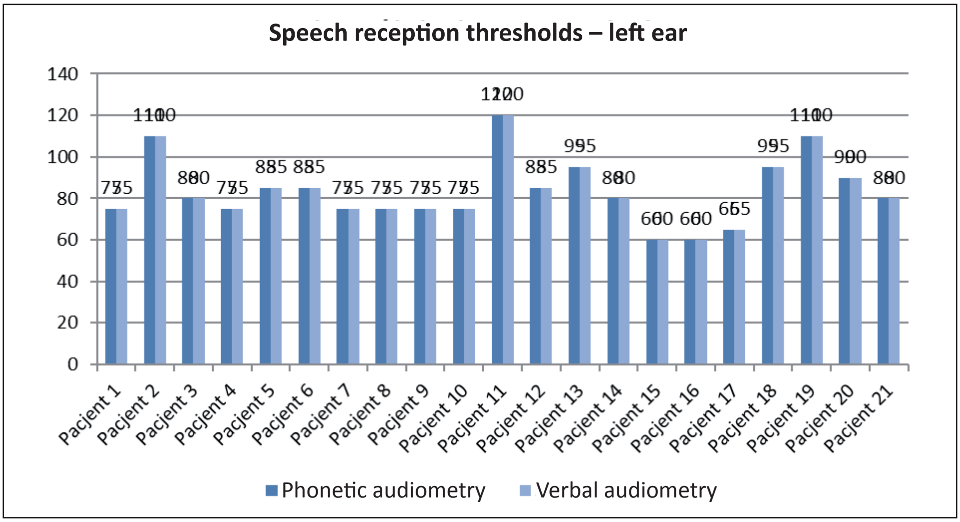

Fig. 11. Speech discrimination thresholds – phonetic audiometry and verbal audiometry
Źródło: Aleksandra Ptaszkowska 2016.

The foregoing data on the speech discrimination thresholds (Table 3, Fig. 10 and 11) show that both in phonetic audiometry and in verbal audiometry these thresholds are achieved at the same volumes. This situation is connected with the way of analyzing the collected data. A patient, in order to obtain a 100 percent of the correctly received signal in verbal audiometry, has to correctly repeat 10 words, at the same time this involves saying all 30 phonemes.

Phonetic audiometry was developed as the Phonetic Audiometric Computer Test "Afon" for the purpose of logopedic diagnosis.

The computer program for phonetic audiometry serves to test the percentage of intelligible sounds at a specific level of speech signal. In this program, sounds are marked that have been omitted or changed by the child. The sets of words change together with the dB level. The level is increased in each set by 5dB. The sets are sent separately to the left ear and the right ear. The obtained graphs during testing enable obtaining the sound recognition level and sound discrimination level. With the start of testing, the child was given an instruction and then the Sennheiser HDA 200 headphones were put on. The testing rules are identical with the previous version.

The panel of the Phonetic Audiometric Computer Test is presented in Fig. 12:

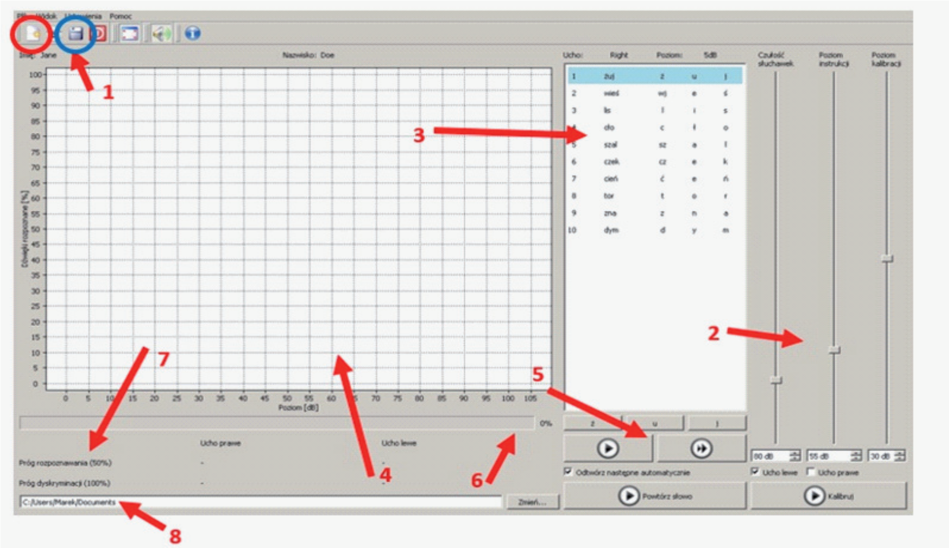

Fig. 12. The panel of the Phonetic Audiometric Computer Test

In order to verify the test, pilot tests were carried out as part of research work at the UMCS Department of Logopedics in normal children (Kamieniecka 2016) and in children with dyslalia (Jezierski 2016). Below are examples of test results in children with dyslalia.

Table 4. Szymon's phonetic audiometric test results and photo questionnaire results (Jezierski 2016)

Sounds Głoski	Szymon				
	Phonetic audiometry				Articulation test
	Right ear		Left ear		
	Percentage of correctly repeated sounds	Number of correctly repeated sounds	Percentage of correctly repeated sounds	Number of correctly repeated sounds	
a	31.58	6/19	58.33	14/24	Normal
e	-	-	-	-	Normal
y	50.00	3/6	42.86	3/7	Normal
i	-	-	62.50	5/8	Normal
o	-	-	66.68	10/15	Normal
u	-	-	50.00	5/10	Normal

Table 4. Szymon's phonetic audiometric test results and photo questionnaire results (Jezierski 2016)

ą	-	-	0.00	0/2	Normal
ę	-	-	-	-	Normal
p	40.00	2/5	42.86	3/7	Normal
pj	-	-	-	-	Normal
b	25.00	2/8	37.50	3/8	Normal
t	7.69	1/13	46.67	7/15	Normal
d	50.00	4/8	25.00	2/8	Normal
c	20.00	1/5	-	-	Normal
dz	-	-	-	-	Substitution
cz	0.00	0/6	40.00	2/5	Substitution
dż	-	-	-	-	Substitution
ć	50.00	1/2	50.00	2/4	Normal
dź	-	-	-	-	Normal
k	15.38	2/13	43.75	7/16	Normal
g	33.33	1/3	50.00	2/4	Normal
f	50.00	1/2	-	-	Normal
w	40.00	2/5	14.29	1/7	Normal
wj	0.00	0/1	-	-	Normal
s	40.00	4/10	-	-	Substitution
z	25.00	1/4	33.33	1/3	Substitution
sz	0.00	0/8	0.00	0/5	Substitution
ż	0.00	0/4	0.00	0/2	Substitution
ś	50.00	1/2	-	-	Normal
ź	-	-	-	-	Normal
h	-	-	50.00	2/4	Normal
m	-	-	60.00	6/10	Normal
mj	-	-	-	-	Normal
n	28.57	2/7	28.57	2/7	Normal

Table 4. Szymon's phonetic audiometric test results and photo questionnaire results (Jezierski 2016)

ń	0.00	0/1	-	-	Normal
ł	42.86	3/7	25.00	1/4	Normal
l	33.33	4/12	54.55	6/11	Normal
r	41.67	5/12	25.00	2/8	Normal
j	37.50	3/8	57.14	4/7	Normal

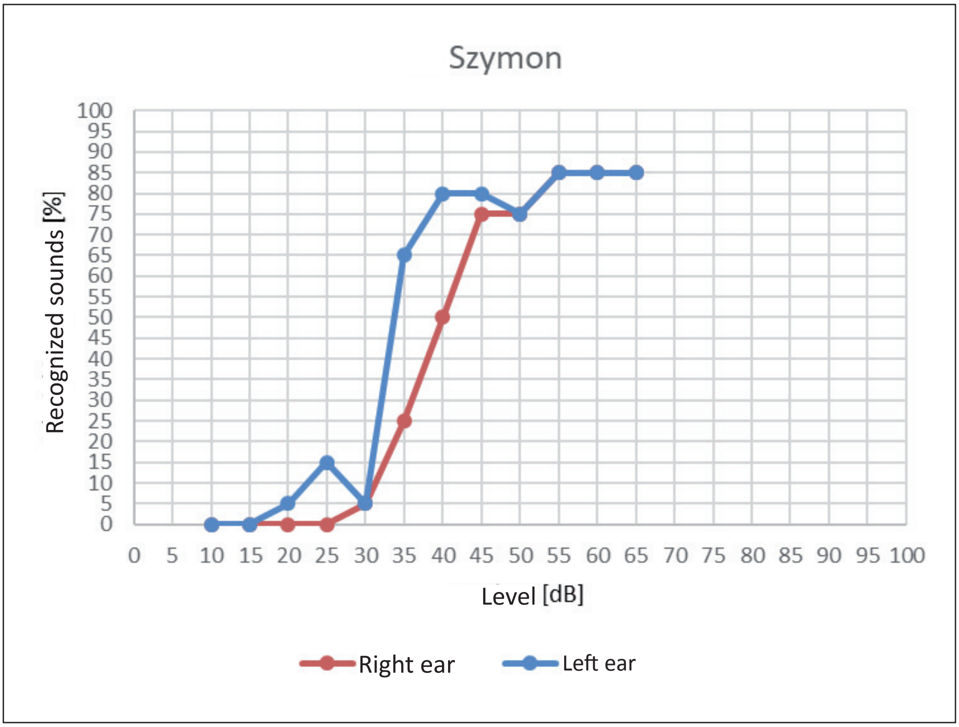

Fig. 13. Szymon's speech audiogram

The results of testing using phonetic audiometry showed that Szymon's recognition threshold was 40 dB for the right ear, and for the left ear – it was 34 dB. The discrimination threshold was reached neither for the right nor left ear. For the right ear, no sound was repeated over the 50% level, while at the 50% level - five sounds were repeated (*y, d, ć, f, ś,*), and for the left ear, 10 sounds were repeated over the 50% level (*u, ć, g, h, l, j, a, m, i, o*). For the right ear, 14 sounds (*t, k, c, b, z, n, a, g, l, j, p, w, s, r, ł,*) were repeated below the 50% level, while for the left ear, below the 50% level, 12 sounds (*w, d, ł, r, n, z, b, cz, y, p, k, t*) were repeated.

For the right ear, the sounds *cz, w', sz, ż, ń* were not repeated, while the sounds *ą, sz, ż* were not repeated for the left ear. During the testing, the test did not use the following sounds for the right ear: *e, i, o, u, ą, ę, p', dz, dż, dź, ź, h, m, m'* , and for the left ear : *e, ę, p', c, dz, dż ,dź, f, w', s, ś, ź, m', ń.*

The testing of articulation using the photo questionnaire showed that the patient incorrectly pronounced sounds: *dz, cz, dż, s, z, sz, ż*.

Another example of test results for a child with dyslalia:

Table 5. Mateusz's phonetic audiometric test results and photo questionnaire results (Jezierski 2016)

Sounds	Mateusz				
	Phonetic audiometry				Articulation test
	Right ear		Left ear		
	Percentage of correctly repeated sounds	Number of correctly repeated sounds	Percentage of correctly repeated sounds	Number of correctly repeated sounds	
a	65.38	17/26	-	-	Normal
e	64.71	11/17	-	-	Normal
y	62.50	5/8	57.14	4/7	Normal
i	-	-	77.78	7/9	Normal
o	-	-	78.26	18/23	Normal
u	71.43	10/14	-	-	Normal
ą	-	-	0.00	0/1	Normal
ę	-	-	-	-	Normal
p	60.00	3/5	50.00	5/10	Normal
pj	-	-	-	-	Normal
b	-	-	42.86	3/7	Normal
t	66.67	12/18	64.71	11/17	Normal
d	40.00	4/10	70.00	7/10	Normal
c	25.00	1/4	66.67	4/6	Normal
dz	-	-	-	-	Distortion
cz	14.29	1/7	0.00	0/6	Substitution
dż	-	-	-	-	Substitution
ć	25.00	1/4	50.00	2/4	Normal
dź	-	-	-	-	Normal

Table 5. Mateusz's phonetic audiometric test results and photo questionnaire results (Jezierski 2016)

k	64.71	11/17	54.55	12/22	Normal
g	60.00	3/5	80.00	4/5	Normal
f	50.00	1/2	50.00	1/2	Normal
w	50.00	3/6	33.33	3/90	Normal
wj	-	-	-	-	Normal
s	50.00	9/18	71.43	10/14	Normal
z	42.86	3/7	-	-	Normal
sz	0.00	0/7	0.00	0/8	Substitution
ż	25.00	1/4	0.00	0/5	Substitution
ś	25.00	1/4	-	-	Substitution
ź	-	-	-	-	Substitution
h	66.67	2/3	33.33	1/3	Normal
m	58.33	7/12	72.73	8/11	Normal
mj	-	-	-	-	Normal
n	-	-	72.73	8/11	Normal
ń	66.67	2/3	-	-	Normal
ł	50.00	3/6	50.00	3/6	Normal
l	-	-	64.29	9/14	Normal
r	58.33	7/12	50.00	6/12	Normal
j	50.00	4/8	80.00	8/10	Normal

The results of phonetic audiometric testing showed that for Mateusz the recognition threshold was 29 dB for the right ear, and for the left ear it was 24 dB. The discrimination threshold was reached neither for the right ear nor for the left ear. However, for the right ear, 17 sounds were repeated over the 50% level (*f, w, s, ł, j, m, r, p, g, y, e, k, a, t, h, ń, u*), and for the left ear - 18 sounds (*p, ć, f, l, r, k, y, l, t, c, d, s, m, n, i, o, g, j*) were repeated over the 50% level. For the right ear, below the 50% level, seven sounds were repeated (*cz, c, ć, ż, ś, d*), and for the left ear three sounds (*w, h, b*) were repeated below the 50% level. For the right ear the *sz* sound was not repeated, and the sounds *ą, cz, sz, ż* were not repeated for the left ear. During the testing, the test did not use the following sounds for the right ear:

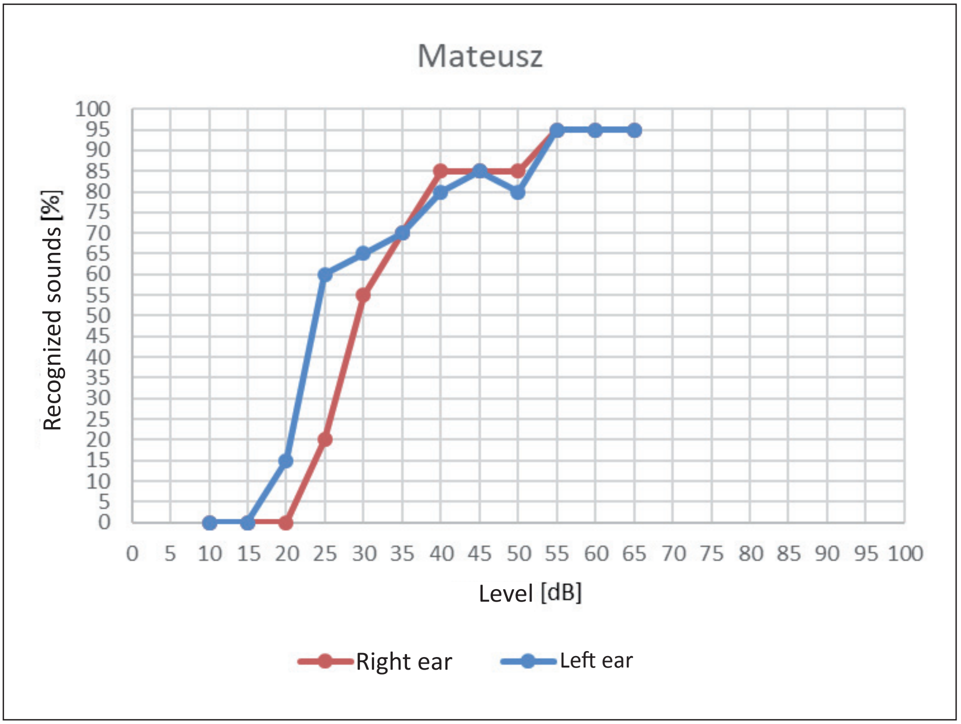

Fig. 6. Mateusz 's speech audiogram

a, e, u, ę, p', dz, dż, dź, w', z, ś, ź, m', ń , and for the left ear : *a, e, u, ę, p', dz, dż, dź, w', z, ś, ź, m', ń.*

The testing of articulation using the photo questionnaire showed that the patient incorrectly pronounced sounds: *dz, cz, dż, sz, ż, ś, ź.*

To sum up, it can be said that "Phonetic Audiometry" developed in the Institute of Physiology and Pathology of Hearing in Warsaw permits the obtention of more adequate results of speech audiometry in assessing the advantages of hearing aids, and first of all in assessing speech intelligibility in patients with articulation disorders. Work on the computer application of Phonetic Audiometry enables use of the technique for audiophonological diagnosis in children with articulation disorders.

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